



Original Research Article

Effects of Urban Heat Island on Air pollution Concentrations

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ABSTRACT

Keywords

Air Pollution,
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Potential
temperature

The spatial variation of temperature generally shows that cities are warmer than the nearby surrounding areas, particularly during nights with clear sky and light winds. The intensive heat island results in a local Hadley type of circulation. The air rising interior of the city and coming down in the suburban areas and again following towards in the interior of the urban area. This results in recirculation and builds up of concentration of urban air pollutants. The local circulations increase the areal extent of urban heat island, but decrease its intensity. The sea and land breezes extend the heat island towards interior in the day time and towards the sea in the night time respectively. In this article we have taken two different areas in Visakhapatnam (One is rural (IMD) and the second one is Urban (Air port)). The daily pressure and temperature of the morning ascent taken at 0530 IST at the surface level and the same parameters at 950hpa level are considered for a period of five years (2009 - 2013). It is clear that the heat island magnitudes essentially depend on the surface wind speeds. It is noticed that during the months of January, March and September, 70% of non-rainy days showed heat island magnitudes of greater than one degree. It is mainly due to the stand still conditions and the large potential temperature gradients. Moderate percentage frequencies of heat island magnitude 64% in February, 59% in October and 52% in December are observed with greater than one degree.

Introduction

During a sunny day with clear skies the earth and all the other objects on the earth are exposed to the same amount of heat energy coming from the sun. But during night time in the absence of solar radiation all the exposed objects including the earth start emitting the absorbed energy in the form of radiation relatively in greater magnitudes. The emitted radiation and its maximum wavelength depend on the

temperature of the radiating body. The Sun emits approximately 6000°K, where as the earth emits radiation at 288°K. So the terrestrial radiation is maximum in longer wavelengths where as the for solar radiation is at shorter wavelengths. The sun's radiation is termed as shortwave radiation and the earth's radiation as long wave radiation. It is a well known fact that the urban areas which are densely covered with

tall buildings and industries retain solar energy for a longer period and act like a warm core, and the unbuilt well exposed surrounding rural areas loose heat energy rapidly and act like a cold zone. Hence, these two heat zones exhibit a temperature difference and excess heat in the urban area is termed as 'Heat Island. It is significant, especially during nocturnal hours. Despite its magnitude may be small on an annual basis, it can be very much more pronounced under certain weather conditions (Weak winds and cloudless skies) (Oke, 1976). It also varies in direct proportion with the size of the city. For a coastal station like Visakhapatnam the flushing action due to Land and Sea breezes not only influences the heat island intensity but also distorts its size and shape due to prevailing local circulations. So in brief, the topographic effects, land-sea breezes and other meteorological factors influence the heat island magnitude considerably.

If the whole earth is taken into consideration, the area covered by the cities is limited. However, they contain a large population, and are important to human life. Many outstanding and comprehensive studies have been made on the urban climate. Howard (1833) was a pioneer of urban climate studies. Since then a great deal of study and comprehensive review on city climatology has been made by a series of researchers (Kratzer,1956; Landsberg, 1970 and Patterson, 1969). These reviews threw new light on the various faces of urban climates. The most remarkable phenomenon in city climate is the high air temperature and it's called city temperature or heat islands (Oke, 1982).On calm and cloud free nights ,the distribution of air temperature in the city shows the steep temperature gradient around the city areas ,which are divided into the inner and outer areas of the city. The

diurnal change of the air temperature in the city area is lighter than in the sub –urban area.

In general the two primary processes that are involved in the Formation of an urban heat island is

- Artificial heat results from man-made structures, Power generation, Industries, home heating, transportation, and human and animal metabolism which warms up the urban atmosphere.
- The green house pollutants, particulate matter, water vapor and Carbon dioxide over a city absorb part of the upward direct thermal radiation emitted at the surface. Part of this radiation is re –emitted downwards to warm the ambient air, a process that tends to increase the low –level stability over the city, enhancing the probability of higher pollutant concentrations. Thus, airborne pollutants not only cause more intense heat islands, but also alter the vertical temperature structure in a way that hinders their dispersion (Patterson, 1969). The process is more complicated in a coastal environment influenced by local circulation.

Meteorological elements influencing the heat island magnitudes

- Heat islands develop more clearly at night.
- The clearer the sky the greater is the development of the city temperature.
- The weaker the wind velocity, the greater the heat island.

Urban heat islands are also common over the cities of even fairly small size. The maximum horizontal gradient of the air temperature between the central part of the

city and suburban's, which is measured on the distribution maps, is on the whole 1 to 2°C/km in small or medium size cities, but it reaches to 5°C/km or even more in extreme cases.

Vittal Murty *et al.*, (1979) have also conducted several data observations over Visakhapatnam and stated that they noticed 3 warm core centres within the city. The surveys of heat islands magnitudes to the actual city size are conducted by Daniel and Krishna Murty (1973) in Bombay, pradhan *et al.* (1976) in Delhi, Bahl and Padmanabhamurty (1979) and Satyanarayana (1977) for Visakhapatnam and stated that heat islands magnitudes are nearly equal to the average of the observed values taken at selected places. Satyanarayana (1982) and Sastry (1982) studied the heat island magnitude over Visakhapatnam. As the islands values are used in computing the urban morning mixing heights, in the contiguous United States of America, Holtzworth (1967, 1969) has suggested a correction factor of '5°C' to all the stations as an urban rural temperature difference. Considering various factors and applying the +5°C correction factor for several stations in India, Vital Murty *et al.* (1982) has concluded That the value yields to very large mixing depths in several cases. Further, they suggested a correction factor of +3°C in winter season and +5°C in all other seasons for Indian stations. Satyanarayana (1982) has verified the validity of the constant +5°C and relied on the day to day computations as the constant is not suitable for the Indian stations. Howard (1833) was the first to provide evidence that the air temperatures are higher in a city than its surrounding countryside. The canopy heat islands are largely a nocturnal phenomenon attributable to urban, rural cooling (rather than heating). Its spatial pattern confirms closure to the distribution

of surface cover characteristics.

According to Oke (1982)

Urban building or canopy layer extends from the ground up to about mean roof level rather like a vegetative canopy layer. The urban boundary layer is a mesoscale internal boundary layer whose characteristics are to be determined.

At about sunset there is a relatively rapid cooling (typically 2 to 3°C/hour) as the surface experience a net radiative energy drain and withdraws from the shallow layer of stable air immediately above it. As the surface temperature drops and the rate of radiative emission decreases, the cooling rate also declines (to about 0.5°C/hour) as the night progresses. As a result, rural air temperature in night exhibits a simple exponential decay curve until just after sunrise, when the pattern is abruptly interrupted by warming. Solar heating of the surface generates a turbulent sensible heat flux, which converges in the surface layer whose depth is limited by the remnant nocturnal radiative inversion above. As the mixed layer grows, the rate of the warming, decline mid afternoon, at which time the maximum temperature occurs. However, the urban regime is very different from the rural. Warming and cooling rates are gradually smaller (except in the later half of the nocturnal period) and noticeably does not show sharp peaks around sunrise and sunset hereby producing a damped diurnal temperature wave. As a consequence of the above, the heat island intensity undergoes a remarked diurnal variation. Diverging rates of cooling between the urban and rural environments around sunset produce a sharp increase in intensity to a maximum a few hours later. Thereafter, slightly greater urban cooling, reduce the intensity until the early day time, rural heating virtually erases the heat islands. In some cities there are even

reports of slightly lower temperature at the central areas in comparison with the country side (Oke, 1982).

Factors influencing the spatial heat islands magnitudes

Combustion heat in the city: The heat is used in industries or in houses was thought to have a great influence on the rise of the city temperature, since the source of heat is concentrated in the city, the temperature becomes higher than the outer area, supposing that the heat released by industries, houses and various human activities directly warms the city air. Kratzer (1956) has summarized the following; a warming of 1.4°C for the 30 m thick layer near the ground in London, energy of 8.1Kcal/cm²/year for Vienna, and 16.8 kcal/cm²/year for Berlin were estimated for the conditions at the beginning of 20th century. The energy product artificially cannot be discharged in city areas. However, ventilation of city air must be taken into consideration. In large cities the waste thermal energy provides for an average of 0.5×10^{-3} cal/cm²/s over areas extending several hundred square kilometres (SMIC,1971). Investigations by Kratzer (1956), Garnet and Bach (1965) and Bornstein (1968) have revealed that the annual heat product artificially in a built-up area varies from 1/3 to 1/6 of that received from solar radiation. Further, it was report that during winter, the amount of heat product from combustion alone were 2 to 2½ times greater than that of solar energy reaching the ground, but during the summer this factor dropped to 1/6. According to Mc Elory (1971) the value of 'H' for Columbus, Ohio during September and march was 1.3×10^{-3} cal/cm²/sec. Thus the heat produced in a city area is proportional to the size of the city, domestic burning, its population, the industrial activity and the transport network.

Haze or smog layer: As it obvious that cities contain a large quantity of fine dust and pollutants like CO₂, SO₂ etc., in many cases the development of city areas is closely connected with that of the surrounding industrial areas. Consequently, dust and other pollutants from the industries cover the city areas; exhaust gases of the various vehicles are no less influential. These effects are remarkable, especially when the wind is low and inversion layer is fully developed. The smog layer absorbs long wave radiation, and so it decreases the incoming radiation by day, and prevents outgoing radiation by night. In consequence the maximum temperature becomes a little lower and minimum temperature become fairly higher in cities. But the city temperature can be observed not only in the night time, but also in the daytime. For a coastal station the haze or smog layer may be diffused with the advent of strong local circulation .However in the morning or evening when there is a succession of land breeze or sea breeze during that period marked by low winds, there is a possibility of haze or smog which will much more pronounced in the presence of an inversion layer.

Exchange of heat due to the turbulence increased by buildings: in cities crowded with buildings, the turbulence of so called mechanical origin increases. Consequently, the vertical exchange heat becomes more active in a city than in outer areas. This causes a comparatively high temperature in night because of ground inversion. However, this applies only when the wind velocity is assumed to be the same both in and outside the city. In general, mean wind velocity itself is weakened by the buildings in the city. There is a correlation between main wind velocity and turbulence. If the streets are narrow and the buildings are tall, the air between the buildings cannot move

under weak upper wind conditions. It can be said that the roughness parameter is very weak in such a situation. Accordingly, the high temperature remains till late in the evening.

Material and shape of the building

A Built up area of a city, unlike the rural areas around it, is covered with cement, asphalt, gravel, stone, brick etc. In the daytime these materials are warmed more gradually than the bare ground surface covered with vegetation. The air temperature does not decrease quickly until night, because these material cool slowly. The phase of diurnal variation of the temperature is slower in the urban centre than in the suburban.

Yoshino (1973) stated that the air temperature at any place in the city has a linear relation to the housing density. As the house density increases by 10% the air temperature on a calm night rises by 0.23%. However, around the time of maximum temperature the rise of the air temperature is comparatively less, i.e. 0.10°C. When it is cloudy, it rises still more slightly, i.e. 0.06°C. This value may be considered common to all medium sized or small cities. The shape of the building also plays a significant role. As has been discussed by Geiger (1965), the rate of effective outgoing radiation from a street surrounded by the rows of houses to the radiation from a comparatively open horizontal surface is below 50% in some cases. The vertical wall of the houses bordering on the street also radiate, but amounts only to about 40% of that on the horizontal surface, because each side of the street surrounded by buildings act like a canyon and each side prevents the other and behaves like a radiation barrier. There are a few studies on the quantitative analysis of

radiation of vertical as well as horizontal surfaces of building in cities, it is certain that the outgoing radiation is reduced in city areas as far as horizontal surface is concerned.

The urban heat island has several effects on air pollution levels in cities. One of the effects is the development of a thin atmospheric layer near the earth's surface over the cities where mixing occurs during the night. This layer extends above the height of smokestacks from industrial plants. This causes pollutants mixed through the surface layer thereby increasing surface concentration. The usual inversion during the night prevents the mixing of pollutants above this thin surface-mixing layer those results from the heat island. Hence, in such a case the industrialist should be aware of lowering the released pollutant concentrations into the atmosphere or should think of transporting the effluents above the usual inversion layer, either by raising the mean stack height or by increasing the heat energy of effluent so as to acquire an adequate buoyant energy to the plume so that the plume will shoot up the inversion layer. However, the former process is expensive and cumbersome.

Another effect of the heat island on pollutant concentration is related to the wind current that may be produced by the heat islands that act as a miniature thermal low-pressure area. There is some indication that light breezes blow toward the centre of the cities because the heat island behaves much like the thermal low and on shore breezes exist during the day time as land surface is warmer than the water. This creates a country breeze from the surrounding countryside towards the heart of the city; such a breeze may intensify air pollution problems since it would be most noticeable when the major wind system is present. The

common location of industrial plants on the outskirts of cities combined with a country-breeze that carries all pollutants toward the heart the city may increase air pollution levels over cities. The effect of urbanization is not only confined to the horizontal temperatures, but also to those in the vertical direction with far reaching consequences. Overseas studies Oke (1974, 1977) have shown that the thermal influence of a city commonly extends up to 200 to 300 m and even to 500 m and more. When the warm air is affected by the wind an urban plume in the downwind region is formed in calm conditions and an urban dome may be created. During later condition at night the city can even create its own circulation with the wind blowing from the cooler surrounding area into the warm city centre bringing the plume from the outskirts into the city area. In both cases, however, these modified urban air layers are invariably being capped by an elevated inversion inhibiting upward dispersion of pollutants. The effect of the heat islands is not only confined to the air below the roof level (the urban canopy) but can extend up to in excess of 500 m (the urban boundary layer above the city). The behaviour of this air layer is found under calm conditions and in the presence of mesoscale wind. The developments of urban dome and plume in places certainly have a far-reaching effect not only in urban centres but also on the immediate rural surroundings. If the spacing between the cities is insufficient, their alignment with the wind may cause accumulative pollution build up. In such a situation the combined emissions from these urban centres may form into a giant plume affecting the surrounding area. In addition, the plume from one city can also become fumigated into the atmosphere of a second one downwind in a similar manner to those shown by Oke (1976). Oke and East (1971) estimated the urban, rural surface cooling

rates from the observations in and around urban Montreal. Their observations indicated that the rural atmosphere near the surface cooled rapidly in the evening hours before midnight, while the urban atmosphere near the surface was maintained at a nearly constant temperature during the same period. After midnight both regions cooled at about 50% compared to the rural site before midnight. Thus, the magnitude of the heat island near the surface increased with time in the early evening, and then remained constant until morning. The cooling rates cause the formation of a surface based stable layer in rural areas, while advection of cool rural air over the uncooled urban surface during the first 6 hours of the simulation caused the formation of slightly unstable layer near the urban surface. During the second 6 hours of the simulation, the decreased surface cooling rates slowed the rate of increasing stability at rural sites, while the urban cooling was unable to completely overcome the effects of advection.

Hanna (1969) has presented the following equation for the measurement of heat island

$$\Delta\theta = \{HW (\partial\theta/\partial z) / C_{pp} U\}^{1/2} \quad (1)$$

Where $\Delta\theta$ is the difference between the air temperature at the centre of urban heat island and a representative air temperature in the rural area.

H is the anthropogenic heat input.

W is the city width.

$\partial\theta/\partial z$ is the rural vertical gradient of potential temperature.

C_p is the specific heat of air constant pressure.

ρ is the air density and

U is representative rural wind speeds.

Padmanabhamurty *et al.* (1973) have also given a linear regression equation for clear

and partly cloudy conditions to determine the heat islands magnitude. According to them

$$\Delta\theta=3.81+0.882\{(T_2-T_1)/U\}^{1/2}\times 10^3 \quad (2)$$

Where (T₂-T₁) is the vertical temperature difference between 48.8 and 6.1 m at a representative rural station and U is the wind speed. The constant in the second term on the right hand side of the above equation (2), compared with equation (1) implies that the anthropogenic urban heat input is of approximately 0.3 ly/min. Several investigators have tried to evaluate a quantitative relationship between the intensity of heat islands and other pertinent meteorological parameters like cloud cover, humidity and wind speed as the main parameters that would affect the heat transfer.

If one observes the lapse rate in the lowest layers, it is seen to be dependent primarily on the variation of surface temperature. As we go up, there is a rapid decrease in the effect of surface conditions in the air temperature. It was assumed that the advection process and the effect of synoptic – scale weather systems on the lower layers of atmosphere were minimized. If we consider only the lapse rates measured outside the city, then both magnitudes of the heat island effect and of the lapse rate are largely determined by the environ surface temperature. The other condition that should be satisfied is the lapse rate and the urban – rural temperature difference should be closely related and the relation should be approximately linear. To develop the regression equation Ludwing and Kealoha (1968) assumed that the nocturnal cooling in the city is much less dependent on meteorological conditions than it is in the country. But the investigations of Oke and Hannells (1968) in Hamilton suggested that

the heat islands effect diminished in insignificant proportion if wind speed is greater than 6 to 8 m/s. They found a relationship between city size (population) and the wind speed necessary to obliterate the heat island effect. The regression equation evaluated by them is given below,

$$U_{crit} = -11.6+3.4 \log P \quad (3)$$

Where U_{crit} is the critical wind speed m/s and ‘P’ is the pollution.

High wind speed within urban area affects the heat islands because the city ventilation increases due to the advection of cold air outside the city. Calm conditions are the most favourable for the heat island formation. Such conditions generally prevail during night time. At the time of inversion conditions the heat island was quite intense because of low winds during the period.

Materials and Methods

The daily pressure and temperature of the morning ascent taken at 0000 GMT (0530 IST) at the surface level and the same parameters at 950 hpa level are considered for a period of five years, over cyclone warning centre, India Meteorological Department Visakhapatnam. The daily surface temperature data at 0530 IST for one year (2013) at the airport, Visakhapatnam are considered. Rainy days are excluded from the analysis

Among the methods discussed above the author has used Summers (1967) formula in the present study on the heat island intensities over an east coast city, Visakhapatnam to arrive the heat island intensity. The formula is found to be feasible for this coastal station after verifying a practical and computed value over the study area. Further believed that the necessary

meteorological parameters which are involved in a summer's formula reflect the influence of the day to day weather changes on the heat island magnitudes. To verify the application of a summer formula to this station the results obtained were compared with the observed field values taken at India meteorological Department (cyclone warming centre) of Visakhapatnam which is far off the coast and the airport station of Visakhapatnam which is far off the coast (about 10 km). The difference between the temperature at 0530 IST at these two stations have been calculated. This value represents the urban-rural temperature difference. In Figure 2.4, the mean monthly heat island intensities for both calculated and observed values of Visakhapatnam city for the year 2013 were presented. In most of the Occasions the calculated mean values were slightly higher than the observed values. Even though the mean computed values are in good agreement with the observed values, the formula yields occasionally unusual large values of heat islands particularly in day to day calculations. The detail of the summer formula is summarized here.

According to summers formula from the upwind edge of the city heat islands magnitude is given by

$$\Delta T = (2XH\gamma/U\rho C_p)^{1/2}$$

Where ΔT - Heat island magnitude ($^{\circ}\text{C}$)

X- The distance from the upwind edge to the centre of the city (cm).

H- Excess heat per unit area in unit time available to heat the air ($\text{cal}/\text{cm}^2/\text{sec}$).

γ = rate of potential temperature increase with height in the lower level of the atmosphere upwind of the city ($^{\circ}\text{C}/\text{cm}$).

U= wind speed through the urban boundary layer (cm/s).

ρ = density of the air (gm/cm^3).

C_p = specific heat of the air at constant pressure ($\text{cal}/\text{gm}/^{\circ}\text{C}$).

The effect of excess thermal energy on air temperature over cities depends on the ability of the atmosphere to mix and disperse the waste energy. As said earlier, for low wind speeds the formula yields unusually large heat islands magnitudes. The formula is not feasible for the day during which the potential temperature decreases with height. Generally, in such conditions the heat island does not exit, as the vigorous mixing is possible.

To estimate the density of air, the surface parameters pressure and temperature are used. The surface level and 950 hpa level are considered as first and second level respectively.

The rate of potential temperature increase with height (γ) has been determined as

$$\gamma = (\theta_1 - \theta_2) / \Delta Z \times 100$$

Where θ_1 and θ_2 refer to the potential temperature of the first and second levels respectively, and ΔZ (in cm) refers to the thickness in between the first and second levels. The distance from the upwind edge of the centre of the city has been computed using the available city map and after converting its area into a circular form and its value is 6, 73, 735 cm. The excess heat H available to the atmosphere from anthropogenic sources and storage in building material is assumed to be constant. The surface wind speed is used to evaluate the heat island magnitudes for all the day. But, when the wind speed at the surface is calm or zero, then 0.1 m/s was assigned to the surface wind speed for computational purpose.

Results and Discussion

The five yearly mean monthly heat island intensity variations are presented in Figure 1. The average highest magnitude of heat islands is 3.9°C Both in January and

September and the lowest was in May (1.5°C). There is a decrease in trend of heat island intensity from January (3.9°C) to March (2.5°C). It further decreases to reach the minimum (1.5°C) in May. There after a gradual increasing trend up in July and then a decrease are noticed. From August to September a sudden increase is observed. Then it decreases till November. A slight increase is noticed from November to December. In general, there is a decreasing trend from January to May and an increasing trend from May to September.

The individual trends of the years were near similar to the average distribution of five years mean distribution in general a gradual decreasing trend of heat island magnitudes is noticed from January to May (Figure 2). In Figure 2 Regarding the heat island intensities in the month of January the 5 year mean value was more than 3°C, where as the highest (3.8°C) is observed in the year 2010. The lowest value (2.5°C) is noticed in 2011.

February also showed a close similar distribution in January and the 5 year annual average was 3.5°C. The height the mean monthly value was 4.5°C in 2013, where as the lowest value is 1.6°C in 2012. In March, the five year mean was 2.8°C. The highest is 3°C at 2013 and lowest 2°C are in 2011. The five year average heat island value for April is 1.7°C. The mean value for individual years shows the lowest value (0.8°C) in 2011 and the highest (1.8°C) in 2009. May month showed the lowest value with a mean value of 1.2°C in general the values are low when compared to the other months. This may be due to the uniform spatial temperature distribution and high wind speed. The highest value is 1.8°C in 2012 and the lowest is 1°C in 2013. In general the values in June are slightly greater than that of May with a mean value of 1.5°C. The highest (1.7°C) and the lowest

(1.1°C) values are observed in 2013 and 2012 respectively. In July the values are greater than that of June. The lowest value is 0.8°C in 2013 and the highest is 3.6°C in 2010. In the month of August the values are less in magnitude when compared to July. But in the years of 2011 and 2013 there is a small increment in the month of August when compared with July. It may be due to the less potential temperature distribution.

The five year mean is 1.2°C. The highest is 2.6°C in 2010 and the lowest is 0.8°C in 2012. In September the mean value is 3°C. In 2010 the maximum is 4.5°C and the minimum is 1.3°C in 2009. In the month of October, 5 yearly mean is between 2 to 2.6°C, the highest is 4.8°C in 2010 and the lowest is 2°C in the years 2013. In November the mean monthly highest is 2.8°C in year 2012 and the lowest is in 2013 with 1.4°C. In December the maximum means monthly value is 3.2°C in 2009 and the minimum is in 2013 with 1.1°C. From the mean Figure 1 one can find the maximum values in January (winter) and minimum values in May (summer).

Here the plots of heat island values along with wind speed for the month of January presented in Figure 1. The wind at the surface dissipate the accumulated heat over the urban centres and hence the lesser magnitude of the heat island. On occasions even greater than 8°C. The clear sky conditions and smaller values of wind speed favoured the growth of the heat islands. It is shown in Figure 5. Especially over Visakhapatnam during the winter season, the potential temperature gradients are present 1 - 2°C /100 m and the low wind speed favoured the heat island magnitudes. In winter the heat island values are above 2°C on most of the occasions. The annual variations are not as significant as the daily values. The same was also found in observed values (Fig. 3).

In October and November (post monsoon season) the heat island magnitudes are slightly higher than the values in south west monsoon season. It is also noticed that the prevailing calm conditions (decrease in surface wind speed) lead to higher magnitudes of heat island.

Month	J	F	M	A
M	J	J	A	S
	O	N	D	
%age	70	64	72	35
32	41	48	17	70
				59
				41
				52

It is noticed that during the months of January, March and September, 70% of non-rainy days showed heat island magnitudes of greater than one degree. It is mainly due to

the stand still conditions and the large potential temperature gradients. Moderate percentage frequencies of heat island magnitude 64% in February, 59% in October and 52% in December are observed with greater than one degree. The months April, May, June, July and November showed less frequency of heat islands intensities with greater than one degree. Large wind speeds during monsoon season dissipate the accumulated heat in the city premises causing very low heat islands. The lowest percent (17%) is noticed in August. The remaining 83% showed less than one degree on account of moderate to large wind speeds that occur during the monsoon season.

Fig.1 Mean monthly heat island intensities (°C) for the five years

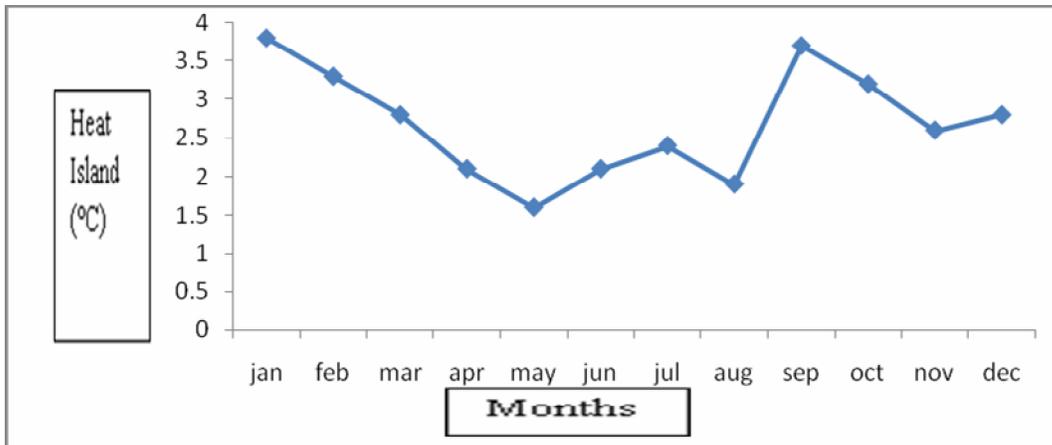


Fig.2 Mean monthly Heat Island Intensities (°C) for the Years From 2009 to 2013

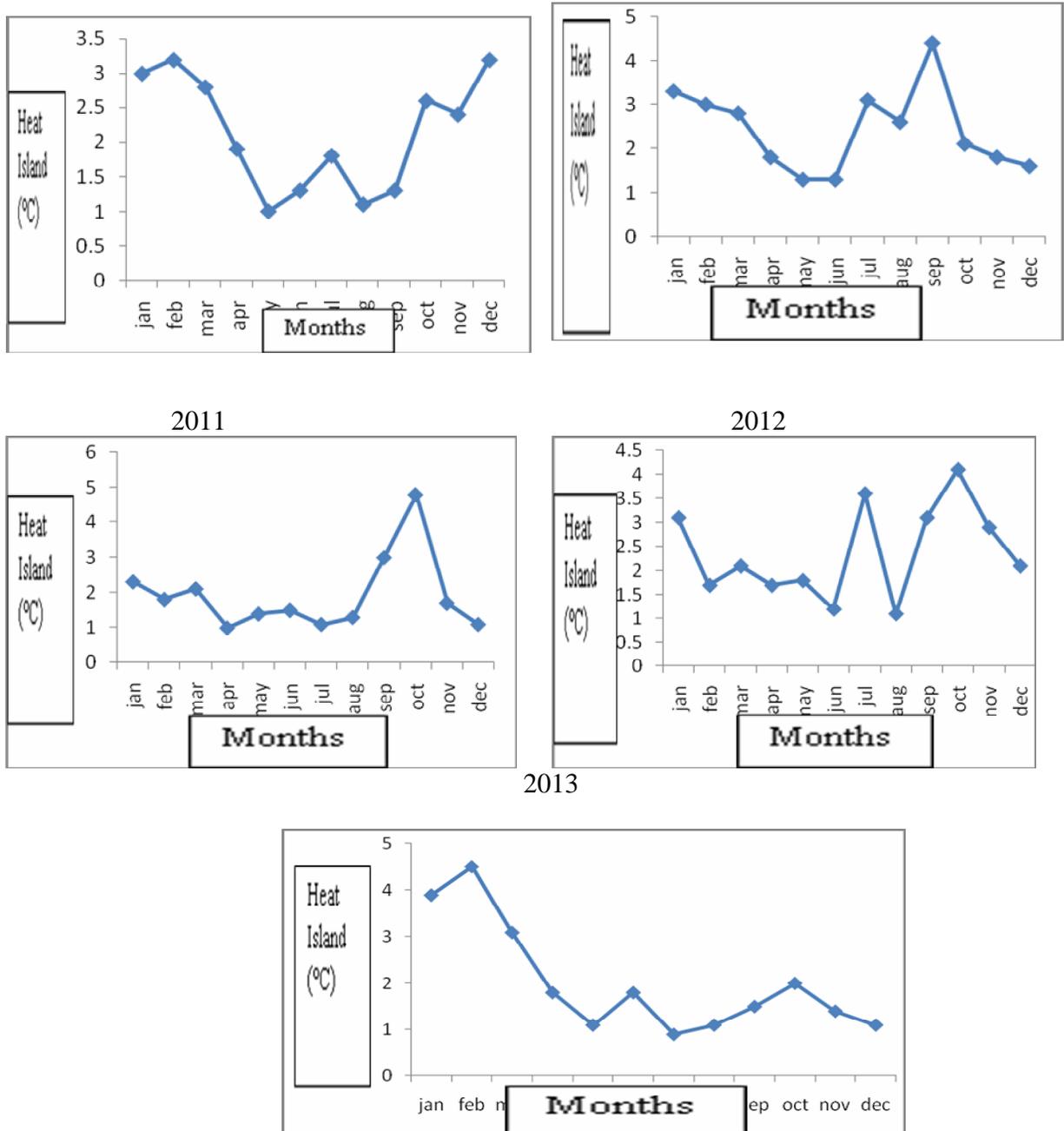


Fig.3 Mean monthly calculated and observed Heat island Intensities for Visakhapatnam for the year 2013

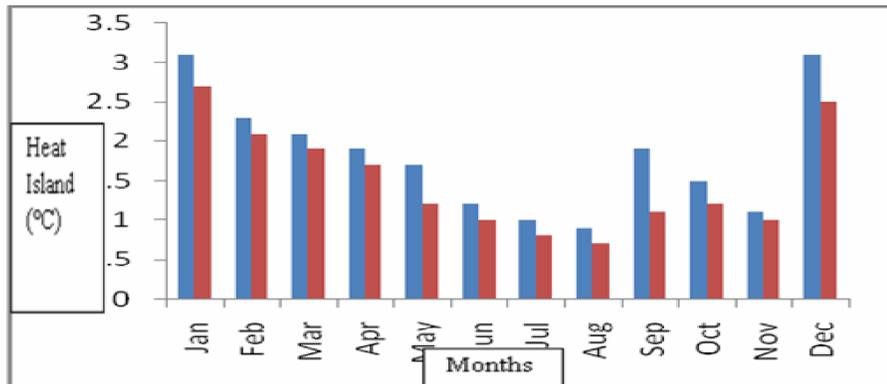
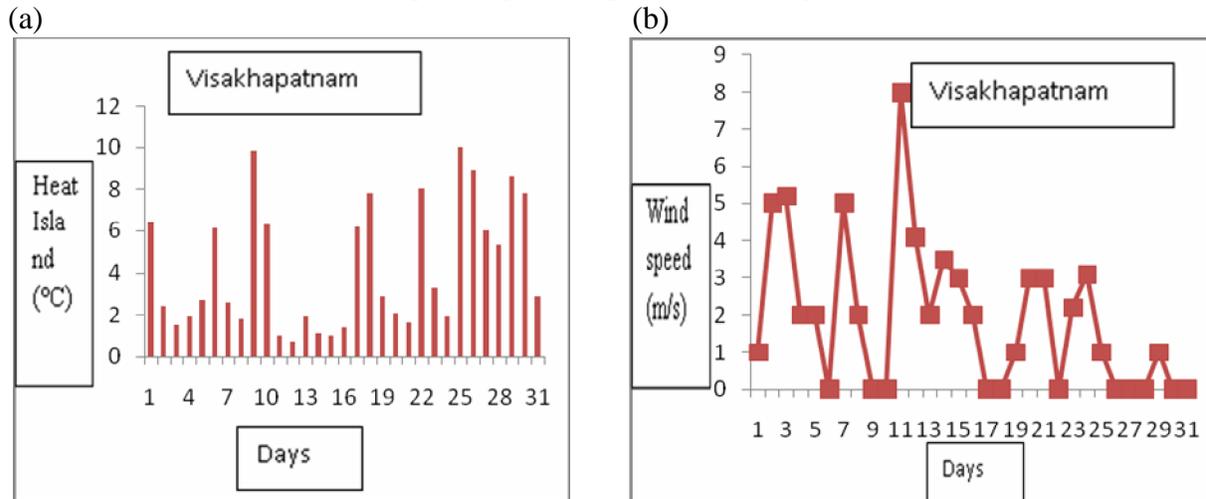


Fig.4 Heat Island intensities (in °C) over Visakhapatnam for January 2009 to 2013(Fig.4a) and corresponding wind speeds (m/s) (Fig.4b)



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