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Some physical features of heat and humidity islands at Delhi

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सार – दिल्ली हरे पेड़ पौधे, खुले क्षेत्र, चौड़ी सड़कें, उद्यान एवं मैदान आदि के बीच छितरी हुई कालोनियों में घरों के समूहों के कारण अनेक छोटे-छोटे गर्म क्षेत्र प्रदर्शित करती है। उष्मा द्वीप तीव्रता की दो उच्चतम मान, एक रात्रि के शुरु में, दूसरी प्रातः तड़के प्रेक्षित किए गए। तड़के का उष्मा द्वीप, रात्रि के शुरू वाले उष्मा द्वीप की अपेक्षा प्रबल रहता है जहां नमी नहीं होती वहां आर्द्रता द्वीप उष्मा द्वीपों से व्युत्क्रम संबंध दर्शाते हैं परन्तु जहां नमी नहीं होती है वहां वे तीव्रता में उष्मा द्वीपों का अनुसरण करते हैं। आर्द्रता द्वीप भी उष्मा द्वीपों की भांति दो उच्चतम मान दर्शाते हैं। तड़के की उच्चतम मान उष्मा द्वीप से समकला में रही परन्तु रात्रि पूर्व उच्चतम मान विषमकला में रहा। दिल्ली में विभिन्न सतहों से जैसे हरे क्षेत्र, कंक्रीट की सड़कें, डाबर की सड़कें, आबादी वाले क्षेत्र से उत्सर्जित ताप विकिरण एक सघन उष्मा द्वीप बनने की अपेक्षा अनेक गर्म क्षेत्र बनाने के लिए उत्तरदायी पाए गए।

ABSTRACT. Delhi exhibited several small warm pockets due to agglomeration of houses in colonies interspersed by green vegetation, open areas, wide roads, parks and maidans etc. Two peaks of heat island intensity were observed — one in the early night and another in the early morning. The early morning heat island is stronger than the early night. Humidity islands exhibited inverse relation to heat islands wherever moisture is not available but followed heat islands in intensity where moisture is available. Humidity islands also exhibited two peaks similar to heat islands. The early morning peak was in phase with heat island but the early night peak is out of phase. The thermal radiant emittance from different surfaces in Delhi like green areas, concrete roads, tar roads, built-up areas are found to be responsible for the formation of several warm pockets instead of a single intense heat island.

1. Introduction

The heat island effect of a city (its relative warmth as compared with pre-urban conditions) is a central research focus in urban climatology. On a daily basis the differential energy exchanges in urban and rural areas retard the nocturnal cooling of urban surfaces between sunset and midnight, when rural surfaces are cooling most rapidly. From about midnight until morning, both surfaces cool at about the same rate. In the morning solar heating causes more rapid warming of rural surfaces as compared to urban surfaces due to the thermal properties of urban building materials. Other factors retarding early morning warming of urban surfaces include shading by the buildings and increased solar attenuation associated with elevated pollutant layers.

It follows from the above that surface heat islands achieve maximum values near midnight and remain fairly steady through the remainder of the night in the mid-latitudes. Daytime heat islands generally show small urban-rural surface temperature differences. The magnitude of the surface heat island at a particular time and place depends on local meteorological conditions such as cloud cover and wind speed. Clear skies favour nocturnal cooling of rural surfaces and hence lead to strong urban heat islands. Low wind speeds allow excess urban heat to accumulate. Of the several areas that require additional observations and scrutiny the urban outgoing long wave energy flux is of special significance for it determines the heat island intensity at any particular city (Bornstein and Oke 1979). Oke *et al.* (1972) made comparative studies of urban/rural cooling rates at night at Montreal and Vancouver and found that the heat island intensity is related to differential rate of cooling of urban/rural surfaces. Tesler (1978) working at Uppsala, Sweden found that at ground level the heat island intensity developes rapidly after sunset in response to different urban and rural cooling rates. Oke (1978) while working on surface heat fluxes in the

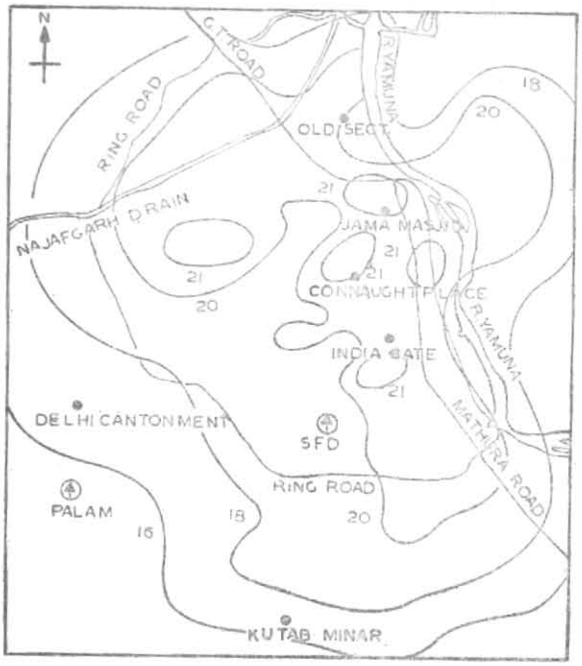


Fig. 1. Isothermal analysis at Delhi at min. temp. epoch (°C), 27-28 March 1979
Sky : clear, Wind : Northwest 2 to 4 kmph

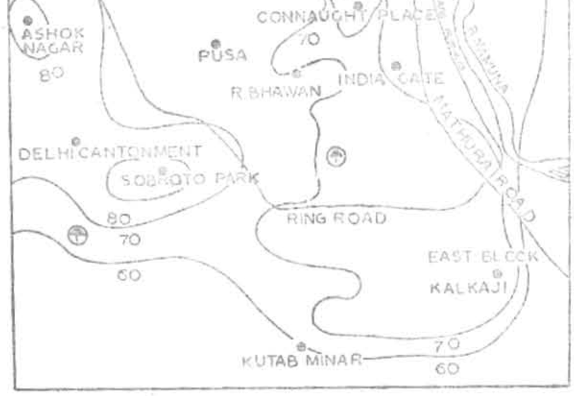


Fig. 2. Isohumes at Delhi at min. temp. epoch, 27-28 March 1979
Sky : clear, Wind : Northwest 2 to 4 kmph

urban boundary layer suggested a study of urban-rural heat fluxes and the contribution of their differences to urban heat island development.

Urban heat island studies in tropics are rather sparse. In India some studies have been made by Philip *et al.* (1974), Daniel and Krishnamurty (1972), Padmanabhamurty (1979), Bahl and

Padmanabhamurty (1979), Padmanabhamurty and Bahl (1980). But no studies have been made on the radiative fluxes of different urban areas. In the present paper it is proposed to present the results of hourly variation of heat and humidity islands in Delhi from sunset to next day sunrise and also the differences in the thermal radiant emittance from different urban surfaces and their role in the physical processes of formation, development, intensification dissipation of heat island and its dynamics on two clear, calm winter nights.

2. Materials and methods

The observational area is the city of Delhi and its environs and its meteorological features were described earlier (Bahl and Padmanabhamurty 1977, 1979). Mapping of urban temperature and humidity fields were also presented by the authors separately (Bahl and Padmanamurty 1979). An additional feature of this study is collection of hourly temperature and humidity observations at 19 points distributed in the city. At the minimum temperature epoch observations are collected at 85 points which include 19 fixed points and 66 mobile survey points. The method of reduction of mobile survey data to the minimum temperature epoch was already described by the authors (Padmanabhamurthy and Bahl 1979, Padmanabhamurthy 1979).

Hourly data of 19 fixed points were collected on two clear winter nights, *viz.*, 22-23 February 1979 and 27-28 March 1979 utilising calibrated psychrometers.

3. Results and discussion

Temperature and humidity data were plotted on locator map of Delhi every hour and also at the minimum temperature epoch and carefully analysed taking care of the effects of hills, ridges, and water bodies.

3.1. *Hourly variation of isohumes and isotherms*

(*i*) *22-23 February 1979*

Hourly observations are taken from 1700 to 2400 hr but at bi-hourly interval from 2400 to 0600 hr and at hourly interval from 0600 to 0800 hr. The isothermal pattern at 1700 hr shows a warm pocket in south Delhi, another in the trans-Jamuna area and an indication of warm pocket in old Delhi near Jama Masjid area. At 1800 hr the south Delhi and the trans-Jamuna warm pockets continued to exist and another warm pocket encompassing Connought Place and Jama Masjid appeared. By 1900 hr the three warm pockets strengthened but shifted their location towards west particularly the south Delhi one. At 2000 hr the three warm pockets continued to exist but the south Delhi one shifted to west while others remained practically stationary. By 2100 hr the warm pockets shrunk but their existence continued through 2200, 2300, 2400, 0200, 0400, 0600 hr gradually intensifying from 2200 hr and attaining highest intensity at 0600 hr. At 0700 and 0800 hr also the warm pockets remained more or less in their position but with less intensity.

Isohumes also indicated several pockets of high humidity one each near Palam, R. K. Puram, Kalkaji, trans-Jamuna Colony, D. P. School. Akashvani at minimum temperature epoch. Where warm pockets appeared low relative humidity islands existed but where there is moisture availability particularly vegetation, rivers etc, heat islands are associated with humidity islands. At 1700 hr humidity islands prevailed over Kingsway Camp, Gandhi Nagar, Jawaharlal Nehru University and a feeble one over Rajouri Garden area. By 1800 hr while the KW Camp and Gandhi Nagar islands persisted and shifted slightly to the left, the Rajouri Garden humidity island disappeared. The humidity island in the south moved towards right and extended upto Lodi Colony. With the march of time in the night these three humidity islands persisted with increasing intensity. An interesting feature is the appearance of another humidity island over Palam area from 0400 hr.

(*ii*) *27-28 March 1979*

The characteristic feature of Delhi, *viz.*, several small heat pockets are also exhibited here. This is because of the topographic feature of Delhi of having clusters of houses in colonies interspersed by green vegetation, open areas, wide roads, parks, maidans etc. At 1700 hr heat pocket in the trans-Jamuna Colony, south Delhi, Jama Masjid area and a feeble one in west Delhi existed. These picked up intensity from 1800 hr and continued to exist till the next morning 0800 hr. The oscillatory nature of these heat pockets, however is exihibited in this survey too.

The pattern of isohumes at the minimum temperature epoch also exhibited high humidity island in the trans-Jamuna Colony, South Delhi, Jawaharlal Nehru University, Ashok Nagar, India Gate and Roop Nagar areas. At 1700 hr the trans-Jamuna and south-Delhi high humidity pockets appeared in west Delhi but by 0500 hr on the next morning the pockets have become stable and appeared over Lodi Colony, Palam, Karampura, Roop Nagar and trans-Jamuna areas. These persisted till the next morning 0800 hr.

The pattern of isotherms and isohumes at minimum temperature epoch are shown in Figs. 1 and 2 respectively.

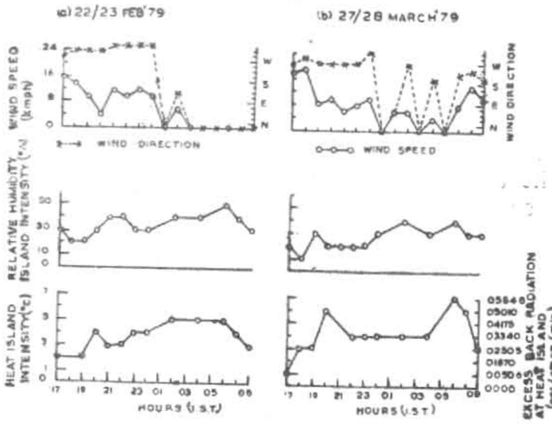
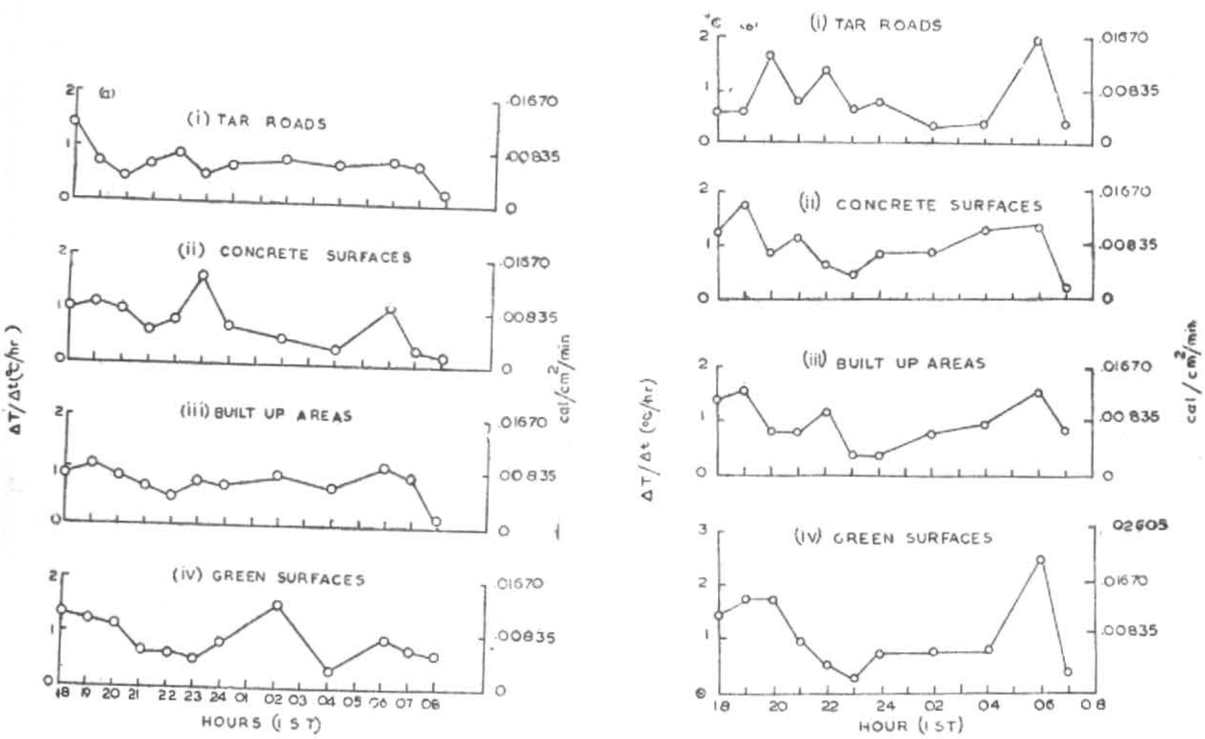


Fig. 3. March of heat and humidity islands, wind speed and wind direction



(a) 22/23 Feb 1979

(b) 27/28 March 1979 (clear sky)

Fig. 4. Rate of change of temp. and thermal radiant emittance in the night from different urban surfaces

3.2. *Heat island intensity with time*

The excess of temperature of the urban centres over the rural environs keeps the urban atmosphere from becoming stable and maintains it either at unstable or neutral conditions. In both the cases [Fig. 3 (a & b)] the occurrence of an early night peak at 2000 hr and steadiness till the early morning and another rise in the small hours of the morning. We observe that the early morning peak is stronger than the early night peak. Similar studies at Pune (Padmanabhamurty 1979) showed also two peaks but little later than the times of occurrence at Delhi. Of the two surveys conducted that in March showed higher heat island intensities in both the peaks; correspondingly the back radiations also were higher; back radiation of 3.5 cal/cm^2/hr is available at the early morning peak in March '79. Back radiation/thermal radiant emittance from different surfaces are computed by Stefan-Boltzman law assuming that the surfaces radiate at black bodies. The effect of humidity and evaporation is automatically taken care of by the temperature attained by the different radiating surfaces.

The first peak is mainly due to large differences between urban and rural temperatures. After the sunset rural areas radiate faster than urban areas owing to nature of their surfaces. These rural areas cool more in the early night and by 2000 hr or so the back radiations from both rural and urban surfaces become stable and result in maximum heat island intensity confirming the observations of Oke *et al.* (1972), Ludwig (1970) and Hage (1972). The back radiations from both the surfaces are also steady till early morning and register a minimum value in the early hours.

3.3. *Humidity island with time*

Here too, two peaks are discernible—one in the early part of the night and another in the early morning. While the morning peak coincided with the heat island peak, the early night humidity island peak has a shift by an hour or so sometimes earlier and sometimes later. As in the case of heat island the latter peak is stronger than the former. Further, both the peaks in February are stronger than in March. Similar studies in Pune (Padamanabhamurthy 1979) showed that the former peak coincided with the heat island peak while the latter did not exhibit any such relation but also declined in strength.

3.4. *Effect of wind on the heat and humidity islands*

In Fig. 3 are also plotted the hourly variation of wind speed and wind direction. It is generally observed that wind speeds were low when heat/humidity island intensity are high suggesting an inverse relationship. When wind speeds are strong it is also observed that heat and humidity islands are displaced downwind. The heat and humidity islands are strong when the winds are from west to north sector in comparison with other directions indicating the contrast between the cold and comparatively dry air in the rural environment with reference to urban atmosphere.

3.5. *Urban/rural cooling rates and thermal radiant emittance*

Oke *et al.* (1972) recognized that urban/rural cooling rates and thermal radiant emittance as causes for the dynamic nature of the urban heat island. As the rates of cooling of different surfaces differ and cause different heat island intensities the present authors have computed hourly rates of cooling and thermal radiant emittance, assuming that the surfaces radiate like black bodies, from different surfaces and presented in Fig. 4 (a & b). The urban-rural thermal system are identified as (1) Tar roads, (2) Concrete surfaces, (3) built-up areas and (4) green surfaces. The figures exhibit characteristic features of the surfaces. The rate of cooling of tar roads is faster immediately after sunset followed by green surfaces. Concrete surfaces and built-up areas cool slowly. It is this differential rate of cooling between urban concrete and built-up areas on the one hand and green rural areas on the other result in the early night peak. Likewise larger rate of cooling of green surfaces in relation to urban areas resulted in another peak in the early morning hours. The thermal radiant emittance, of all the surfaces, is highest from green surfaces and lowest from concrete surfaces followed by built-up areas and tar roads. This is the reason why in Delhi which is interspersed by built-up areas, tar roads, concrete buildings with wide maidans, parks and lawns with greenary, results in a number of small warm pockets in contrast to Pune where mainly one heat island is noticed (Padmanabhamurty 1979, Bahl and Padmanabhamurty 1979). The study, therefore, suggests that built-up areas and concrete surfaces interspersed with wide lawns and parks tend to mitigate the formation of intense heat islands. This prevents the air from the surrounding countryside flow towards the urban centre. This type of landscaping and building construction does not allow formation of intense heat islands which otherwise would have produced local centripetal near surface winds strongest across the steep thermal gradient of urban margins that would tend to bring encountered pollutants during their travel from the surrounding areas towards the heat island.

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