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Assessment of Role of Water Body on Thermal Comfort in Ahmedabad, India

Hardik Gajjar and J Jai Devi[*]

Dept. of Civil Engineering, IITRAM, India

[*]j.jaidevi@iitram.ac.in

Abstract. Increasing urbanization at rapid pace is definitely reducing the green cover and ultimately increases the urban temperature. The side cause of this elevated temperature at city centre compared to the suburbs and rural areas (Urban Heat Island) is enhancement of human thermal discomfort at the outdoor spaces and may even cause death due to heat stroke. This factor becomes a key role for urban planners and designers to create safe and pleasant spaces to live, work and commute. Several research works has been done to assess the role of green cover in reducing the UHI intensity and improve the thermal comfort, but less shade has been given on the cooling potential of urban water bodies. This work tries to investigate the effectiveness of Kankaria lake (Ahmedabad, India) that may have in cooling its nearby places (<500 m) and also on assessing outdoor thermal comfort using an index PET. Simultaneous ground measurement were taken around Kankaria lake at 4 selected locations on 10 minute interval starting from 14:00 to 16:30 in month of October for 7 days. Microclimatic parameters like air temperature, wind velocity, relative humidity, globe temperature and mean radiant temperature were measured using hand-held devices. Results indicate that the western side of Kankaria Lake observed drop in 0.2°C compared to the eastern side. Whereas, PET showed drop in maximum of 1.44°C on the western side, but it was still under the stress condition as per PET scale for sub-tropical climate zone.

1. Introduction

Achieving a pleasant outdoor thermal environment is important for any outdoor space. Rapid urbanization is leading to significant changes in land-use thereby, influencing the environment [1]. Research has shown that a comfortable outdoor thermal environment can promote outdoor activity and thus improve physical and mental health [2]. The thermal budget of a human body can be strongly influenced by electromagnetic waves that are coming from the sun, convection in the surrounding air and evaporation of sweat. Even a rise of 1 °C can trigger regulatory mechanism by increasing skin perfusion and sweating. Therefore, high levels of heat exposure may result in health problems ranging from normal heat rashes, heat cramps and heat exhaustion to lethal heat strokes [3-4]. Globally, significant amount of research is carried out to understand and quantify thermal comfort in open spaces of urban regions, often with the aim of providing design guidance to generate better quality of urban spaces that could offer better thermal comfort. Thermal comfort is defined by ASHRAE 55-2010 [5] as '*The condition of mind in which satisfaction is expressed with the thermal environment*'. Thermal comfort is a subjective parameter that varies from person to person depending upon the person's age, body type, metabolism, type of cloth he is wearing and many more [5]. Several indices have been developed to assess the thermal comfort of human beings, taking environmental conditions and energy balance of a human body into consideration like Predicted Mean Vote (PMV) [6], the new effective temperature (ET), the Standard Effective Temperature (SET) [7], and Physiological Equivalent Temperature (PET) [8]. The PMV index is based on the predicted mean vote of large group of people who assess an actual thermal sensation, generally analysed by carrying out questionnaire

survey [5]. The PMV index uses the ASHRAE 7-point thermal sensation scale ranging from -3 to +3; where negative value indicates cooler perception and positive value indicates warm and hot perception and 0 indicates neutral feeling or acceptance of current environment. Whereas, PET is that air temperature at which, in a typical indoor setting (without wind and solar radiation) the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed [8]. PET are based on climate-chamber analysis of human energy balance and integrated effects of microclimatic parameters like air temperature, wind velocity, relative humidity and mean radiant temperature on a human body. PMV and PET indices are widely used in outdoor thermal comfort studies [9-12].

Abundant research has been done on thermal comfort in indoor spaces, focusing on classrooms [13 – 15], residential buildings [16 - 18] and offices [19 - 21] as compared to that on outdoor spaces which mostly focuses on pedestrian level thermal comfort [10, 11, 22]. One of the important factors for this is that people spend almost 80-90% of their time indoors [23] as opposed to only 10-20% outdoors. Furthermore, outdoor spaces face variable and uncontrollable climatic conditions as compared to indoors where one can adjust the conditions as per convenience. It also becomes difficult to reach thermal steady state in outdoor environment to get proper thermal comfort results [24]. Limited studies have been carried out in India in domain of outdoor thermal comfort. An objective and subjective survey was carried out in a tropical city of Bhopal in three different type of open spaces which included urban parks, lakefronts and open lanes of a market [9], The results indicated that the thermal comfort index (PET) was higher at urban parks than the defined comfort limit of 30 ℃ during the afternoon hours of the study. Another study was carried out in context of redevelopment of slum areas of Dharavi in Mumbai to obtain optimal thermal comfort [25]. They found that vertical morphology was the most suited for better thermal comfort. Studies have shown that high-rise buildings have 'cooling effect' due to it shading compared to 'low-rise' buildings and wide streets which caused 'heat island' during afternoon due to stagnated wind and incident solar radiation [26]. Wind amplification combined with shading effect also could generate thermally comfortable conditions in the open ground floor, beneath an elevated building [27]. Lower SVF values closer to zero indicate barely visible sky and higher SVFs closer to 1 indicate highly visible sky. It was observed that lower daytime temperature (cool island) and higher night time temperature (heat island) were usually co-related with lower SVFs [28, 29].

Of particular interest, to provide better thermal comfort is the provision of vegetation and green cover. Both large and small parks have been found to provide cooling with the effects propagating to a distance approximately half the park width away, dependent upon local street layout [30-32]. Open water bodies offer a source for moisture in order to back up the oasis effect over day duration, especially the region is invaded by drier, larger-scale warmer surroundings [33, 34] of urban environment. Water bodies are also particularly supposed to assist in cooling down the air around them via evaporation [34] and convection [33]. The objective of this study is to investigate the cooling potential of a water body on the microclimate of city streets around it during afternoon hours.

2. Data and Methodology

2.1 Study area

Ahmedabad, an industrial city in Gujarat, India, is located on the bank of river Sabarmati between latitude 22 ° 56′ N and longitude 72 ° 41′ E. Climatic condition of Ahmedabad is classified as 'Bsh', hot steppe climate (semi-arid) according to Köppen and Gieger classification [35]. Ahmedabad experiences three main seasons: Summer, Monsoon and Winter, of which weather is hot from March to June with an average summer maximum of 43°C and average minimum of 13°C. The south-west monsoon brings humid climate from mid-June to September and annual average rainfall is estimated to be about 800 mm. This study was carried out around Kankaria Lake, which is second largest manmade lake in Ahmedabad, India located in south-eastern part of the city (23.006 N, 72.6011 E). The diameter of the lake is approximately 560 m and maximum depth is 7 m [36].

2.2. Data collection
Air temperature, relative humidity, globe temperature and wind speed was measured in the site. The first three parameters were measured using Tenmars TM-188D and wind speed with Testo 405i. Sampling points were selected as South West, North West, North East and South East directions of the lake and are named as Site A, B, C and D respectively, as shown in Figure 1. The distance of sites from the nearest periphery of lake were 182.65 m, 102.95 m, 188.43 and 200.23 m respectively. Data recording were started from Site A at 14:00, after 10 minute of interval i.e. at 14:10 next measurement was taken at Site B and in similar manner for next two sites. The measurements were continuously taken till 16:30. At each site 4 data points were collected in a day. The procedure was repeated for 7 days from Oct. 13-20, 2018. It was also observed after 16:30 H that the shadow of buildings and trees were reduced the air temperature significantly. So the role of lake on air temperature could not be deduced during shades. Therefore, an attempt to record further was not made at any day after 16:30 H. The measurements were taken at a height of about 1.1 m above the ground and about 1 m away from any nearby building or wall as per ASHRAE 55-2010 guidelines [5]. Care was taken to avoid discrepancies of additional heat due to vehicles by keeping distance of about 1 m. Mean radiant temperature (T_{mrt}) is defined as 'the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in actual non-uniform enclosure'[5]. It is influenced by both short-wave and long-wave radiation and has a strong effect on human thermal comfort [24]. It is calculated using equation (1) [37].

$$T_{mrt} = [\frac{(T_g+273)^4 + (1.10*10^8*v^{0.6})*(T_g - T_a)}{\epsilon * D^{0.4}}]^{1/4} \qquad (1)$$

Where, T_a is air temperature (℃), T_{mrt} is mean radiant temperature (℃), T_g is globe temperature (℃), v is air velocity (m/s), D is globe diameter (m) (=0.05 m in this study) and ε is emissivity (=0.97),

Figure 1. Sampling points (Image adopted and modified from Google maps)

3. Results and discussion

3.1. Intra-urban heat island analysis
Urban heat island is a phenomenon where the city tends to face higher temperature compared to its suburbs and rural areas [38]. There are factors that cause higher temperature at city centre like heavy traffic, concrete buildings and pavements that tends to absorb incoming solar radiation and release it during night time which in turn gives rise to night time urban heat island effect. Whereas, in rural and suburbs, the above mentioned factors are in less proportion with an increase fraction of green cover and vegetation compared to the city. The same can be observed within the city as well which can be

termed as intra-urban heat island effect. This is due to the fact that the area in the city having green cover or water bodies helps in reducing the air temperature of its nearby area, approximately to the extent of width of the river. [39, 40]. In this study, an attempt was made to check for any reduction in air temperature due to the presence of water in the Kankaria Lake during the peak sun hour. The daily averaged air temperature variation around Kankaria Lake during the time of measurement is shown in Figure 2. Site B in the north-west direction to the lake was the coolest of all whereas, Site C was hotter than rest. From Figure 2, it can be seen that the Site B's periphery is covered with lush green trees and the streets are wide which helps in reducing temperature. Site C was found to have heavy traffic flow that increased the air temperature [41].
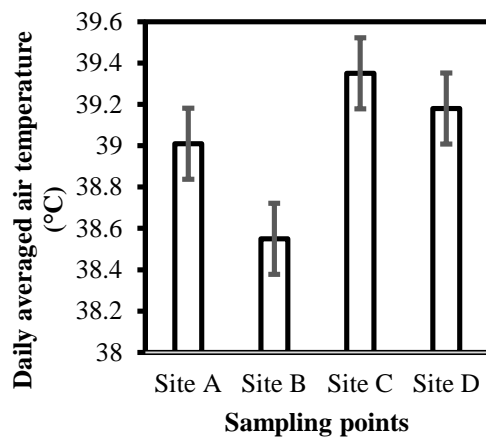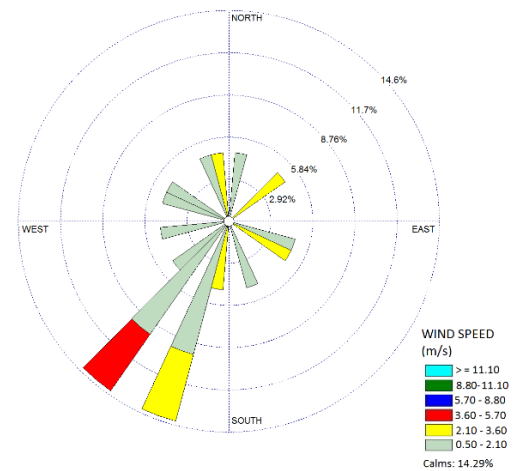

Figure 2. Daily averaged temperature

Figure 3. Wind rose plot for Kankaria Lake

Figure 3 show the wind rose plot for Kankaria Lake consisting of hourly (14:00 to 16:30) wind speed (m/s) and hourly wind direction (degrees) of all study days. Wind speed and direction were retrieved from the weather station (reference station), installed at elevation of about 30 m above ground level and is approximately 3 km away in eastern direction from the Lake. From Figure 3 it can be seen that the strongest wind gust was blowing from the south-west direction i.e. from Site A towards north-east (Site C) that infers the upwind direction was cooler by 0.34 ℃ than the downwind direction. This could be due to the prominent effect of air turbulence near surface that minimizes the effect of wind direction, if any, on the air temperature.
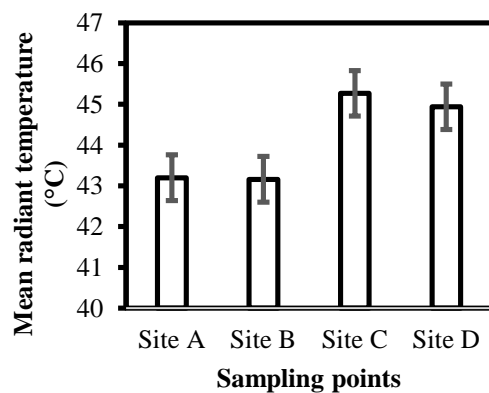

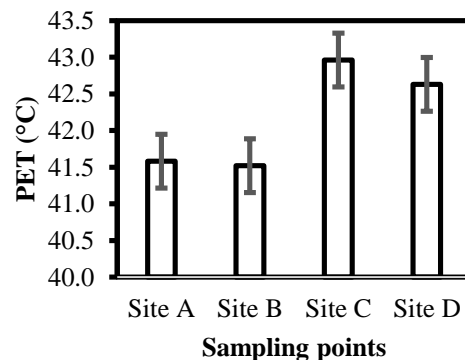**Figure 4.** Daily averaged Mean radiant temperature

Figure 5. Daily averaged PET

Figure 4 shows Site C has highest mean radiant temperature of 45.27 ℃ followed by Site D with 44.94 ℃. The reason behind this is that, Site C and Site D were directly exposed to sun during the measurement duration. Although Site A and B were not directly exposed to sun due to obstruction of buildings and dense tree covers, but were observed to have low to moderate traffic flow. Hence, direct exposure to sun played prominent role in elevating air temperature and green covers and buildings (from Site A and Site B) played role in suppressing the air temperature. In general, it is street orientation, aspect ratio and green cover control the intra-urban heat island effect and similar was observed by [26 - 29]. The differences between air temperatures of study area were again compared with the reference station. This could give some idea about intra-urban heat island effect.

As altitude difference can have an impact on temperature due to lapse rate, but that will vary with time of day and weather. A study was carried out to compare the air temperature measured by weather station to that measured by Tenmars 188D from 1430 H to 1600 H. The air temperature measured near the surface was 1.91 ℃ warmer than that of the weather station. This value was added to generate urban reference temperature in order to account for the height difference. ∆T for sites A, B, C and D were found to tbe 0.5 °C, 0.1 °C, 0.8 °C and 0.7 °C, respectively. The results clearly indicate that the reference site is cooler than the lake. This is because the reference station is surrounded by dense building form and narrow street width which creates higher rate of turbulence to wind, that ultimately helps in reducing the temperature. This means that, the lake didn't had positive effect on cooling the surrounding as it was hypothesized, but it was building orientation and aspect ratio of the urban land form that was playing role in cooling the reference site and site A and site B of the study area.

3.2 Physiological equivalent temperature (PET) – an index for thermal comfort assessment
Outdoor thermal comfort is mainly associated with the UHI phenomenon [38, 42]. However, the air temperature is an inadequate measure to investigate the thermal comfort [43, 44]. Human thermal comfort is mainly based on a combined effect of the physical and climatic parameters. According to Höppe [8], wind speed, air humidity and solar radiation also affect the thermal comfort conditions. The outdoor thermal comfort conditions have been investigated in different areas around the world, based mainly on the mean radiant temperature and physiological equivalent temperature (PET). PET is based on human energy balance in terms of Munich Energy Balance Model for Individual [8, 45, 46]. he daily PET was estimated by using RayMan Pro software [47, 48]. Variation in PET with respect to the direction from lake is represented in Figure 5. Variation in PET showed similar fashion as air temperature. Western part was cooler than eastern part, with north western side being 1.44 ℃ cooler than north eastern side and south western side was 1.05 ℃ cooler than south eastern side. The PET values obtained indicate that the 'Hot' thermal sensation prevails as per the PET scale defined for temperate climate [49]. This means that, there is very mild effect of the water mass of the lake.

4. Conclusion
The present study was carried out in order to assess the cooling potential of the Kankaria lake to its surrounding areas which lead to contrasting results as hypothesized, as the lake didn't seemed to have been actively engaged in regulating temperature. Western part of the lake was found to be cooler than its adjacent eastern part and the reason found out was the street orientation (observed for Site C and D) and building geometry (observed for Site A and B) played role in varying temperature. Similar results were obtained when the temperature difference between reference site and the study points were analysed; where the reference site was found to be cooler than the study points. Thermal comfort was also assessed using simulation software RayMan Pro in which PET was calculated which showed similar pattern in variation as same as air temperature. It was found that the PET was still in the 'Hot' thermal sensation as defined by PET scale for temperate climate probably due to the aspect ratio, street orientation and sky view factor playing active role in governing the temperature variation.

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