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Effect of urban Morphology on Subtropical Humid Microclimate: the case of Bhopal, India

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***Abstract*: *In a humid subtropical atmosphere, urbanisation leads to increased thermal stress. The outside thermal stress depends on the flexibility of the geometrical arrangement of the buildings and its morphology and also materials to absorb solar radiation (albedo). The purpose of this study is to look at the influence of the morphology and water bodies on the microclimate of Bhopal, a town in central India. In this study the impact of urban morphology on microclimate is assessed through filed measurements. The field measurements included ambient air temperatures, humidity and wind speed. These metrological parameters were measured at nine sites in which three are in the old city, four in a new city and two sites falls in the suburbs. All three types of sites differed in terms of the building height by street width (H/W) ratio, ground cover, and distance to the lakes. In urban areas air high-temperature differences were mostly found during daytime. A highest intra-urban dissimilarity of 6ºC has been traced on clear days. Within the urban areas, the humidity was found normal (up to25-30%), and showed little diurnal variation. Few other factors that affected the temperature were also observed and are discussed in this paper*.**

Keywords:* *Urban geometry; Subtropical climate; Climate-sensitive urban design; urban heat island; Bhopal city morphology

I. INTRODUCTION

In India in 1971 there were only about 150 cities with a population of more than half million but in 2015 this figure had reached 500. And if this trend persists, it is expected that more than 800million people will live in Indian cities by 2050. (Nandy 2011).Because of reckless urbanization in India, bionomical impoverishment has been taking place very rapidly. It is causing a lot of troubles like excessive air and noise pollution due to heavy traffic and industries, land insecurity, worsening water eminence, and the troubles of waste dumping. (Singh 2017). Due to rapid urbanization, several environmental changes are observed. This have been observed that researches in fields like climatology, agriculture, geography, and medicine (Gibson & Harrison 1976, Lake et al. 1993) are receiving more attention. Attention is also been receiving in the urban climate of tropical cities (Emmanuel et al., 2006).

II. URBAN CLIMATE DEVIATION IN SUBTROPICAL CITIES

Over the last sixty years in the developing world, a dramatic growth of its urban population is seen and it is related to serious degradation of environmental quality. Most of the part of population of developing countries is found in subtropical –tropical regions, (Roth M, 2007). The effect of Urban Heat Island, at night time is studied well. But at the day-time urban climate is not taken seriously because it is observed that in general, the rural-urban differences are shorter by day than by night,(Arnfield 2003, Emmanuel 2005). This is studied well that building shade on streets can lead to a cool daytime island in deep canyons (Oke et al. 1991, Johansson 2006). A tropical Urban Heat Island observation for both, daytime heat and Cool Island has been studied by Johansson (2005).In comparison to cooler climates, hot climates tend to lead to larger intra-urban thermal differences (Emmanuel 1997). Emmanuel (2005) discusses the variation in urban microclimate and its effect on thermal comfort in the hot-humid tropics. Ample work on microclimate has been conducted in, Southern and Central American cities. Also few researches been performed on Indian subcontinent cities. Case study of Tripathi et al., (1996) on seasonal variation of concentration of nitrate and sulfate aerosol in ambient air in Varanasi; Latha, and Badarinath, (2005) studied in Hyderabad on a variation of air pollution in different seasons. Varshney and Padhy(1998) performed experiments to determine the total pollutant in Delhi. Sharma and Maloo, (2005) assessed the concentration of pollutants in ambient air in Kanpur, Ghose, et al., (2005) assessed the characteristics of urban air pollutant with their effect on the health of Kolkata residents.

III. THE AIM OF THE STUDY

Many studies on urban thermal comfort at street reveal that urban morphology of any city is one of the major factor, which is responsible for change in its microclimate. These studies might facilitate urban planners and designers to designing buildings and to plan better urban areas harmonious with microclimate and thermal comfort. Therefore the aim of this study is to analyse the result of morphology on microclimate for thermal comfort of open streets within the subtropical humid city of Bhopal This study is additional descriptive experimental work that seeks to point the physical meteorology of sub-tropical cities.

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number of past reviews has been found on the topic of Urban climate-related work , but in cities located in the subtropical region, all lamenting the relative lack of studies carried out. Inquiry into sub tropical urban climate also lags behind that for cities of developing country like India.

Urban heat island intensities are usually lesser as compared to those of temperate cities with a comparable population and show a seasonal variation with lower /higher intensities throughout the wet /dry season(Roth M,2007).The amount of UHI studies in tropical cities has magnified in recent decades (Arnfield 2003). However in subtropical cities, studies are very few as compared to the amount in temperate climates, particularly regarding the influence of urban microclimate at daytime. This study will facilitate within the climatic condition design of the building to reduce the energy consumption in a very similar form of climates.

IV. Study Area

Bhopal has a median elevation of five hundred meters. It situated within the central a part of India and is placed on a plateau. Town has very less flat grounds and consist of little hills inside its boundaries. Geography of Bhopal city includes two lakes particularly upper lake and lower lake, put together called the Bhoj wetland. The microclimate of Bhopal varies from place to place while concerning geographical conditions.

A. Urban structure

Bhopal, capital of Madhya Pradesh, is a mesmerizing combination of magnificent beauty, an old historic city, and contemporary urban development. It still preserves its old attraction of being a historical city speckled with monuments, vibrant bazaars, and lakes. The City is mostly separated into two parts viz. old Bhopal and new Bhopal, based on the period of development of the city. Most of the residential buildings in Bhopal city are low-rise. Now with the extension of the city, the development is going towards the form of medium rise buildings. Also, due to various schemes of government, several government residential colonies are now being converted into medium rise buildings. The city has grown in all the directions (Fig. 1). In new Bhopal, wider streets and low-rise buildings give low H/W ratios, while a high H/W ratio observed in the case of old Bhopal. The city also has many parks. The outskirts of Bhopal are characterised as semi-urban; buildings are found on both side of the roads and therefore the areas in between accommodates agricultural land, together with cash crop fields and open areas.

B. Urban morphology and type of construction in City

Microclimate within the streets is affected by its morphological character, geometric pattern, orientation, built density, and available green spaces [Kushol S et al., 2013]. A major design consideration is the visual impact of the building. Buildings were constructed of materials (steel and concrete) that are not suitable for the region's environment. Dwellings constructed as a large enclosed glazed space with very less provision for ventilation and protection from the sun. Also, construction of almost all buildings in new Bhopal is of a reinforced cement concrete (RCC) system. RCC is used in columns, beams, floors, and roofs; with bricks and cement plaster for the exterior walls and interior wall partitions. A major design consideration is that of the visual impact of the building. Buildings were created of materials (steel and concrete) that aren't appropriate for the region's setting. Buildings created as an oversized glazed area with terribly provision for ventilation and protection from the sun. It's utilized in columns, beams, floors, and roofs; with bricks and cement plaster for the outside walls and interior wall partitions. All this construction is without the use of any insulation materials. Whereas in old Bhopal, old structures made of stone and load-bearing walls are still intend. But most of the load-bearing structures in residential buildings are now having been converted into framed structures.

Fig. 1: Building materials and construction system used.

In Table 1, for study of city morphology the principal indicator of typical modern and conventional structures of new and old Bhopal respectively are summarised. That includes identical parts, like design style, form of construction, building materials, and micro-climate. Alternative influencing factors like social customs and social science have conjointly been mentioned.

Table 1: Main features for typical modern /old buildings of Bhopal

SN	Main points	Type of residential buildings in new Bhopal	Type of residential buildings
1	Architectural design	Houses are either detached or attached one-sided only.	All houses are attached commonly from three sides
		Usually no courtyard are give but balcony are provided everywhere and somewhere terraced are also given. Front rooms look outwards to garden then road after that.	Courtyards are provided.
		Flat roofs with parapet, not forever high enough to prevent being overlooked. Solely temporary roofs are pitched roofs.	Same as in new Bhopal.
		Most floors are of same height 9’ to 11.’	Floors height is variable 11’ to 15.’
		Outside openings on to street after giving some space, as per provision given in bylaws.	Outside direct openings on to street.

2	Construction and building material	Wall construction: the development systems in most homes are skeletons frame. No cavity Wall construction is seen , in general, there are bricks used in wall construction	Load bearing structure is in most of the buildings, as the construction is quiet old in this area.
		One brick and one and half brick Wall are constructed with plastering exterior and interiors by cement mortar. Wall engineered of various thickness (20-30cm) and covering exterior and interiors by cement mortar. Also, forms of materials used on exteriors (e. g.) Marble, glass, stone for adornment.	The thickness of the wall is 30 cm and more than 30cm almost in all houses.
		Roof construction: The majority of homes have flat roofs. The permanent roof construction is of concrete having slab thickness of 10-12cm. in addition roofing materials given are of asphalt, cement mortar, roof tiles or simply a light-weight concrete layer of five cm thickness. Most of them haven't use insulation materials.	Same as in new Bhopal
		In few houses pitched roofs are given. Pitched roofs are generally of asbestos sheeting or GI sheets, i.e. temporary roofs, however, few houses have pitched roof for giving good aspect.	Same as in new Bhopal
		Most homes have decoration within and out of doors with completely different use of color and different material like glazing. The different colours are utilized in the external and internal wall of the house which is unsuitable for the climate, significantly the colour of the interior walls.	Same as in new Bhopal
		Building Material: Some of the materials like bricks are produced locally, and some material like sand is transported from the Narmada valley near Bhopal. But wood, mosaic, and marble are transported from other states	In old buildings, locally available materials are used
		Residents want to utilize all open area to be covered and utilised ; many houses covered the balconies too.	Same as in new Bhopal
3	Consideration of microclimatic conditions	Microclimatic conditions were not considered during design.	Same as in new Bhopal
		Houses are detached or semi attached, hence more than one side is exposed to sun.	Generally, only one side is exposed to the sun. Internal open spaces were provided.
		Roofs and walls are exposed to direct radiation, and multiplied thermal gain	Same as in new Bhopal
		Houses face on to wide streets. Mutual shading of buildings explicitly in front side has not seen against sun rays throughout summer.	House faces narrowing streets provide shadow in summer due to mutual shading.
4	Social customs &Economics	Most families are elementary family.	Most families are joint family, or in one house, more than one family is living.
		Few building materials that has been used for construction not offered in native Markets. Result at high cost: — construction by professionals & trades individuals.	Same as in new Bhopal

C. *Climate conditions*

There is an average range of hours of sunshine in Bhopal of 6-7 hours in winter and 13-14 hours in summer. Temperatures in summer, on the other hand, are somewhat high and are along with average relative humidity of 40-50%. There is a median vary of hours of sunshine in Bhopal of

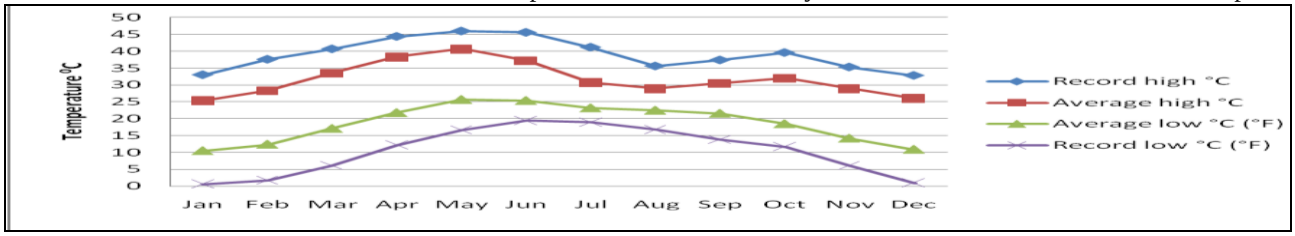

Fig. 2: Temperature variation years around in Bhopal; source Bhopal weather data

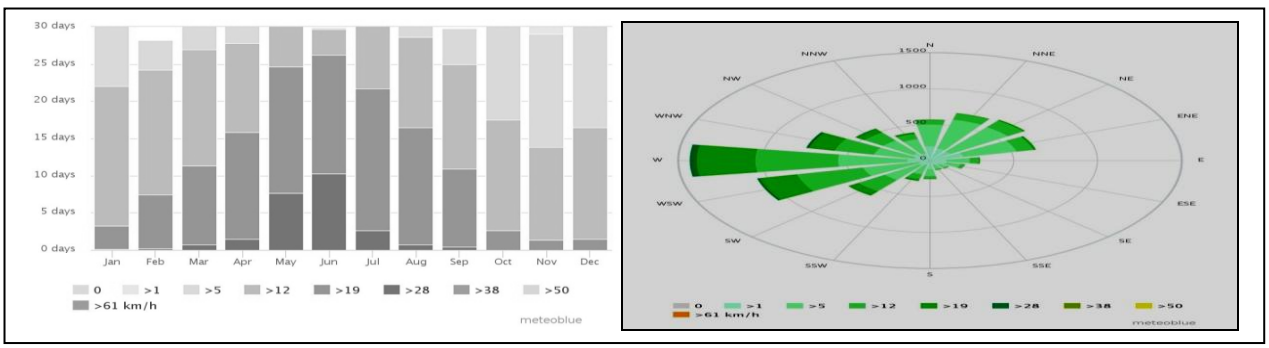

Fig. 3: (a) Number of days in each month with average wind;(b) Wind Rose Diagram, source Meteoblue Weather, https://www.meteoblue.com

6-7 hours in winter and 13-14 hours in summer. Temperatures in summer, on the opposite hand, are somewhat high , beside this humidity is also average varying from 20-50%. The most extreme temperature ascend in Bhopal is up to 45ºC. Rainstorm as a rule begin from early July and last till September end. Storms make unfaltering, solid breezes from December to April; however calm breezes from June to October.

V. METHODOLOGY APPLIED

The methodology applied after examine the buildings, for investigating other factors was selection of sites. The sites are selected by taking into consideration the factors for microclimate. Steps followed for analyse microclimate of the city are described below.

A. Selection of measurement sites

In light of the ecological states of the city, it may be very well anticipated that the significant factors that impact typical urban weather in the city are morphology, land cover and the distance from the lakes. For this exploration, nine measurements destinations have been chosen, three inside the old city and six in the new city of Bhopal including suburban areas (see Fig. 4). The urban locales speak to various neighborhoods extending from scattered, low-ascent rural territories in thickly populated midtown zones and the tall buildings in commercial areas. Type of road material used (asphalted roads and cemented roads) and green cover has also studied. There are three primary lakes in Bhopal, and chose locales are in the region of these lakes.

The land cover-up in the region of each measurement site varied, the surface materials in the urban canyons are also different, shown in Table 2. However, urban geometry and distance to the water body varied.

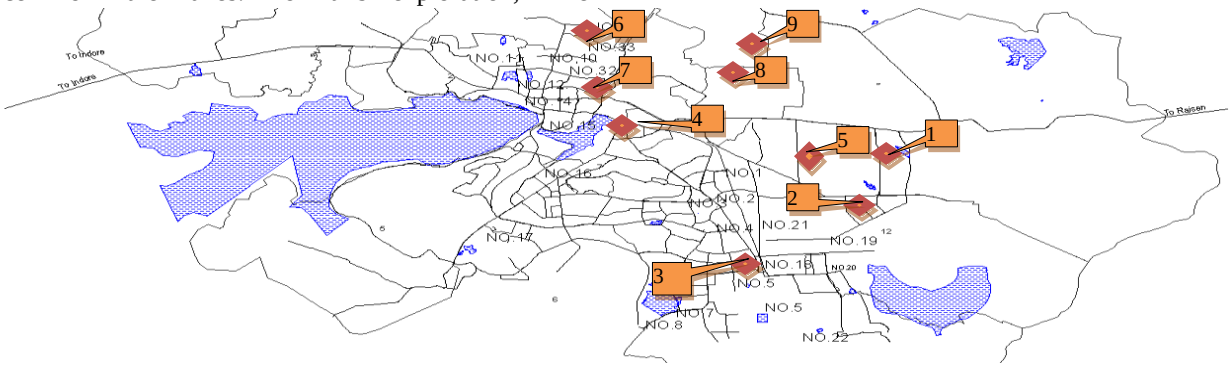

Fig.4. Bhopal Map with suburbs and locations of the measurement sites

Table 2: Details of selected factors on every site

Station no.	Site	General Description	Land Use	Buildings	Ground cover (%)[a]		
					Built-up	Roads	Green Pavings
1.	Hoshangabad Road	National highway, heavy traffic, far to lake	Commercial /Residential	Shopping malls and Low rise residential	15	75	10
2.	Air port road	National highway			10	80	10
3.	Shahpura lake	Downtown location, old residential buildings, close to the lake, medium vegetation	Residential	Low rise	30	40	30
4.	VIP road	Lake side ,medium vegetation	-	-	-	60	40
5.	Vishal Mega Mart, zone 1	Upstream location, central business district. Far from the lake, some trees	Commercial /Office	Medium rise., offices and malls	30	60	10
6.	Lalghati crossing	Barren land and rocky hill	Residential		10	40	10
7.	4 – Patee	Mixed-residential and commercial center.	Commercial /Residential	Low to medium rise	60	30	10
8.	Peer Gate	Heavy traffic area, connecting old Bhopal to new Bhopal, surrounded with old structure made of stone.	Commercial /Residential	Medium rise	40	40	20

9.	Marwari road	Main wholesale market of old Bhopal, heavy rush, and traffic.	Commercial /Residential	Medium rise	70	30	0

[a] percentage of surrounded buildings, the area, covered with road and area covered with greenery concerning the total area.

Table 3: Street details (for site keys, see Table 1).

St. no.	Type of street	H/W[a]	Openings behind buildings	Orientation	Vehicle Traffic[b]	Ground cover			Distance to Lakes(km)[c]
						Paving	Road	Green	
1.	8-lane highway	0.3	>10m	N/S	Medium	Concrete	Asphalt	Less	10
2.	6 lane highway	0.1	Fields	N/S	Medium	Concrete	Asphalt	Very less	12
3.	Residential(medium width) street	0.6	Up to 5m	ENE/WS	Medium	Concrete	Asphalt	Less	0.25
4.	Medium street	0.1	-	E/W	Medium	Concrete	Gravel	More	0
5.	Commercial, medium width street	1.0	>10m	E/W	Medium	Concrete	Asphalt	Less	6
6.	Broad street	0.1	10m	E/W	Medium	Concrete	-	Less	3
7.	Residential, medium width street	1.0	0	NNE/SSW	High	Gravel	Asphalt	Less	2.5
8.	Connecting new and old Bhopal. Old buildings which are now converted into government offices, 4lane	1.2	0m	E/W	High	Asphalt		Very Less	1
9.	A very narrow street, old whole sale market of Bhopal.	2.0	0m	N/S	High	Asphalt		Less	3.5

[a] approximate values (average)

[b] restricted vehicular, but lively pedestrian, traffic; high, medium and low traffic flows are flows all relative to the type(width) of the road, for example, less traffic in single lane road arises jam, and there seems heavy traffic.

[c] Shortest distance perpendicular to the sea

B. Field measurements

Field measurements were done during the time of October' 2016 to June'2017. The estimations were taken twice per month at mid-early afternoon to quantify most extreme day time temperature. For the present examination, perceptions are considered are in pinnacle winter (December-January) and pinnacle summer (May-June). During the estimation time frame, the normal diurnal temperature and relative mugginess have additionally been estimated from the Bhopal climate site.

(a)Anemometer (b) Hygrometer

Fig 5: Tools used in field experiment

C. Fixed stations

Ambient temperature and relative humidity (RH) inside the street canyons were estimated ceaselessly. Estimated parameters and the instruments utilized are given in Table 3 and Fig. 5. The temperature measuring device and humidity probes were set in the shade during measurement. Subsequently, the devices were placed at minimum one meter from the facades at the entire site.

Table 4: Method of observing Parameters

Parameter	Measuring height (m)	Sampling interval (day)
Ambient air temperature, Relative humidity and wind.	1.5m	15

VI. RESULTS

A. Classification of days

The estimation time frame included climate conditions going from fairly sunny morning and afternoons. The measurements have not taken during rainy and cloudy weather.

B. Air temperature

During summer, difference in air temperature has found significant in old and new Bhopal. I.e. slightly greater in comparison to winter. The difference between stations in the new city is also significant, which is due to many reasons such as distance from the lake, vegetation, and traffic etc.

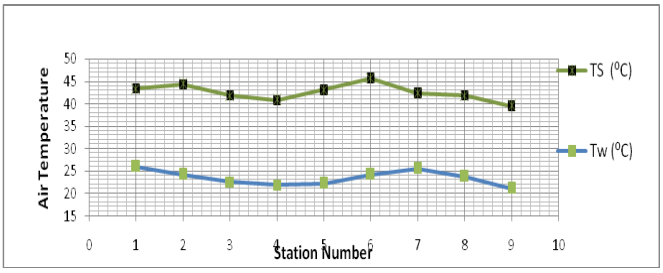

Fig. 6 Average Temperature in summer (TS) and winter (TW) at all the stations

C.. Daytime temperatures at the fixed stations

During the month of May, heat islands were observed by observing peak day temperature. Similarly in the month of January highest day temperature were observed at the urban sites. In summer, the intra-urban temperature distinction of 6°C was watched, and the majority of the old city locales were cooler than the new city station (Fig. 4). In the case of Bhopal, the observed reason for relative cooler in the old city is likely to be a due to mutual shading of the buildings.

The consequence of urban morphology is demonstrated by the inclination towards one parameter which is temperature (defined in this study as the maximum temperature was observed at 14:00 h LST). The temperature of the street decreases with increasing height by width (H/W) ratio, as shown in figure 7. The warmest site watched was station number 6, which has the most minimal H/W proportion, while the coolest destinations on mid noon watched were have higher H/W proportions. A reason is that less solar radiation is retained at

road level for bigger H/W proportions. Concentrates in hot-dry atmospheres additionally demonstrate a similar pattern, e.g.,Bourbia&Awbi (2004) and Johansson (2005).

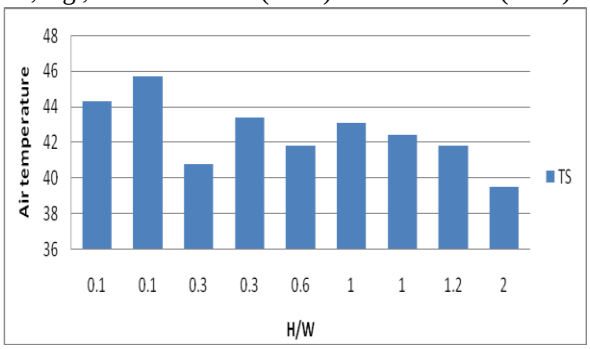

Fig.7 Temperature Variation with H/W ratio.

The clearest proof of the lake impact is the distinction of day time temperatures between the Shahapura lake (St. No 3) and VIP street (St No. 4) sites. Both sites are beside the lake, but the street near Shahapura Lake is relatively warmer. This may be due to blocking of the cool breezes by buildings. Additionally due to lake effect, significant difference in temperature difference has been observed between the cool VIP road (St No. 4) near lake and the warmest site, Lalghati crossing (St No. 6). Station no. 6 is 3 km away from the lake. Evidence of the lake effect can also be found at the Peer gate site (St No. 8, about half Km from lake) where the temperature is found lower despite heavy traffic and congested area. It is not known how deep into the city the lake effect is considerate, but the results indicate that there is a not very significant effect at street level where development is dense, as shown in figure 8. Nieuwolt (1966) had observed the same finding in Singapore. Places near the water body, or where the urban morphology permitted the breeze from nearest water bodies to infiltrate, were discovered cooler than the remainder of that city. As the H/W proportion, just as the separation and receptiveness to the water body, vary between the sites, it is beyond the realm of imagination to expect to gauge the general impact of each factor on the relatively cooler places.

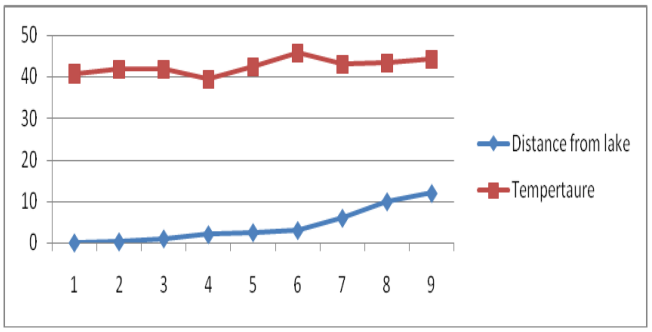

Fig 8 : Variation of temperature with distance from the lake

The ground cover likewise impacts the temperature. The vegetationless site which are covered with rocks, (Lalghati crossing) high temperature was observed, in contrast with different destinations. In any case, it must be noticed that the deliberate breeze paces were moderate,

particularly inside high-thickness building zones (by and large <2 m/s,). There is no reasonable connection between urban geometry communicated as either H/W proportion or SVF. The reason could be that these sites, which have a low H/W proportion and ground fronts of thick, dark surface materials, assimilate and store high measures of warmth during the day that is then discharged after dusk.

D. Humidity

The relative humidity (RH fluctuated between sites, yet was average around 30%, during summer and 25% during winter and dropped at the warmest sites up to 24%, shown in figure 9.

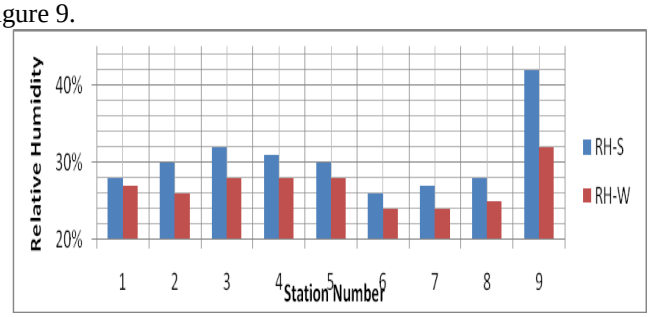

Fig. 9. Average relative humidity RH-S (Relative Humidity in summer) and RH-W (Relative Humidity in winter) on 'clear' days

E. Wind

Wind information detailed from the official climate stations demonstrated low wind speeds of about 2 m/s at the city station — and wind directions were discovered changing during the principal month of the estimation time frame. At that point thereafter, higher breeze paces are seen in summer in course less predictable from the SW, toward the part of the bargain. A set number of immediate estimations demonstrate that breeze velocities are higher in narrow streets surrounded with buildings and at the sites which are open to the lake (station number 1 and 2) than in the more profound streets (station number 8&9).

VII. DISCUSSION

This study showed that while designing urban streets, high H/W ratios might be favorable, as this leads to lower daytime air temperatures by providing shade at street and opposite buildings. However, humidity may arise when the width of the street is too less, because of inaccessibility of sun rays. The cool breeze from lake infiltrated the city ought to be encouraged by opening up the barriers. At present, medium-rise structures go about as an obstruction along lakeside and crossing points comprise primarily of thin avenues. Vegetation is important to give shade to individuals, structures and urban surfaces. This could be accomplished by planting more greenery by any method (green roof, green wall etc.). Places with Less vegetation and uncultivable soil expanded the temperature.

Heavy Traffic on the roads is one of the reasons for rise in the temperature in old Bhopal though due to high H/W ratio and lake nearby prevent more rise in temperature.

VIII. CONCLUSIONS

The microclimate has been estimated at seven urban sites (4 in the new city and 3 in the old city) and two at the suburban areas of the Bhopal city of India. The temperature variations of 6ºC were observed between the two urban sites on clear days. Hence a significant effect of Urban morphology on daytime air temperatures; is seen in this investigation. It is seen that the most extreme day temperature decreases with expanding street H/W proportion. There was likewise proof of water body impact; destinations close to the lake were essentially cooler than other urban sites which are far from lake. In each of the three distinct areas of the sites, the intra-urban and urban-rural temperature difference were discovered which is more in summer seasons. Wind speed were low, yet would in general decline in deep streets. The discoveries of this investigation could add to the advancement of climate-sensitive urban design guidelines for urban morphology, street layout, and landscape control in Bhopal and other cities with a similar climate. Additionally this investigation reveals that how the development pattern of a city effect microclimate. To improve the microclimate in different parts of the city, further studies are needed to develop adaptation strategies. Computer simulations with experimental work can assess more climate responsive design ideas. Increasingly experimental studies are expected to investigate various approaches to make conceal in the urban condition without lessening air flow.

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