Contribution of Street Design towards Creating Best Possibleurban Micro Climate- Analyzing the Effect of Street Geometry

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Abstract— **The street is the interface of the Urban and Architectural scales. Designing the street is, hence a key issue in a global approach for the environment urban design. The street design influences both outdoor and indoor environments. Understanding how this happens and formulating recommendations to create the best possible urban microclimate, is the aim of this paper. Streets as considerable parts of urban open spaces have a significant role in creating the urban microclimates. As street geometry and orientation influence the amount of solar radiation received by street surfaces and also airflow in urban canyons. This paper discusses the current literature and evidence for the effects of street design on the urban microclimate with highlighting the impacts of streets geometry (H/W ratio) on solar access in an urban canyon. Researches conducted on this term have proved that street's geometry and orientation are key factors in providing a pleasant microclimate at pedestrian level in an urban canyon.**

Index Terms: **Microclimate, Street Geometry, Regression Analysis.**

1. INTRODUCTION

The various land uses are to be woven together by a network of streets. Land use and

Circulation should go together to grow in a planned direction.

The street and road system of the development is one of the major design elements of the site plan. Not only it is the single greatest construction, but it acts as the framework for lot and building layout, greatly affecting solar access to the development.

Since the beginning man has been affected by climate & its influence on earth. There is no doubt that climate is among the important factors that influence the quality of the planning solution from the energetic point of view, and should be taken into consideration during the planning process. Yet, we witness repeated attempts to implant an universal, international style in planning. Such a style is, generally, more a matter of fashion than consideration towards the location. On the other side, examples from history can teach us that sustainable planning is created only while paying attention to the local conditions, using and taking advantage of its natural resources. Therefore, a constant dialog and direct link should generate between location, climate, and planning.

In the words ofPhilosopher Vitruvius, " *we must at the outset take note of the countries and climate in which buildings are built."*

Studies show that when a landscape of plants and soil give way to bricks and concrete, the local climate changes with the scenery. Understanding how this happens can help us to take control of the process. We can design subdivisions so as to create the best possible urban microclimate. The result will be:

- A more comfortable environment.
- Less energy needed for indoor comfort
- Money saved.

Instead of expensive technology natural environment must be used as a planning tool.

2. NECESSITY OF THE PRESENT STUDY

The street is the interface of the urban and architectural scales. Designing the street is, hence a key issue in a global approach for an environmental urban design. The street design influences both outdoor and indoor environments i.e. the potential for passive solar gains inside and outside the building, the permeability to wind flow for internal and urban ventilation, the absorption verses reflectance of radiation, as well as the potential for cooling of the whole urban system. By implication, the street form affects the thermal sensation of people as well as the global energy consumption of urban buildings.

3. OBJECTIVE OF THE PRESENT STUDY

This study seeks to understand the contribution of street design i.e. the aspect ratio, solar orientation, vegetation and material, towards the development of a comfortable microclimate at street level for pedestrians. The focus is to put the results obtained by literature survey in the form of design guidelines for the five major identified climatic zones. And detailed study of nine urban areas of Nagpur City and Statistical Analysis of the impact of its H/W ratio on the ambient Temperature.

4. METHODOLOGY

To attain the objective following aspects are investigated-

- Study of modifying factors of Micro climate of street.
- Traditional city layout and climate.
- Requirements of different zones of climate.
- Identification of key strategy of street design for promoting comfort.
- Summarizing the significant findings in the form of recommendations.
- Detailed study of nine urban areas of Nagpur City and Statistical analysis of the impact of its H/W ratio on the ambient Temperature.

5. LITERATURE REVIEW

5.1Modifying factors of Micro climate of street

The various modifying factors are aspect ratio, orientation, construction material, presence of vegetation etc.

5.1.1 Impact of street width and orientation on urban climate

The orientation and layout of streets has a significant effect on the microclimate around buildings and on the access to the sun and wind for use in building.

The width of street determines the distance between the buildings on both sides of the street, with impacts both on the ventilation and solar utilization potential. The layout of streets also greatly determines the ventilation potentials of the buildings, as well as the outdoor ventilation conditions.

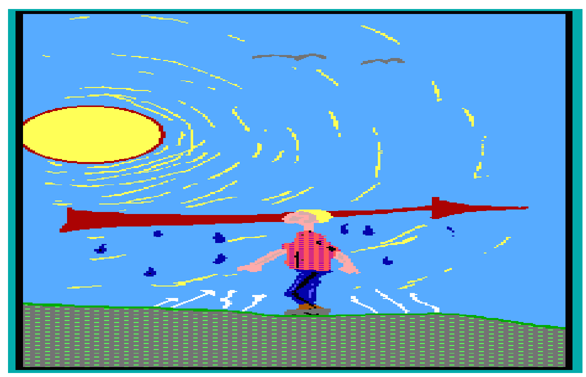
Proper street orientation and layout of homes can have considerable effect on the shading, which affects the urbanmicro-climate and environmental performance of the buildings. Building heights, proximity, and street width influence the heat generation characteristics of the street surfaces and surrounding grounds in the local urbanmicro-climate.

The orientation of streets affects the urban climate in several ways

- Sun and shade in the streets and the side walks.
- Solar exposure of the buildings along the streets.
- Wind conditions in urban areas as a whole.
- Ventilation potential of the buildings along the streets.

Important Factors of Climate

- The Sun Factor
- The Wind Factor



The Sun Factor

The amount of direct radiation received on the street is determined by the street width. The orientation affects the time of the day when the radiation is received. Modulating the street width and orientation can very effectively control solar radiation.

The Solar altitude and azimuth determines the position of the sun. The street width to building height ratio determines the altitude upto which solar radiation can be cut off. The street orientation determines the azimuth upto which solar radiation can be cut off. As a result they can be used very effectively to minimize or maximize heat gain.

The Wind Factor

Air movement in streets can be either an asset or liability, depending on season and climate. It affects body cooling. Wind is desirable in the streets of hot climates to cool people. It does not decrease the air temperature but causes sensation of cooling due to heat loss by Convection and due to increased evaporation from the body. It also becomes a potential resource to cool building by cross ventilation.

In Dust prone areas, common in Hot dry regions, wide streets parallel to the wind direction may aggravate the dust problem in the town as a whole. As the wind direction in many of the hot-dry regions is from the west, there is a conflict between the solar and the dust considerations with respect to street orientation. This conflict can be resolved by design means aimed at suppressing the urban dust level in the whole city. Street width to building height ratio also affects the daylight received.

Tall buildings on narrow streets yield the most wind protection, while shorter buildings on wider streets promote more air movement.

5.1.2 Vegetation

The vegetation is a modifying factor of the local climate. The use of vegetation is a complimentary strategy for mitigating heat stress at street level. The use of the green as a strategy to mitigate the urban Heat Island (UHI) and improve the micro-climate has been widely emphasized. Primarily, the vegetation possesses three main properties which affects the climate:

- Shading
- Humidification(evapo-transpiration)
- Wind break.

Indirectly, it also acts as a medium to trap water inside the soil. Any use of vegetation for improving the microclimate has to exploit judiciously these properties according to site comfort requirements.

Within an urban structure, the climatic effectiveness of the vegetation depends on the ratio green area/built up area, as well as on the size and own characteristics of the plant (species, density, shape size, vol. etc.)

Basic aim of vegetation must be-

- Increasing wind movement in summer
- Allowing solar access in winter.

Selection of species of tree is very important, otherwise it can influence the microclimate negatively.

For cold climates using the vegetation as screen against high winds is more appropriate and dense vegetation located at the urban edges is advisable.

5.1.3 Importance of the pavement material

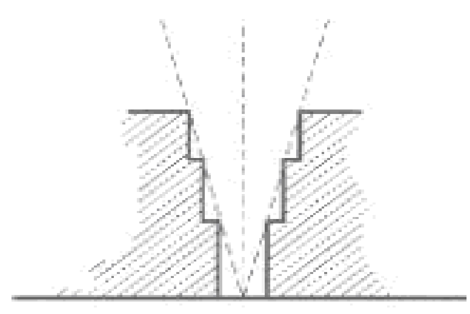
Depending on the ground surface, incident radiation can be absorbed, reflected or stored and reradiated later. Depending upon the climatic context we can either increase or decrease the radiative heat gain during the daytime or increased during the night time. The colour and texture of a material's surface determined its reflectivity. The lighter the colour and smoother the surface, more the reflectivity of the material. The darker the surface and rougher it is, the lower the reflectivity. Such materials would store more heat and reradiate it at night when the surroundings are at a lower temperature.

Asphalt pavement emits an additional infrared radiation as compared to a bare soil surface. The water contents in a bare soil and its evaporation produces much lower surface temperature. A combination of hard surface i.e. tiles and grass can be a best solution for hot climates. Concrete streets reflect more heat back into the atmosphere; asphalt streets absorb and store more heat.

6. STREET DESIGN AND THERMAL COMFORTFOR VARIOUS CLIMATIC ZONES

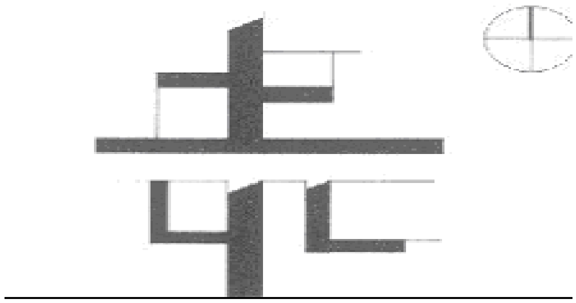
6.1 Hot - Dry

The reduction of heat gains by solar radiation has a higher importance. Sun protection is essential. The mutual shading of adjacent buildings should be used and narrow streets and alleys should be provided and oriented for minimum exposure to the sun only during a short time of the day.

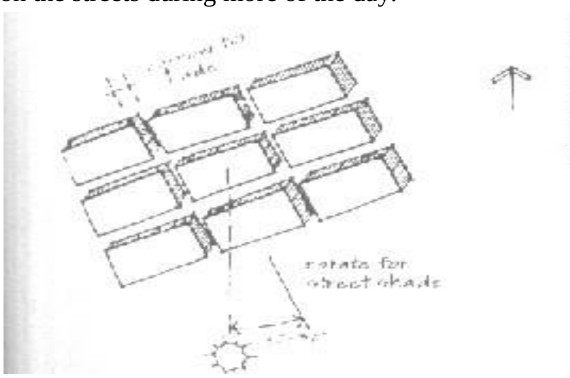


Small street width to building height ratio ensures narrow streets and , thereby, shading

Street widths in hot climates
Narrow North-south streets minimize eastern and western radiation

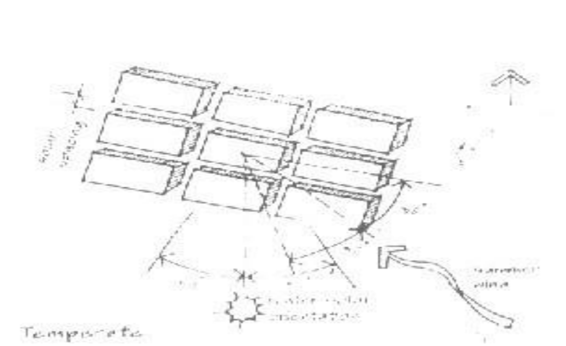


Wide E-W running streets allow south sun
Rotate the street from cardinal to provide more shade on the streets during more of the day.



Suppressing the dust level is also a must in most of the regions of this zone. Narrow alleys give protection against dusty winds and sand storms. Trees will also filter blowing dust form the air. Trees are Nature's own evaporative coolers perfect for the dry climate Strategies must modulate the urban fabric in a way that responds to seasonally changing solar geometry, encouraging a shaded pedestrian realm in summer and solar access to buildings in winter. The exact orientation of the streets can be determined by considering the solar geometry in combination with building heights. This will enable to orient the streets such that uncomfortably low sun is shielded off by the buildings.
For Hot climate, the best use of the vegetation should profit from its shading property to mitigate the intense solar radiation. The evapo-transpiration is often weak owing to the lack of water in the soil
In Hot climates ground surfaces should preferably be green in order to minimize heat gain. When hard surfaces are unavoidable they should be rough and not dark.This makes the surface less reflective and also not highly absorptive. The ground surface also reflects light and in sunny climates this leads to uncontrollable glare. Hence, hard paving should be minimized and rough

6.2 Warm-HumidClimates
In a warm humid climate, we need air movement to keep us comfortable. Streets and buildings must be oriented to catch the breeze. A mix of building heights promotes ventilation. Vegetation must not impede air movement, trees with branches far from the ground, such as palms would be ideal. Rainfall is heavy, so permeable surfaces are needed, to reduce urban storm water runoff
In warm-humid climates the primary need is for air movement. Streets should, therefore, be oriented to utilize the natural wind patterns.
Orient streets 20-300 oblique to summer wind. Provide wide streets for wind flow.



6.3 Composite Climate
This has no consistent climate. Their characteristics changes from season to season. This set a difficult task for the designer. Solution suitable for one season may not be suitable for other. Difficulty arises with conflicting or incompatible requirements. In order to develop optimal design standards which are appropriate to composite climates as a whole, it is necessary to establish some form of weighting whereby priorities can be allocated. Such a weighting system can be based on the length of different seasons and the relative severity of the conditions. Mark the monthly effective temperature and calculate the discomfort level for each month. This discomfort level multiplied by the duration gives the discomfort index and thus the predominant season is established

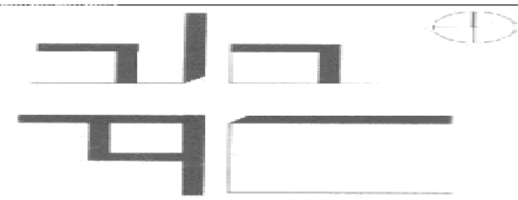
and then planning considerations for that season is recommended.

6.4 Temperate Climate

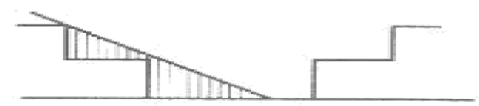
In a temperate climate, the wind direction usually changes with the season. It may be possible to choose a street layout which will block the winter wind, yet allow cooling summer breezes through the city. Cooler parts of temperate zone or on exposed sites we need maximum wind protection (tree shelter belts, closely spaced buildings of constant height, main streets perpendicular to the prevailing wind)

6.5 Cold Climates

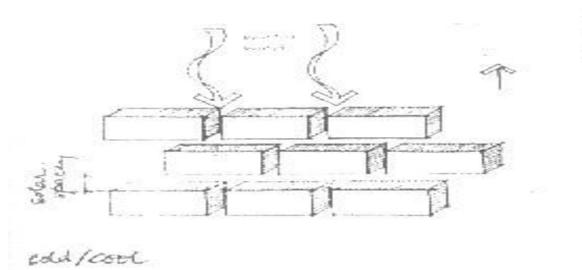
In cold climates, wide streets, especially the east-west streets allow buildings to receive the south sun. However the need here is not just to gain heat but also conserve that which is received. So settlements should be compactly planned. North-south streets should be narrow. Low building heights are preferred. This would enable heat gain from the roof to be maximized. However, heat loss also has to be minimized.



Street widths in cold climates- Wide east-west streets maximize the scope for south winter sun. Narrow N-S streets cut off horizontal sun



Strict cardinal orientation for sun Discontinuous streets in direction of winter winds. Space E/W streets for solar access.



For cold climates using the vegetation as screen against high winds is more appropriate and dense vegetation located at the urban edges is advisable

In cold climates heat gain would be maximized by reflecting and storing it by providing dark and smooth pavement. This would increase absorptivity and reflectivity.

7. RECOMMENDATIONS

Type of climate	Climatic features	Aim/Strategy	Recommendations
Warm-Humid	Hot, sticky conditions and continual presence of dampness. Temp.21-32^{0}C. Little variation between day and night. High humidity. Low speed wind almost constant in direction	need air movement to keep us comfortable	• Streets and buildings must be oriented to catch the breeze. • Orient streets 20-30^0 oblique to summer wind. • Provide wide streets for wind flow • Vegetation must not impede air movement, trees with branches far from the ground, such as palms would be ideal. • Rainfall is heavy, so permeable surfaces are needed, to reduce urban storm water runoff
Hot-Dry	Temp. 22^0 – 49^{0}C, Humidity Moderate to Low, No cloud cover to reduce the high intensity of direct solar radiation The dry air, low humidity and minimal rainfall discourage plant life, and the dry dusty ground reflects the strong sunlight, producing an uncomfortable	prime need is to minimize heat gain sun protection is essential. suppressing the urban dust level	• Small street width to building height ratio ensures narrow streets and , thereby, shading • Rotate the street from cardinal to provide more shade on the streets during more of the day. • Sparser vegetation well mixed within the urban structure to produce as much shadow as possible. • Ground surfaces should preferably be green in order to minimize heat gain.

	ground glare. The Local thermal wind often carry dust & sand		• When hard surfaces are unavoidable they should be rough and not dark
Composite	Neither consistently hot and dry, nor warm and humid. Characteristics changes from season to season. Significant differences in air temp, humidity, wind, sky and ground conditions	In order to develop optimal design standards which are appropriate to composite climates as a whole, it is necessary to establish some form of weighting whereby priorities can be allocated. Such a weighting system can be based on the length of different seasons and the relative severity of the conditions.	
Temperate	The climate is generally arid, characterized by hot summers and cool or cold winters, and wide variations between extremes of temperature at given locations Mean monthly Maxm. Temp between 25-30^0 C the wind direction usually changes with the season	Block the winter wind; allow cooling summer breezes through the city. Cooler parts of temperate zone or on exposed sites we need maximum wind protection	• choose a street layout which will block the winter wind, yet allow cooling summer breezes through the city
Cold	Mean monthly Maxm. Temp below 25^0 C	the need not just to gain heat and also conserve that which is received. heat loss has to be minimized Receive the south sun.	• Strict cardinal orient-ation for sun. • Discontinuous streets in direction of winter winds. • Space E/W streets for solar access • North-south streets should be narrow • Settlements should be compactly planned. . Low building heights are preferred. This would enable heat gain from the roof to be maximized. • dark and smooth pavement • Using the vegetation as screen against high winds is more appropriate and dense vegetation located at the urban edges is advisable

8. STUDY AREA FINALIZATION AND ABOUT CASE FABRIC

Nine urban areas of Nagpur city is selected for detailed study and analysis

The choice of the urban fabrics is motivated by-

1 Diversity of the urban morphology between the selected fabrics

2 The different periods of the fabric construction (old and new)

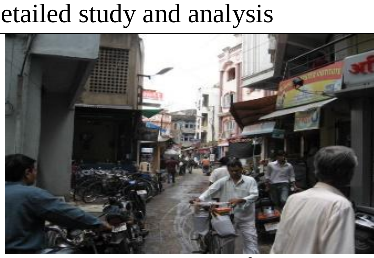


Figure 1 : Typical lane of Itwari

A1-ITWARI

The Itwari area is situated in the North-east zone of Nagpur city is extremely compact. The Buildings normally 3-5 storeys high with mixed land use. The streets are narrow and cut deep canyons through the area. No transport by car is possible except for A few distributor roads. The street network is irregular which increases the mutual shading by buildings. This area has only a few trees i.e sparsely vegetated.

Figure 2: Typical lane of Jafer Nagar

A2-JAFER NAGAR

Jafer Nagar is located in the North-west zone of Nagpur city, The new area-Jafer Nagar is sharp contrast to the Itwari area. Buildings are outward looking and the streets which are designed for motor vehicles, are wide and provided with wide pavements. The street pattern is regular. The buildings usually consist of single or few double storied structures.

 *Figure 3: Lane of Ravi Nagar*	A3- RAVI NAGAR On the west zone of the city this is a residential area withquarters for government employees. They are basically low rise structures mainly ground and ground plus first floor structures. The street pattern is regular. Wide and has wide pavements. There are wider front and rear and side marginal spaces and lots of green area around
 *Figure 4: Typical lane of Sadar*	A4- SADAR On the central zone of the city, this area is extremely compact. The streets are narrow and cut deep canyons through the area. The street network is irregular which increases the mutual shading by buildings
 *Figure 5: Typical lane of Mahal*	A5- MAHAL This area is situated in the south-east zone of Nagpur city and is a very congested old area with narrow and irregular streets. The Buildings normally 3-5 storeys high with mixed land use. The narrow and irregular street network increases mutual shading. No heavy vehicle is possible to move in this area only two wheelers and pedestrian movement is possible. Vegetation is sparse. The overhangs on roads add to the shading of the streets.
 *Figure 6: Lane of Wardhaman Nagar*	A6- WARDHAMAN NAGAR It’s a residential area in the east zone of Nagpur city where buildings are outward looking and the streets which are designed for motor vehicles, are wide and provided with wide pavements. The street pattern is regular.
 *Figure 7: Lane of Friends Colony.*	A7- FRIENDS COLONY This is a comparatively newly developed planned residential area in the north-west zone of Nagpur city with regular wide roads and pavements. It has planned open spaces and wider marginal open spaces around each building
 *Figure 8:Typical lane Medical college Quarters*	A8- STAFF QUARTERS AJNI This is a residential colony for the medical college Doctors. It is located in the south zone of Nagpur city. They are basically single storied structures. The street pattern is regular and wide and the layout has wider front and rear and side marginal spaces and lots of green area around.
 *Figure 9: Typical lane Govt. Quarters ,Civil lines*	A9- GOVERNMENT QUARTERS-CIVIL LINES This is a residential colony for government officers in the west zone of Nagpur city. They are basically single storied structures. The street pattern is regular and wide and the layout has wider front and rear and side marginal spaces and lots of green area around

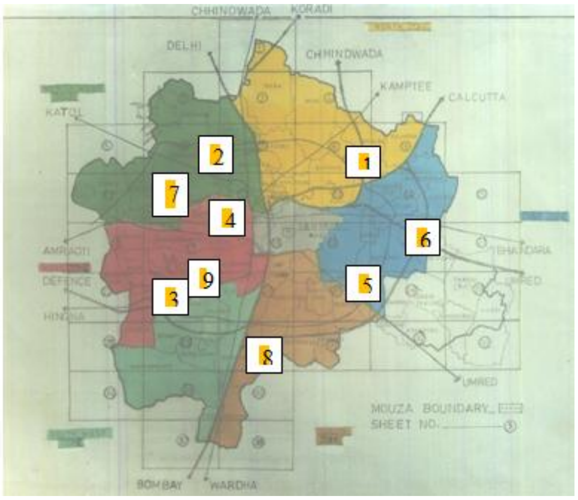


Fig 10: The selected nine urban areas in the city of Nagpur

The nine urban areas in the city of Nagpur, Maharashtra, were selected with similar building materials, road paving materials, topography, mean sea level and nearness to waterbodies and industries, thereby keeping these parameters constant and then the impact of percentage distribution of landuse and H/W ratio can be easily studied.

To study the micro level impact an area of approximately 0.5km X 0.5Km of each of the nine selected urban fabrics are documented and analysed in detail.

The details are summarized in the table 5.10 given below.

Table 1 – Land use % distribution and H/W ratio of the nine study areas.

S.No	Name of the study Area	Built up area %	Road network %	green area %	open space %	Ave.height to width ratio
1	Itwari	77.96	18.1	0.6	3.34	2.34
2	Jafernagar	26.98	8.64	1	63.38	0.52
3	Ravi Nagar	23.95	9.12	7.56	59.37	0.2
4	Sadar	78.2	18.1	0.5	3.2	2.5
5	Mahal	78.7	17.2	0.7	3.4	2.68
6	Wardhaman Nagar	27.5	8.6	1.1	62.8	0.67
7	Friends Colony	27.8	8.15	1.05	63	0.62
8	Staff Quarters- Ajni	24.0	9.8	7.8	58.4	0.22
9	Government Quarters- Civil Lines	24.8	9.5	7.6	58.1	0.26

9. FIELD MEASUREMENTS OF THE STUDY AREA

Once the study areas are identified and after the detailed study of the urban parameters of the selected areas the spadework for the work is actually done the on site recording of the air temperature in each of the nine study areas is done.

The summer temperatures and Relative Humidity were recorded by selecting 12 widely scattered days from the months of April, May and June representing the summer..Thus we have data for 12 days of temperature in 0C recorded at three time periods, namely 05:00hrs, 14:00 hrs and 20:00 hrs. This data is tabulated below:

Table-2 Temporal and Spatial distribution of summer temperature in degree C

Day	Area-1	Area-2	Area-3	Area-4	Area-5	Area-6	Area-7	Area-8	Area-9
D1	34.6	33.3	31.1	35.1	35.8	33.5	33.9	31.1	31.9
	41.3	47.7	49.5	41.8	43	46.4	46.2	47.9	48.8
	36.3	38.1	39.1	36.5	36.1	38	37.4	39.1	39.1
D2	34.8	33.5	31.2	35.3	36.1	33.7	34.1	31.3	32.1
	41.5	47.9	49.6	42.4	43.3	46.6	46.1	48.1	48.9
	36.6	38.3	39.5	36.7	36.3	38.3	37.7	39.4	39.4
D3	35	33.7	31.4	35.5	36.3	34.1	34.6	31.6	32.5
	41.8	48.1	50	42.6	43.6	47	46.6	48.5	49.3
	36.8	38.5	39.8	36.9	36.5	38.7	38.2	40	38.9
D4	35.3	34.2	31.8	35.9	36.6	34.4	34.8	31.9	32.6
	42.4	48.6	50.6	43.1	43.7	47.3	46.8	48.7	49.5
	37.3	38.9	41.5	36.3	36.9	38.8	38.4	40.6	39.2

D5	35.1	34.6	31.9	35.7	36.4	34.8	35.1	32	32.7
	42.5	48.4	50.4	43.4	43.4	47.6	46.7	48.6	49.3
	37.5	39.2	41.3	36.5	36.7	39.1	38.7	41.1	39.5
D6	34.9	34.3	31.7	35.5	36.2	34.5	34.8	31.8	32.7
	42.7	48.2	50.2	43.1	43.1	47.3	46.5	48.4	49.2
	37.2	38.9	39.9	36.7	36.5	38.8	38.5	40.7	39.7
D7	34.7	34	31.4	35.3	36	34.2	34.6	31.6	32.4
	42.4	48	50	42.9	42.8	47	46.4	48.1	49.1
	37	38.7	39.6	36.9	36.3	38.5	38.3	40.1	39.6
D8	34.6	33.8	31.2	35.1	35.9	34	34.3	31.4	32.2
	42.2	47.8	49.8	42.6	42.5	46.8	46.2	47.9	48.9
	36.9	38.5	39.3	36.7	36.1	38.3	38	39	39.4
D9	34.5	33.5	31.1	34.9	35.8	33.8	34.1	31.3	32.1
	42	47.6	49.6	42.2	42.2	46.6	46	47.7	48.7
	36.8	38.3	38.9	36.5	35.9	38	37.7	39	39.1
D10	34.3	33.2	31	34.7	35.7	33.5	33.7	31.1	31.9
	41.8	47.5	49.3	41.9	41.9	46.5	45.8	47.5	48.5
	36.7	38.2	38.5	36.3	35.7	37.8	37.5	38.5	38.8
D11	34	32.9	30.8	34.5	35.5	33.3	33.3	30.9	31.8
	41.5	47.3	49.1	41.8	41.6	46.3	45.6	47.3	48.3
	36.5	37.9	38.3	36.2	35.5	37.6	37.3	38.2	38.5
D12	33.7	32.7	30.7	34.4	35.3	33	32.9	30.8	31.6
	41.3	47.1	48.9	41.9	41.3	46.2	45.4	47.1	48.1
	36.3	37.8	37.9	36.1	35.4	37.5	37.1	37.8	38.2

Similarly the winter temperatures at these nine areas were recorded by selecting widely scattered 12 days from the months of November, December and January.

Table-3 Temporal and Spatial distribution of winter temperature in degree C

Day	Area-1	Area-2	Area-3	Area-4	Area-5	Area-6	Area-7	Area-8	Area-9
D1	23.4	21.9	19	22.5	22.8	22.5	22.2	19.3	19.7
	30.2	26.5	27.8	30.2	30.4	27.1	25.6	28.3	28.5
	28.2	24.1	25.6	27.6	30.1	24.6	24.2	25.9	26.6
D2	22.7	21.5	18.9	22.5	22.7	22.2	21.9	19	19.5
	29.7	26.2	27.7	30.1	30.3	26.9	25.5	27.9	28.2
	27.8	23.9	25.3	27.6	27.9	24.5	24	25.8	26.3
D3	21.2	21.1	18.7	22.3	22.5	21.9	21.7	18.8	18.9
	29.5	25.6	27.6	29.9	30.1	26.7	25.3	27.8	28
	27.6	23.9	25.3	27.5	27.7	24.5	23.9	25.5	25.8
D4	21.4	20.6	18.7	22.3	22.3	21.9	21.7	18.7	18.7
	29.3	25.4	27.6	29.7	29.9	26.5	25	27.8	27.9
	27.5	23.7	25.1	27.4	27.7	24.3	23.6	25.3	25.6
D5	21.5	20.6	18.5	22.2	22.2	21.7	21.3	18.5	18.5
	29.1	25.1	27.4	29.5	29.7	26.1	24.7	27.6	27.8
	27.2	23.3	25.1	27.2	27.5	24.1	23.4	25.1	25.4
D6	21.4	20.5	18.2	22	22	21.4	21	18.3	18.5
	29	24.7	27.2	29.5	29.5	25.7	24.4	27.5	27.7
	26.8	23.1	24.9	27	27.2	24	23.2	24.9	25.2
D7	21.4	20.3	18.2	21.8	22	21.1	20.7	18.3	18.3
	28.9	24.4	27.2	29.3	29.3	25.3	24.3	27.4	27.7
	26.6	22.9	24.8	26.8	26.9	23.8	23	24.8	25.1

	21.2	20.2	18.1	21.8	21.8	20.8	20.5	18.1	18.3
D8	28.8	24.1	27.1	29.2	29.2	25	24	27.4	27.5
	26.3	22.8	24.7	26.7	26.9	23.6	22.8	24.7	25
	21.1	19.9	17.9	21.6	21.6	20.7	20.5	18.1	18.2
D9	28.6	23.7	27.1	29.2	29.2	24.5	23.6	27.2	27.3
	26.1	22.6	24.7	26.5	26.7	23.2	22.6	24.7	24.9
	20.8	19.8	17.6	21.4	21.4	20.5	20.1	17.8	18
D10	28.6	23.3	26.8	28.9	28.9	24.1	23.1	26.9	27.1
	26.1	22.4	24.6	26.3	26.5	22.8	22.4	24.6	24.8
	20.8	19.7	17.4	21.4	21.4	20.1	19.8	17.5	17.8
D11	28.4	22.9	26.8	28.7	28.7	23.7	22.7	26.8	26.9
	25.7	22.1	24.4	26	26.2	22.6	22.3	24.4	24.6
	20.4	19.5	17.3	21.1	21.2	19.8	19.7	17.3	17.6
D12	27.9	22.5	26.8	28.5	28.5	23.3	22.3	26.8	26.8
	25.3	21.8	24.2	25.8	25.8	22.2	21.9	24.2	24.6

10. DATA ANALYSIS

Qualitative analysis showed a relationship between local temperatures and urban morphology of each location. The maximum temperature is considered as the temperature recorded at 14:00 hrs. and the minimum temperature is taken as temperature recorded at 05:00 hrs..

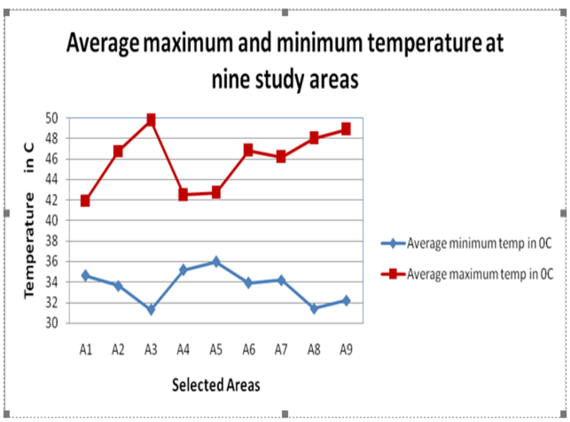


Figure 11: Maximum and minimum temperatures of summer at nine study areas

From the graph it is clearly seen that those areas where the street network is very narrow and irregular, the maximum temperatures (i.e. temperature recorded at 14:00 hrs) are low as compared to the areas with wider streets and with low height of abutting structures. The reason may be that in the case of narrow streets with high rise abutting structures the streets are shaded by the buildings and the sun's rays are not penetrating into the narrow lanes.

Apart from this it has been observed that these compact areas had high minimum temperatures i.e. temperatures recorded at 05:00 hours.

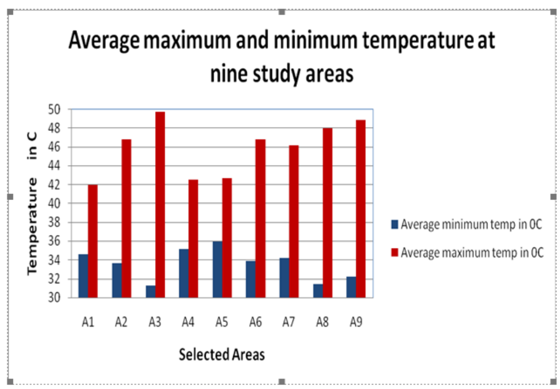


Fig 12: Comparison of Maximum and minimum temperatures of summer of the nine study areas

QUANTITATIVE ANALYSIS

To do the detailed study of the nine study areas AutoCAD drawings of all the areas were prepared and the area distribution in terms of built-up, area covered by roads, green area and the left over open spaces was calculated. Sections were drawn to calculate the ratio between height of the structure and width of the road. Table 5 shows the percentages of the area distribution and H/W ratio of all the nine study areas.

Table 4 – Land use % distribution and H/W ratio of the nine study areas.

S.No.	*Name of the study Area*	*Built up area %*	*Road network %*	*green area %*	*open space %*	*Ave.height to width ratio*
1	*Itwari*	*77.96*	*18.1*	*0.6*	*3.34*	*2.34*
2	*Jafernagar*	*26.98*	*8.64*	*1*	*63.38*	*0.52*
3	*Ravi Nagar*	*23.95*	*9.12*	*7.56*	*59.37*	*0.2*
4	*Sadar*	*78.2*	*18.1*	*0.5*	*3.2*	*2.5*
5	*Mahal*	*78.7*	*17.2*	*0.7*	*3.4*	*2.68*
6	*Wardhaman Nagar*	*27.5*	*8.6*	*1.1*	*62.8*	*0.67*
7	*Friends Colony*	*27.8*	*8.15*	*1.05*	*63*	*0.62*
8	*Staff Quarters- Ajni*	*24.0*	*9.8*	*7.8*	*58.4*	*0.22*
9	*Government Quarters-Civil Lines*	*24.8*	*9.5*	*7.6*	*58.1*	*0.26*

Outline of analysis:

The analysis of the research is carried out in the following steps:

1. Study of relationship and development of functional relationship between:
   a) Maximum average temperature in summer and average height to width ratio.(H/W)
   b) Minimum average temperature in summer and average height to width ratio (H/W) .
   c) Maximum average temperature in summer and percentage of built up area.
   d) Minimum average temperature in summer and percentage of built up area.

2. Summary with Concluding remarks:
   A) Relationship between average Maximum temperature in summer and H/W

To study the relationships between average Maximum temperature in summer and the ratio between average height of the structures abutting the road and the average width of the road(H/W) regression lines are plotted and the regression equation is formed.

Table 5– Maximum and minimum temperature of summer and H/W ratio of nine study areas

Area No.	H/W	Average maximum temp in ^{0}C	Average minimum temp in ^{0}C	Difference between Max. and Min. temp.
A1	2.34	41.9500	34.6250	7.3250
A2	0.52	46.7667	33.6417	13.1250
A3	0.20	49.7500	31.2750	18.4750
A4	2.50	42.4750	35.1583	7.3167
A5	2.68	42.7000	35.9667	6.7333
A6	0.67	46.8000	33.9000	12.9000
A7	0.62	46.1917	34.1833	12.0083
A8	0.22	47.9833	31.4000	16.5833
A9	0.26	48.8833	32.2083	16.6750

Regression Analysis: Ave. max. Temperature during summer versus H/W

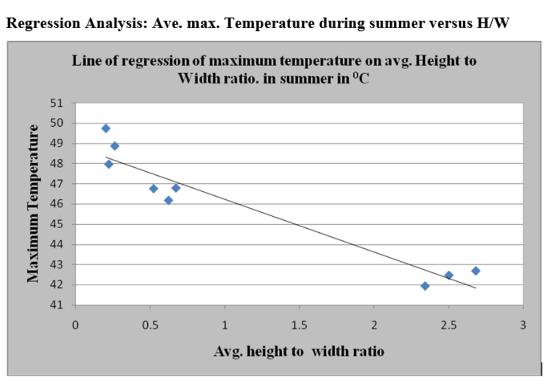


Figure 13:Line of regression of average maximum temperature on H/W

This regression line clearly depicts that the average maximum temperature in summer increases as the value of H/W decreases. This means that in case of areas with low H/W ratio the width of the street width is more and the abutting structures are low height structures and hence these streets are highly exposed to solar radiation explaining the cause of higher temperature.

The regression statistics indicates that the proportion of variation in the response data(Average maximum temperature) explained by the predictor(H/W) in the regression model is 0.915(R^{2}). This explains high correlation between the two.

As per the Table of regression coefficient the regression equation can be written as

$Y_1 = -2.609X_5+48.84$Where

Y_1: Average maximum temperature (in ^{0}C) of summer (measured at 14:00 hrs)

X_5: average ratio of height of structures to width of the road

B. Relationship between average Minimum temperature in summer and H/W

Regression Analysis: Ave. min. Temperature during summer versus H/W

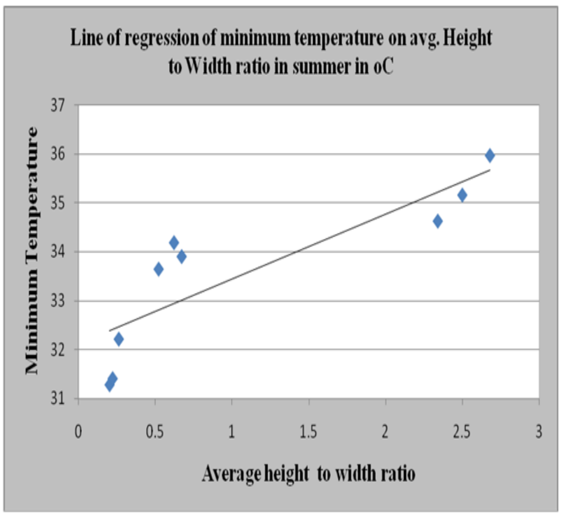


Figure 14:Line of regression of average minimum temperature on H/W

This regression line clearly depicts that the average minimum temperature in summer increases as the value of H/W increases. This means that in case of areas with high H/W ratio the width of the street is less and the abutting structures are of more height and hence these streets are mutually shaded by the structures and are not exposed to direct solar radiation explaining the cause of lower temperature. But as the atmospheric temperature lowers down in the late night and the early morning hours, the heat emitted by the structures and the anthropogenic heat is also not allowed to move out of the narrow urban canyons explaining the cause of higher minimum temperature as compared to the other study areas.

The regression statistics indicates that the proportion of variation in the response data(Average maximum temperature) explained by the predictor(H/W) in the regression model is 0.729(R^{2}). This explains high correlation between the two.

As per the Table of regression coefficient the regression equation can be written as

$Y_2=1.323X_5 +32.12$

Where

Y_2: Average minimum temperature (in ^{0}C) of summer (measured at 05:00 hrs)

X_5: average ratio of height of structures to width of the road

C) Relationship between average Maximum temperature in summer and % of built up area

Table 6 – Maximum and minimum temperature of summer and %built up area of nine study areas

Area No.	Average Built Up area in %	Average maximum temp in ^{0}C	Average minimum temp in ^{0}C	Difference between Max. and Min. temp.
A1	77.96	41.9500	34.6250	7.3250
A2	26.98	46.7667	33.6417	13.1250
A3	23.95	49.7500	31.2750	18.4750
A4	78.2	42.4750	35.1583	7.3167
A5	78.7	42.7000	35.9667	6.7333
A6	27.5	46.8000	33.9000	12.9000
A7	27.8	46.1917	34.1833	12.0083
A8	24.0	47.9833	31.4000	16.5833
A9	24.8	48.8833	32.2083	16.6750

Regression Analysis: Ave. max. Temperature during summer versus % of built up
Area

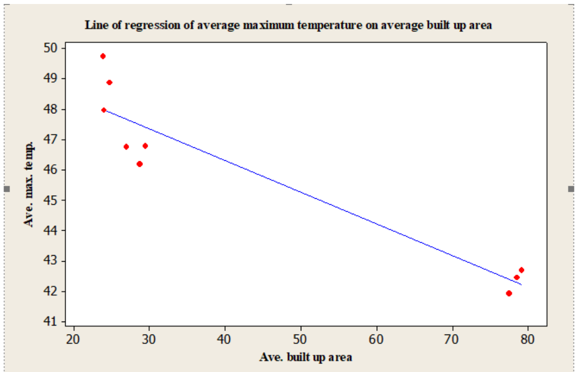


Figure 15: Line of regression of average maximum temperature on% ofbuilt up area

The regression line clearly depicts that the average maximum temperature increases as the percentage of built up decreases. This means low density areas are highly exposed to solar radiation and hence there is a rise in the temperature.

As per the Table of regression coefficient the regression equation can be written as

$Y_1 = 50.5 - 0.105 \times X_3$Where

Y_1: Average maximum temperature (in ^0C) of summer (measured at 14:00 hrs)

X_3: built up area %

D) Relationship between average Minimum temperature in summer and % of built up area

Regression Analysis: Ave. min. Temperature during summer versus % of built up Area

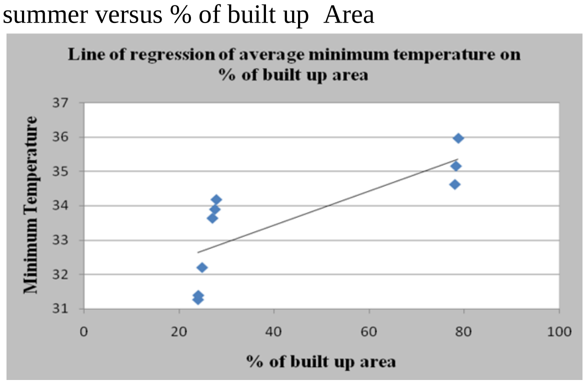


Figure 16: Line of regression of average minimum temperature on% ofbuilt up area

The regression lines clearly depicts that the average minimum temperature increases as the percentage of built-up area increases, while the maximum temperature i.e the temperature at 14:00 hrs decreases with the increase in the percentage of built up area.

This means low density areas are highly exposed to solar radiation and hence the temperature at 14:00 hrs is high as compared to high density areas, but at the same time because of high density and low sky view factor the radiative cooling is low and hence the minimum temperature is higher in these areas as compared to the low density areas.

The regression statistics indicates that the proportion of variation in the response data (Average minimum temperature) explained by the predictor (% of built up) in the regression model is 0.629($R^{2)}$. This explains high correlation between the two.

As per the Table of regression coefficient the regression equation can be written as

$Y_2=0.049X_3+31.45$

Where

Y_2: Average minimum

X_3: built up area %

11. OBSERVATION AND CONCLUSION

- Smaller the ratio of height of the structure to width of the road, more is the difference between maximum and minimum temperature of that area.

- This important observation explains the following natural climatic phenomenon: The deep canyon has low air temperature variation because of the fact that it has low sky- view factor which reduces both incoming short wave radiation by day and radiative cooling by night. The shallow canyon had large variations in surface temperature which is explained by the fact that it has high sky- view factor which increases both incoming short wave radiation by day and radiative cooling by night.

- The following predicting equations were developed-

1. $Y_1 = -2.609X_5+48.84$ Where

Y_1: Average maximum temperature (in ^0C) of summer (measured at 14:00 hrs)

X_5: average ratio of height of structures to width of the road

2. $Y_2=1.323X_5 +32.12$Where

Y_2: Average minimum temperature (in ^{0}C) of summer (measured at 05:00 hrs)
X_5: average ratio of height of structures to width of the road

3. $Y_1 = 50.5 - 0.105 \times X_3$Where
Y_1: Average maximum temperature (in ^{0}C) of summer (measured at 14:00 hrs)
X_3: built up area %

4. $Y_2=0.049X_3+31.45$Where
Y_2: Average minimum temperature (in ^{0}C) of summer (measured at 14:00 hrs)
X_3: built up area %

REFERENCES AND BIBLIOGRAPHY

References

[1] Geoffrey Broadbent, Emerging Concepts in Urban space design, Van Nostrand Reinhold, London ,New York,1990.
[2] Arvind Krishnan, Nick Baker, Simos Yannas, SV Szokolay, Climate responsive Architecture, Tata McGraw-Hill Publishing Company Limited, New Delhi,2001.
[3] Sanjay Udmale, Architecture for Kutch, English Edition Mumbai, 2003.
[4] P.V. Begde Ancient and Medieval Town-Planning in India, Sagar Publications New Delhi, 1978.
[5] Koenigsberger, Ingersoll, Mayhew Szokolay, Manual of Tropical Housing and Building, Orient Longman Limited,1988.
[6] KR Thooyavan, Human settlements, A planning Guide to Beginners,M A Publication Chennai, Chennai ,2005.
[7] Ishwar Chand, P.K.Bhargava. The Climatic Data handbook, CBRI, Roorkee.

Bibliography

[8] AroninJ.A.(1992),Climate and Architecture, Reinhold Publishing Corporation, USA.
[9] Bansal NK, Hauser G, Minke G. Passive building design, a handbook of natural climatic control. Amsterdam: Elsevier; 1994.
[10] Barry R. G. and Chorley (R. J. (1998). Atmosphere, Weather &Climate, (7th ed.), Routledge, London.
[11] Beer, A. and Higgins, C., 2000: Environmental planning for site development, 2nd Edn., Spon, London.
[12] Bentley, I, Alcock, A. Murrain, P., McGlynn, S. andSmith, G. P, Responsive environments: a manual fordesigners, Architectural Press, London, 1985.
[13] EmmanualRohinton, (2005). An Urban Approach To Climate Sensitive Design-Strategies For The Tropics, Spon Press, Taylor and Francis Group, London and New York
[14] Fukuoka, Y. Physical climatological discussion on causal factors urban temperature. Memoirs of The Faculty of IntegratedArts and Sciences, Hiroshima University, Ser. IV, vol 8, 1983.