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Optimizing Urban Morphology to Mitigate Urban Heat Islands: A Case of Hyderabad

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Highlights

- Delineates a methodology to study urban residential neighborhoods to understand the effect of urban morphology on microclimate.
- Enumerates morphology parameters that can be modified to reduce the UHI phenomenon.
- A numerical model, ENVI-met, simulates microclimate and various statistical models to evaluate the extent of the inter-relationship between critical morphology parameters and climate variables.

Abstract

Urbanization, changing urban geometries and surfaces, forms hotspots called urban heat islands (UHI). Several studies have been conducted to understand its cause, intensity, and impact on urban microclimate. The current study attempts to assess the impact of the urban morphology of multiple residential urban blocks in Hyderabad on urban heat island intensity. The study explores the possibility of UHI mitigation by modifying morphology constructed on policy measures like zoning regulations. Six urban residential blocks under the city's peri-urban belt are studied for their morphology and microclimate. Field study, 2D building database, and satellite imagery are used to develop urban built geometry of the blocks. The microclimate, i.e., air temperature and wind speed, is determined using a numerical model, ENVI-met. The simulated microclimate data is used to compute UHI intensity based on reference climate data of an urban block at the time of the investigation. The urban morphology is then modified to reduce UHI intensity. The modified urban geometry with a significant reduction in UHI intensity is used to suggest planning/design recommendations through zoning regulations. Further, the paper reinforces the significance of the correlation between UHI and urban morphology, which can be regulated through zoning.

Keywords: Microclimate, Urban heat island, Urban morphology, UHI mitigation, Zoning regulations

Introduction

Indian metro cities are undergoing rapid urbanization with a growing economy and population. The natural population growth or migration has resulted in densification and spatial expansion of cities, with a surge in infrastructure and natural resources demand. This led to the saturation of land and other resources in cities, permanently modifying the surface and material properties, resulting in heat accumulation and an imbalance in urban energy flow. To accommodate and cater to the demands of the growing population, suburbs of metro cities become prospective for planned development. This allows the newer developments to follow a top-down approach of planning sustainable neighborhoods and siting green buildings within them to reap maximum benefits of their efficiencies against the conventional bottom-top approach of designing green buildings in an overbearing climate context. Following are the concepts dealt with in different sections of the paper.

Urban Morphology: The unprecedented growth of cities led to the rapid modification of urban morphology or changes in the tangible elements that create a city's urban form. These tangible or physical elements that are continuously evolving include the natural setting, street, street block, plots, buildings, etc. Urban morphology can be discussed by its morphology parameters or the various physical characteristics of urban form, which include measurable aspects like size, density, building height, pattern, etc. [1].

Urban Microclimate: Morphology varies across an urban area, and its interaction with atmospheric climate creates a unique microclimate. This divergence of urban climate conditions from the atmospheric conditions due to changes in urban surfaces and forms is called urban microclimate [2].

Urban Heat Island: Oke [3] defines an urban heat island as a measure of near-surface air temperature contrast between urbanized and adjoining rural areas or urban centers with different forms. This model works in units of degrees Celsius and uses an empirical formula.

Urban Block: It is a neighborhood with homogeneity in design, demography, and socioeconomic status. Urban blocks are considered minimum planning units where planning tools can be implemented to regulate development [4]. They hold 500 to 5000 people on 15 to 500 acres of land with shared retail and community facilities (elementary school, park).

UHI studies in India were initiated in the early 20th century [5]. These studies are carried out in metro cities to examine the presence of UHI, its intensity, and influencing factors. Hyderabad is a rapidly urbanizing city, witnessing an urban sprawl of planned residential developments along the outer ring road [6]. These developments are controlled by zoning regulations, which must be climate-informed to achieve a better quality of life and human comfort in the face of climate change. Hence, the current paper focuses on this requirement to study the upcoming residential neighborhoods for magnitude and factors responsible for UHI. Modification of responsible factors, the urban morphology, regulated by policy framework is attempted as a mitigation measure of Urban Heat Islands [7]. Following are the research questions explored in the paper.

1) How do urban morphology and its parameters impact microclimate?
   a) What morphology parameters shape an urban form?
   b) What is the extent of the impact of morphology parameters, individually and collectively, on the climate of an urban block in terms of an urban heat island?
2) How does zoning regulation define urban form or morphology?
   a) How can its modification through zoning regulations alleviate an urban heat island created by an urban morphology?

Methods

The methodology developed in this study can be applied to other studies and is not typical of the study area demonstrated in this paper. The study methodology is developed by an extensive literature review, which inquiries about the data collection models, computation tools and techniques. The five segments of study are (1) Urban morphology and parameters- Data and computation, (2) Climate variables- Data collection and methods, (3) Relationship between morphology parameters and climate variables- Analysis and results, (4) Urban heat island- Computation and results (5) UHI mitigation- Measures and approaches. The methodology used in this is shown in Figure 1.

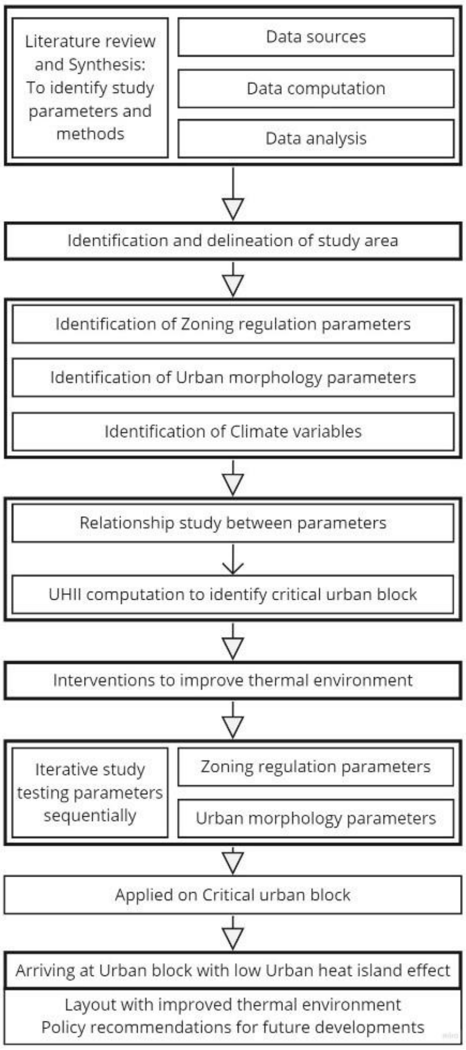

Figure 1: Illustrative methodology chart

The study synthesis led to the identification of urban morphology parameters and zoning regulation parameters. The mentioned empirical formulae and software tools calculate the parameter data. This is followed by analyzing their relationships with various microclimate variables using statistical tools like correlation and regression analysis, where simulated climate data from the numerical ENVI-met model is used [2]. The inputs of the numerical model include the site's physical properties and nearest weather station data. The results from the analysis are used to identify the study block experiencing higher air temperatures compared to the rest, called the critical urban block. Based on the relationship results, interventions to the urban form are tested on the critical urban block to reduce the effect of Urban heat islands.

Need for UHI study in Hyderabad

Hyderabad ranks as the third-largest metropolitan city in terms of area and the fourth-largest in terms of population in the country. The development plan for 2031 by the planning body HMDA 2008 projects a growth rate of 428.8% in the Peri-urban belt, out of which 30% is a gross residential area [6], compared to the growth rate of 1.02% in the city centre, 37.8% in the urban belt. Hence, an understanding of the microclimate of planned residential urban blocks in the Peri-urban belt gives an insight into the mitigation measures and their scale of implementation. The approach to studying UHI using atmospheric temperature data helps understand the effect of urban geometry on microclimate, unlike the multiple existing studies [6] [8] [9], which use land surface temperatures that only account for the influence of surface material and green cover. The scope of the current study is to investigate mitigation measures at the scale of modifying urban form and not just through surface properties or green covers.

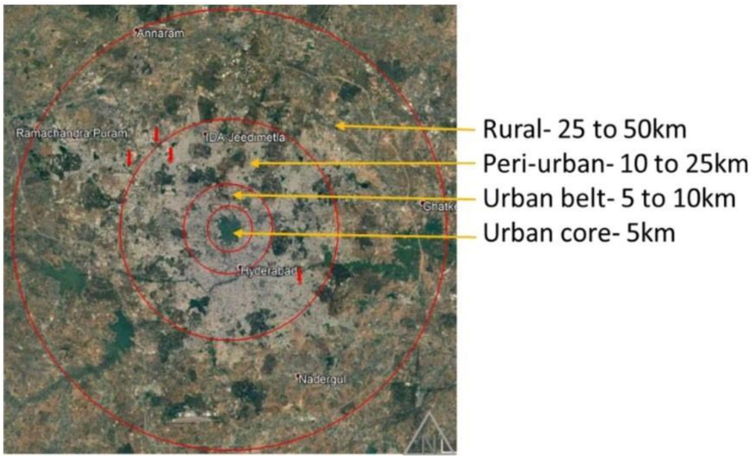

Figure 2: Urban belts of city development with the location of six study sites

The six study blocks (MN, PN1, PN2, VN1, VN2, and AL) selected have similar properties with variations in physical parameters, which provides a scope to study their influence on block microclimate. The following are the criteria taken into consideration during site selection:

Table 1: Study Urban blocks NS-EW oriented (left), NESW-NWSE oriented (right)

Criterion	Pragathi Nagar1 (PN1)	Pragathi Nagar2 (PN2)	Matrusree Nagar (MN)
Block area & dimension	35,200sqm & 220x160m	35,200sqm & 220x160m	59,925sqm & 225x235m
Deviation from North	0°	0°	3.5° NE
Face blocks	5	4	7
Building blocks	65	63	71
Building height	G to G+5	G to G+5	G to G+6
Road width	18 | 12 | 9 | 7.5m	18 | 12 | 9 | 7.5m	9 | 7.5m
Open space type	Vacant plots	Play ground	Play ground
Green space type	Street vegetation	Street vegetation	Park | Jogging track
Building coverage ratio	34.4%	33.3%	26.2%
Building volume density	4	3.5	4.2
Green coverage ratio	26.5%	20.7%	29.5%
Nearest weather station	AWS 10995- Kukatpally Balanagar	AWS 10995- Kukatpally Balanagar	AWS 10995- Kukatpally Balanagar

Criterion	Vivekananda Nagar1 (VN1)	Vivekananda Nagar2 (VN2)	Alkapuri (AL)
Block area & dimension	46,000sqm & 230x230m	46,000sqm & 230x230m	40,000sqm & 200x200m
Deviation from North	45.6° NE	45.6° NE	42° NW
Face blocks	6	6	3
Building blocks	84	75	74
Building height	G to G+4	G to G+4	G to G+4
Road width	15 | 9 | 7.5m	15 | 9 | 7.5m	12 | 9 | 7.5m
Open space type	Vacant plots | School ground	-	Vacant plot
Green space type	Street vegetation	Public park | street vegetation	Street vegetation
Building coverage ratio	35.7%	32.11%	35.3%
Building volume density	2.95	2.45	3.12
Green coverage ratio	47.8%	54.5%	26%
Nearest weather station	AWS 10995- Kukatpally Balanagar	AWS 10995- Kukatpally Balanagar	AWS 11204- LB Nagar GHMC

Planned residential neighborhoods in the Peri-urban belt are identified. The blocks comply with GO 168 (zoning regulations followed in Hyderabad).

- The block length dimension ranges from 150-250m with a peripheral road as a physical boundary marker.
- The building typology in the block includes Residential and essential commercial/retail along roads.
- Building heights vary from low rise (up to G+3) to mid-rise (up to G+5) with ground coverage according to plot size.
- Variations in road width, ranging from 6m to 12m ROW.
- Variations in street orientations; NS-EW orientation and NESW-NWSE orientation.
- The number of open spaces in a block is responsible for variations in building volume density; FAR.
- Open spaces and green space coverage in the study blocks vary. They include Vacant plots, open playgrounds, incidental open spaces, neighborhood parks, and street vegetation.

Study parameters

Urban morphology parameters

The parameters used for the study are selected based on their recurrence in the existing literature and are termed critical morphology parameters. The scale at which the five identified parameters are studied is categorized into intra-block and Inter-block comparisons. In intra-block, street aspect ratio and its orientation and sky view factor are studied for their influence on microclimate within the block. In inter-block comparison, building coverage ratio, building volume density, and green coverage ratio are studied for their influence on microclimate across the six blocks. This comparative study gives an insight into the scale of interventions in urban form that can be implemented. The urban morphology data from ground surveys, 2D maps, and Google Earth images are used to compute the parameter data using established empirical formulae.

Table 2: Urban morphology parameters

Comparison	Morphology parameters	Definition	Empirical formula
Intra block	**Street aspect ratio and orientation**	The aspect ratio is the ratio of the **mean height** of the buildings to the **width of the street**. One metric of studying **urban street canyon**; a space above the street and between the buildings.	*Symmetrical= H/W* *Asymmetrical= (H1+H2/2)/W*
Inter block	**Building coverage ratio**	BCR- The ratio of the **lot area** that is covered by **building area**, which includes the total horizontal area when viewed in plan.	*ΣBuilding footprint/Block area*
Inter block	**Building volume density**	Or **urban land density**- is the ratio of the **built-up area** to the buildable area in a block. Refers to FAR at building level	*ΣBuilding footprint x height / Block area*
Inter block	**Green coverage ratio** (open space ratio)	Used as an **index of an amount of plants**. A ratio of the areas of plants to the total area of investigation	*ΣVegetation cover/Block area (Block area Building+ green/Block area)*
Intra block	**Sky view factor** (indirect parameter)	The ratio at a point in space, between the **visible sky** and a hemisphere centered over the analyzed location (Oke 1981). 0<SVF<1. Second metric of studying **urban street canyon.**	*Skyhelios & RayMan*

Zoning regulation parameters

A review of the zoning regulations followed in Hyderabad gives an insight into the various parameters covered. According to the previously identified urban morphology parameters and their empirical formulae, zoning regulation parameters are associated. The basis of zoning regulations in Hyderabad is the road width ROW and the plot size, which decides the allowable building height and marginal open space MOS.

Table 3: Zoning regulation parameters

Morphology parameter	Zoning regulation parameters		
Aspect ratio	ROW	Height	MOS
Sky view factor	ROW	Height	MOS
Building coverage ratio	Plot size	MOS	
Building volume density	Plot size	MOS	Height

ROW= Right of Way
H= Building height
MOS= Marginal open space

Climate variables

The study focuses on the urban heat island effect, which measures higher air temperature in urban areas. It also deals with urban form, which involves the aerodynamics due to street aspect ratio, its channelizing effect and street vegetation, their wind-blocking effect. For these contextual reasons, air temperature and wind speed are studied and analyzed for their modification caused by morphology parameters, creating a microclimate. The microclimate is studied for diurnal variation using results of six hours of investigation (10hr, 14hr, 18hr, 22hr, 2hr, 6hr) at a four-hour frequency, covering a 24-hour cycle.

Results

Relationship between zoning regulation parameters and urban morphology parameters

The correlation and regression analysis is carried out with 93-125 observations, where zoning regulation parameters are the X 'independent' variable and urban morphology parameters are the Y 'dependent' variable. The outcome of each analysis is in terms of the percentage variability of the Y variable that can be predicted by the X variable, both collectively and individually.

Their R^2 and P- values consolidate the analysis results to a set of zoning regulation parameters that can be attributed to modifying morphology parameters. Building height (R^2=62.49%) and marginal open spaces (R^2= 26.28%) have a higher degree of influence on the Aspect ratio and Sky view factor, plot size (R^2=3.46%) on the building coverage ratio and building height (R^2=1.81%) on the building volume density. The terms of these parameters are used to bring variations in urban morphology parameters and, in turn, on the microclimate.

Critical urban block

Mean air temperature at each hour of investigation (10hr, 14hr, 18hr, 22hr, 2hr, 6hr) is collected from the microclimate simulation of the six urban blocks. This data is used to compute urban heat island intensity using the following formula,

$$\Delta T = \text{Max. } T_{X,\text{ mean}} - \text{Min. } T_{Y,\text{ mean}}$$

Where $T_{X,\text{ mean}}$ - Mean air temperature of Urban block of investigation and $T_{Y,\text{ mean}}$- Mean air temperature of reference Urban block at the time of the investigation. The reference urban block is the one with the minimum mean temperature at the time.

Table 4: Computation of UHII for a critical urban block

Canopy layer air temperature

	10hrs	UHI	14hrs	UHI	18hrs	UHI	22hrs	UHI	2hrs	UHI	6hrs	UHI
MN	30.750	5.175	33.490	4.86	29.235	0.785	25.800	0.855	**24.750**		26.110	2.960
PN1	30.195	4.620	32.585	3.955	**28.450**		**24.945**		24.860	0.110	25.925	2.775
PN2	31.085	**5.510**	33.675	**5.045**	29.260	**0.810**	25.240	**0.295**	25.165	**0.415**	26.460	**3.310**
VN1	30.605	5.030	33.220	4.590	28.890	0.440	25.110	0.165	25.045	0.295	26.285	3.315
VN2	30.675	5.100	33.235	4.605	28.795	0.345	25.085	0.140	25.040	0.290	26.420	3.270
AL	**25.575**		**28.630**		31.830	**3.380**	30.585	**5.640**	27.910	**3.160**	**23.150**	

The urban block PN2 experiences the highest temperatures during the day (after sunrise), 3.3°C to 5.5°C higher than the reference block AL. AL experiences higher temperatures at night, 3.1°C to 5.6°C higher than the reference blocks MN and PN1. Though the occurrence of high-temperature shifts from day to night, PN2 is continuously exposed. This reason for prolonged exposure to high temperatures during both day and night is the criterion that makes PN2 the critical urban block where the thermal environment needs improvement through the mitigation of Urban heat islands.

Relationship between urban morphology parameters and climate variables

This is to study the diurnal variation of microclimate in terms of air temperature and how the urban morphology parameters affect this variation. The analysis is carried out where urban morphology parameters are the X 'independent' variable and climate variables are the Y 'dependent' variable. The outcome of each analysis is in terms of the percentage variability of the Y variable that can be predicted by the X variable, both collectively and individually. The relationships are studied at six hours of investigation, at a four-hour frequency, covering a 24-hour cycle. The analysis takes daytime and nighttime hours separately to understand this effect in the identified critical urban block.

Observations at the intra-block level show that during the day, around 4% of the variation in air temperature can be accurately predicted by the two urban morphology parameters collectively and peaks at 18 hours with 9.7% predictability. Out of the two urban morphology parameters, street aspect ratio ($R^2$10hrs=3.6%, $R^2$14hrs=1.6%, $R^2$18hrs=7%) has a higher degree of influence, followed by sky view factor planar ($R^2$10hrs=0.38%, $R^2$14hrs=2.27%, $R^2$18hrs=3.21%), on the variation of air temperature. During the peak hour of influence, i.e., at 18hrs, a unit increase in the H/W ratio causes a 0.693-unit decrease in air temperature (-ve correlation). A unit increase in SVF planar results in a 0.0054-unit increase in air temperature (+ve correlation). Around 3-4% of the variation in air temperature during the night can be accurately predicted by the two urban morphology parameters collectively and peaks at 22 hours with 7% predictability. Out of the two urban morphology parameters, street aspect ratio ($R^2$22hrs=5.6%, $R^2$2hrs=1.32%, $R^2$6hrs=0.4%) has a higher degree of influence followed by sky view factor planar ($R^2$22hrs=0.06%, $R^2$2hrs=1.32%, $R^2$6hrs=2.8%), on the variation of air temperature. During the peak hour of influence, i.e., at 22hrs, a unit increase in the H/W ratio causes a 1.513-unit decrease in air temperature (-ve correlation). A unit increase in SVF planar results in a 2.754-unit decrease in air temperature (-ve correlation).

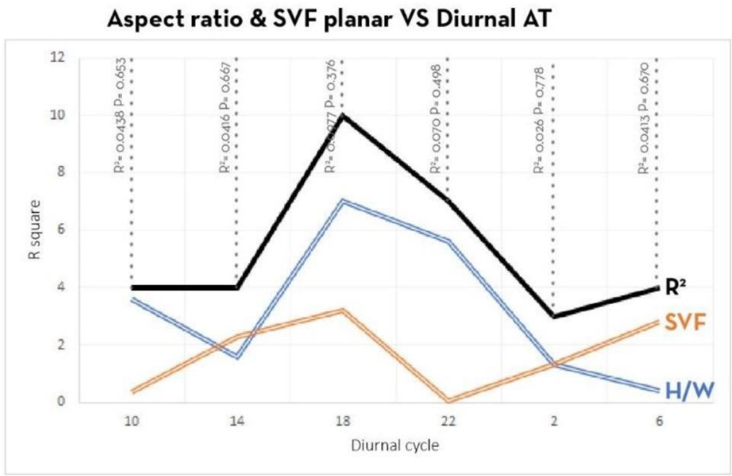

Figure 3: Diurnal variation of regression results- Aspect ratio and SVF vs. Air temperature

Observations at the inter-block level show that during the day, around 80-99% of the variation in air temperature can be accurately predicted by the two urban morphology parameters collectively and peaks at 14hrs with 98.94% predictability. Out of the three urban morphology parameters, GCR ($R^2$10hrs=58.33%, $R^2$14hrs=55.96%, $R^2$18hrs=58.46%) has a higher degree of influence, followed by BCR ($R^2$10hrs=32.67%, $R^2$14hrs=36.59%, $R^2$18hrs=12.31%), then by BVD ($R^2$10hrs=7%, $R^2$14hrs=6.46%, $R^2$18hrs=6.15%) on the variation of air temperature. During the peak hour of influence, i.e., at 14hrs, a unit increase in GCR ratio causes a 0.25°C increase in air temperature (+ve correlation). A unit increase in BCR results in a 0.036°C decrease in air temperature (-ve correlation). A unit increase in BVD results in a 4.022°C increase in air temperature (+ve correlation). During the night, around 9096% of the variation in air temperature can be accurately predicted by the three urban morphology parameters collectively and peaks at 6 hours with 96.9% predictability. Out of the three urban morphology parameters, GCR ($R^2$22hrs=71.09%, $R^2$2hrs=35.38%, $R^2$6hrs=74.44%) has a higher degree of influence, followed by BCR ($R^2$22hrs=14.22%, $R^2$2hrs=40.1%, $R^2$6hrs=22.56%), then by BVD ($R^2$22hrs=2.84%, $R^2$2hrs=16.51%, $R^2$6hrs=2.26%), on the variation of air temperature. During the peak hour of influence, i.e., at 6hrs, a unit increase in GCR ratio causes a 0.171°C increase in air temperature (+ve correlation). A unit increase in BCR results in a 0.053°C decrease in air temperature (-ve correlation). A unit increase in BVD results in a 2.644°C increase in air temperature (+ve correlation).

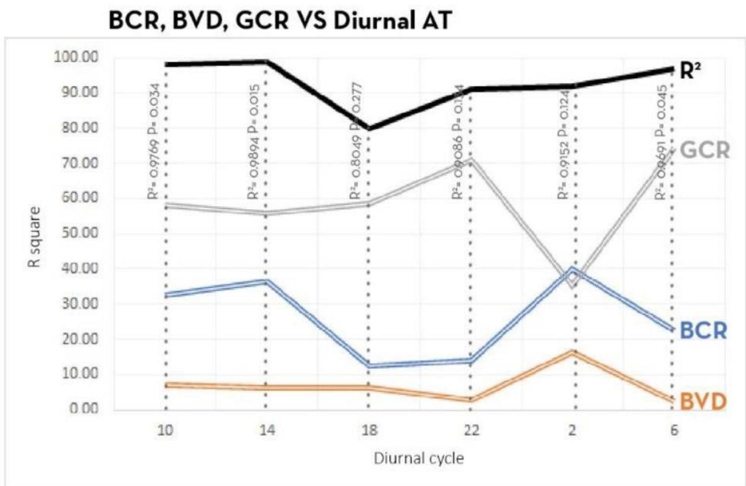

Figure 4: Diurnal variation of regression results- BCR, BVD, and GCR vs. Air temperature

Their R^2 and P- values consolidate the correlation and regression results to a set of urban morphology parameters that can be attributed to modifying the air temperature of the microclimate. These urban morphology parameters are prioritized while formulating the design intervention options.

Table 5: Prioritized urban morphology parameters

INTRA BLOCK	PN2	Remark
Orientation & Aspect ratio	***High priority***	+ve correlation with AT for 2/3 of diurnal cycle As H/W increases --> AT increases (peak influence at 18 followed by night)
SVF	Low priority	Changes with H/W
INTER BLOCK		**Remark**
BCR	***Mid priority***	High coverage by urban surfaces --> Cool spots due to absorption during day & Hot spots due to release and trapping of heat at night
BVD	Low priority	Trapping of heat in canyons
GCR	***High priority***	Night time cooling by presense of trees Trap heat during day

Discussion

The sequence of iterations to improve critical blocks and results

Based on the priority of urban morphology parameters' influence on climate variables, different street orientation and aspect ratio variations, building coverage and green coverage ratios are tested for their microclimate performance compared to the existing base case. Each case is a set of variations of one morphology parameter. The iteration of a case with a lower temperature is carried forward to introduce the next set of variations of the succeeding case. The result is the best-suited urban form that improves the thermal environment of the identified critical urban block PN2.

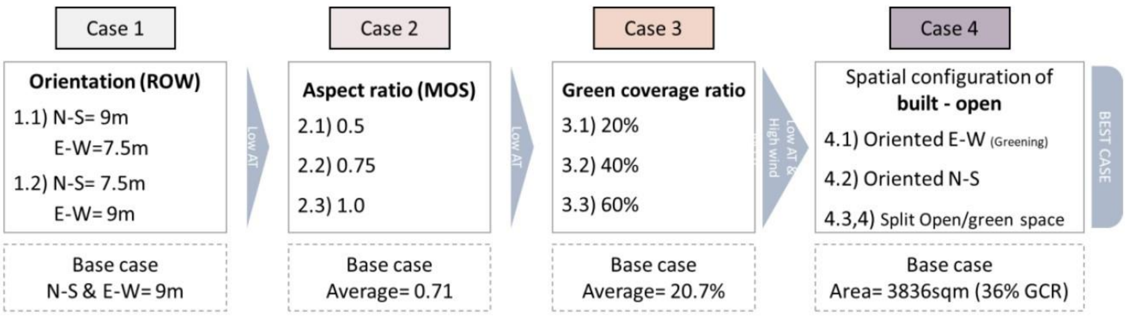

Figure 5: Sequence of iterations and details of each case

Results of Case 1 - Orientation (ROW)

Hourly air temperature difference between the two iterations of varying ROW widths according to their orientation is examined. The base case has no consistency in the ROW, with the width of the internal streets ranging from 6m to 9m. Case 1.1, with N-S streets of 9m and E-W streets of 7.5m, experiences a temperature reduction of 0 to 0.44°C. This reduction varies with the time of the day, as visible in the results of the six hours of investigation.

Results of Case 2 - Aspect ratio (MOS)

Hourly air temperature difference between the three iterations of varying aspect ratio, corresponding front MOS and the base case of H/W ratio of 0.71 are examined. Case 1.1 is used to introduce the new variations of aspect ratio. Case 2.3, with a H/W ratio of 1.0, experienced a temperature reduction of 0.52 to 1°C. SVF being an indirect parameter dependent on aspect ratio, Case 2.3 gives access to the night sky with an SVF of an average of 0.76, ranging from 0.63 to 0.85.

Results of Case 3 - Green coverage ratio

Hourly air temperature and wind speed difference between the three iterations of varying green coverage ratio and the base case of GCR of 20.7% are examined. Case 2.3 introduces the new variations of the green coverage ratio. Case 3.2, with a GCR of 40%, experienced a temperature reduction by -3.17 to 5.075°C from 25 to 34°C of the base case. Mean wind speed is in the range of 0.75 to 0.785m/s compared to the base case of 0.7 to 0.75m/s. The effect of vegetation along the streets and in the open space is visible modulation of diurnal temperature fluctuations and channelization of wind in street canyons of different orientations.

Figure 6: Final layout of Urban block PN2

Results of Case 4 - Spatial Configuration

Hourly air temperature and wind speed variation achieved by the four iterations of varying built-open space configurations is examined. Case 3.2 is used to reconfigure the open-green space into lots further. Case 4.2, with open-green space oriented north-south, experiences a temperature reduction of 3.3 to 5.3°C from the base case. The mean wind speed ranges from 0.75 to 0.785m/s compared to the base case.

Conclusion

The thermal environment in the urban block is improved by a reduction in maximum temperature by 0.43 to 0.54 °C from the base case, occurring at 14hrs. The minimum air temperature is reduced by 0.53 to 10.05°C, occurring 6hrs. On average, air temperature reduction ranges from 0.63 to 5.3°C. The maximum wind speed is increased by 0.07 to 0.13 m/s; on average, there is an increase of 0. 04 to 0.065 m/s.

Table 6: Improvements in the thermal environment from the base case

Air temperature °C		10	14	18	22	2	6
PN2	Max	32.12	35.25	29.85	26.37	25.76	26.99
	Min	30.05	32.1	28.67	24.11	24.57	25.93
	Avg	31.085	33.675	29.26	25.24	25.165	26.46
Improved PN2	Max	31.69	34.71	33.35	31.89	29.76	26.46
	Min	20.28	22.05	23.81	24.47	24.04	19.85
	Avg	25.985	28.38	28.58	28.18	26.9	23.155
Reduction	Max	**0.43**	0.54	-3.5	-5.52	-4	**0.53**
	Min	9.77	**10.05**	4.86	-0.36	**0.53**	6.08
	Avg	5.1	**5.295**	**0.68**	-2.94	-1.735	3.305

Wind speed m/s		10	14	18	22	2	6
PN2	Max	1.45	1.41	1.37	1.38	1.39	1.49
	Min	0	0	0	0	0	0
	Avg	0.725	0.705	0.685	0.69	0.695	0.745
Improved PN2	Max	1.53	1.51	1.49	1.51	1.52	1.56
	Min	0	0	0	0	0	0
	Avg	0.765	0.755	0.745	0.755	0.76	0.78
Increment	Max	0.08	0.1	0.12	**0.13**	**0.13**	**0.07**
	Min	0	0	0	0	0	0
	Avg	0.04	0.05	0.06	**0.065**	**0.065**	**0.035**

Design recommendations

The street's orientation and width, defined by ROW in zoning regulations, play a significant role in exposure to solar radiation. The N-S streets are less exposed to intense late afternoon southwest radiation and long hours of morning radiation from the southeast due to overshadowing by buildings abutting the street. However, they experience brief exposure to intense high-altitude radiation from the south during mid-day. Hence, the lesser temperature at a width of 9m. The E-W streets have prolonged exposure to the southwest and southeast radiation and exposure to intense, high-altitude radiation in the case of broader ROW. Hence, a 7.5m wide ROW facilitates over-shading by buildings.

1. Internal streets- N-S streets with a ROW of 9m and E-W streets with 7.5m.

A macro-level investigation of the zoning regulation parameter, front MOS, and the corresponding aspect ratio reveals that a compactly built morphology that allows mutual shading and shading of the open street results in air temperature reduction.

2. Achieve an aspect ratio of 1.0 by modifying front, rear, and side marginal open spaces according to the setbacks prescribed as per plot size, abutting ROW, and permissible building height.

Adding street vegetation proved beneficial by shading streets and modulating air temperature. Wider canopy trees, heart-shaped or spherical, can shade the E-W streets prone to prolonged exposure to radiation. The cylindrical avenue variety of street trees channelizes wind and sometimes increases the wind velocity. This is evident in the N-S streets. Though not oriented along the prevailing wind direction, the cylindrical tree canopies channel and accelerate the wind. The amount of green coverage must be mandated in the zoning regulations regarding the green coverage ratio of the planned development. Specifications regarding the type of plants, their canopy style, and their location along streets can be suggested.

3. A 40% green coverage ratio is introduced by vegetation along the street and in open areas, along with the prescriptions of onsite green strips.

4. Trees of the wider canopy shade E-W streets.

5. N-S streets' wind channelization by cylindrical canopy trees.

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