Research Paper

Urban Climatic Design

Form based parameters for Climate responsive residential development, Delhi

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Abstract

Urbanization is the most transformative trend of 21st century being witnessed by mankind. The United Nations 2018 report envisages Delhi to be world's most populous city by 2028 with 37.2 million people. As per McKinsey, it is expected that India will add more than 20 billion square metres of residential floor area to meet the housing needs of the increasing population. The paper investigates three key phenomena in the rapidly urbanizing Delhi Metropolitan region: Climate change, housing demand and its impact on outdoor thermal comfort. The main hypothesis of this applied and action-based research is that urban housing typologies, morphological transformations and changing spatial patterns have been playing a major role in contributing to urban heat islands. Form-climate relations have been investigated at the local level in six sites in Delhi by conducting field-based survey using calibrated instruments for site-based measurement. Through the research findings, a set of eight form-based guidelines for spatial planning and design have been formulated to evaluate the environmental performance of housing morphology. The research project aims to strengthen disciplinary knowledge in building climate friendly and sustainable urban environment by investigating relationships of urban housing form and outdoor thermal comfort with Delhi as a case.

Keywords

Urban morphology, climate responsive design, urban heat island effect, thermal comfort

1. Introduction

1.1. Project Overview

India has committed in its Nationally Determined Contributions (NDC) that by 2030 the country will reduce the emissions intensity of the GDP by 33-35% below 2005 levels. It is expected that by 2030 the global urban population will double, and the built-up area would triple (taking 2000 as the base year). The urban population of India reached 31.16% of the total population as per Census 2011; this was a marked increase from 27% in 2001.

As per McKinsey, it is expected that India will add more than 20 billion square meters of residential floor area to meet the housing needs of the increasing population. The current and anticipated rapid growth in the residential building stock across India necessitates for energy conservation in this sector. Housing is an integral part of urban design, where built forms and outdoor spaces play a key role to determine indoor and outdoor comfort. The density of built form in housing is predominantly determined by Development Control Rules (DCR).

As India is urbanizing rapidly and cities are witnessing high-density residential development, there is an urgent need to study the relations between form, microclimate and consequent impacts on urban heat Islands in outdoor conditions and assess environmental performance at an urban level. It is a challenge as well as an opportunity for the designers to develop these new housing stocks as energy efficient both in terms of embodied energy as well as operational energy.

The urban form of the city and its relationship to depleting open space has an impact on how larger collection of built form and open space configurations are contributing to Urban heat island effect. It is important to address the housing policies in the Master Plan that incorporates specific approaches for development of plotted housing, up-gradation, and re-densification through redevelopment of existing housing areas including unauthorized colonies. In view of the limited availability of land and increased requirement of housing, plotted residential development shall be discouraged and it is proposed to adopt a multi-pronged housing strategy for provision of housing stock to all classes and for delivery of serviced land.

Here, it is important to understand that housing form is changing with the need to incorporate more population in the capital, and this points to that fact that with change in housing form, Delhi's contribution to the UHI and climate change is getting adversely affected.

The research considers energy and comfort as deterministic parameters to develop three-dimensional forms for climate sensitive housing in India. These prototypical design explorations will offer design solutions from the macro level to micro level.

The main hypothesis of this applied/action-based research is that urban housing typologies have been contributing at different scales to urban heat islands. The aim of this research is to assess the UHI effect in housing sector and develop design parameters to mitigate the impact.

1.2. Objective

A research project is a multidisciplinary approach that lies at the nexus of built morphology of urban housing and urban thermal environment. Housing is an integral part of an urban neighbourhood in cities. In the metropolitan region of National Capital Region Delhi, different housing typologies are studied and documented. This research project aims to study the built morphology in residential areas and its implication on the urban thermal environment. Buildings are not independent systems –the indoor climate and physics of the building interact continuously with the outside micro-climate.

The aim is to evaluate contemporary housing typology based on factors influencing its built form such as master plan, building regulations, stakeholders, logistics, real estate forces, changing technology, etc. and their response to climatic variables of temperature, humidity, wind, radiation, etc.

The objective is to conduct a study of micro-climatic variables in the metropolitan region of Delhi. The focus areas are on the peripheral areas of the city which are predominantly residential and are representative of similar housing morphology in the region. Six sites have been selected in Rohini, Greater Noida, Gurugram, Faridabad and R.K. Puram. The assessment of micro-climatic conditions in these regions on 4 indices of Universal Thermal Comfort: temperature, relative humidity, CO₂ and wind velocity will help us in determining the urban heat island effect and assess the outdoor environmental conditions in this area.

The evaluation of urban housing forms will be undertaken by performing field-based surveys in different climatic conditions and using calibrated simulation software.

2. Urban Climatology

2.1. Overview

Urban climate, any set of climatic conditions that prevails in a large metropolitan area and that differs from the climate of its rural surroundings. Urban climates are distinguished from those of less built-up areas by differences of air temperature, humidity, wind speed and direction, and amount of precipitation.

These differences are attributable in large part to the altering of the natural terrain through the construction of artificial structures and surfaces. The challenge to understand the urban climate lies in the complexity and multiplicity of controls acting on urban climates at several spatial scales. The urban micro-climate is affected due to the urban systems interacting at three levels: building form, street delimited by buildings (canyon), and urban morphology of the neighbourhood and city block. The four climatic indices used for assessment of thermal comfort are:

a. Radiation

Radiation is the transmission of the sun's energy in the form of electromagnetic waves through space. The effects of urban structure on a quantity of radiation vary within a two-dimensional canyon. Initially, a facet receives direct-beam irradiance, a portion of which is reflected. This radiation spreads diffusely manner: some exits the canyon, and some are intercepted by the opposite wall and the canyon floor. This recipient surfaces also absorb and reflect in turn. This process of multiple reflection is repeated ad infinitum with progressively less energy being exchanged because each unit absorbs a portion of the radiation they receive. Multiple reflection makes a canyon a more efficient absorber of shortwave radiation than the albedo of the individual canyon facets.

An overview of factors in canyons show how they vary with $H:W$. Notice that at $H:W = 1$ the value of floor sky equals 0.4 (as does wall) and floor X wall equals 0.3 (and vice versa), so the view factor for the floor is chiefly occupied by canyon walls. Consequently, 60% of the radiation emitted by the floor is intercepted by the canyon itself, most of which is absorbed and subsequently re-emitted to other canyon surfaces.

Materials with radiative properties (reflectivity, absorptivity and transmissivity) are used to control building climates and exterior environments. Exterior paints and roof coverings can be chosen to minimize heat absorption, control glare and so on. Similarly, window glass can be selected to help control interior daylighting or minimize interior solar heat gain or reflect long wave radiation.

Whole facades of high-rise buildings can be covered with low-emissivity glass. A surface with low emissivity has an equally low long wave absorptivity, and since canyon facets transmit almost no long wave radiation, they are very good reflectors of long wave arriving from facets lying in their view.

b. Airflow

Air-flow velocity in a street canyon is strongly related to its aspect ratio good ventilation the wind velocity above the canyon should be high and nearly parallel to the canyon axis and the aspect ratio should be low (0.3-0.6). When the ambient wind speed is considerably higher than the wind speed inside the canyon and dominates buoyancy effects, the natural ventilation potential in single and cross-ventilation configurations is seriously decreased inside the canyon. The assessment of airflow reduction inside the canyon is mainly a function of the corresponding wind direction. When the ambient flow is almost perpendicular to the canyon axis, the flow inside the canyon is nearly vertical and parallel to the window, the pressure coefficients and hence the ventilation rate inside a building are much lower than would be calculated from ambient wind conditions. Site tall buildings carefully as they can cause vortex flows between the tall building and its small neighbours. For reduced site wind sensitivity building heights should be as uniform as possible. The effects of tall buildings can be evaluated using wind tunnel studies. Avoid funnel-like gaps between buildings. Larger gaps (3–5 meters or greater) will aid solar access and avoid vulnerable passages where the wind rushes through.

c. Atmospheric Humidity

Atmospheric humidity is generally lower during the daytime due to lower evaporation (E) rates compared to open areas owing mainly to the smaller fraction of vegetative cover. The corresponding RH field also follows the built-up outline and density patterns inside the city. The spatial distribution in the UCL follows the density of built structures and land cover. Conversely, at night and in winter generally, there is an urban moisture excess (UME).

Urban Canopy Layer: In summer there is an urban daytime moisture deficit and nighttime surplus. The former is mainly a result of lower E in the city due to the greater impermeable surface cover (pavement, buildings) and compacted soils.

Urban Boundary Layer: Upward transport is usually the more significant by day due to evaporation from the ground and trees, plus F from vehicles, vents and chimneys. Some emissions directly enter the UBL from building vents and chimneys; routes that bypass the UCL.

d. Urban Heat Island Effect

An urban heat island is an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human-induced activities. The temperature difference can be a reason for the urban heat island effect at different levels: subsurface, surface area, urban canopy layer and urban boundary layer. Alterations to the energy and temperature rates are caused by changes to the surface energy balance, anthropogenic heat flux and emissions.

2.2 Outdoor Thermal Comfort

A person's perception of thermal comfort in an environment is influenced by six basic parameters: physical activity (i.e. metabolic heat released), the insulation provided by clothing, air temperature and humidity, relative air velocity and mean radiant temperature, deriving from the temperatures of the surfaces/objects surrounding the subject (sun, sky, walls, ceilings, floors, windows, etc.); the amount of time spent in that environment and the average seasonal temperature. Thermal comfort is based on the energy balance between the heat produced and the heat released into the environment, to keep the internal temperature of the body at a constant (36-38 °C).

The outdoor thermal comfort of cities mainly depends on air temperature, humidity, wind speed and solar radiation. Outdoor comfort depends on the energy balance of the neighbourhood, which, in contrast to the buildings, can rely not only on the principles of conduction, convection and radiation, but also on evaporation (from vegetation, soil, water bodies...), in the same way as the human body. The street orientation, vegetation and buildings along the street edge plays great role in the outdoor thermal comfort. By creating a design appropriate for the neighbourhood, it is possible to control the outdoor environment and make it as comfortable as possible, achieving, at the same time, beneficial effects on the energy consumption of the buildings.

The Urban Thermal Climate Index (UTCI) is adopted as a metric for assessing the outdoor environment. The UTCI equivalent temperature for a given combination of wind, radiation, humidity and air temperature is then defined as the air temperature of the reference environment, which produces the same strain index value. (Urban Climates, T.R. Oke)

3. Delhi Climate and morphology

3.1. Understanding the composite climate

Delhi and the National Capital Region have a composite climate. The region lies 215m above sea level. The temperature changes every six months in a year. This region has dry-hot summers, cold-dry winters and hot-humid rainy season. Temperature ranges from 3°C in winters to 45 °C in summers. Wind flow changes accordingly four times in a year. Prevailing wind is considered harsh both in peak summer and winter. To help assist architects, planners and designers in analyzing the climatic data, and easy to understand and meaningful graphical representation of the climatic data for Delhi Climate- the year around data of Temperature, Wind Velocity and Humidity has been compiled together. Using the climate Consultant software annual 8760-hour EPW format climate data is translated into meaningful graphical charts and organized to represent this information in easy-to-understand ways that show various attributes of climate, and its impact on built form.

Figure 1 Annual Temperature range

Figure 2 wind Velocity Chart

Figure 3: Monthly diurnal variation

Figure 4 Psychrometric Chart

3.2. Housing Typology

The sites for this project were initially taken in different morphological districts in Composite climatic region of Delhi NCR. For evolving the case study is divided into different phases. In the 1st phase, indoor and outdoor climatic conditions are observed in different locations for winter session. In 2nd phase, study is elaborated to 6 locations in Delhi NCR based on different building typology and density. Based on this study finally six sites were chosen to conduct the micro climatic site-based study.

There are different kind of urban form characteristics, at different locations in the city. The various types of existing urban typologies in Delhi NCR for preliminary study are as follows.

1. Compact High-Rise

Comprising of a dense mix of tall buildings higher than nine floors with few or no trees, where the landcover is mostly paved with podium and basement below and where the construction materials include concrete, steel, stone and glass.

2. Compact Mid-Rise

Comprising of a dense mix of midrise buildings between five-eight stories, that are clustered round an open space with no basement and has a mixed landscape of trees, shrubs, groundcover, etc. The landcover is mostly paved and the construction materials include stone, brick, tiles, and concrete.

3. Compact Low-rise/Plotted housing

Comprises of linear arrangements of low-rise buildings of about one to three stories, with two side shared walls. It also has shared parks and parking spaces along the street, patches of tree cover and parks and the construction materials comprise of wood, brick, stone, tile, and concrete.

Figure 5 The location of six sites selected for study

4. Microclimatic Data Collection and Analysis

4.1. Urban Morphology

The research project aims to conduct a micro-study of the various housing typologies existing in the metropolitan region of Delhi. The focus areas are on the peripheral areas of the city which are

Figure 6 Morphological study of different areas

predominantly residential and are representative of similar housing morphology in the region. The study will include a detailed analysis of high rise, walk-up apartments and plotted housing typology. Six sites have been selected in Rohini, Greater Noida, Gurugram, Faridabad and R.K. Puram. The site area selected is within a 250m radius around the housing complex considering the contextual influences as well. The detailed analysis is undertaken for these six sites for built open ratio, built use, building heights, ground coverage, FAR and different types of open space in the 500 X 500 region.

4.2. Urban Environmental Simulation

SIMULATION SOFTWARE: 3D model ENVI-met, version 4.4. To study and analyze the urban thermal environment with respect to five climatic indices: Temperature, Relative Humidity, wind flow and CO₂.

APPLICATION: The investigation was carried out by using the three-dimensional numerical model ENVI-met, which simulates the microclimatic changes within urban environments in a high spatial and temporal resolution. Model calculations are run for a typical summer day in June 2019 in Delhi (28.7041° N, 77.1025° E, and 227m a.s.l.), a region characterized by a hot and dry climate.

INPUT PARAMETER: The ENVI-met model requires two user-defined input files. The area input file is a 3-D representation of the configuration of buildings and open space with vegetation, artificial surfaces and soils. The configuration file contains meteorological

parameters and surface properties for the initialization of the model and computation of energy exchange. The area input file is a 2m horizontal and 2m vertical resolution with 50x50x30 grids for the whole modelled area.

OUTPUT PARAMETER: Every result in Envi-met represents the general state of the atmosphere at the given model time. Following are the various results given by output file.

Wind Flow direction, Wind Speed, Wind Speed Change, Pressure Perturbation, Potential Air Temperature, Air Temperature Delta, Air Temperature Change, Specific Humidity, Relative Humidity, Mean Radiant Temperature, Direct Shortwave Radiation, Diffuse Shortwave Radiation, Reflected Shortwave Radiation, Leaf Temperature, CO2 flux etc.

Time	Sea level	Sea level	SW dir	SW dir	SW dir	Global
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SUMMER ANALYSIS

ANALYSIS: ENVI-met is a pure physical model. It is ideally designed for high-resolution simulations, but the model physics will also work for much larger spaces and coarser grid resolutions. Using ENVI-met files, most of the processes in the atmosphere can be analysed.

For this project ENVI-met V4.4.4 lite software is used with a grid size of 50x50x30.

Figure 7 Envimet environmental simulation

4.3. Spot Data Collection

DEVICE: TESTO 480 - Digital Temperature, Humidity, Airflow and CO2 meter

APPLICATION: The device is a high-precision digital temperature, humidity and air-flow meter which allows you to measure, analyze and log all relevant ventilation and indoor air quality parameters with only one device. The "Easy Climate" software allows your readings to be transferred directly to the computer. The IAQ probe is particularly suitable for monitoring indoor air quality and record CO2, temperature and relative humidity at the same time.

RESULT: Micro-climatic measurements of Temperature, Humidity, wind velocity and CO2 of each site at a distance of 1.5m above ground level is measured and recorded.

Units of each parameter:

Temperature- in degree Celsius; Humidity - relative humidity on a scale of 1 to 100%; Wind velocity - meter per seconds; Co2 - ppm2.5

In this study, Testo 480 is used to measure the micro-climate of each selected site. Measurements are taken during peak of Summer, Autumn and Winter season. Below are the given spots that are used to

categorize each spot measurement. These six categories are strictly followed on all sites to emphasize the micro-climatic variation in different housing forms.

Figure 8 The different locations where the data was collected using the instrument

Figure 9 Data collection and analysis for summer-summer-winter season

5. Design Principles for Urban Climatology

5.1. Design Parameters

There are 8 form-based parameters that are taken into consideration for guiding the design principles:

Figure 10 The 8 form based design parameters

Figure 11 The different form based parameters that are applied in the spatial planning and design for residential development

The different scales of Intervention these principles are being applied to:

- Building Level
- Cluster Level
- Street network
- neighbourhood level

BUILDING

- Building Facets
- Building Orientation
- Building Influence Zone

CLUSTER

- Distance between Buildings
- Cluster arrangements
- Open space configuration

STREET NETWORK

- Canyon Ratio
- Street Orientation
- Aspect ratio (H:W) vs Skyview factor

BLOCK

- MIG Layout/HIG Layout
- FAR 1.75/2/2.25/2.5
- Linear/ square site configurations
- Different cluster arrangements

5.2 Building Facet

The solar radiation exposure was studied for delhi weather conditions on different facets of the building. The analysis was undertaken for four solistices and throughout the year. Radiation exposure is lowest on north facade annually and highest on roof. A rectangular building with longer side aligned eastwest intercepts less solar radiation than the same building aligned north south. Urban heat island mitigation strategies should look at minimizing heat radiation on roof through green roof techniques and similar passive strategies.

Figure 12 Radiation study on building facets over different seasons

5.3 Building Orientation

The solar radiation is lowest on north facade annually and highest on roof. To make the most of the sun for warmth and natural light, the usable spaces in a building should face north. The larger glazing in the building, such as windows and glass doors, should preferably face north. Ideal Building orientation is between 11-23° towards east. Radiation value oscillate between 500-1500kWh/m²

Figure 13 Building orientation and impact on radiation on building facet

5.3 Building Influence Zone and building geometry

To investigate the effects of building geometry and radiation properties on urban thermal environment. The parameter of varying building height is studied as 11 different cases and evaluated. The cases are simulated for two time periods:

- Summer (March-October)
- Winter (November- February)

Effects of building radiation properties on horizontal urban thermal environment is evaluated.

To investigate the effects of building geometry and radiation properties on urban thermal environment. The parameter of varying building height is studied as 11 different cases and evaluated. The cases are simulated for two time periods:

- Summer (March-October)
- Winter (November- February)
- Effects of building radiation properties on horizontal urban thermal environment is evaluated.
- The influence zone for each building with varying height from 10m-60m is simulated for radiation studies is analyzed and compared with building regulations for similar height.
- Horizontal and vertical displacement is proposed for varying height(10-60m) for achieving thermal comfort on horizontal plane.

BUILDING INFLUENCE ZONE					
S. NO.	BUILDING HEIGHT(IN M)	MARCH TO OCTOBER		NOVEMBER TO FEBRUARY	
		Vertical Displacement	Horizontal Displacement	Vertical Displacement	Horizontal Displacement
1	10	8	6	8	3
2	15	8	6	8	6
3	20	10	8	10	8
4	25	10	8	10	8
5	30	12	10	12	10
6	35	12	10	12	10
7	40	15	12	15	12
8	45	18	15	15	12
9	50	20	18	20	15
10	55	22	20	20	15
11	60	25	25	20	15
					ACCORDING TO BUILDING REGULATIONS
					One third of height of building
					3
					5
					6(18), 7(21)
					8(24), 9(27)
					10
					11
					12
					13
					14
					16
					16(55+)

5.4 Street network and Orientation

- Street have significantly higher annual sunshine penetration in East-West street orientation when compared to North-South orientation.
- The plot division should be done to maximize the frontal ratio towards north-south and reduce towards east-west.
- Frontal area ratio: area of a building facet facing the maximum radiation should be minimum. For Delhi weather, the building facet towards north-south should be maximized and minimized towards east-west.

Canyon ratio

- Canyon aspect ratio ($H=W$) is most important aspect for determining impact of thermal factors of radiation, wind, humidity.
- The value of $H:W$ regulates access to sunshine (daytime warming), radiative heat loss at night (nocturnal cooling), shelter from the ambient wind and street ventilation (air quality).
- North-South is good for lower canyon ratio whereas East-West is good for higher canyon ratio.

Figure 14 Street orientation and impact on radiation on ground level within the canyon

5.5 Conclusion

The field-based study established that urban morphology and different built form typologies contribute to urban heat island effect and affect outdoor thermal comfort for its inhabitants. The various parameters affecting UHIE are quantified and used to develop form-based design guidelines for housing morphology. Through simulations of various urban form and combinations it was concluded that the four parameters of building orientation, canyon ratio, distance between buildings and street orientation have a major role to play in modifying the urban microclimate. Hence, the set of form-based guidelines was developed to enable architects, designers and sustainability professionals in building a more climate responsive built environment. The focus of this research is to mainstream outdoor thermal comfort in affordable housing sector in India. This research is a step towards achieving that goal by considering Delhi as a case.

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