# Resilient Urban Edges: Adaptive and Mitigative Design in Chennai

**Enos, V. and Schiano-Phan, R.**

PLEA 2017 EDINBURGH

*Design to Thrive*

# Resilient Urban Edges: Adaptive and Mitigative Design in Chennai

**Vaishali Marlene Enos[1] and Rosa Schiano-Phan[1]**

[1] Architecture and Environmental Design MSc, Department of Architecture, University of Westminster, London, United Kingdom.

**Abstract:** This paper investigates design responses to El Nino-mediated climatic disturbances, using the December 2015 Chennai floods as a test case. The effects of such disturbances are exacerbated by human intervention: urbanisation-led impermeabilisation of soil accentuates the urban heat island, makes water percolation difficult, increasing surface run-off. Using literature, precedents and on-site interviews with residents of a tenement block in severely-flooded Chennai, downstream of the River Adyar, key issues were identified. Additionally, impact of existing morphology on comfort conditions were derived using analytical tools of Envimet, Ladybug and CFD (outdoor) and TAS (indoor). The conclusions informed testing of hypotheses which merged with informal recycling practices of the residents. The paper discusses strategies employing recycled and local materials to build permeable surfaces (water-air-ground interfaces) to be embedded into existing architectural objects (by retrofitting), or utilised to build new experimental floating structures complementing the existing. The design studies show how strategies bring extreme temperatures of 42°C within a comfortable range in indoor and outdoor spaces; whilst contributing to flood mitigation. The paper speculates upon a resilient live-work environment for 2050 employing productive self-build networks to alleviate socio-economic polarisation characterising riverfronts, contributing to urban permeability and responding adaptively to daily, seasonal and extreme events.

**Keywords**: Chennai, El Nino, adaptive, mitigative, permeable

## Introduction

The El Nino is associated with temperature differences in the east-central Equatorial Pacific caused by trade winds moving towards South America instead Asia, resulting in weak monsoons in Asia. In India, particularly in urban areas like Chennai (fig 1), El Nino-mediated climatic disturbances manifests itself as dual conditions of droughts and floods. The drought scenario is exacerbated by the Urban Heat Island (UHI) effect (Amritham, 2016) resulting in extreme temperatures and water and food shortages, while floods are made worse due to construction on the flood plains and unplanned rapid urbanisation. The effects of unplanned concretisation of the city are found in the existence of the UHI indicating an intensity of 2.48°C and 3.35°C during summer and winter respectively (fig 3). Rapid urbanisation (fig 2) has resulted in vegetative areas declining from 70% to 48% (1991-2012) in the metropolitan area, with built areas increasing from 1.46% to 18.5% and projected to be 36% in 2026 (Ramachandra et al, 2016). Further, India's population is estimated to increase four-fold by 2050, with new populations living in urban areas, 60% of which are not yet built (McKinsey, 2015). The city is unable to satisfy the needs of its 12 million, creating a paradox of an increasingly polarised thirsty metropolis, expanding onto flood plains of rivers of the city.

Figure 1. Location

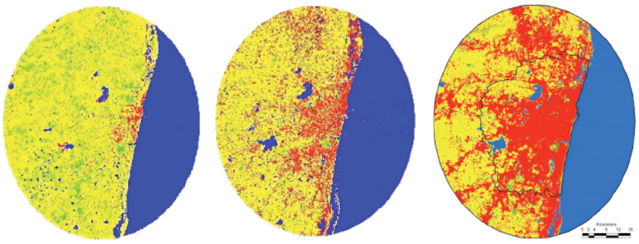

Figure 2. Growth from 2000, 2010 to 2026

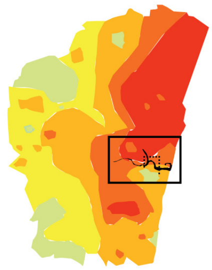

Figure 3. Heat Islands

***Area of focus – River and tenement settlements***

The area of focus is the river Adyar (fig 1), which burst its banks following the release of water from the Chembarakkam lake due to 539mm of rainfall on one day in December (which is the average rainfall for the month). The 12.2015 flood (fig 4,5a) turned the roads into water canals which perforated the urban fabric. The site chosen is a tenement settlement in Kotturpuram, which is on the curvilinear flood plain of the river and was inundated causing destruction to life and property - residents had to move to the terrace or be evacuated by boat. Chennai has a large number of such blanket developments built through a government housing scheme on low lying land unfavoured by real estate with informal settlements located around them. These blocks are generic in organisation with no attempt to engage with the informal lifestyle of its occupants. Therefore, the aim of this paper is to formulate design proposals that would allow for adaptation and mitigation of extreme weather events and typical conditions whilst engaging the city and local communities.

Figure 4. Before and after the flood

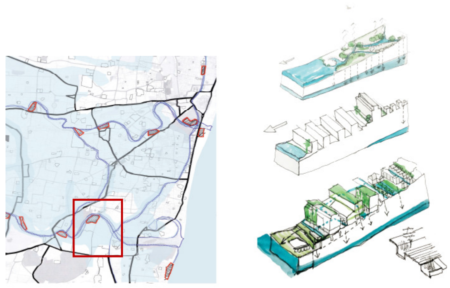

Figure 5. a) Site and b) hypotheses

***Hypotheses***

Hypothesis 1 - Mitigative strategy: What proposals can be introduced in the urban fabric to address El Nino-mediated extreme climatic events? The hypothesis is that layers of permeable surfaces, derived from the recycling economy and introduced in the fabric, will rethink landscape in cities, mitigate the heat island effect and provide ownership to the locals. This mitigative strategy explores permeability by using vegetation, water and synthetic materials in different ways in the urban and architectural fabric.

Hypothesis 2 - Adaptive strategy: What proposals can be introduced in the building fabric to address temperatures that are out of comfort for 95% of the year? The hypothesis is that layers of transitions spaces, buffers and screens will aid in achieving outdoor and indoor temperatures within the comfort band throughout the year. This hypothesis is a design intervention where existing street typologies and unit typologies were tested, evaluated, redesigned and later applied to new typologies on the site.

Hypothesis 3 - Participative strategy: How can a riverfront be utilised to integrate the city and promote ecological awareness? The hypothesis is that a river can be more than just a connection point from A to B but also: a mobility infrastructure, a productive channel, a public realm and a climate mediator. As a participative strategy, this is an urban design place making strategy that investigates integrating the neglected rivers and its polarised edges with the rest of the city (fig 5b).

## Climate

Located at 13.0827° N 80.2707°E, Chennai has a tropical wet and dry/savanna climate (Köppen-Geiger classification: Aw) with a maximum air temperature between 41°C in the month of May and 20°C in the month of December. The climate variations from the IPCC A1B scenario for 2050 (fig 6) that were considered are an increase in temperatures (1-2°C) and out of comfort temperatures for 90% of the time, an increasing trend in rainfall in the monsoon season from October-December, increase in the global horizontal radiation annually (2716 hours of sunshine per year) and capitalisation on sea breeze from the East.

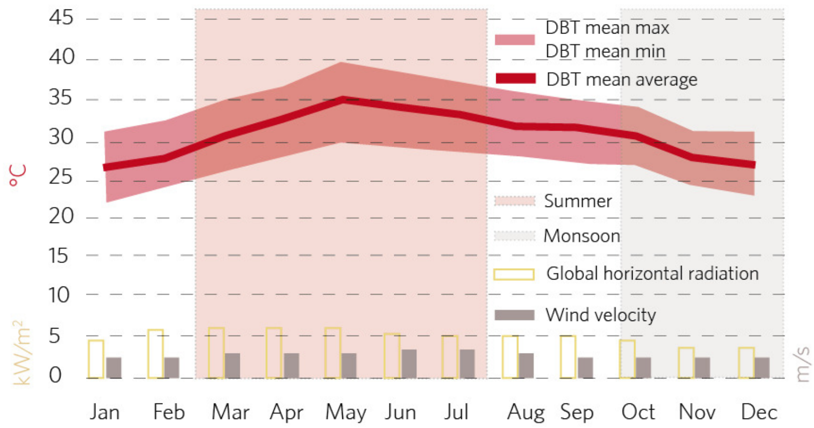


Figure 6. Monthly Average Climate Parameters - IPCC (2050) showing a rise in temperatures by 2°C

## Scope of work

The site consists of primarily 80 blocks within an area of 84,430 sqm. The orientation of the blocks (fig 7) (32x8x12m high) creates more asphalted streets in the form of East-West canyons (2.8-3.5m) than North-South canyons (8-10m). There are predominantly two types in the settlement - a ground + 3 typology (80% of blocks) where the ground and first floors were severely affected by the floods while the rest are of ground typology, which were washed away. The work is divided into two sections - Outdoor microclimate studies analyse street typologies and indoor studies compare thermal performance of units.

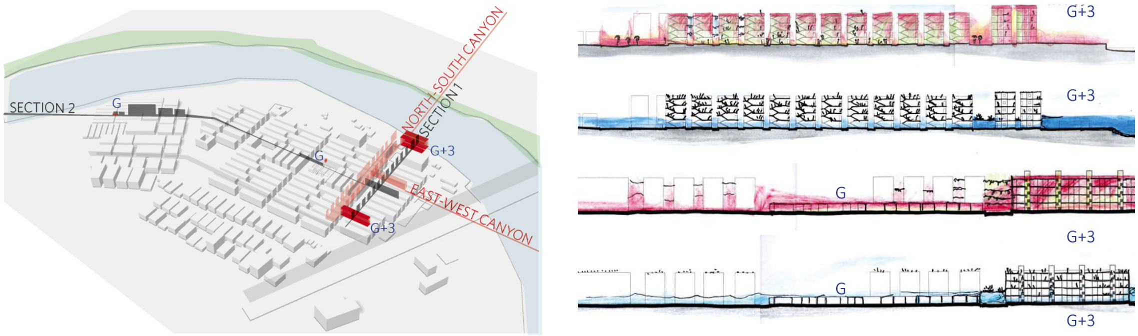


Figure 7. Sections and types (G+3/G) – orientation, behaviour during summer and monsoons

## Analytical work – existing fabric

### *Outdoor microclimate – street typologies*

The canyon geometry was analysed for solar access, wind velocity (sea breeze from the East) and existing outdoor conditions with Envimet (32°C average DBT, concrete construction and asphalt ground during Summer (May) and the following observations were made (fig 8) – The East-West canyon (30% Sky View Factor and Height-Width ratio 5:1) restricts more solar radiation than the North-South canyon (52% sky view factor and Height-width ratio 3.7:1) as a result of street geometry, morphology and sky view factor. At 14:00 hrs, the North-South canyon achieves a Dry Bulb temperature of 42°C while the East-West canyon achieved 39°C. At 2:00 hrs, the North-South canyon and East-West canyon both achieve 29°C. This indicates the North-South canyon re-radiated faster (higher sky view factor) than the East-West which behaved as a heat sink (Oke 1981). However, the wind velocity in the canyons was lower because of the lack of stacks, systematic open spaces and staggered edges which does not allow heat trapped in the lower layers to be dissipated to the upper layers. Also, the 180° orientation of blocks allows wind but 90° orientation blocks the flow. In addition, the river to the North modulates temperatures considerably.

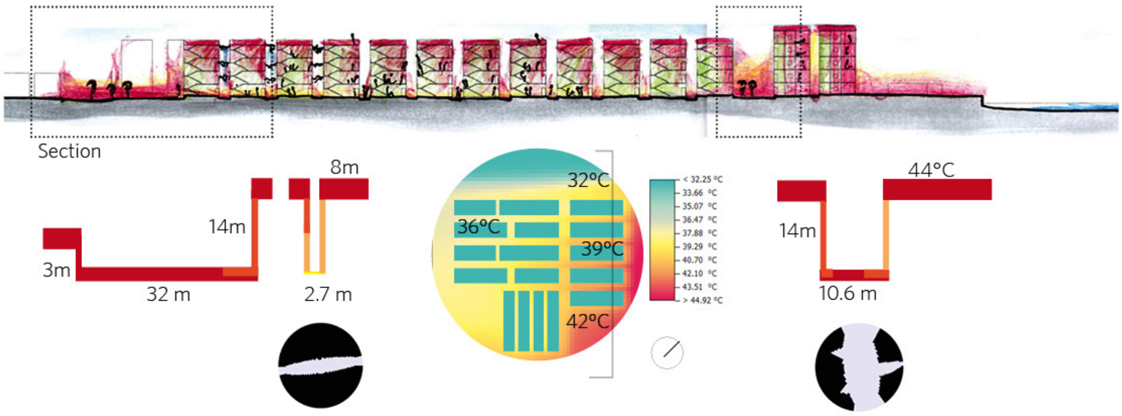


Figure 8. Typical canyon types - East-West (2.7m), North-South (10.6m) and Envimet analysis

### *Indoor – unit typologies*

The Ground+3 type typical flat (fig 9) consists of a living room, kitchen, bed and bath organised within 9.5x3.4x3m (4-6 people) of permanent concrete frame construction. The

Ground type is 6x4x3-3.5m high consisting of two multipurpose rooms with a bath (5 people) of temporary local wood and metal sheet construction.

A comparative study using dynamic thermal simulation (TAS 9.xx software) showed that indoor units (62%) have double the tendency to be out of comfort when comparing the Dry Bulb Temperatures. The G+3 type performed better (figure 11) than the G type because of obstruction from the context and materiality. However, hot air from the kitchen moved into the living room, instead of being expelled due to the lack of cross ventilation or stacks. In addition lack of night time ventilation increased hot conditions during the night. In case of semi-open areas, the stairwell had a maximum of 47% out of comfort hours, the in-between zones recorded 42% and the DBT recorded 31% indicating that urban morphology, materiality and anthropogenic heat sources caused heat retention. Therefore, strategies have been proposed to achieve indoor comfort (fig 11):

a) Ventilation- Night time cross and stack ventilation and the use of the stairwell to expel heat from indoor and semi-open spaces during the night to cooler outdoors.

b) Solar radiation- Shading surfaces (facades, windows, ground and roofs) exposed to solar radiation. Vegetative walls induced evaporative cooling bringing down temperatures by 3°C (Saito et al, 1990). Roof layers act as insulation and offer scoop ventilation.

c) Daylight - The design sky illuminance of 22,000 lux requires small openings for light, reducing the perception of heat.

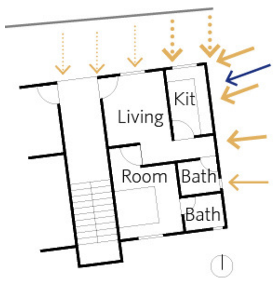


Figure 9. Typical plan

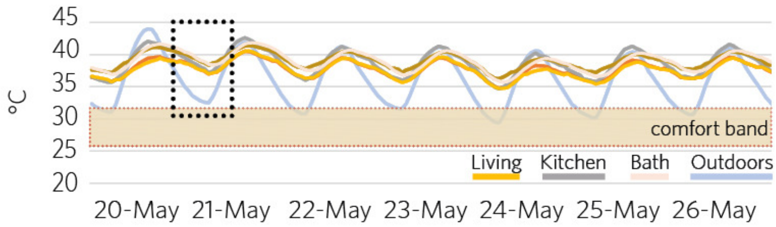


Figure 10. TAS Analysis (May 20-26) showing lack of night time ventilation

## Site strategies

The proposal involves a fluid strategy which revolves around the recycling economy using the river as its main mode of movement. It aims to turn the site from inward-looking to oriented towards the river (fig 11). This includes bringing the river into the site in the form of channels which will reduce temperatures in the interior and help in percolation. The different areas of the site are for the arrival areas for raw materials, distribution areas and workspaces. Two areas are detailed design interventions – existing street based and new floating typologies.

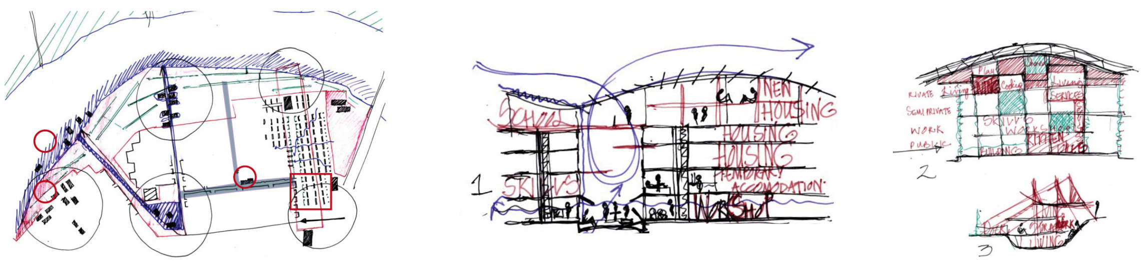

Figure 11. Site strategies – Street-based and floating types

## Propositions – existing streetscape

### *Street based typologies*

The intervention for the existing typologies included four stages – introduction of a new horizontal (0-6m high - fig 12.2) to mitigate floods and become informal workspaces, reorganization of existing floors (6-12m) to improve organisation and ventilation, introduction of new floors (12-18m) to increase densities and a community roof (18-21m).

The results of tested outdoor concepts were that solar access (Ladybug software – fig 12.1 and 12.2) was reduced by 50% on the East and 80% on the streets. Wind study (Autodesk CFD – fig 12.3) simulations showed that wind velocity increases from 0 to 3m/s when the block is raised by 6m and a jagged roof creates turbulence. Outdoor microclimate modelling and simulation (Envimet - fig 12 A and B) showed that when concrete construction is replaced by brick, a permeable roof, earth on the ground, vegetation and water channels are introduced, the temperatures reduce from 42 to 31°C (North-South canyon) and 39 to 30°C (East-West canyon) at 14:00 hrs on May 15 (Summer – average temperature 35.2°C). At 02:00 hrs, both measured 29°C (same as the weather station). This shows that change of material decreased sensible heat in the canyons reducing temperatures by 5-6°C, water modified edge temperatures extensively by 7-10°C, earth (instead of the asphalt) reduced temperatures by about 6°C and vegetation reduced temperatures by 2-3°C. For indoor existing units, the kitchen was reorganised and new stack windows of 24-28% window to floor area for 6m² and 45-55% for 9m² on North-South facades, and 30% for 3.5 m² on East-West facades (with shading) required. The new floors included staggered unit floor profiles to create turbulence for wind and outdoor living rooms for residents. Here, the living rooms and kitchen are combined into one cross ventilated space, built with mud, tile and stone aggregates.

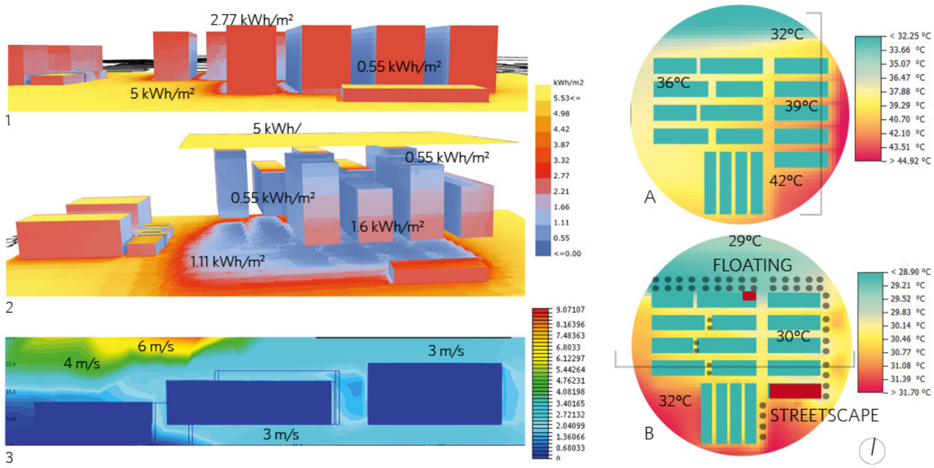


Figure 12. Monthly average daily solar radiation (1 - existing, 2 - proposed), wind studies (3 - proposed) and Envimet Comparative Analysis (A and B)

### *Floating typologies*

Floating typologies (fig 13) use the principles from the street typologies to house residents of the Ground typologies (largest risk to floods). The ground has workspaces, while living units (3x3x5.5m) and communal kitchens areas are lifted off the ground by 3m. Solar access was reduced by the larger insulated roof and inverted profiles beneath. The ventilation strategies included monsoon windows, small openings at floor and large stacks near roof to increase extraction of heat. Vegetative walls on East and West induced evaporative cooling. To mitigate flooding, the type is a light weight structure of metal, wood and coconut pith boards placed on a framework of PET bottles and binding wire.

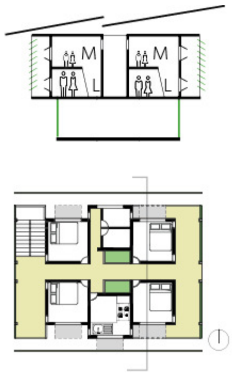


Figure 13. Configuration

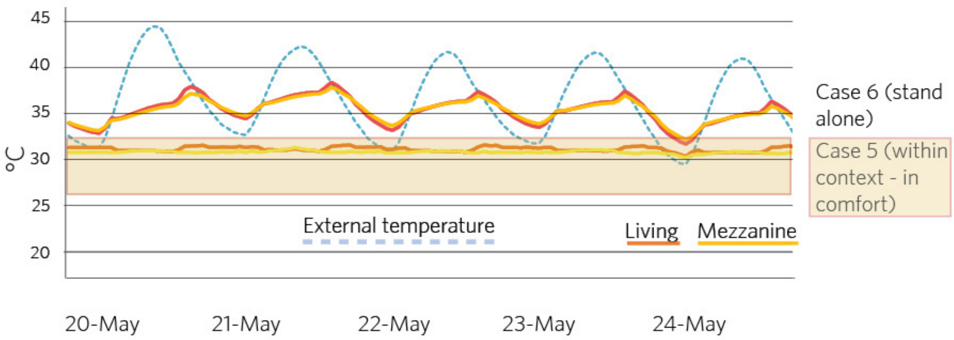


Figure 14. Case 5 + 6 TAS Comparative Analysis

*TAS Analysis – floating typologies*

Cases 1-5 were tested as stand-alone units without surrounding context during May 20-24 (Summer) to examine whether they perform within the comfort range of 26-32°C. Case 1 tested a shoebox of wooden walls within a metal framework and coconut fibre boards as insulation. The units were out of comfort in comparison with diurnal DBT of 32-42°C. Case 2 included windows (2x1.2m on North-South) and stacks (1.5x.5m at 2.1 and 5m) which were enabled between 19-32°C and 90% open. Here, temperatures are in tandem with the DBT indicating the need for shading and ventilation regimes for different window sizes. Case 3 included louvered shading, stacks in floor and extensive night time ventilation instead of day time to achieve resultant temperatures of 32 to 36°C. Case 4 included internal gains of 2 people in each (9m2) unit of the living, kitchen and bath zones with different schedules. Here, the units come into range during the night.

Case 5 and 6 (fig 14) tested the principles from the outdoor analysis in Envimet. Case 5 included context (urban layout) and vegetative walls, the river and permeable ground and case 6 was tested without. Case 5 was in comfort but Case 6 required extra shading for exposed surfaces - vegetation for walls, bamboo mat shading for the roof and thicker light weight insulation.

**Conclusions**

The design interventions focused on a riverside tenement block in a metropolis susceptible to urban heat islands and floods, in part aggravated by El-Nino-mediated climatic disturbances, but also caused due to anthropogenic interventions. Therefore, in addition to redevelopment of the riverside tenement block, the urban strategies also aimed at integrating the tenements by using the river and the recycling economy as a source of production. The materials derived from debris and garbage around the area is reused and re-integrated into different interfaces of the built areas to provide affordable respite to the UHI effect and mitigate the effects of flooding during the monsoons.

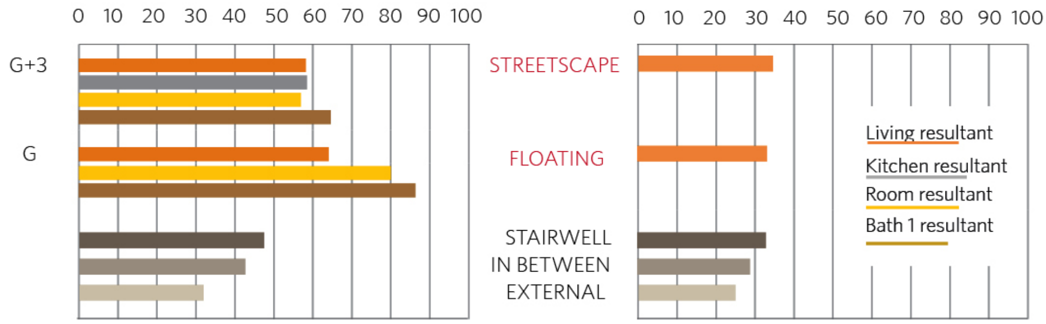


Figure 15. % of out of comfort hours : Comparison between existing (left), retrofitted and new types (right)

The streetscape type – redevelopment from existing G+3 typology into a G+5 type employs heavy weight material while the floating type (replacement for the ground type) is built from lightweight materials resting on a floating mechanism. By employing outdoor and indoor strategies, these permeable materials are tested reducing discomfort hours in the indoors by almost 50% and in the in-between areas by 12-15% (fig 15) throughout the year. This is achieved by transitionary areas, shaded streets, screens and staggered buffer zones without compromising on density in order to house low income residents. The proposal aims to involve residents in a participatory process of regulating their microclimate, generating income and claiming ownership of unfavoured areas along rivers in fast developing metropolises.

## Acknowledgments

This work is the outcome of a Thesis Project for the Architecture and Environmental Design MSc, Department of Architecture, University of Westminster, London.

## References

Amirtham et al, (2009). Mapping of Micro-Urban Heat Islands and Land. *The International Journal of Climate Change: Impacts*, 1(2), pp 72-83.

Amirtham, L. R., (2016). Urbanization and its impact on Urban Heat Island Intensity in Chennai Metropolitan Area, India. *Indian Journal of Science and Technology*, Volume 9(5).

Jeganathan et al, (2012). Temperature trends of Chennai City, India. *Theoretical and Applied Climatology* 111(3-4),

Landsberg, H., (1981). *The Urban Climate*. New York: Academic Press.

Nleworks.com. (2017). Makoko Floating School | *NLÉ*. [online] Available at: http://www.nleworks.com/case/makoko-floating-school/ [Accessed 16 Feb. 2016].

Oke, T. R., (1987). *Boundary layer climates*. London: Routledge.

Ramachandran et al, (2016). Visualization of Urban Growth Pattern in Chennai Using Geoinformatics and Spatial Metrics. *Journal of the Indian Society of Remote Sensing*, 44(4), pp 617-633.

Saito I, I. O. K. T., 1990. Study of the effect of green areas on the thermal environment in an urban area. *Energy and Buildings*, s.l.: s.n.

Santamouris, M., 2002. *Energy and Climate in the Urban built Environment*. London: James and James