PROJECT REPORT

APPLICATIONS OF CFD SOFTWARE FOR COMPARING ENERGY RESOURCES OVER CHENNAI CITY URBAN SPRAWL

ENERGY IN BUILT ENVIRONMENT (MEE2065) UNDER THE GUIDANCE OF

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Abstract

In recent years the urban heat island effect has played out in many south Asian cities. Exaggerated heat stresses over these regions not only impact human comfort indices but also have an impact on local and regional microclimates. Dereliction and uncontrolled slum populations over many south Asian cities include soot and black carbon emissions from archaic methods of cooking. The aim of this study is to explore the urban landscape of the north Chennai slums incorporating its most tenuous heat and particle emissions, combining satellite-based remote sensing with the power of computational fluid dynamics. This paper first quantifies the first kitchen induced impacts over five distributed slums in Chennai and thereafter quantifies the particles and heat dispersion locally. Established codes are used to quantify the slum heat flux contribution to the UHI in this first study.

INTRODUCTION

In this era of socio-economic advancement and awareness, the history of the Anthropocene has taken a subtle turn — a reflection of which has manifested during the “Glasgow Climate Summit 2021” — where the developed nations responded to their fair-share of climate pollution and fossil fuel was deemed as the focal driver of climate change, forming a momentous event. Amidst the political wrangling a line was drawn to keep the 1.5oC treaty at a push by phasing out coal usage.

A city’s power consumption in turn subjects to its population density and geo-climatic position. Thus it only makes sense to consider the meteorological factors like, temperature, precipitation, moisture presence etc, while designing and organizing the fenestrations along with the vegetation and the landscape. In India unbridled expansion of cityscapes have taken size of towering metropolises — Kolkata, Chennai, and Mumbai pinned to large slums— with deplorable standards. a building dated back to 1945, Golconde — The first modernist building in India — utilizes weather elements for better ventilation and less heat adsorption: the idea of cooling roof, well placed facades along its length, adjustable louvers and north to south lengthwise architecture made this possible. Golconde and other energy efficient buildings depicts a stark effect on energy loads and human comfort, they have paved a path for sustainable architecture, although exponential increment in population and need for housing did not allow such practices.

The sporadic layout of slums and building material of high thermal capacitance invigorates UHI . Unsupervised distribution of thermal mass and greenery emanates an artificial surface texture, which leads to increased temperature and patches of high and low temperature regions along the landscape; in short, a change in local microclimatic condition occurs and that in turn encourages climate change. This climatic phenomenon of local temperature augmentation is known as urban heat island effect. Furthermore, the air heated due to UHI carries the industrial and vehicular-tailpipe emissions trapped in building canyons in the form eddies carrying pollution and heat to cloud level resulting in generation of convective clouds affecting the surface temperature and rainfall patterns. To mitigate these issues along with sustainable building we need to adopt the climatic factors in our designs through: building material, pavement width, building height, roof material, road material etc. c. All this factors are hardly taken into account while building slums, in this paper, our main discussion will focus on slums of Chennai; its architecture, human comfort, ventilation loads, diurnal temperature change and improvement of the architecture. A recurring record breaking nature of the temperature level of Chennai portends a message of climatic depreciation. We will also investigate the governance of the city's cloud cover over the weather. By and large, the aim is to quantify the heat stress and propose a sustainable architecture for the slums for amelioration of the above mentioned issues. All meteorological data was derived using "Weather Research and Forecasting" code, and necessary inputs regarding building height, pavement width etc was obtained using GIS data and "ARCGIS ESRI City Engine". 3d phenomena like wind shear were captured using a 3d computational simulation, a commercial package also known as "Envi Met" was used for this purpose.

PROBLEM STATEMENT

Poor architecture, rapid urbanisation, dense population per sq ft coupled with geographical location has given rise to local microclimate and urban heat island effect in the city of Chennai, formerly known as Madras. We can see the difference in thermal mass accumulation along the terrain in Fig 1, the main source of heat stress. It is necessary to quantify the heat stress and study the wind flow pattern to comment on the human comfort level, suggest improvements in city architecture and HVAC loads.

In 2019, an article from The Hindu mentions: "The number of hot days in which the temperature breached the 40-degrees Celsius mark has gone up in the city recently. The impact of global weather changes and urban heating following rapid urbanisation cannot be denied," he adds. Studies, too, indicate an upward trend in the day and night temperatures, especially during summer, over the past three-four decades…

In 2019, an article from The Times Of India, As the urban environment changes it also affects the temperature that can climb up by nearly 2˚C in the heart of the city. The closely packed high-rises, congested roads and lack of trees, restrict movement of air and notches up the heat in areas such as T Nagar resulting in a phenomenon called urban warming or urban heat island (UHI) effect...

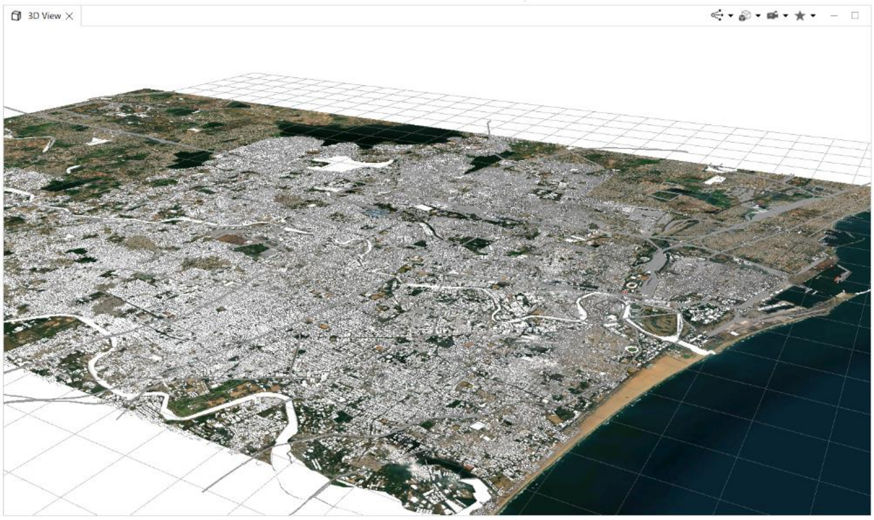
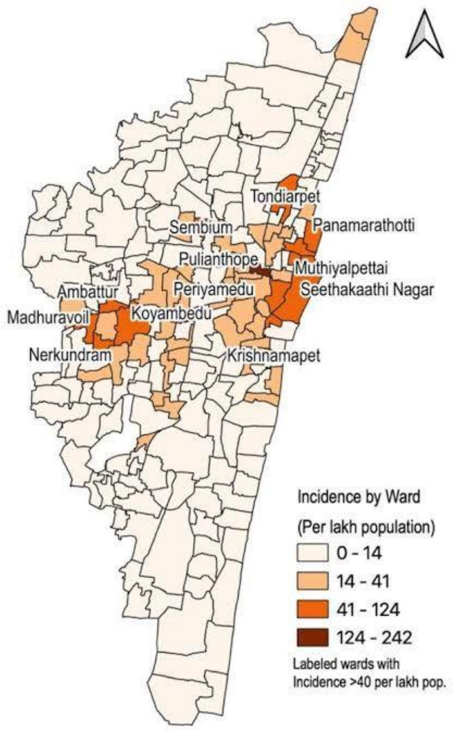


Figure 1 GIS data based modelling of city of Chennai describing the three layers: urban, sub-urban and rural

ENERGY CONSMUPTION PATTERNS OVER CHENNAI

In recent times the power consumption of Tamil Nadu has declined by more than 7% in 2021 from 2020 which is the highest among all the states across the nation and is primarily caused due to the pandemic. The demand for electricity in the Chennai city is most in its northern part which is around 2100 megawatt per day. According to a government survey, the population in the slums of the city and its north part basically has increased by 51.85 % from 2001 to 2014 which is in a single decade. This is the prime reason of the most power consumption across the area. It is also found that the energy consumed in and across the Chennai area and Coimbatore area is the most in the state of Tamil Nadu primarily due to urbanization and industries. The industries in the northern part of Chennai is consuming much more energy than those in the south and also due to the heavy population density in the area (and the slums) has caused the northern part of the city to consume approximately twice as much as the domestic energy consumed in the south (for the detail value see the datafile). Overall, North Chennai consumes almost twice as much as energy consumed in the South Chennai. It can be concluded that the population of the northern part of the city is much more than the southern part and the most populated regions such as Ambattur also comes in North-West Chennai. This could be the prime reason for much more domestic consumption of energy in the North Chennai. It has to be noted that due to its geographic location Chennai faces more heat than the other metropolitan city in the country and this causes the demand of 3,277 MW of power just for using air conditioners by its residents which is more the entire average demand of the entire state of Kerala.



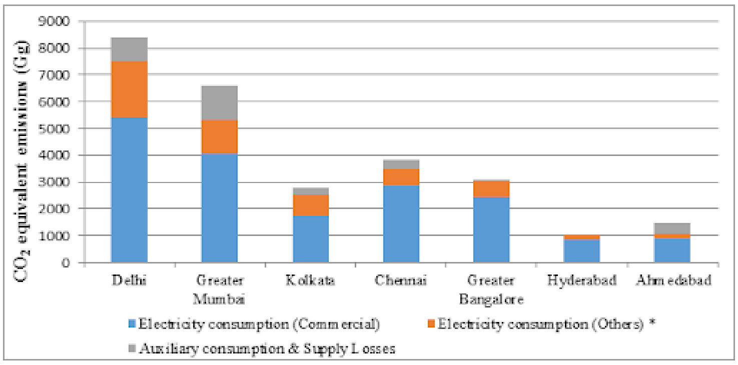


Figure 2 a) Staggered and brick made buildings of Chennai, b) Population distribution over map of Chennai, c) Amount of CO2 emission in different metricities

THE EFFECT OF URBAN HEAT ISLAND EFFECT

Rapid progress in urbanization could lead to local climate modifications which significantly alters the atmospheric properties and landscape conditions in and around an urban agglomeration. Unplanned urbanization in modern cities, transformation of radiative, thermal, moisture and aerodynamic characteristics of the surface, an increase in energy consumption and an alteration of the urban climate as well as a modification of air quality gives rise to the UHI effect. Warmer nocturnal temperatures than the surrounding landscapes is major characteristic of the UHI.

UHI is governed by Factors such as:

1. The cloud cover of the city, prolonged clouds over the city might enhance the urban heat island via night-time radiative forcing
2. Presence of moisture and pollution mass-transfer.
3. Land-sea breeze.
4. Uneven distribution of thermal mass and vegetation distribution.
5. Poor city architecture governing wind shear which causes change in mixing ratio causing an interaction with the atmospheric boundary layer.

To study these phenomenon in a time-scale basis weather research and forecasting model will be used integrating the meteorological variables with cityscape.

CONCEPT AND METHODOLOGY

Geospatial data and meteorological data is fed into wrf to produce the details of climatic conditions at the area of interest on preferred date. For more accurate results and computational constraint, the domain is of a vast area involving the study area. The slums can be defined as nests for high resolution solution, although this will require more computational power depending on the number of nests used and their area. To adjust different parameters including building material, building height, roof width etc., we need a detailed view of the area, this is made possible through ESRI city engine offering us a downscaled view of the great city. The results of wrf vaguely express the interaction between meteorological variables and topology, even with high-resolution nests. For our study, we require a detailed view depicting interaction between the slum architecture and wind shear. For this purpose the ESRI model is sent to Envi Met module in Google sketch up. Envimet offers a 3d view of the area of interest along with all climatic factors. Our goal will be to quantify all the flaws and faults in the current architecture of the cramped up slums and to propose a new plan with all the climatic factors incorporated. The new plan will utilize the climatic conditions for natural heating and cooling, thus cutting down energy loads.

Downscaling: Dynamical Downscaling Method

Weather or climatic data entails a considerable portion in various decisions making processes, like: expansion of a city, industrial investments, agriculture, spreading of vector-borne diseases, precipitation and temperature estimation etc. This study tends to describe the governance of local surface texture — modified by anthropological activities — which will require meticulous data input regarding local topology and thermal mass distribution.

To elaborate, a certain area in the GCM is defined as nested area to undergo RCM, thus urban morphological data and other details are defined for the nested area. The boundary conditions are obtained from the GCM model which are solved inside the nested domain along with other morphological features. In WRF code the slums can be defined as nested domains and the whole Chennai city along with its urban and rural areas will become the parent domain. GIS data was processed using ESRI city engine to generate a panorama of the city and the slums, providing a bird's eye view of thermal mass distribution and vegetation. Inputs for Urban Canopy Model of WRF were adjusted based on the city engine view. Also, both GCM and RCM do not consider the building energy model and the governance of the cityscape on the local microclimate which are all adjusted in WRF multi-layer urban canopy model and WRF-BEM module respectively. Thus downscaling has provided us with better quality of results.

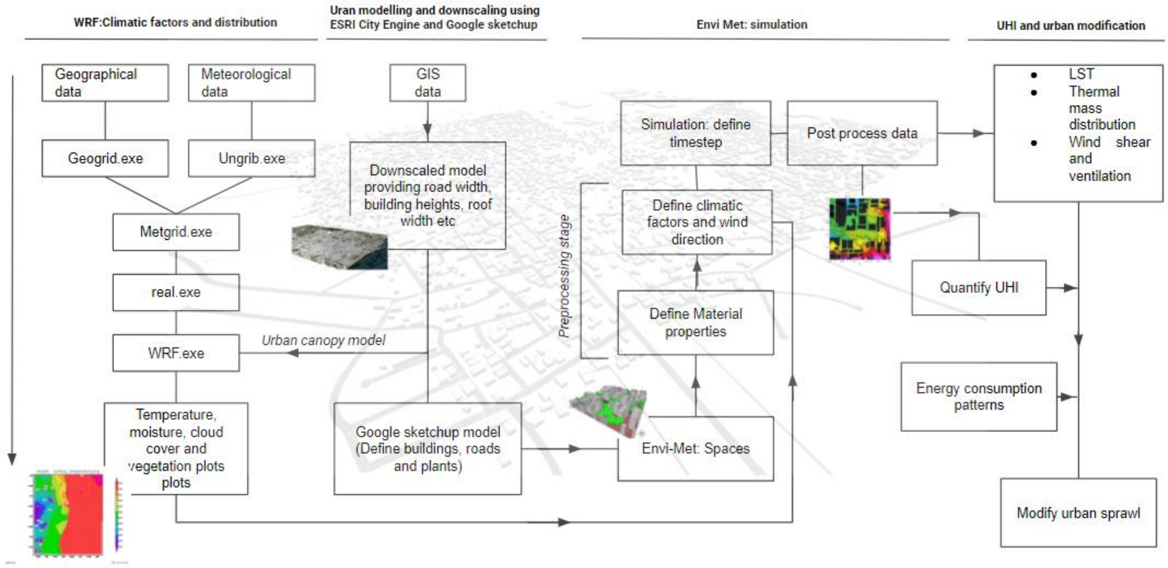


Figure 3 Flowchart depicting methodology

MODELLING OF CITY AREA

Google Sketchup is an essential tool for modelling of 3D landscape and producing facade orientation/shadow range which is helpful to calculate net radiation reductions for ground surface. Facade orientation evaluation will help designers to deploy materials with lower U-value on building surfaces. Sketchup allows third party plugins which helps us integrate with envimet and create envimet objects: buildings, plants, soil and terrain, Read geo-location, read SKPINX:a file that contains envimet objects information, Import envimet system and user library for materials.

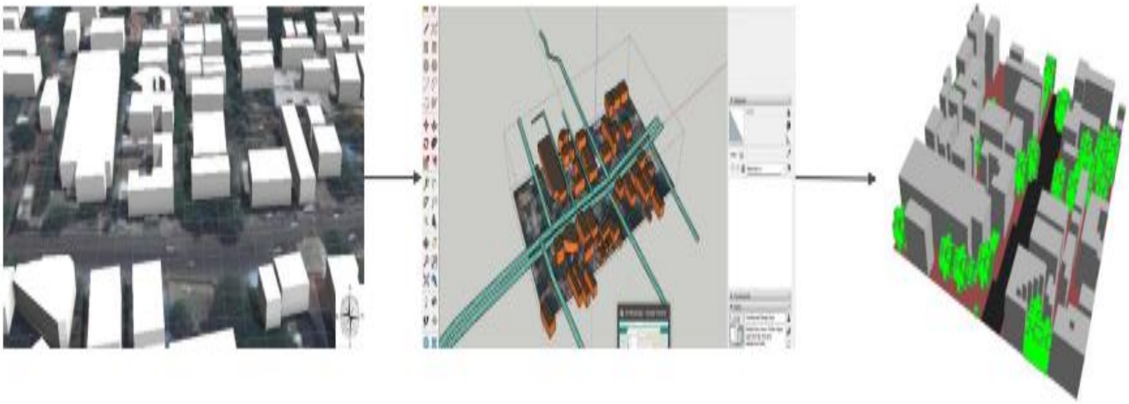
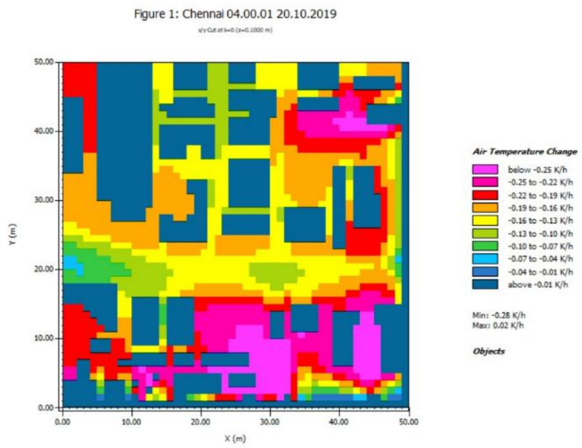
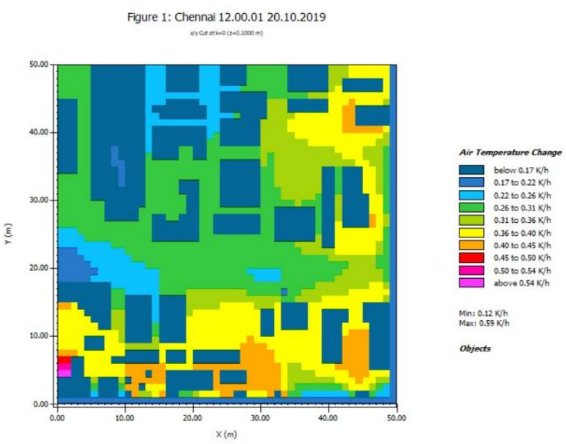


Figure 4 Downscaling diagrammatical representation

RESULTS AND DISCUSSION

- The maximum temperature change is recorded at sites with open and wider roads and vegetation, indicating UHI at a micro-scale.
- Around 4am we can distinctly point out patches of temperature zones each zone is depicts different temperature change or shift, representing uneven urban distribution and ventilation
- The cooling zone has maintained its existence throughout the day, this is due to Bernoulli effect due to clusters formed by vegetation and buildings.





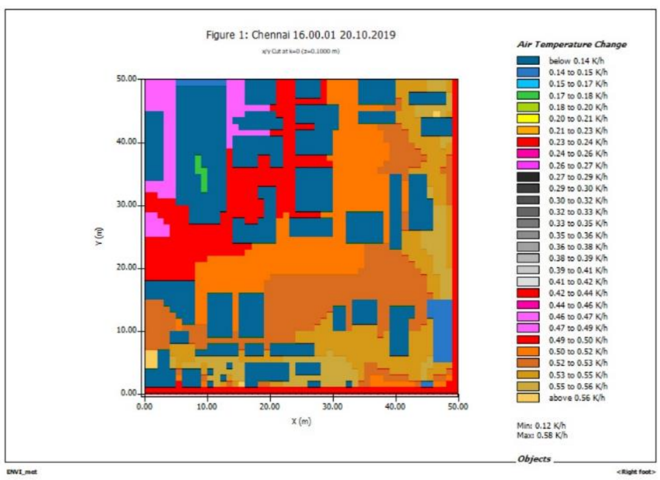


Figure 5Envi met results

POSSIBLE ARCHITECTURAL CHANGES FOR AMELIORATION:

- A possible solution is demolishing the sporadic layout, replacing it with structured high rise buildings made of low thermal capacity material. The high-rise buildings will act as heat fins. By incorporating features from Golconde we can boost the heat dissipation characteristics. The idea of cooling roof using passive or active systems and windows with adjustable louvers can help improve indoor and outdoor ventilation characteristics. The new exposed areas can be planted with vegetation to improve heat dissipation characteristics of the entire neighbourhood. – Deepyaman
- If we install shading windows, roofs (blocking of sunlight before it hit the glass or ceiling) then it can reduce the surface temperature of the houses or slum. The method of earth coupling to reduce the overall surface temperature of the building walls and to transfer the heat to the ground using conduction method. – Harsh
- Evaluating facade orientation using the current methodology we can create urban heat mitigation strategies such as implementation of materials with lower U value/reflective properties on buildings external façades and road surfaces. Maintaining layout of buildings depending their orientation which significantly affect transport of pollutants and ventilation relative to the prevailing wind direction. Inclusion of artificial lakes and ponds can help mitigate heat waves through evaporation. – Mosaab

INFERENCES

The envi met simulations provide us with deeper insights relating to the change in meteorological factors in an urban scape and their interaction. We can draw certain conclusions:

1. Building clusters are blocking proper circulation of air throughout the area.
2. Uneven outdoor wind flow along with sporadic distribution of vegetation gives off irregular cooling effect.
3. UHI is eminent and easily detectable in early mornings.
4. Contrasting disparity in temperature shift in different areas over a period of 12 hours is recorded. Extrapolating it in a larger case, this provides a vague idea regarding the demanding energy requirement in slums.
5. It is necessary to restructure the neighbourhood with an aim to use the bioclimatic conditions to reduce active ventilation and lighting loads and to provide a healthy environment for slum people. Based on the Glasgow conference India is relying on fossil fuels for upcoming future to support its economic development and to meet the energy consumption requirements. A large part of the energy consumption occurs in cities for lighting, cooling, etc. The aim of our project is to restructure the slums based on its local microclimate which will directly affect its energy demand, as the new design will use bioclimatic buildings sensitive to climatic factors