Thesis entitled

Redefining Urban Planning Process through Human Biometeorological approach for Sustainable Urban Development

Thesis submitted by

Rohini Mazumder Chakraborty

Index No.: D-7/ISLM/74/16

Doctor of Philosophy

Department of Architecture

Faculty of Interdisciplinary Studies, Law & Management

Jadavpur University

Kolkata-700032, India

2023

JADAVPUR UNIVERSITY

KOLKATA-700032, INDIA

2023

Department of Architecture

Faculty of Interdisciplinary Studies, Law & Management

1. Title of Thesis:

   "Redefining Urban Planning Process through Human Biometeorological approach for Sustainable Urban Development."

   Date of Registration: 19^{th} September, 2016

2. Name, Designation and Institution of the supervisors:

   Prof. (Dr.) Debashish Das,

   Professor, Department of Architecture, Jadavpur University, Kolkata, India.

3. List of publications:

A. Journal:

i. Chakraborty R.M., Das D. (2019), "A Review of Urban Microclimate Concepts and Thermal Indices in the Analysis of Outdoor Thermal Comfort in Tropical Humid Climate -Case Study on Kolkata", Ind. J. of Landscape Systems and Ecological Studies 42 (2) December-2019, pp 102-115, ISSN 0971-4170. https://www.ilee.org.in/PdfDocs/ILEE_Volume_42_No2_December_2019.pdf.

ii. Chakraborty R.M., Das D. (2023), "Analysing Outdoor Thermal Comfort due to Proximity to Water Surface in Tropical Humid Climate - A Case Study in Kolkata Municipal Area, West Bengal, India", Indian Journal of Spatial Science Autumn Issue: 2023:14(3) pp.69 – 80, ISSN: 2249 – 3921, EISSN: 2249 – 4316. https://www.indiansss.org/ijss/current-issue

B. Edited Book

i. Das D, Chakraborty R.M., Bhadra (2016), "Aspects of Urban Climate Map and its Importance in Urban Planning: Case study of Kolkata". Environment and Sustainability, (TCIL), India, ISBN No.: 978-93-83010-30-1

C. Conference proceeding (volume)

i. Chakraborty R.M., Das D. (2018), "Influence of Built Form, Air Temperature and Wind Speed on Outdoor Thermal Comfort", ENVIRONICA, Vol.II, January, 2018: Compiled

Volume of the Third International Conference on Mother Earth: Environmental Crisis and Sustainable Strategies, Department of Environmental Science, University of Burdwan, West Bengal. ISBN No.: 9789 384106973

D. List of patents- Nil

E. List of National/ International Presentations/ Conferences/Symposium/ Workshops

i. Presented Paper on "Aspects of Urban Climate Maps and its importance in Urban Planning-Case study of Kolkata" in the UGC Sponsored National Seminar on 'Environment and Sustainability-A Geographical Perspective' held on 18th and 19th November, 2016, West Bengal State University.

ii. Presented paper on "Influence of Built Form, Air Temperature and Wind Speed on Outdoor Thermal Comfort- Case study of Kolkata" in the Third International Conference on Mother Earth: Environmental Crisis and Sustainable Strategies, Department of Environmental Science, held from 11th to 13th January, 2018 at University of Burdwan, West Bengal.

iii. Presented paper titled "Analysing Outdoor Thermal Comfort with Proximity to Water Bodies in Tropical Humid Climate-Case study of Kolkata" in the Symposium on Challenges in Applied Human Biometeorology held in Albert-Ludwigs University, Freiburg, Germany on 2nd and 3rd March, 2020.

iv. Presented poster titled "Analysing Outdoor Thermal Comfort in Tropical Humid Climate, - Case Study in Kolkata Municipal Area", in 2022 International Association for Urban Climate (IAUC) Virtual Poster Conference at University of New South Wales (UNSW), Sydney, from 30th August to 1st September 2022.

STATEMENT OF ORIGINALITY

I, Rohini Mazumder Chakraborty, registered on 21st September, 2016, do hereby declare that this thesis entitled "**Redefining Urban Planning Process through Human Biometeorological approach for Sustainable Urban Development"** contains literature survey and original research work done by the candidate, undersigned, as part of the Doctoral research work.

All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical codes of conduct. I declare that, as required by these rules of conduct, I have fully cited and referred all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti-Plagiarism, Jadavpur University, 2019", and the level of similarity as checked by the iThenticate software is **6%.**

Rohini Mazumder Chakraborty

Signature of Candidate

Rohini Mazumder Chakraborty

Date: 19.9.2023.

CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled "**Redefining Urban Planning Process through Human Biometeorological approach for Sustainable Urban Development"** submitted by Rohini Mazumder Chakraborty, registered on 21st September, 2016, for the award of Ph.D. , degree of Jadavpur University of absolutely based on her own work under the supervision of Prof. (Dr.) Debashish Das and neither her thesis nor any part of her thesis has been submitted for any degree/diploma or any other academic award anywhere else before.

Certified by Supervisor:

Debashish Das
19.9.2023

Prof. (Dr.) Debashish Das

Department of Architecture,

Jadavpur University,

Kolkata-700032

Professor
Department of Architecture
Jadavpur University
Kolkata-700032

Dedicated

to

Jyotiraj & Jasashwi

ACKNOWLEDGEMENT

The journey, since the beginning until the submission, of this thesis has been an experience for me and it would not have been possible without the support I received from many people.

I would like to begin my acknowledgement by expressing my gratitude to my supervisor, Professor Debashish Das, Professor, Department of Architecture, Jadavpur University, for his encouragement, constant guidance and patience. I am deeply grateful to Sir for giving me the opportunity to meet stalwarts and experts in the field of Outdoor Thermal Comfort. I am also indebted to him for allowing me to work on such an interesting topic that I wish I could do more justice to.

I am grateful to the Vice Chancellor, Jadavpur University and Dr. Abhra Chanda, Secretary, Faculty of Interdisciplinary Studies, Law & Management, Jadavpur University for his kind help and co-operation as I submit this report as a part of the degree for Doctor of Philosophy.

I would like to thank my External Supervisor, Dr. Lakshminarayan Satpati, Professor of Geography and Director, UGC- Human Resource Development Centre, University of Calcutta, for his valued suggestions in different stages of this journey.

I would also like to thank Dr. Debasree Bhadra, Professor, Department of Geography, and Lady Brabourne College for helping me find a ground to start on.

I thank Dr. Jayeeta Neogi, Professor, Department of Architecture, and Jadavpur University for her friendly exchange with, us, scholars.

I am thankful to all my colleagues and friends with whom I had the good chance of talking to and exchanging insights with. They deserve mentions- Ms. Piu Dutta, Ms. Sohini Sen, Mr. Santanu Bajani, and Mr. Soumik Sarkar.

Colleagues and friends, helpers and well-wishers who came forward to help me in many other ways too made surveys enjoyable. In this regard, I thank Mrs.Padma Das.

I thank everyone who helped me during my surveys, especially my parents and parents-in-law for looking after our infant, while I was away with instruments. I thank my father, Mr. Pradip Kumar Mazumder; my mother, Mrs. Mukta Mazumder who supported me to their utmost ability. I thank Mrs. Subrata Chkaraborty and Dr. Jayanta Kumar Chakraborty for their kind consideration. With all their blessing, I had started this endeavor

I thank my husband, Dr. Jasashwi Chakraborty, together we have seen the crests and troughs during our student-ship and who has been rock steady in his support, guidance, encouragement. Without his help and continuous advice, I would not have reached thus far.

I thank my son, for being so co-operative and understanding. I am here because of him.

I render my gratitude to the Almighty for bestowing blessings during this journey.

Rohini Mazumder Chakraborty

Kolkata.

LIST OF FIGURES

Page No.

LIST OF TABLES

Page No.

LIST OF ABBREVIATIONS

ASHRAE	**-**	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CDP	-	City Development Plan
CFD	-	Computational Fluid Dynamics
DP	-	Dynamic Potential
DBT	-	Dry Bulb Temperature
EbA	-	Eco-System-Based Adaptation
HVAC	**-**	Heating Ventilation Air Conditioning
IPCC	**-**	Inter-governmental Panel for Climate Change
ISO	-	International Organisation for Standardization
JNNURM	-	Jawaharlal Nehru National Urban Renewal Mission
KMA	-	Kolkata Municipal Area.
LIR	**-**	Low Infra-Red
LISS	-	Linear Imaging and Self Scanning Sensor
LST	**-**	Land Surface Temperature
LCZ	-	Local Climate Zone
LULC	-	Land use and Land Cover
mPET	-	Modified Physiologically Equivalent Temperature
NDVI	-	Normalised Differential Vegetation Index
NDWI	-	Normalised Differential Water Index
NDBI	-	Normalised Differential Built Index
NIR	-	Near Infra-Red
OLI-TIRS	-	Operational Land Imager -Thermal Infrared Sensor
OTC	-	Outdoor Thermal Comfort
PAN	-	Panchromatic

PET	**-**	Physiologically Equivalent Temperature
RGB	-	Red Green Blue
RH	**-**	Relative Humidity
SWIR	-	Short-Wave Infra- Red
SWOT	-	Strength Weakness Opportunity Threats
SVF	-	Sky View Factor
TL	-	Thermal Load
Ta	**-**	Air Temperature
Tmrt	-	Mean Radiant Temperature
Tg	-	Globe Temperature
THI	-	Temperature-Humidity Index
Ts	**-**	Surface Temperature
TSV	-	Thermal Sensation Vote
UTCI	-	Universal Thermal Climate Index
UV	**-**	Ultra-violet
UC-An Map	-	Urban Climate Analysis Map
UC-Re Map	-	Urban Climate Recommendation Map
UHI	-	Urban Heat Island
UNEP	-	United Nations Environment Programme
Va	-	Wind Speed
VP	-	Vapour Pressure
WBGT	-	Wet Bulb Globe Temperature

ABSTRACT

Human Biometeorology is a subset of applied climatology that study the reactions of human bodies with changes in atmospheric environment (J.E. Hobbs,1980). In the recent publication of IPCC report 2022, 6th Assessment Report, the heat wave of Kolkata is expected to grow at 2^0 C. With such conditions, the outdoor heat stress is expected to increase for present and future generations. Adaptation to such conditions include awareness programmes, capacity building, toolkits, policy making, technological innovation and application. Outdoor thermal comfort and microclimate conditions have been considered in urban planning reports around the world. However, there is a need for micro-scale climate studies to be included in urban planning and regional planning methods in India. The recent Delhi City Development Plan for 2040 has recognised the need for improving outdoor thermal comfort of the city. Climate inclusive urban planning process is essential to create a comfort-oriented city development plan with eco-based adaptation strategies and acceptable microclimate at neighbourhood scale.

Climate inclusive urban planning will include both objective and subjective assessment of Outdoor Thermal Comfort conditions. Objective assessment of an area includes study of microclimate conditions, surface cover conditions and using such data in Outdoor Thermal Comfort Index. Microclimate parameter include, Air temperature (Ta), Relative Humidity (RH), Globe Temperature (Tg), Mean Radiant Temperature (Tmrt) and Wind speed (Va). Study of Urban surface cover as an independent variable in influencing the microclimate of a region. In order to study the urban surface cover conditions, Plan Area Fraction is used to calculate the share of natural surface and built and impermeable surface. Natural surfaces are sources of cool fresh air. Areas with larger share of natural surface have higher dynamic potential (Ng, 2015) (Urban climatic map studies in Vietnam: Ho Chi Minh City, 2015) (Welsch, 2015) (Wong, Kardinal Jusuf, Katzschner, & Ng, 2015) (Ren, Lun Lau, Ng, & Po Yiu, 2013) and higher share of built and impermeable surface have greater thermal load. (Ng, 2015). Subjective assessment is based on Thermal Perception study or people's perception of outdoor thermal conditions at neighbourhood level or microscale.

Outdoor Thermal comfort is defined as 'that condition of mind which expresses satisfaction with the thermal environment' is a definition given by ANSI/ASHRAE Standard 55. Outdoor thermal comfort can be calculated using Outdoor Thermal Comfort Index. Physiologically Equivalent Temperature(PET) is a universally accepted index to study outdoor thermal comfort conditions and can be calculated using the MEMI model which assumes Air Temperature (Ta) = Mean Radiant Temperature (Tmrt) for indoor thermal conditions. The Tmrt becomes

important in PET calculation. Tmrt can be calculated using Globe temperature that represents the weighted average between ambient convective energy and radiant energy (Thorsson, Lindberg, Eliasson, & Holmer, 2007) (Tan, Wong, & Jusuf, 2013) (Johansson, Thorsson, Emmanuel, & Kruger, 2014). Globe temperature can be used using a globe thermometer. Later, clothing level (Clo) and human metabolism was included as an important determinant of heat stress The recent modifications to PET for hot-humid subtropical regions have been incorporated in mPET which recognises the importance of adaptation through metabolic rate and clothing (Clo) patterns.

The following research work has two parts: first, the objective assessment that aims to showcase the difference in comfort conditions for four seasons (Spring, Summer, Autumn and Winter) in different surface cover in 2019 and secondly, the subjective assessment show difference in thermal perception for the four seasons 2019. The importance of surface cover and the need for dynamic potential is established using Hypothesis testing. Hypothesis testing helped retain or reject the null hypothesis that stated that the distribution of mPET values is same across the surface cover categories. mPET values show greater levels of comfort for stations with larger share of natural surface or dynamic potential. A comparison between two stations showed the importance of water breeze and importance of water surface in dynamic potential. Dynamic potential is found in stations with combination of water surface, vegetation and open surface. A questionnaire schedule is used to record the response against thermal sensation scale according to ASHRAE and ISO standards. The thermal perception study is instrumental in calculation of Proposed neutral temperature, acceptable range of temperature and comfortable locations within the limits of Kolkata Municipal Corporation area.

Based on the need for dynamic potential and surface cover conditions of stations within comfortable locations, recommendations are made for future planning purpose. The planning recommendations include the surface cover share for every neighbourhood scale of 100m diameter to enhance and improve the microclimate conditions and maintain acceptable and neutral thermal conditions. Stakeholder participation at governmental, non-governmental and grass root level will enable the proper use of information pool in Micro-climate information system. City development plan in future can include microclimate comfort levels in SWOT analysis and evaluation with community participation. The approach of Human Biometeorology will allow for the development of a sustainable and comfortable city through Climate-Inclusive Urban Planning Process.

CONTENTS

CHAPTER1: INTRODUCTION

1.1 THERMAL CONDITIONS IN KOLKATA

Heat stress and thermal discomfort, during hot summers that the urban areas in India and in South Asia is expected to face, is a growing issue. In Kolkata, heatwaves and heat-related mortality similar to 2015 will be more recurrent, every year. Risk of drought, flood, sea-level rise, tropical cyclone and subsidence will make the city more vulnerable to loss (IPCC, 2022). Urban areas in India and South Asia are going to face hotter summers, greater energy demand, lowering of ground water along with increasing population pressure. Kolkata has been mentioned as one of the megacities to be vulnerable to extreme climate change (IPCC,2022). Kolkata is also expected to see a rise in heat-related mortality. Impact of heatwaves at scenarios 1.5^0 C and 2^0C, show that Kolkata will experience heatwaves similar to 2015, every year. Kolkata is also vulnerable to drought-risk. By 2050, 20 largest coastal cities will face flood losses. Of these, 9 in Asia, including Kolkata, is vulnerable to seal level rise, flooding and subsidence. Tropical cyclones and coastal flooding will become a problem in Kolkata (IPCC, 2022).

Ecological based and manmade based adaptations, such as controlling the surface material, management of storm water and land use regulations will help reduce the incidence of heat trapping and increase in thermal load. Characteristics of a space such as the thermal properties of the surface materials, the climate conditions and the scale or extent to which it continues, makes an urban area different from a rural area(Cortesão et al., 2016). Landcover study assesses the different combinations of urban greenery and urban waterbodies in subjective and objective perceptions of thermal comfort. Heat mitigation strategies include urban greenery, water bodies and reflective characteristics of surface. Accordingly, the surfaces categories such as green surface, blue surface or grey surface and their heat mitigation potential is assessed. The following study shows the different surface cover and microclimate conditions and its impact on outdoor thermal comfort.

Heat related morbidity, mortality and mental illness is expected to rise in regions where urban heat island conditions exacerbate the temperature conditions such that it exceeds physical, mental and thermal comfort threshold. Increase in number of days with high temperature or unintended increase in temperature are hazardous conditions that will ensure the severity of the risk. Adaption to climate change can be in natural systems. Humans can adapt through natural systems or EbA (eco-system-based adaptation) such as urban parks, green spaces, mangroves and wetlands, urban agriculture and stormwater management or man-made systems such as behavioural change through change in livelihood habits and cultural shift, or change in urban governance through urban plans for urban areas, financial plans to combat microclimate conditions and legislation. For extreme heat island conditions due to urbanization, adaptation of the urban area by incorporation of ecosystem based land use such as urban parks; green spaces will be effective high confidence level from studies on human wellbeing (IPBES, 2019)[1].

1.1.1 Lack of Thermal Comfort Assessment in Urban Development Plans

The 7th Five Year Plan (FYP) (1985-1990) first observed that urbanization and economic development is closely linked. In 1983, the Planning Commission organised the Task Forced on Planning of Urban Development. The 8th FYP directed the need for small and medium towns to grow as nodes of employment opportunities in order to shift focus from the metropolises. The need for a Master Plan was first mentioned in the 3rd (FYP).

City Development Plan (CDP), anchored in the JNNURM, is a vision document for city assessment or examination of various aspects of a city in detail in order to formulate strategies. The broad headings under this assessment covers Urban Infrastructure and Governance and Basic Services to the Urban Poor.

For City Assessment Report, there is assessment of the physical environment that covers, geology, topography, natural resources, environmental parameters such as Air quality, water quality, environmental sensitivity and natural heritage sites and climate parameters. 'the climatic parameters like temperature, relative humidity, rainfall, wind direction and circulation in a city determines the level of comfort and factor conducive for developing various activities'('Revised Toolkit for Preparation of City Development Plan, JNNURM: Executive Summary', 2009). City assessment is based on SWOT analysis (Strength, Weakness, Opportunities and Threats) which will be reflected in the City Development Plan. Review of development goals and sector plans will involve grass root participation and urban local bodies, institutional and technical assessment, investment plans.

[1] The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

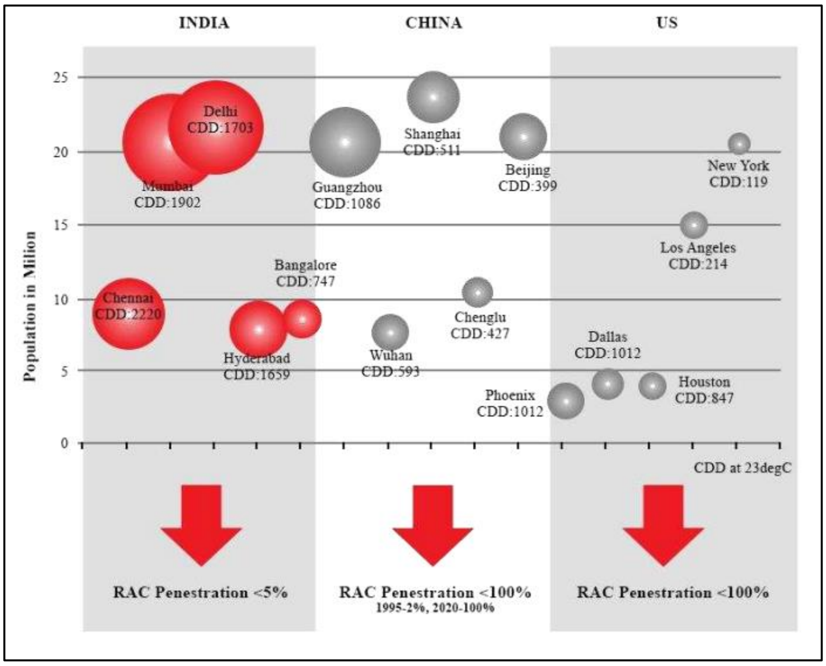


Figure 1.1 Demand for cooling in India, 2019. Source- Ministry of Environment, Forest and Climate Change, India Cooling Action Plan, New Delhi.

The environmental profile of the city for the CDP of Delhi(2013), deals with climatic parameter such as wind direction, dust storms, air quality and suspended particulate matter, levels and sources or air pollution (Ecosmart, no date). SWOT analysis of the Delhi CDP mentioned Degradation of River Yamuna , air quality , traditional water systems, depletion of ground water, congestion of arterial roads and commercial zones and so on (Ecosmart, no date).

City assessment report of Ahmedabad (2006-2012) following the guidelines of CDP toolkit does not mention any analysis on climate conditions and thermal comfort conditions, though it mentions the need for open spaces (open, garden, playground, green belt) for recreation purposes.

The UDPFI Guidelines specifies the standard of 8-10sq.m open space per person, but for the Ahmedabad City Assessment Report, the city had 0.37sq.m area per person(Ahmedabad Municipal Corporation; Ahmedabad Urban Development Authority; CEPT, 2012). The revised City Development Plan report of Pune (2017) mentions the need for green spaces, parks, open spaces, plantations and urban forestry and urban corridors to improve the local climate. A common concern is the stabilising of climate change which cannot be possible with the given emission rates at most cities studied. (JnNURM, 2012).

It was not until the study on demand for indoor cooling exposed the demand for comfort among population. The demand for indoor cooling soared and this gave an insight to the urban planners on the discomfort and high stress environment in urban areas. Studies were already published in other countries that looked into microclimate conditions of the cities at neighbourhood level. In countries like Sweden, Germany, Taiwan, Singapore, Brazil, Spain, started using Urban climate Maps as tool to evaluate outdoor thermal conditions and implement land use landcover corrections in regional planning. improvement of environment for purpose of comfortable thermal condition, is missing in most strategies.

The need for comfort in outdoor and indoor conditions have been recognised in the Delhi Master Plan for the year 2041. Green-blue spaces have been suggested in the built fabric because the functionality of large parks is the creation of 'comfortable micro-climate', shaded areas, and also provide recreation like meditation, yoga and other activities. Green landscape for an improved microclimate with 80% pervious surface, encouraging community gardens and mandatory wild grasses for lands with government ownership. Outdoor Comfort is also included in Walk plans with access to green and safe mobility paths for walking cycling. Pedestrian comfort with planting of trees and high albedo paving materials have also been considered. Indoor microclimate for comfortable journey is incorporated in transport services. Thermally comfortable and energy efficient buildings shall be promoted. Building design will encourage proper ventilation in order to reduce use of HVAC (Authority, 2007).

1.1.2 Importance of Microclimate Data for Policy Makers

'Limits to adaptation' was introduced in the AR5 report of IPCC reports. Limits to adaptation refers to the inability of the system to protect its needs from the risks by means of adaptation (Klein *et al.*, 2015). Limits or constraints may be soft limit if it can change with time. Limits that do not change with time are hard limits. Intolerable risks are those which do not offer any more opportunities of improvement of the system through adaptation.

Rising temperatures of Kolkata will lead to extremes of climate with high heat and humidity levels and the urban population will be exposed to the discomfort. Kolkata is expected to experience heat wave record of 2015 every year under 2^0 C warming (IPCC, 2022). Opportunities to adapt include awareness programmes, capacity building, toolkits, policy making, technological innovation and application. Factors which act as constraints to adaptation can be due to economic and socio-cultural conditions, quality of governance, planning and policy making, lack of information, presence of physical barriers and biophysical and meteorologic conditions of the region. The same barriers can become limits that will not allow adaptive actions to secure the needs of the system. (Klein *et al.*, 2015).

Of the limitations of urban climate planning is the stakeholders in planning process cannot apply meteorological data in urban plans and designs due to lack of proper interpretation and analysis of data. The same data can be represented in a map as a comprehensive tool carrying information on land use, landcover, environmental conditions and weather conditions. In Ho Chi Minh city, areas with same climate characteristics were grouped to make climatopes. Each climatopes have three aspects- the thermal load, ventilation and air pollution (VDI,1997). Building volume and sealed areas were demarcated as contributors to heat concentrations above heat capacity by preventing air exchange and heat stagnation. Green space are contributors to heat absorption and cooling. The areas are then assessed according to climate functions: areas that has favourable microclimate vs areas that create climatic stress. In Hankou, Wachung and Hanyang, China the planning process aims at reducing urban density as well as air impermeability. Urban climate map studies in Japan Sakai in Osaka represent areas of restoration such as water bodies and channels, areas of preservation such as sea breeze and wind paths, areas of reduction such as centres of potential heat pools and areas of 'feeling coolness'(Ng, E., Yau, R., Wong, Ks. Ren, C. and Katszchener, 2012). Data on relief type, land roughness, land use showing building volume and sealed areas, landcover showing spread of greenery and waterbodies and wind flow models will help define the ventilation paths. These need to restored and preserved ventilation paths and to ensure air exchange that will prevent air stagnation is found in the study, increase of 1m/s in wind speed can help mitigate rise in air temperature by two degrees (Ng *et al.*, 2008). There is evidence of effectiveness (IPCC 2022) in the of adaptation strategies such as the Heat Action Plan, Gujarat and Sponge city Guangzhou, China, the latter being an example of Ecosystem based adaptation (Ahmedabad Municipal Corporation, 2016; Chan *et al.*, 2018; ADB Briefs, 2020)

1.1.3 Existing Challenges in Urban Planning with Respect to Climate-Inclusive Planning

i. Maladaptation - In response to adaptation measures undertaken, there is strong confidence in the unavailability of evidence recording responses to adaptation or that the adaptive measures and responses are adequate. There is high evidence on the co-benefits of adaptive measures in urban areas such as management of landcover land use, agroforestry, urban design. But there is also strong evidence on the increase in maladaptation's (IPCC, 2022). Adaptation related risks refer to responses to the adaptation which instead of decreeing the risks, increase them. The different measures to combat heat have sometimes created a negative response in context of forestry, fisheries, migration and agricultural practices. Urban interventions such as tree shade to allow cooling and cooling roofs, may be insufficient in areas of high heat waves. An example of luxurious green estates along coastal urban areas may instead displace local workers and may affect the local ecology. These are termed as maladaptation. (IPCC, 2022)

ii. Knowledge gap may arise for inadequate reporting of responses. The key responders are individuals and households; and national and local government.

- Adaptation gaps or maladaptation or adaptation related risks may not be documented.
- Adaptation at various levels of civil society and all walks of life may not be adequately researched
- Adaptive responses may be different at different levels from individual, household to community level
- Under reporting in remote marginalised areas with minority population.

iii. Limits to adaptation- Adaptation may be recommended to reduce risks but adaptation may not prevent all climate conditions. the soft limits of adaptation are those that can change with time as new adaptive possibilities emerge. Hard limits of adaptation are those limits that is difficult to overcome. The limits affect the effectiveness of the adaptation measures, makes their adequacy and risk reduction capacity questionable. Risks can be tolerable or intolerable. When risk is tolerable through adaptive behaviour or adaptation then there is room for further adaptive responses. But intolerable risk cannot be avoided through adaptation since the system may have reached an irreversible threshold and hence, this limit to adaptation to cause this system to be abandoned or transformed.

iv. In Asian cities, there is the problem of accountability and transparency especially the interaction with grass root level of the marginalised society in cities and responsibility towards them. Also in urban adaptation, while participatory planning and ‘co-producing solutions’ with multiple stakeholders may act as a boost, most interventions are ‘reactive’ in nature (Dulal, 2019). Institutionalising the adaptation program is a possibility but at present in most Asian cities, it lacks orientation with short term foresight that overlooks the long term goals (Francisco and Zakaria, 2019)2.

v. Knowledge networks such as C40, ACRN, A-PLAT is applicable but there are data gaps on climate studies and projections (Fünfgeld, 2015). City level knowledge creation and the tools for vulnerability assessment as well as cost benefit analysis is missing3.

vi. Capacity building with awareness programs that are inclusive in nature can be implemented(Reed et al., 2015). However, the risk assessment tools are not well established yet(ADB, 2013).

vii. Finally, the financial planning for adaptation programs suffers from the problem of insufficient funds and sources4,5.

1.2 IMPORTANCE OF HUMAN BIOMETEOROLOGY

Human Biometeorology studies the reactions of human bodies to the changes in the atmospheric environment and biological variability as a function of variation in weather and climate (J.E. Hobbs,1980) it is a subset of applied climatology. The subject also explains the relation between atmospheric conditions and importance in controlling the maintenance of health or spread of diseases. It deals with the aspect of urban climate on human comfort or discomfort and heat stress in outdoor or indoor conditions. Human biometeorology is divided into three categories based on climatic determinism at different scales of climate. According to M. Bates (1966), there are three levels of climatic conditions that affect human response: Microclimate, Ecological climate, Geoclimate or geographical climate (Savindra Singh, 2012). The climate condition of the smallest unit of areal extent from less than 100 m and vertically, 100m from the ground surface. most of the microclimate data is available through primary surveys on different surface covers. The variation in microclimatic conditions depend on the variation on surface cover.

Reference from IPCC WGII Sixth Assessment Report- [2] Francisco, H. A. and N. A. Zakaria, 2019: Understanding Climate Change Adaptation Needs and Practices of 21 Households in Southeast Asia: Lessons from Five Years of Research | SpringerLink. In: Handbook of Climate 22 Mitigation and Adaptation. SpringerLink. Available at: 23 https://link.springer.com/referenceworkentry/10.1007%2F978-3-319-14409-2_67

[3] Lee, T. and M. Painter, 2015: Comprehensive local climate policy: The role of urban governance. Urban Climate, 14, 55 566-577, Doi: 10.1016/j.uclim.2015.09.003.

[4] Cook, M. and E. Chu, 2019: Between Policies, Programs, and Projects: How Local Actors Steer Domestic Urban Climate Adaptation Finance in India | SpringerLink. doi:10.1007/978-3-319-65003-6_13

[5] Narender, A. and M. Sethi, 2018: Mainstreaming co-benefits in urban policy, governance and finance. In: 16 Mainstreaming Climate Co-Benefits in Indian Cities. Springer, pp. 341-373

There are three scales of interest in urban areas (Oke, 1984):

(a) **Microscale** – typical scales of urban microclimates are set by the dimensions of individual elements: buildings, trees, roads, streets, courtyards, gardens, etc., extending from less than one to hundreds of meters.

(b) **Local scale** – this scale includes climatic effects of landscape features, such as topography, but excludes microscale effects. In cities this means the climate of neighborhoods with similar types of urban development (surface cover, size and spacing of buildings, activity). Typical scales are one to several kilometers.

(c) **Mesoscale** – a city influences weather and climate at the scale of the whole city, typically tens of kilometers in extent. A single station is not able to represent this scale.

Urban climate includes the topics of Urban Heat Islands, Thermal Load & Dynamic Potential, Surface Cover conditions, Thermal comfort,

1.2.1 Outdoor Thermal Comfort

A single environmental parameter cannot account for conditions for thermal comfort. (Lin 2011) Outdoor environment has more variation than the indoor environment. PET or Physiologically Equivalent Temperature is defined as 'the air temperature at which in a typical indoor setting, the heat balance of a human body is maintained with core and skin temperature equal to those under the conditions being assessed'(Hoppe,1999). In other words, it is the air temperature of a typical indoor room generating the same core and skin temperature as the actual complex outdoor conditions. (Lai, et al. 2014) PET is more universally accepted to study outdoor thermal comfort conditions and is based on the MEMI model. Pet can be calculated using the MEMI model which assumes Air Temperature ($Ta_{)}$ = Mean Radiant Temperature (Tmrt) for indoor thermal conditions. MEMI uses the formula,

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \qquad \textbf{Eq.1}$$

where M - metabolic rate (internal energy production), W – metabolic rate, R - net radiation from body, C -the convective exchange of heat, ED- perspiration with latent heat flow , E_{re} – heat flows affecting air humidity, E_{Sw} heat flow due to sweat evaporation , and S – stored heat.

The study of PET includes parameters such as Air temperature (Ta), Mean radiant temperature (Tmrt) , Relative Humidity, Wind Velocity and thermo-physiological parameters such as clothing and level of activity. The Tmrt becomes important in PET calculation during days with low wind velocity. (Matzarakis and Amelung n.d.). Tmrt is defined as the uniform temperature of a hypothetical spherical surface surrounding the subject that would result in the same net radiation energy exchange with the subject as the actual, complex radiative **environment**.

Tmrt considers both shortwave and long-wave radiation and represents the **weighted average** temperature of an imaginary enclosure that gives the same radiation as the complex urban environment. (ISO7226, 1998) The difference between Ta and Tmrt is significant for outdoor conditions than indoor. (Walikewitz, et al. 2015) Tmrt can be measured using a globe **thermometer** (BEDFORD and WARNER 1934) (Kuehn, Stubbs and Weaver 1970)**.** Globe thermometer, introduced by Vernon in 1930, help understand the impact of radiation, wind velocity and mean radiant temperature on human thermal comfort. Globe temperature also called ‘radiation convection temperature’ and its excess or deficit than the air temperature is called ‘effectual radiation temperature’,by Vernon , which the human body is subjected to. (BEDFORD and WARNER 1934) According to ISO 7726 Standard, formula 2 is used most frequently for calculating Tmrt under forced convection and for the standard globe with a diameter of 150 mm,

$$Tmrt = \sqrt[4]{(Tg + 273.15)^4 + \frac{1.1 \times 10^8 \times Va^{0.6}}{\sum D^{0.4}} \times (Tg - Ta) - 273.15}$$ **Eq. (2)**

Where va =wind velocity [m/s] ; ε =emissivity of sphere (¼0.95) ; D =diameter of the sphere [mm] ; Tg =globe temperature [C]; Ta =air temperature [C]. (Walikewitz, et al. 2015) (Thorsson, Lindberg, et al., Different Methods for estimating the mean radiant temperature in an outdoor urban setting 2007) [6]

T_{mrt} is an important parameter in human biometeorology. (Khrita, et al. 2017) It can be calculated by several methods. One method involves ‘radiation fluxes from all six directions multiplied by the angular factors between a person and the surrounding surfaces’ while another method uses the globe thermometer. (Thorsson, Lindberg, et al., Different Methods for estimating the mean radiant temperature in an outdoor urban setting 2007) (Khrita, et al. 2017) Globe temperature represents the **weighted average** between radiant energy and ambient

[6] [The equation can be written as : **Tmrt=** $\sqrt[4]{[(Tg+273)^4+h_{cg}/h_r(T_g-T_a)-273]}$

$\varepsilon = 0.95*5.67*10^{-8}=5.38*10^{-8}$ and $h_{cg}=6.3(Va^{0.6}/D^{0.4})$ for forced convection and $h_{cg}= 1.4[(Tg-Ta)/D]^{0.25}$ for free convection. (Innova Airtech Instruments n.d.)]

convective energy and when T_g is in equilibrium, it represents the equilibrium between the two energy flows. (Thorsson, Lindberg, et al., Different Methods for estimating the mean radiant temperature in an outdoor urban setting 2007) (Tan, Wong and Jusuf 2013) (Johansson, et al. 2014) Conventional globe thermometer consists of a thermometer with its thermal sensor at the centre of a black hollow sphere. Most commonly a copper globe, with 6-inch diameter, is used though it responds to the conditions of non-sweating environments. Kuehn, Stubbs and Weaver recommend choosing the emissivity value before selecting the diameter of the globe. There exists an inverse relation between emissivity and diameter of the globe where emissivity of 0.95 should need a black globe diameter of 6 inches (Kuehn, Stubbs and Weaver 1970) . A smaller globe of 40 mm is suggested instead avoiding the inconvenience of the 6 inch globe in indoor conditions. (Humhreys 1977) Globe thermometer may not be as accurate as the study involving radiation flux; however, it is cost effective in outdoor conditions. Globe with diameter less than 50 mm, have a faster response time but gives greater scatter due to increased wind velocity and solar radiation. (Khrita, et al. 2017) In other words, with increasing wind velocity, a small globe (smaller than 15cm diameter) may show more sensitivity by rapidly cooling down and Tg value becomes an underestimated value. (M.Budd 2008) In order to minimise this effect an average of 10 minute readings of Va and 5 minute average of readings of Ta and Tg were taken respectively (Johansson, et al. 2018). Black globe thermometer of 40mm diameter (or lesser) is used in several studies. (Johansson, et al. 2018) (Huang, Cedeno-Laurent and D.Spengler 2014) (Johansson, Thorsson, Emmanuel, & Kruger, 2014) Only a significant difference between the mean radiant temperature and air temperature will reflect a difference in reading between a large and small globe thermometer in indoor conditions (Humhreys 1977). Instrument standards such as ISO7726(1998) and ASHRAE Handbook of Fundamentals (ASHRAE,2001) recommend a grey 40 mm globe instead of a black globe as it reflects the radiation of outer clothing conditions of a person. The ellipsoid shape is more desirable as it helps give a better estimation of the Tmrt of a standing person; spherical globe thermometers are more appropriate for mid to higher latitudes. (Olesen, et al. 1989)

T_{mrt} can also be calculated using the integral radiation measurement. The mean radiant flux density (S_{str}) can be calculated by multiplying the angular factors (radiation received from the surrounding six directions) F_i (i=1-6) with the individual measurements of the short wave radiation and long wave radiation. (Walikewitz, et al. 2015) (Thorsson, Lindberg, et al., Different Methods for estimating the mean radiant temperature in an outdoor urban setting

2007) This is the most accurate method even though the high angle of incidence and the orthogonal orientation of the instrument may pose errors. (Johansson, et al. 2014)

$$Sstr = a\lambda \sum_{i=1}^{6} Kifi + \Sigma p \sum_{i=1}^{6} Lifi$$

Eq.3 (VDI, 2008; Höppe,1992)

K_i is the radiation, short-wave r fluxes (i =1-6), L_i is the radiation, long-wave fluxes (i = 1-6), Fi is the angular factors between a person and the surrounding surfaces, a_k absorption coefficient Fi is 0.167 for all six directions.' Formula 4 helps to calculate Tmrt according to the Stefan-Boltzmann Law. Using 5-minute mean value may reduce the difference in results between the two methods. (Thorsson, Lindberg, et al., Different methods for estimating the mean radiant temperature in an outdoor urban setting 2007)

$$Tmrt = \sqrt[4]{\frac{Sstr}{\Sigma_p \delta}} - 273.15$$

Eq.4

The standard method for measuring Tmrt is set by ASHRAE but such indoor standards cannot be applied to outdoor conditions due to variable flux conditions. (Spagnolo and de Dear 2003) Tmrt can also be calculated using an algorithm (5) from Staiger and Jendritzky involving long and short-wave radiation measurement.

$$\mathbf{Tmrt = \sqrt[4]{(T^4_{DIR} + T^4_{DIF} + T^4_{REF} + T^4_{IR})}}$$ **Eq.5**

where T_{DIR}=Direct radiation, T_{DIF}= Diffused Radiation T_{REF}= Reflected Shortwave Radiation; TIR= Infrared radiation (Spagnolo and de Dear 2003)The formula for seated and standing persons are also different. (ISO7726). Tmrt can also be calculated using the Rayman software, provided the necessary input data is available (Kruger, Minella and Matzarakis 2013).

1.2.2 Thermal Comfort Indices

The calculation of Tmrt is followed by the calculation of PET. Verein Deutscher Ingenieure (VDI) has given a guideline 3787, part 2 "Methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning, part I: climate" recommending the use of PET index in the study of thermal comfort conditions in different climates of the world[26]. The standard ranges of the PET index help us to evaluate the outdoor thermal comfort conditions. The values of thermal stress is comparable to PMV ranges (VDI 1998) and are derived from the studies of Fanger (1972). The subjective feeling of stress or comfort can be studied with a questionnaire schedule that inquiries about the thermal state of a person.

Indices	Parameters	
Effective Temperature	RH, Tmrt=Ta	Yaglou and Minard
Corrected Effective Temperature	Air velocity, Dry bulb temperature, RH, Clothing	
WBGT	radiant heat, solar heat, air movement	Yaglou and Minard
Operative Temperature	Heat exchange by radiation and convection in uniform and non-uniform enclosure	
Equivalent Temperature	Unsuited for high temperature and humidity	
Equivalent Warmth	Dbt=mrt, RH, still air	
Resultant Temperature	Underestimates cooling effect of air	Missenard
Equatorial Comfort Index	Temperature of still saturated air, clothing	Webb
Tropical Summer Index	Still air, RH	
Thermal Strain Index	heat transfer mechanisms	
Thermal Acceptance Ratio	heat acceptance and heat production by a unclad person	
Predicted 4 Hour Sweat Rate	physical stress by sweat rate, pulse or internal body temperature.	
Heat Stress Index	evaporative cooling	
Index Of Thermal Stress	cooling rate produced by sweating	
PMV	sweat secretion and mean skin temperature of body	Fanger
New Effective Temperature	temperature of the uniform closure, RH, net heat exchange by radiation, convection, evaporation	
PET	Air temperature, relative humidity, globe temperature, wind speed, surface temperature, physiological data, cloud cover, Clo	PETER HOPPE
UTCI	Air temperature, relative humidity, globe temperature, wind speed, surface temperature, physiological data, cloud cover,	
mPET	Air temperature, relative humidity, globe temperature, wind speed, surface temperature, physiological data, cloud cover, Clo	

Table 1.1 Showing indices for calculation of Outdoor thermal comfort.

1.2.3 Choice of Index -Physiologically Equivalent Temperature (PET) and Modified PET (mPET)

- PET allows the evaluation of thermal conditions in a physiologically significant manner, too.
- VDI-guideline 3787 part 2 "methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning, part I: climate "(Verein Deutscher Ingenieure 1998) recommends the application of PET for the evaluation of the thermal component of different climates to emphasize the significance of PET further. This guideline is edited by the German Association of Engineers ('Verein Deutscher Ingenieure' VDI)
- The PET thermal index is suitable for the evaluation of the thermal environment not only in summer, but also throughout the year.
- Its unit (°C) makes it easily understood as an indicator of thermal stress.
- PET analysis can be applied widely and there are various possible ways of illustrating its results.
- Bioclimatic maps of whole cities can be generated by use of PET for application in urban plans.
- The consequences of a changed thermal environment caused by different planning variations can be quantified by use of PET
- mPET or modified PET has been used for calculation of neutral temperature and acceptable range of temperature because PET is more widely applicable for temperate locations. Until recently, PET was used for hot-humid tropical regions. However, Prof. T.P.Lin introduced modified PET for tropical and sub-tropical hot-humid regions. PET was used for calculations, also because, mPET was not incorporated in RayMan software until very recently. Nowadays, since 2021, most hot-humid regions of tropical latitudes use mPET for analysis of outdoor thermal comfort.

1.3 INFERENCE

- In Indian context, IPCC 2022 warns extreme climatic conditions in Kolkata that will affect health, economy and need for better housing.

- Microclimate data is important for policymakers in order to include the adaptive opportunities for a more comfortable outdoor environment, especially with the prediction of rising temperatures, extreme heat and humid conditions in Kolkata city.
- Slow development of climate inclusive planning is a challenge in micro level urban planning. There are challenges in the initiatives of climate-inclusive planning.
- Tmrt is calculated using equation 2. Calculated Tmrt is used for calculation of PET and mPET.

CHAPTER2: LITERATURE REVIEW

2.1 SYSTEMATIC LITERATURE REVIEW

Bibliometric analysis of studies related to Outdoor thermal comfort; showing the research gaps in analysis of Thermal sensation and Outdoor thermal comfort using PET index in Sub-tropical humid city.

2.1.1 Bibliometric Analysis for Objective Assessment

In order to understand the present scope of study, a review of the extensive literature on outdoor thermal comfort has been conducted. The review helped identify the extent of studies in subtropical humid cities. The search of original research articles and conference proceedings based on studies in Outdoor Thermal Comfort was conducted based on categories i) Microclimate ii) Surface cover iii) Season change in sub-tropical humid cities

Search for studies with topic names “outdoor thermal comfort" and "urban microclimate" and publication dates between 2015-2021 yielded 88 results. Out of the 88 articles, 80 are articles, 8 are review articles, 1 is early access and 1 is proceedings papers. There are few publications from the field of Geography, Urban studies, regional urban planning, geography and remote sensing fields. The highest publications in this search is from Italy with 18 publications out of 88, followed by People’s Republic of China (13 out of 88), Australia, USA, Singapore (10 out of 88) and Germany and Malaysia (7 and 6 out of 88 respectively). India has 1 publication which is 1.136 % of 88 publications.

A similar search with keywords “outdoor thermal comfort” and “microclimate” with published dates ranging between 2015-2022, gave a result of 334 publications with 11 works based in locations in India.

Subsequent search was made with keywords “wind” and “urban microclimate “from 2015-2022 gave a result of 111 publications from Web of Science Core Collection of which 2 were based on the studies in humid regions of India(Bherwani *et al.*, 2021)(Bherwani, Singh and Kumar, 2020). A search of the topics on Web of Science with keywords “wind” and “outdoor thermal comfort”, during the published years of 2015-2022 gave 915 results from Web of Science Core Collection. The articles were filtered by relevance of topic and keywords.

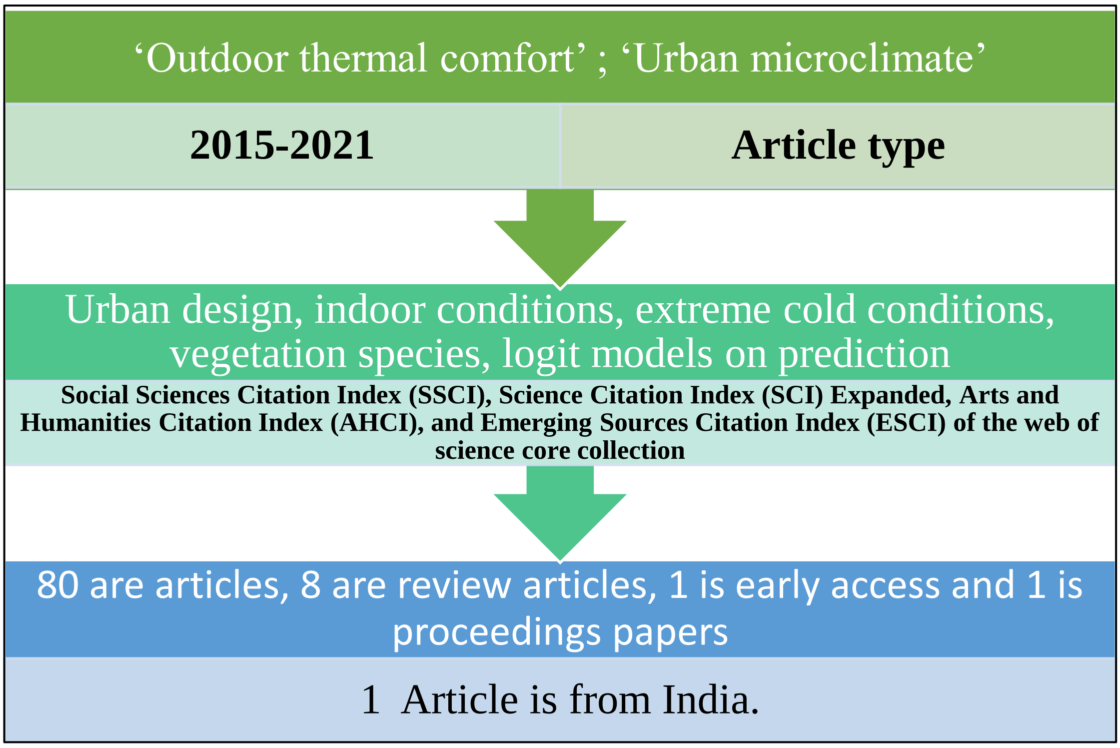


Figure 2.1 Literature search for 'Outdoor Thermal Comfort' and 'Urban Microclimate'

Countries	Number of publications (2015-202)	Out of 915 publications
Peoples R China	308	33.661%
USA	107	11.694%
England	89	9.727%
Australia	69	7.541%
Iran	62	6.776%
Brazil	50	5.464%
Germany	37	4.044%
Italy	35	3.825%
Canada	32	3.497%
Singapore	32	3.497%
Turkey	30	3.279%
India	29	3.169%

Table 2.1 showing number of publications for few among many countries with keyword search 'Outdoor Thermal Comfort'.

Of the 37 publications in India, parameters such as wind, air temperature, surface temperature and SVF that are related to outdoor thermal comfort are used in simulation on Envimet software (Mohammad *et al.*, 2021) and includes studies on local precipitation, aerosol conditions in relation to wind turbulence (Qian *et al.*, 2022). The thermal effects are quantified and then possible strategies and recommendations are quantified and visualized through Thermal comfort indices and ENVIMET simulations. Other software such as CFD, DART, SOLWEIG are also employed to make simulations. Mapping areas of thermal comfort using PET and other indices and ENVI met simulation helps us to understand the spatial distribution of thermal comfort conditions and microclimate conditions in high density urban areas, interpolation with Geo-mapping tools(Shi *et al.*, 2016).

Principal Authors in the Field

Analysis of bibliographic coupling by author include sorting by number of citations. The minimum number of publications and the minimum number of citations were both set to 5. Out of 1107 authors, only 30 met the threshold. The prominent authors in this field who have been cited in large number of studies are F.Salata , A.L.Pisello ,A de lito Vollaro, I.Golasi, K.Lau, J.Niu, E.Ng, J.Liu, C.M.Mak , F.Cotana, Z.Lin, M.Taleghani, A.Matzarakis, U.Berardi , T.P.Lin . Recent publications in 2019 include A.Middel, D.Lai, H.Jin, D.Zhou and A.L.Pisello..

Frequently used keywords

In the analysis of co-occurrence of keywords, the most frequently used keywords are retrieved from author keywords and fractional counting method. The minimum occurrence of a keyword is set at 5. Out of 1119 keywords, 49 meet the threshold.

In this search, the top 20 keywords by occurrence are outdoor Thermal Comfort, Thermal Comfort, Microclimate, Envi-Met, Urban Microclimate, Urban Heat Island, Mean Radiant Temperature, Physiological Equivalent Temperature and Outdoor Comfort, Urban Design, Urban Morphology, PET, Outdoor Thermal Environment, Thermal Adaptation, Thermal Sensation, Urban Climate, Vegetation, Climate Change, Air Temperature, Heat Stress.

Keyword	Occurrences	Total Link Strength	Keyword	Occurrences	Total Link Strength
Outdoor Thermal Comfort	103	84	UTCI	8	8
Thermal Comfort	68	56	Courtyard	7	7
Microclimate	62	51	Mediterranean Climate	7	7
Envi-Met	54	47	Microclimate Simulation	7	5
Urban Microclimate	49	39	Numerical Simulation	7	6
Urban Heat Island	48	43	Physiologically Equivalent Temperature	7	7
Mean Radiant Temperature	20	18	Shading	7	6

Table 2.2 Frequently used Keywords

From the above short discussion on the different studies of microclimate, we understand the need for data on vegetation, urban built surface, pattern, design and surface properties to study urban microclimate conditions.

2.1.2 Bibliometric Analysis for Subjective Assessment

Outdoor thermal comfort' and 'Outdoor thermal sensation' were the two keywords that was entered as the topic for period 2015-2021 and article as the document type. Articles with overlapping study on urban design and vegetation species for landscaping, extreme cold environment or extreme hot environment and indoor ventilation, other heat balance models, prediction-based logit models were excluded from literature review. Topics such as Indoor thermal comfort condition, indoor temperature and air conditioning mechanisms, indoor layout and design, indoor simulation and energy efficiency models and indoor clothing insulation was also excluded. A total of 289 articles were generated that was sorted in accordance to number of times cited. Social Sciences Citation Index (SSCI), Science Citation Index (SCI) Expanded, Arts and Humanities Citation Index (AHCI), and Emerging Sources Citation Index (ESCI) of the web of science core collection was applied in order to search for articles on the given topic.

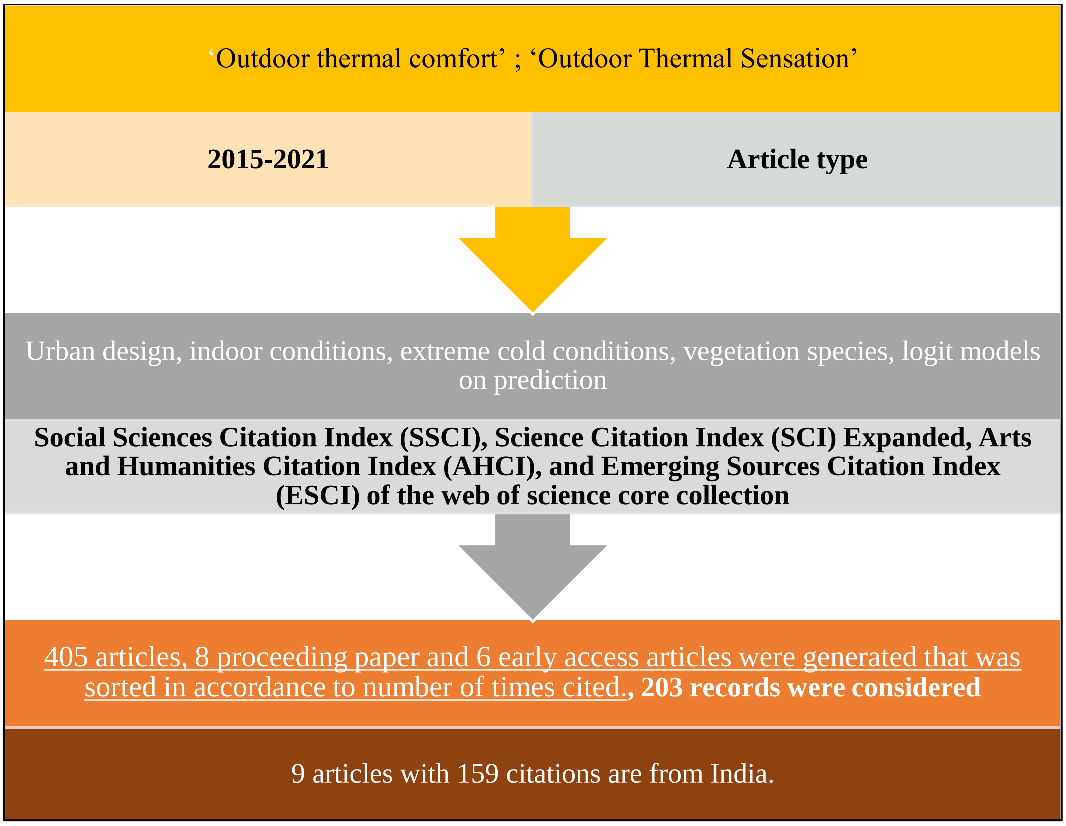


Figure 2.2 Literature search for 'Outdoor Thermal Comfort' and 'Outdoor Thermal Sensation'

Out of 303 articles and 7 proceeding papers, 203 records were considered for bibliographic analysis using the VOS viewer. The following table shows that the maximum publication of 59 was made in the year of 2020.

Publication Years	records	% of 203
2021	10	4.926
2020	59	29.064
2019	40	19.704
2018	31	15.271
2017	25	12.315
2016	20	9.852
2015	18	8.867

Table 2.3 publication in Outdoor thermal comfort and Outdoor Thermal Sensation from 2015-2021

Countries/Regions	Records	% Of 203	Countries/Regions	Records	% Of 203
Peoples R China	82	40.394	Canada	2	0.985
Australia	27	13.3	Chile	2	0.985
Usa	20	9.852	Ecuador	2	0.985
England	17	8.374	Malaysia	2	0.985
Germany	14	6.897	Poland	2	0.985
Japan	13	6.404	South Korea	2	0.985
Brazil	12	5.911	Argentina	1	0.493
Singapore	10	4.926	Austria	1	0.493
India	9	4.433	Belgium	1	0.493
Iran	8	3.941	Cyprus	1	0.493
Italy	8	3.941	Denmark	1	0.493
Greece	7	3.448	France	1	0.493
Netherlands	6	2.956	Ghana	1	0.493
Hungary	5	2.463	Ireland	1	0.493
Israel	4	1.97	Russia	1	0.493
Sweden	4	1.97	Saudi Arabia	1	0.493
Egypt	3	1.478	Scotland	1	0.493
Finland	3	1.478	Serbia	1	0.493
Portugal	3	1.478	Switzerland	1	0.493
Spain	3	1.478	Thailand	1	0.493
Tanzania	3	1.478	U Arab Emirates	1	0.493
Bahrain	2	0.985			

Table 2.4 Countries showing publication in the topic Outdoor Thermal Comfort and Outdoor thermal sensation

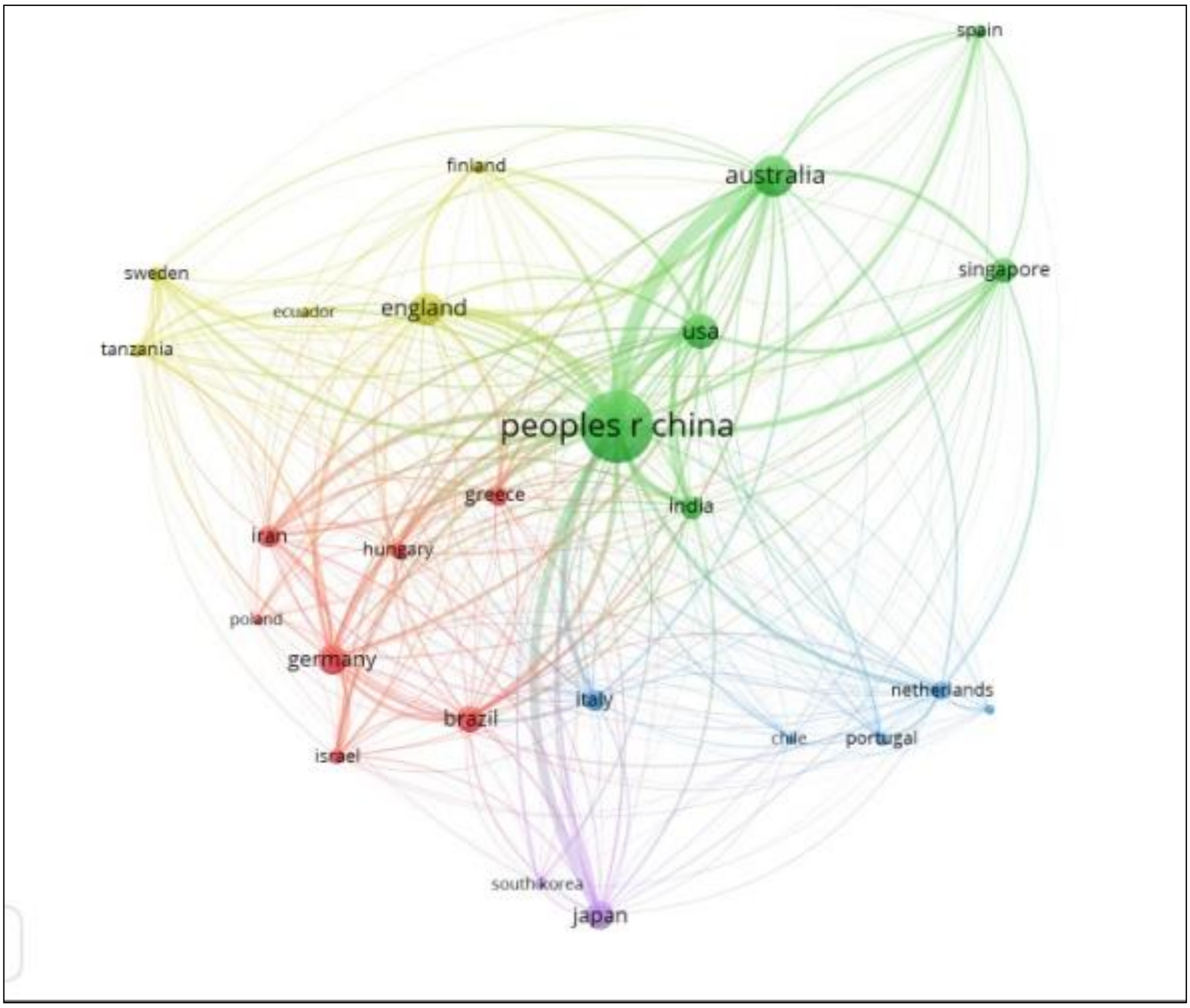


Figure 2.3 Visualization Network Map showing Countries showing publication in the topic Outdoor Thermal Comfort and Outdoor thermal sensation

People's Republic of China has 82 documents with 1195 citations Followed by Australia, USA, England, Germany, Japan, India, Iran, Singapore, Brazil, Italy, Netherlands, Sweden. Figure shows network visualization where two countries located closer and with similar colour to each other show relatedness and stronger citation links between the as well as similarity in topics. Larger circle show more publications from the country as the size of circle represents the number of documents. Fig shows that in density visualization of Bibliographic analysis of countries, People's Republic of China have the greatest concentration of publications and also with the strongest link.

Principal Authors in the Field

In analysis of citation of cited authors, minimum number of citations were set at 50, and out of 3386 authors only, 29 met the threshold. For each of the 77 authors, the the total strength of the co-citation links with outer authors were calculated and the authors with greatest link was selected. M.Nikolopoulou has the maximum number of citations (216) ; close behind is T.P.Lin (215) and A.Matzarakis with 215 citations. All the authors have been referred in this thesis study.

Author	Number of times cited	Author	Number of times cited
Nikolopoulou, M	255	Kruger, E	71
Lin, TP	246	Kruger, El	70
Matzarakis, A	217	Spagnolo, J	67
Hoppe, P	146	Salata, F	69
Thorsson, S	125	Iso	64
Fanger, Po	121	Brode, P	58
Johansson, E	110	Ng, E	57
Lai, Dy	112	Fiala, D	59
Kantor, N	95	Cheng, V	55
Pantavou, K	85	Humphreys, Ma	61
Chen, L	75	Jendritzky, G	53
Knez, I	76	Liu, Ww	61
Yang, W	72	Ali-Toudert, F	53
Mayer, H	72	Gagge, Ap	52

Table 2.5 Principal authors in the present field of study

Frequently used keywords

In analysis of co-occurrence of author keywords, the minimum number of occurrences of a keyword is set at 5 and out of 600 keywords, 20 met the threshold. ‘Outdoor thermal comfort’ has maximum occurrences of 67 times with highest link strength of 43. The following keywords with number of occurrences and total link strength are mentioned in order. A few other keywords with occurrences of 4 and less; and strength of 4 and less are ‘tropical climate’, 'thermal neutrality', 'heat stress', 'Envi-met', 'thermal history', 'questionnaire survey', 'skin temperature', 'urban planning', 'mean radiant temperature' and 'PMV'. Keywords such as 'thermal history', 'Envimet', 'tropical climate' are found in the most recent articles published in 2020.

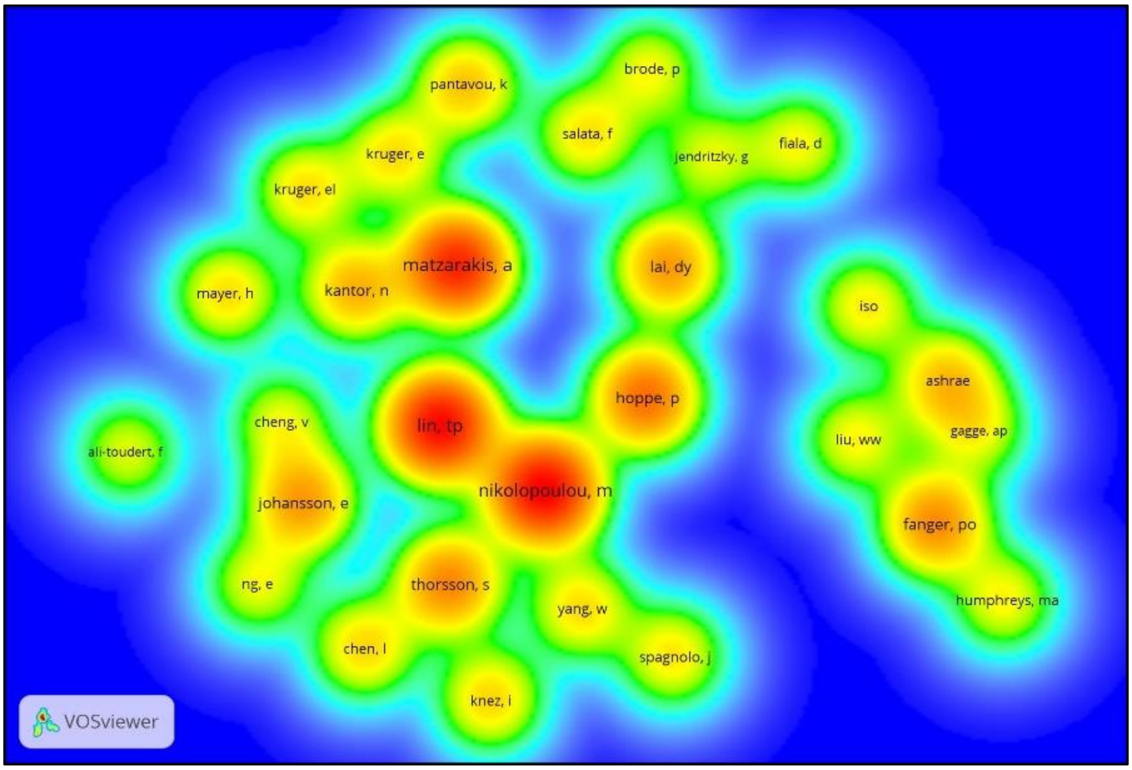


Figure 2.4 Principal authors in the present field of study.

Keyword	Occurrences	Total Link Strength	Keyword	Occurrences	Total Link Strength
Outdoor Thermal Comfort	67	43	Neutral Temperature	7	6
Thermal Comfort	60	32	Urban Climate	7	6
Thermal Sensation	32	25	Field Survey	6	5
Thermal Adaptation	16	16	Clothing Insulation	5	5
Microclimate	14	9	Energy Saving	5	3

Physiological Equivalent Temperature	11	11	Envi-Met	5	4
UTCI	11	10	Outdoor Thermal Environment	5	5
Thermal Perception	9	7	Physiologically Equivalent Temperature	5	5
PET	8	8	Skin Temperature	5	5
Questionnaire Survey	5	5	Urban Microclimate	5	4

Table 2.6 Showing frequently used keywords,

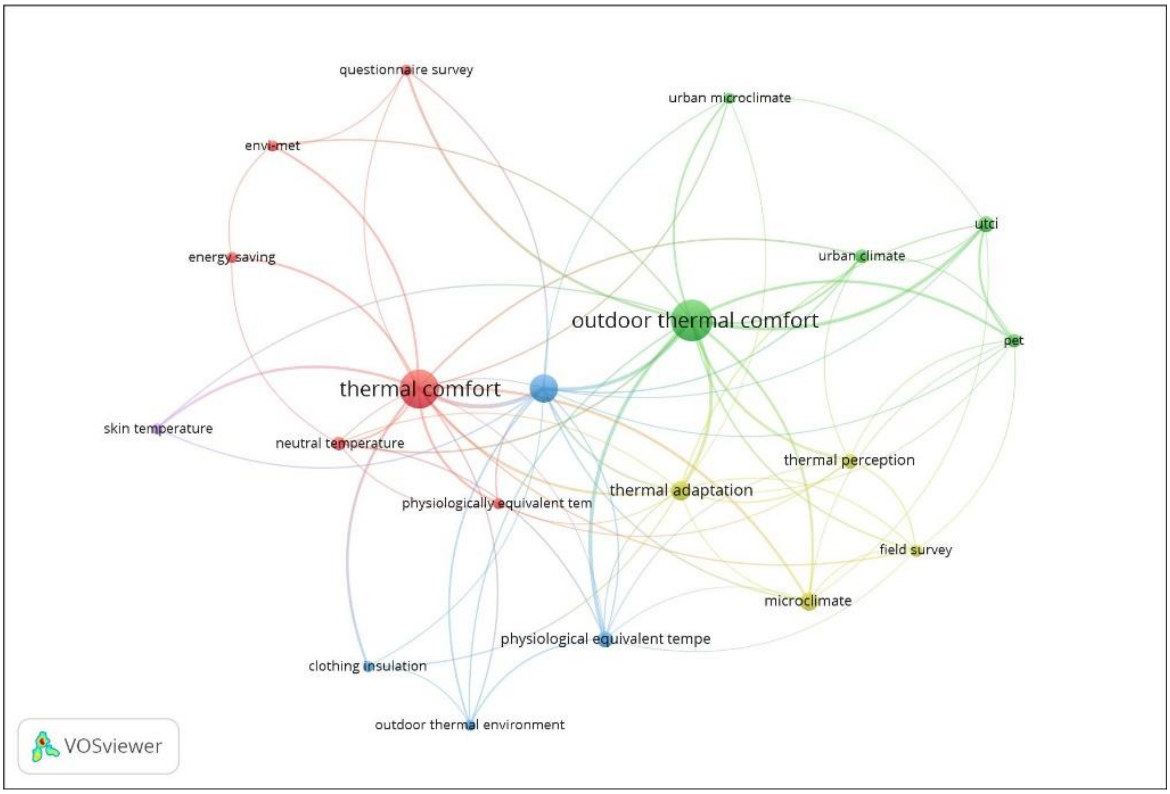


Figure 2.5 Showing keywords used in present field of study.

2.1.3 Bibliometric Analysis for categorization of urban surface cover

The Plan area fraction provides the Landcover at neighbourhood level where the features were considered at scale of 1cm=100 km. One of the urban surface properties include surface cover which can be represented as a ratio of the area of a surface feature (A_x) to the total ground surface area (A_t). This is called Plan Area Fraction represented in Equation 1 where x stands for the surface cover of a feature which can be vegetation, built surface, waterbody etc (Climates *et al.*, no date).

Plan area fraction is used as a tool to study the relation between the loudness of birdsong and visible green area in low density residential areas (Hao, Kang and Krijnders, 2015). Plan area fraction is also used to study the computational fluid dynamics in an urban morphology to predict surface wind speed (Gutiérrez *et al.*, 2015) or radiation and reflection of rooftops (Bianchi *et al.*, 2020). , building density, building coverage and noise levels(Hao *et al.*, 2015) microclimate and atmosphere surface interactions (Best and Grimmmmond, 2015). Plan area Fraction

Plan area fraction is not widely used for landcover study. In few of the studies, plan area fraction was applied. A study applied water fraction to find the size of water bodies. The larger water body show stronger cooling effect while smaller water body in larger number cool a larger area (Theeuwes, Solcerová and Steeneveld, 2013). Plan area fraction is applied to analyse that vegetation helps improve comfort conditions by adding to humidity through evapotranspiration (Meili *et al.*, 2021). In this study, vegetation shows significant correlation with mPET in summer showing that vegetation adds to discomfort in summer. In an already humid region like Kolkata, it is accepted that increased evapotranspiration during daytime adds to the heat. Greenness fraction is used to find the extent of urban greenery and its potential to mitigate urban heat stress(Peng and Ye, 2007).

In order to understand the present scope of study, a review of the limited literature on Plan area fraction is conducted using Web of Science database. The search of original research articles and conference proceedings was conducted based on categories "Plan area fraction'; the publication date between 2015-2021. A total of 5 articles and 1 editorial material were generated that was sorted in accordance to number of times cited. Of the total 6 publications, 3 were published in England, 2 in Netherlands,2 in USA, 1 in People's Republic of China and 1 in Spain.

2.1.4 Inference from Bibliometric Analysis

- In search for literature in 'Outdoor Thermal Comfort', 'Outdoor Thermal Sensation' studies in respect to changing outdoor thermal conditions with changing season was not found.
- There are studies on Outdoor thermal perception study and Mean Thermal Sensation Vote that helps in calculation of Neutral Temperature and Acceptable range of temperature. However, there is no mention of extracting the comfortable regions within the city based on Subjective and Objective assessment with factorial analysis or any other analysis.
- In search for literature review from 2015 to 2021, with objective and subjective assessment, there has been very few works in India to understand the scope of work within the country.
- Plan area Fraction or Coverage ratio is found in handful studies to describe the study area at microclimate level (100m diameter and/or 100m by 100m area).
- The acceptable range of mPET is different for temperate and sub-tropical hot humid regions. The number of studies in tropical and sub-tropical humid regions of South Asia are few in number.

LITERATURE REVIEW BASED ON BIBLIOMETRIC ANALYSIS

2.2 URBAN MICROCLIMATE AND OUTDOOR THERMAL COMFORT

Information on microclimate is analysed in different aspects in different studies. The studies and their results are divided on the basis of

- The effect of urban surface on urban microclimate and
- Parameters of urban microclimate.
- Effect of social inequality and building layout on microclimate and thermal discomfort
- Effect of HVAC and Air quality on microclimate
- Effect of microclimate and urban landscape on urban vector ecology.

In understanding the effect of microclimate and urban landscape on urban vector ecology, a study shows that in three different scenario of urban green roof, low altitude blue-green space and bare rooftop in aiding breeding of vector borne mosquitoes, using microclimate conditions to investigate. High altitude with wind turbulence may not aid in vector ecology but in low altitude green roofs with poor drainage system or low wind flow in hot humid conditions may lead to mosquito breeding. In this study low altitude blue-green space was most susceptible to mosquitoes (Wong and Jim, 2017).. In understanding the effect of social inequality and building layout on microclimate and thermal discomfort, a study shows that higher income group facing sea breeze and shading opportunity has better thermal comfort conditions than the lower income group who are located at urban periphery and marked by high air temperature and hight tmrt (Pereira, Masiero and Bourscheidt, 2021) The effect of HVAC Urban Vector Ecology and Effect of social inequality on microclimate is beyond the scope of this research topic.

2.2.1 Parameters of Urban Microclimate

Air Temperature (Ta)

Ambient air temperature is considered to be the most dominant parameter in outdoor thermal comfort. In the calculation of PET, Tmrt is a more important parameter than air temperature since there is marginal difference in air temperature between locations but a wider difference was noticed in thermal comfort conditions. The main difference in Tmrt is due to availability of shade in one site and absence of shade in another (Makaremi *et al.*, 2012). Although it is said that Urban greenery and waterbodies help in reducing ambient air temperature, it does not affect Tmrt after nightfall. Sky view factor on the other hand show correlation with Tmrt. Thermal preference for solar radiation, wind speed, humidity is linked to air temperature as higher the air temperature, higher will be preference for windspeed than solar radiation and humidity(Lai *et al.*, 2014). Sites with shaded trees record lower air temperature while site close to lake records higher humidity(Chen *et al.*, 2009).

Relative Humidity (RH)

A study tries to understand the importance of humidity and windspeed at site to create discomfort or improve outdoor comfort. In this study, data collection took place at four different landcover types- dense vegetation, less dense urban forest with grass carpet and palm trees, low rise residential buildings, artificial water body. The analysis was done for both in-situ data collected for site as well as over the seasonal changes, THI, WBGT, and PET indices were applied and subjective questions pertaining to individual comfort, thermal acceptability and overall perception was recorded. The results show that all the sites show general note of discomfort with humidity being the most important criteria contributing to discomfort. Exposure to strong sun rays also lead to preference for windier and cooler conditions. Therefore, shade with greater tree canopy that will also allow evapo-transpirative cooling(Chow *et al.*, 2016). Another study showed that increase in humidity and reduced air temperature due to irrigation may improve outdoor thermal comfort in urban areas during heatwaves. The base model did not include irrigation and the difference in Ta at 3pm between a water body and urbanised area was 9 degrees Celsius. With continuous cooling in hypothetical situation modelling, the pervious surface requiring more irrigation were cooler by 9 degrees Celsius while the residential areas cooled by only 1 to 3 degrees Celsius. Increase in volume of water decreases cooling efficiency. So, the cooling with irrigation at night is more efficient in cooling than daytime cooling(Broadbent *et al.*, 2018). A study show that complete lack of effect of vegetation and humidity leads to 'strong heat stress'(Kamel, 2021)

Wind speed (Va)

A study in Jordan shows that in four types or urban layouts, the windspeed is higher in East-West orientation instead of North-South orientation(Othman and Alshboul, 2020) North south orientation shows lower values of PET than east-west orientation(Kannamma and Sundaram, 2014). In the downwind direction, of a park area, at an intensity of 2.3 m/s allows cooling up to 1 degree Celsius up to 27m but at distance of 117m, the cooling reduces by 0.6 degree Celsius(Mughal *et al.*, 2021). Envimet simulations underestimate or overestimate the PET values and sometimes, the perception is lower than simulated result.(Schaefer *et al.*, 2021). At higher latitudes, wind obstruction for windspeed 8 m/s and above, will improve OTC by lowering the chill(Brozovsky *et al.*, 2021).Increased wind turbulence helps in perceived cooling due to reduction in skin temperature(Yu *et al.*, 2021). Objective measurements show that thermal comfort is related dominantly to air temperature, but perceptive subjective measurements show that thermal comfort also depends on windspeed and radiant heat , visual appreciation of landscape, air quality and 'environmental acoustics'(Tan *et al.*, 2019a). When wind speed increases from 0.5 m/s to 2 m/s there is considerable reduction of Tmrt but when wind speed increases from 2 m/s to 3.5m/s then there is not much change in Tmrt(Sangkertadi and Syafriny, 2016).

2.2.2 Microclimate parameters in Urban studies

Sr.No.	Author and year	Parameters	Study	Methodology	Results
1	(Tan *et al.*, 2021)	Surface temperature, air temperature	Mitigate UHI, lower surface temperature	Image pixels, R software for analysis	Use of trees in unshaded areas and low albedo material will lower surface temperature.
2	(Brozovsky *et al.*, 2021)	Wind speed, direction. A, RH, TS	Association between microclimate, built environment and OTC	ENVI-met, Questionnaire, infrared thermography	Wind sheltering provides outdoor thermal comfort.
3	(Kamel, 2021)	urban canopy air temperature, mean radiant temperature, wind speed dry bulb temperature, relative humidity, solar irradiance	Impact of solar radiation on pedestrians and outdoor thermal comfort	UTCI, Grasshopper , outdoor comfort calculator	High heat absorption material along with no vegetation and high humidity create heat stress.

4	(Salman and Saleem, 2021)	TA, TMRT, RH, VA, tree cover%, surface cover%, building height.	Strategies for mitigation of UHI	Envimet	Shade and cool materials are good strategies, urban geometry and planting tree is an important component, Tmrt is an important parameter.
5	(Nazarian, Acero and Norford, 2019)	REVIEW PAPER		CFD, 3D MODELLING	OTCA
6	(Schaefer *et al.*, 2021)	Microclimate data for PET, SPM concentrations, behavioral adaptation to heat stress data	Outdoor thermal comfort of pedestrians due to pollution	PET, Questionnaires	Proposals for bioclimate based urban street designs to incorporate association between air pollution and thermal discomfort.
7	(Ghaffarianhoseini *et al.*, 2019)	Soil data, physiological data, meteorological data, building data,	identifying uncomfortable locations, their characteristics and design and at same time enhance the OTC	Envimet, IES -VE	Shade areas have higher comfort Open spaces with no shade have higher PET Tree always do not guarantee comfort. Wind movement becomes unsteady with built environment
8	(Wong and Jim, 2017)		Impact of bare roof, green roof and blue green surface on mosquito infestation		Green roof and gardens with water space are both susceptible to mosquito infestation though for the latter it is more.
9	(Herath, Halwatura and Jayasinghe, 2018)	Microclimate necessary for Envimet simulation.	Impact of urban green on urban tropical microclimate.	ENVI-met v. 4.4	Temperature reduction for all scenarios from 100% , 50% green roofing to green walls.

10	(Ferwati *et al.*, 2019)	Soil data, physiological data, meteorological data, building data,	Reducing surface and ambient temperature by planting mature trees along side of roads of less dense urban area.	ENVI-met v. 4.4, partial differential equations (PDE)	Low density buildings with shading allow for lower mean radiant temperature though overall share of urban cover should be less.
11	(Bachir *et al.*, 2021)	meteorological data	Simulation with different vegetative options.	ENVI-met 4.4.5	Tree alignment can have cooling effect on the city up to 1.2 degree Celsius.
12	(Rossi *et al.*, 2020)	Surface temperature	Use of high reflective awning tiles for pedestrian comfort	PET, Questionnaire	PET reduction up to 2.5 degree Celsius
13	(Othman and Alshboul, 2020)	Solar radiation, ambient temperature, surface temperature, relative humidity, wind direction, wind speed, specific humidity.	Different urban forms for outdoor and indoor comfort	Envimet & RAYMAN	Shading is more effective than wind in adding comfort but both together will create comfortable environment.
14	(Mughal *et al.*, 2021)	Tree height, tree coverage, leaf size, soil, asphalt,	Urban Park effect on OTC and air temperature	Open FOAM	Absence of vegetation leads to high heat stress conditions.
15	(El Kenawy *et al.*, 2021)	Data for key pollutants and secondary aerosols	Surface UHI during COVID 19 lockdown	Remote sensing imagery,	Reduction od surface UHI due to lowered pollutants in COVID 19 lockdown.

17	(Parida *et al.*, 2021)	LST images from Terra-MODIS, European weather forecasting organization sourced data	LST changes due to COVID 19 lockdown	Temperature anomaly compared between years, LST standardized anomaly	Day time LST increased due to reduce of pollutants, aerosols and water vapor.
18	(Yu *et al.*, 2021)	Age, height, weight, BMI, activity, wind direction, wind velocity, thermal conductivity, specific heat of body skin	Effect of wind flow in outdoor conditions and influencing thermal perception	Boundary layer wind tunnel	Physiological and perceptive comfort due to cooling from turbulence.
19	(Pontes *et al.*, 2022)	TA, RH, VA, Solar radiation,	Understanding plantation cover in thermal comfort	Olgyay bioclimatic chart	Measurements in shaded points have lower temperature. Plantation cover inadequate for thermal comfort.
20	(Xue, Gou and Lau, 2017)	Meteorological measurements, SVF, main shading orientation (MSO), personal sensation	Site configuration, design guidelines and perception of microclimate.	Correlation	Changes in site configurations and design guidelines to include comfort sensations.
21	(Banerjee and Chattopadhyay, 2020)	meta-analytical review			Insufficient literature on human biometeorology low income or informal settlements in tropical hot humid regions.

22	(Binarti *et al.*, 2020)	Review for indices for outdoor thermal comfort and range of neutral temperature in hot humid regions.			PET is most widely used in hot humid regions. mPET gives neutral range of 21-30 degree Celsius as an adaptive range. In recent times UTCI has been used but for hot humid regions, mPet is used in the years that UTCI have been used.
23	(Banerjee, Middel and Chattopadhyay, 2020)	Microclimate data, thermal perception data.	Thermal comfort in informal activity area.	PET, ANOVA, Thermal comfort perception study.	neutral PET = 23.6 °C; neutral PET range is 19.5 °C - 27.6 °C.

Table 2.7 Showing parameters considered for study in the given publications

2.2.3 Influence of microclimate on Outdoor thermal comfort

- Effect of wind on thermal comfort in high latitudes
- Effect of wind on thermal comfort in tropical areas
- Effect of solar radiation on thermal comfort in high latitudes
- Effect of solar radiation on thermal comfort in tropical areas

One of the important parameters of microclimate is wind that can be used to modulate urban comfort and energy savings. Pedestrian level wind circulation can be modelled through CFD or wind tunnel tests. While in some studies, wind helps in amelioration of thermal conditions especially in tropical areas (Lu *et al.*, 2016), in other studies, wind can be a source of discomfort especially in winter in higher latitudes(Yu *et al.*, 2021). Netherlands has a wind nuisance standard (NEN 8100) for constructions over 30m as such high building may cause wind turbulence at pedestrian level(Janssen, Blocken and Van Hooff, 2013). In most papers, all the microclimatic parameters are closely related. Papers with theoretical review give a detailed understanding of the microclimate approaches in recent studies related to thermal comfort conditions (Bherwani, Singh and Kumar, 2020). Many studies use CFD to make models on building ventilation (Subhashini and Thirumaran, 2020) (Maher *et al.*, 2021)(Vaishnani *et al.*, 2020). Microclimate effect on thermal comfort in arid areas (Kumar and Sharma, 2022) of exercising people in semi-arid regions (Kumar and Sharma, 2022) importance of aspect ratio and canyon orientation in humid area of Rajarhat town near Kolkata (De and Mukherjee, 2018) and tropical maritime humid regions such as Mumbai to interior dry locations such as Bhopal (*A regression-based three-phase approach to assess outdoor thermal comfort in informal micro-entrepreneurial settings in tropical Mumbai - PubMed*, no date; Ali and Patnaik, 2018a; Banerjee, Middel and Chattopadhyay, 2020, 2022). Information on setting apparatus for measurement of different parameters for different scales of scales of urban microclimate (Oke, 2007) and the concept of urban heat island in Context to LCZ (Stewart, 2011) and the different platforms of analysis especially geospatial software and remote sensing tools such as Arc GIS and Python (Bherwani *et al.*, 2021) is found through literature review. A study based on primary data collection and simulation through ENVIMET and IES software, has considered sunny and cloudy sky conditions for onsite data collection. Air temperature, relative humidity, wind speed, wind direction and solar radiation are the parameters measured in varying sky conditions. The same study has elaborated tropical conditions of high air temperature during mid-day, high relative humidity and low wind speed. Microclimatic conditions with high mean radiant temperature and high solar radiation create thermally uncomfortable locations in Kuala Lumpur (Ghaffarianhoseini *et al.*, 2019).

Similarly, another study conducted microclimate data collection from 9 am to 6 pm for different locations and for different seasons. The microclimate parameters considered are wind speed, relative humidity, globe temperature and air temperature. Both this study and the previous study have followed the guidelines of ISO7726, 1998. In this study, the questionnaire survey is conducted within 3m radius of the instrument setup and the effect of the neighbouring areas and street junctions is reduced. Like the previous study, this study too shows tropical conditions with high values of air temperature, globe temperature, mean radiant temperature and relative humidity and low wind speed. The microclimate measurements were used to estimate the neutral temperature and the acceptable range of temperature using PET and TSV for city of Dhaka(Sharmin, Steemers and Humphreys, 2019a).

In yet another study, Weighted Outdoor Thermal Comfort Autonomy (OTCAw) was calculated to understand the period of stay in a thermal zone, affecting the extent of thermal acceptability or deviation towards thermal stress The three parameters of OTCAw are urban airflow, surface heating and reflected radiation. While OTCAw is not a new index, it uses present indices to evaluate the performance of indices to measure thermal comfort or thermal stress(Nazarian, Acero and Norford, 2019). A study in Baghdad has shown comparative study of the microclimatic parameters such as air temperature, relative humidity, wind speed and mean radiant temperature, sky view factor and surface temperature along with computation of PET in Envimet and Rayman. Influencing Mean radiant temperature by adjusting the surface cover and wind flow for simulation purposes create scenarios of high surface albedo that help create an acceptable microclimate (Abaas, 2020). Wind plays an important and indirect role in influencing perception of comfort conditions (Tan *et al.*, 2019a). While all the studies above mention the importance of green cover, studies use microclimate data and PET calculations to test the effect of energy reflectance properties of surface materials or solar awnings (Rossi *et al.*, 2020)or examine the changes in landscape required to reduce air temperature by encouraging loss of energy by reflectance (8) or use shade walls, green walls to help mitigate the heat (Priya and Senthil, 2021). Studies have examined the role of spatial distribution of urban green surface(Bachir *et al.*, 2021) or performance of trees or role of vertical greenery to ameliorate the microclimate condition(Meili *et al.*, 2021; Perera *et al.*, 2021; Priya and Senthil, 2021). However, in high latitudes, outdoor comfort is improved with solar radiation and wind restriction (Brozovsky *et al.*, 2021). Most studies using Bioclimate index and measurement of thermal indices consider microclimate data for calculation, simulation and modelling (Kamel, 2021; Pontes *et al.*, 2022).

Obstruction to wind flow can influence urban microclimate and enhance Tmrt (Othman and Alshboul, 2020)**.** The influence of urban morphology and urban form on outdoor microclimate is also shown in studies using PET index and Envimet simulations(Salman and Saleem, 2021) (Othman and Alshboul, 2020). Studies also involve thermos-physiological conditions ,such as clothing, metabolic activity to understand the active heat regulation of the body and the passive heat exchanges from inside and surface of body, to understand the impact of microclimate changes on thermal comfort perception (Othman and Alshboul, 2020).

From the above short discussion on the different studies of microclimate, we understand that effect of microclimate on thermal comfort and the effect of vegetation, built form, pattern, design and surface properties have impact on urban microclimate. Also, the thermal effects are quantified and then possible strategies and recommendations are quantified and visualized through Thermal comfort indices and ENVIMET simulations. Other software such as CFD, DART, SOLWEIG are also employed to make simulations.

2.3 SURFACE COVER AND URBAN MICROCLIMATE

2.3.1 Types of Surface Cover

Built Surface

Landscape has an impact on microclimate (Kannamma and Sundaram, 2014). Built surface has an impact on Land Surface Temperature (LST) during Hot period and the daytime-nighttime difference depends on city size and urban morphology(Morabito *et al.*, 2016).Also if sunrays are blocked by urban morphology; higher SVF helps in cooling in open spaces in hot humid regions(Lai, Maing and Ng, 2017)Street canyon built form with different pavement materials show that high albedo materials reduce surface temperature while porous material increases surface temperature since the surface becomes dry, after an event of rain, thus suggests 'porous and reflective' materials to mitigate UHI (CFD)(Ferrari *et al.*, 2020). A study has compared primary data on microclimate conditions with Envimet simulation models. Base case along with 6 scenario models were run. The scenarios included light coloured pavement materials, grass surface and increased trees by 200%. The results showed that there is reduction in surface temperature by adding grass surface and increasing the number of trees but not much difference from base model by adding water surface. Changing of pavement material only brings difference of 0.25 to 0.75 degree Celsius only. Thus, in this study shade play a more important role in reducing heat stress(Yang, Lin and Li, 2018). Photovoltaic materials are also more efficient in reducing urban temperature than soil or asphalt(Efthymiou *et al.*, 2016). High albedo materials can be a cooling strategy (Tan *et al.*, 2021).A study shows that in all open spaces with higher PET may have a common characteristic of low albedo asphalt surface (Ghaffarianhoseini *et al.*, 2019)Another study with Envimet simulation also show that high albedo materials increase the direct shortwave radiation and hence deteriorate the microclimate condition. Instead of asphalt or bare soil, light red pavement materials show lower surface temperature(Ferwati *et al.*, 2019). In this case, grasses and tree plantation can help in cooling through evapo-transpiration. (Salata *et al.*, 2015). Cool materials for construction, intended to tackle Urban Heat Island(UHI) and reduce energy load in summer in buildings in urban canyons, the high albedo materials may in turn cause reflective heat related thermal stress for pedestrians(Rosso *et al.*, 2018). Built form with high rise buildings, green areas and waterfront may allow better ventilation at pedestrian level. Envimet simulations show improved thermal comfort with water fronts and vegetated surface and built materials with high reflectance in during hot season (Karakounos, Dimoudi and Zoras, 2018). Canyon orientation and aspect ratio differences result in different thermal comfort conditions (Chatzidimitriou and Yannas, 2017). UHI zoning can help zoning of urban forms. Height-Width (H/W)ratio has direct and inverse relation to Outdoor thermal comfort while lower Sky View Factor (SVF) will cause lower OTC due to less incoming solar radiation in the Middle East (Sanagar Darbani *et al.*, 2021). Urban high rise built form has an effect on ventilation and for better ventilation performance of urban areas, sea breeze should be considered in urban planning and urban design process in order to mitigate the urban microclimatic conditions (He, Ding and Prasad, 2020). Urban form and its impact can be simulated on Envimet software. Impact of different urban forms can be studied with simulations that includes data on wind direction, wind velocity, building height, building distance, ratio of building distance to building height, Floor area ratio etc. same study shows that reducing building distance may increase sun shading and improve thermal comfort but the building distance cannot be reduced too much as it may affect ventilation and cause heat related illness(Xuan *et al.*, 2016). Street geometry plays an important role in outdoor thermal comfort. Narrow streets offer more shade and more comfortable. Higher the height to width ratio, lesser is the air temperature and PET(Amirtham, Horrison and Rajkumar, 2014). Higher aspect ratio has lower PET values than traditional streets that are wider but records higher PET values. High aspect ratio also helps in mutual shading of buildings (Kannamma and Sundaram, 2014).

In open spaces, PET can be lowered through loss of radiation and shade (Ali and Patnaik, 2018b).Interpolation can involve the effect of urban built space, urban geometry, greenery and waterbodies wither by using weights orby cokriging but the characteristics of each site are very different and hence diverse weights may be considered(Shi *et al.*, 2016). Open spaces around low rise buildings are cooler than high rise buildings. With higher humid conditions around low rise buildings in Iranian summer (Monam and Rückert, 2013). Building structures such as pergolas when planted helped in reduction of air temperature(Kittas *et al.*, 2015). Albedo, surface roughness and thermal conductivity of surface properties also affect the urban environment

Vegetation Surface

Trees in wooded areas, may reduce radiative cooling and restrict windspeed negligibly, but the cooling effect due to shade outweighs the negative impacts(Cheung, Fung and Jim, 2020) but to reduce overall thermal comfort, vegetation alignment along with urban form will have to be considered together (Bachir *et al.*, 2021). Urban greenery help to mitigate UHI (Doick, Peace and Hutchings, 2014) and tree alignment can help reducing surface temperature by 4 degree

Celsius as well as help in cooling by 1.2 degree Celsius (Bachir *et al.*, 2021). Urban green landscaping and rooftop greeneries provide a cooling effect (Dimoudi and Nikolopoulou, 2003; Priya and Senthil, 2021). A study also shows that the importance of open spaces in thermal cooling, depends on the arrangement, number and size of shade provided by trees. Shaded areas have a lower Tmrt value than unshaded areas. Unshaded areas record higher PET values(Ghaffarianhoseini *et al.*, 2019). Yet, another study shows that the species of trees providing shade is important because 9 out of 10 plant species studied, shading provided no remarkable reduction in temperature in an university campus (Tan *et al.*, 2021).Study of tree species in that contribute to OTC have been studied through simulations on Envimet(Perera *et al.*, 2021). Tree lining along pathways and coastal areas showed reduction in temperature both in coastal and highly urbanised areas. At neighbourhood scale, effective cooling will be with planting of mature trees at 10m interval and of 10m height, along the road sides(Ferwati *et al.*, 2019).trees and vegetation help in lowering PET by protecting from direct solar radiation(Makaremi *et al.*, 2012).

A study on vegetation cover shows Landcover fractions such as, Λ_{TREE} and $\Lambda_{GROUNDVEGETATION}$ (the plan area fraction of tree cover and ground vegetation cover, tree radius is one-fourth of Λ_{TREE}) and plan area fraction of impervious surface ($\Lambda_{impervioussurface}$). Landcover fractions show tree cover and ground vegetation representative of the area. The same study mentions that vegetation fraction will vary in the LCZs and the effect of vegetation on thermal comfort index, such as UTCI, will vary due to varying availability of sunlight, photosynthesis and 'convection efficiency'(Meili *et al.*, 2021). In the study of vegetation parameters clubbed into categories of, vegetation amount, vegetation structure, vegetation properties, rainfall intercepted, and physiology of tree and ground vegetation. Cooling effects of trees is clearly seen in LCZ 5 and LCZ 3 mostly due to shading. In LCZ6tree cover more than50% will lead to slightly higher UTCI but with tree cover fraction with 30% to 50%, the lowest average UTCI is recorded. Hence there is an optimal tree cover fraction that provides cooling during midday(Meili *et al.*, 2021). In tropical and sub-tropical hot humid and densely populated regions, thermal sensation, visit pattern to a location can be adjusted with greenery in a space. Total view factor and green density have a negative relation with balance of microclimate parameters but positively correlated with stay duration in a space(Xue, Gou and Lau, 2017). Green areas can extend cooling effect 50 m into the urbanised areas, while waterfronts can allow ventilation into the urbanised part of the city even if the axis of the ventilation corridors may not align (Lan *et al.*, 2021).

The size of the green space and the replacement of vegetation kay help creating comfort conditions but tropical plants having greater evapotranspiration does not show much difference. ‘Aerodynamic shading’ or blocking of winds by buildings result in heat trapping behind the buildings. The streets parallel to parks continue to receive cool air form the park. Another important factor is the effect of distance from the park. The cool air forms the park spread out behind the park until it reaches the hotspot around the high-rise buildings which block the wind path. Above 1.5 m, the effect of vegetation decreases as windspeed increases.(Dimoudi and Nikolopoulou, 2003). Trees at a height of 15m reduces wind velocity by 1.15 m/s which is a reduction by 78%; due to evapotranspiration, air temperature decreases by 0.6 degree Celsius and increases relative humidity. Areas with no vegetation has no drag and the windspeed is high with high surface temperature as well.

<table>
<tr><th>Consequences Of Climate Change</th><th>Greenery Helps Combat</th><th>Effect On Environment at Local Scale</th><th>Impact On Health</th></tr>
<tr><td>UV Radiation</td><td>Trees Reflect and Cool</td><td rowspan="2">UV Radiation Reduces</td><td rowspan="2">Reduces Effects of Ozone Like Cancer, Cataract, Ageing</td></tr>
<tr><td>Heatwaves in UHI</td><td>Evapotranspiration</td></tr>
<tr><td></td><td>Heat absorption and retention</td><td>Cooling Of Environment</td><td>Reduces Heat Stroke and Heat Related Mortality</td></tr>
<tr><td>Ground Level Ozone</td><td>Plants Remove Pollutants</td><td rowspan="2">Reduce Ozone Formation and Dry Concentration of Ozone</td><td rowspan="2">Reduces Ozone Related Health Issues</td></tr>
<tr><td></td><td>‘Some species emit ozone precursors’</td></tr>
</table>

Table 2.8 shows the need for greenery in urban areas as Adaptation strategies in climate change condition at local scale. Source: (Sharma and Tomar, 2010)

A study shows that two different sites of observation: one with tree alignments and the other without vegetation. The difference in vegetation between two sites is 23% and therefore the difference in soil temperature is 10 degrees Celsius. The site with trees have higher humidity, lower soil temperature due to shade and lower PET values(Ep-Bellara and Abdou, 2016). Other studies also mentions that park and green areas record cooler temperatures.

Water surface

A study has tried to understand the impact on thermal condition before and after adding an experimental water body to a model with makeshift blocks, which represent low rise-built surface. The data collected during June-September shows that during the peak summer temperature, the cooling effect is recorded clearly. During the day, the temperature above the pond is lowest while at night, the temperature near the pond is higher. However, heat mitigating effect works for both day and night, albeit lower for night time. In the same study, when windspeed <1 m/s, the air temperature shows difference but at higher windspeed, the temperature profile does not show much difference. In respect to windspeed and solar radiation, the air temperature conditions was studied under effect of shade or water bodies. With more solar radiation and windspeed, cooling effect was more prominent due to increased evaporation(Syafii *et al.*, 2016).

2.3.2 Effect of Built Surface on Urban Microclimate

The land surface temperature data from 2001 to 2013 using MODIS remote sensing data shows that there is a positive relation between urban built surface and urban thermal environment (Morabito *et al.*, 2016). The building design and surface orientation also play important role in affecting microclimate and thermal comfort (Allegrini, Dorer and Carmeliet, 2015). Buildings with different aspect ratio and asymmetrical urban canyons may affect air flow and admittance of solar radiation (Qaid and Ossen, 2015). Streets with different aspect ratio show difference in PET values (Kannamma and Sundaram, 2014) Surface materials with high albedo may reduce surface temperature, but the re-radiation causes low thermal comfort(Qaid and Ossen, 2015)(Salata *et al.*, 2015)(Yang, Lin and Li, 2018). Alternative pavement materials such as photovoltaic materials is effective than bare soil or asphalt pavement can help reduce surface temperature (Efthymiou *et al.*, 2016)(Salata *et al.*, 2015). Watering surface through irrigation can reduce microscale air temperature (Broadbent *et al.*, 2018). Porous pavement and high albedo materials help in cooling through evaporation as well as higher surface reflectance, yet the radiation exchange between pavement and wall surfaces may not be discernible(Ferrari *et al.*, 2020). Building layout can help provide shade and higher the SVF, higher is the loss of energy via long wave radiation(Lai, Maing and Ng, 2017). Surface temperature also reduced during covid 19 lockdown (El Kenawy *et al.*, 2021). A study shows the effect of landscape design on thermal comfort and microclimate. The parameters in this study are globe temperature, air temperature, relative humidity and wind speed measured at aeras with specific urban geometry with certain SVF, urban greenery and surface thermal properties. Different scenarios of urban design are investigated on Envimet software. In this study, there is reduction in air and surface temperature in simulation with urban greenery and high albedo pavements but did not reduce heat stress. Water bodies did not reduce surface or air temperature maybe due to high humidity and low wind condition. (Yang, Lin and Li, 2018). Further studies have involved analysis of built form and microclimate (31,40,41,32–39).

2.3.3 Effect of vegetation and water surface on urban microclimate

- Effect of wind restriction due to vegetation
- Effect of cooling through shading of trees
- Effect of cooling through evapo-transpiration
- Effect of waterbodies in mitigating heat

In a study area where built surface accounts for substantial cooling as investigated in Envimet simulations (Tan, Lau and Ng, 2016). In Beijing, manmade shading device performs best in energy saving and thermal cooling while a combination of tree and shading device works optimally (Xu *et al.*, 2017) . Built surface records higher UTCI and THI values than over 94% then simulation models on Envimet show that the replacement scenarios of built surface with urban parks lead to significant cooling and formation of cool islands(Lin and Lin, 2016). A study shows that, in a given CFD simulation, areas with no vegetation have high wind speed due to less roughness elements. Areas with vegetation but less evapotranspiration do not help in reducing air temperature by evaporative cooling within the canopy. Also shading helps reducing surface temperature(Mughal *et al.*, 2021). A study using UTCI shows that street vegetation with highest transpiration will create outdoor thermal comfort(Meili *et al.*, 2021). In spite of high humidity, portions of urban areas that have greenery record the lowest air temperature (Chow *et al.*, 2016). In the Indian city of Bhopal as well as tropical Sri Lanka, urban parks and urban greenery recorded lower air temperature than the built areas that can help improve outdoor comfort conditions(Ali and Patnaik, 2018b; Herath, Halwatura and Jayasinghe, 2018). Along with cool pavements, addition of trees on unshaded streets helped in lowering surface temperature and aided in pedestrian comfort(Taleghani, Sailor and Ban-Weiss, 2016). Green surface can also be viewed as a an area of thermal healing or a landscape that provides thermal satisfaction (Xue, Gou and Lau, 2017). However, a study showed that shading by concrete surface with high albedo may show significant reduction in surface temperature than tree canopy (Tan *et al.*, 2021). Tree canopy is substantial in reducing Tmrt especially in low SVF but in high SVF canopy, air temperature shows a reduction. Urban greenery and wind path design may also create natural landcover in eastern India. ‘Xeriscaping’ has been used in context of dry locations(Chow and Brazel, 2012; Shojaei *et al.*, 2017). Trees and buildings impede wind speed and urban parks and riverfronts record higher relative humidity and thermal comfort is measured using the TSV index (Tong *et al.*, 2017). Studies also include waterbodies to evaluate the effect of cooling or heat mitigation in context of air temperature, surface temperature or outdoor thermal comfort(Xu *et al.*, 2017, 2019; Zhao and Fong, 2017a, 2017b; Cheung and Jim, 2019a). Tree canopy will create comfort conditions by providing shade that will reduce the air temperature, but the heat trapping will depend on location of the tree and its surroundings(Mohammad *et al.*, 2021).

2.3.4 Studies on Built Surface and Outdoor Thermal Conditions

Sr.No.	Author and year	Type of climate	city	Results
1	(Xuan *et al.*, 2016)	moderate humid subtropical climate	Guangzhou, China	distance between buildings can be reduced to have the combined advantage of ventilation and shade of the sun. .
2	(Manavvi and Rajasekar, 2020)	Subtropical climate	Chandigarh, India	Six directional method is more effective in Tmrt calculation
3	(Cheung, Fung and Jim, 2020)	subtropical climate	Hongkong	TA, V, RH and solar incoming radiation play an important role in cooling from trees
4	(He, Ding and Prasad, 2020)	Hot dry	Greater Sydney, Australia	Precinct ventilation due to sea breeze effect in high rise-built area is important for urban planning and recognition of urban scale n urban climate studies.
5	(Sanagar Darbani *et al.*, 2021)			Predicts outdoor thermal comfort conditions in urban setting

6	(Taleghani and Berardi, 2018)	Temperate	Toronto, Canada	The effect of different materials on PET. Higher albedo makes pedestrians uncomfortable. Through solar re-radiation, introduction of water body led to further cooling by 0.5 degree Celsius.
7	(Salata *et al.*, 2015)	Mediterranean	Rome, Italy	Materials with high albedo provide good microclimate if SVF is high. Best microclimate condition is in the configuration that includes vegetation.
8	(Yang, Lin and Li, 2018)	Equatorial	Bedok, Singapore	High albedo material does not provide relief, shade from tree significantly reduce air temperature.
9	(Efthymiou *et al.*, 2016)	Mediterranean	Athens, Greece	Photovoltaic pavement can help reduce surface temperature.
10	(Lai, Maing and Ng, 2017)	subtropical climate	Hongkong	Shading will help cooling of open spaces by reducing exposure to radiation.
11	(Karakounos, Dimoudi and Zoras, 2018)	Mediterranean	Serres, Greece	Increased solar reflectance and introduction of water and vegetation will reduce surface temperature.
12	(Morabito *et al.*, 2016)	Mediterranean	Cities in Italy	Sealing of areas with built surface leading to higher impact on land surface temperature.
13	(Broadbent *et al.*, 2018)	Hot dry	Adelaide, South Australia	Irrigation as a means to cool during heat wave conditions.
14	(Allegrini, Dorer and Carmeliet, 2015)	temperate	Zurich, Switzerland	Urban structures influence wind flow; increased air temperature and decreased wind flow lead to higher discomfort.
15	(Ferrari *et al.*, 2020)	Simulation based		Pavement material characteristics such as porosity, permeability, reflectance influence surface temperature.high albedo and permeable materials can help mitigate UHI.
16	(Qaid and Ossen, 2015)	Hot-humid	Putrajaya Boulevard, Malaysia	Aspecct ratios help understand if asymmetrical streets improve shade.

17	(Chow *et al.*, 2016)	Hot-humid	Singapore	Wind and shade under tree canopy help in improving outdoor thermal comfort.
18	(Pereira, Masiero and Bourscheidt, 2021)	tropical coast	Santos, Brazil	Low H/W ratio and high SVF can lead to heat stress in middle income group housings.
19	(Deb and Ramachandraiah, 2010)	Hot and humid	Chennai railway station	High adaptivity and tolerance to stress with neutral temperature being 31.93 degree Celsius.
20	(Mohan, Gupta and Bhati, 2014)	Hot and humid	Kolkata, Chennai, Mumbai, Delhi, India.	Effective uncomforbality is highest in Kolkata and Chennai from April to September, highest in may, compared to Delhi and Mumbai.
21	(Sangkertadi and Syafriny, 2016)	Hot-humid	Manado, Indonesia	Wind helps improve OTC, high SVF reduces OTC,
22	(Ali and Patnaik, 2018a)	tropical savanna climate	Bhopal, India	Thermal comfort is lowest in-built environment followed by water environment and highest in green environment.

Table 2.9 Showing studies on built surface and outdoor thermal conditions.

2.3.5 Studies on Natural Surface and Outdoor Thermal Conditions

Sr.No.	Author and year	city	Study	Methodology	Results
1	(Völker *et al.*, 2013)	Review paper			Blue space has the capacity of lowering ambient temperature during heat stress.
2	(Han *et al.*, 2011)	Wuhan, China	Impact of water bodies on city area	Field survey	River wind along streets and roads provide better thermal conditions as opposed to streets where river wind is blocked by buildings.
3	(Völker and Kistemann, 2013)	Review paper			Urban blue space and urban green space is a requirement for well-being and good health.

4	(Murakawa *et al.*, 1991)	Hiroshima, Japan	Vertical measurement of microclimate in fine weather, horizontal differences in temperature along sections of the city and river area		River is a source for cooling. There is difference in air temperature between city area and area around the river, proportionate to the share of water around the city. Wind and building density also influenced air temperature.
5	(Coutts *et al.*, 2013)	Proposal of water sensitive urban design			Green infrastructure has cooling potential, to implement water based urban design in dense urban environment without vegetation.
6	(Völker and Kistemann, 2011)	Metanalysis of systematic review			Blue space has emotional benefit, recreation and health benefits.
7	(Hathway and Sharples, 2012)	Sheffield, UK,	Field survey with instruments and monitoring of microclimate variables.		Cooling effect of river by 1^{o} Celsius to 2^{o} Celsius till June, in June the cooling effect is low.
8	(Manteghi, Bin Limit and Remaz, 2015)	Review paper			Size and distance of water bodies is essential. if water is warmer in hot seasons, then it may work adversely in night time thermal comfort conditions.
9	(Theeuwes, Solcerová and Steeneveld, 2013)		Surface temperature of lake and surrounding region and its impact on thermal comfort	WRF, Water fraction	The effect of lake weakens at night. If air temperature is higher than water temperature, then the lake has a cooling effect. If air temperature is lower than water temperature, then lake has a warming effect. Larger water body size has stronger effect of cooling. Smaller water body size but in large numbers cool greater area in the city.

10	(Emmanuel and Johansson, 2006)	Colombo, Sri Lanka	Classified sites based on h/w, distance from sea and ground cover.		h/w, directing sea breeze into the city and horizontal shading is an important component in lowering air temperature
11	(Jiang and Tian, 2010)		Effect of vegetation on surface temperature	Temperature-Vegetation Index, NDVI, vegetation fraction, LST, LULC	Negative correlation between LST and NDVI, vegetation has cooling effect
12	(Cheung and Jim, 2019b)	Hongkong	Lowering air temperature	Fish eye lens, Rayman, Pearson's correlation coefficients, ratios of surface cover to zone of buffer	Sea,Road, SVF has positive association with air temperature.
13	(Tong *et al.*, 2017)	Northern China	Impact of tree on ambient air temperature	Field instrumentation and survey, TSV, ASHRAE	Shade from buildings and evapotranspiration from trees help in cooling. Trees obstruct wind but introduction of water spaces help in increasing RH in summer.
14	(Banerjee and Chattopadhyay, 2020)	meta-analytical review			Insufficient literature on human biometeorology low income or informal settlements in tropical hot humid regions.

Table 2.10 showing studies on natural surface and outdoor thermal conditions.

2.4 STUDIES ON THERMAL LOAD AND DYNAMIC POTENTIAL

Urban microclimate has been studied through real time data collection, data analysis and representation and recommendation for adaptation through land use changes and behavioural acclimatization. This knowledge of climate conditions needs to be comprehensive so that the gap [1]with interdisciplinary fields such as for urban planning and policy can be easily bridged (Alcoforado et al., 2009; Eliasson, 2000; de Schiller and Evans, 1991).

In order to be able to do so, urban climate maps have been developed as an evaluation tool that bring together climatic information and urban planning process in two-dimensional platform (VDI, 1997; Baumüller et al., 1992; Scherer et al., 1999). The urban climate has two parts: the **Climate Analysis Map** (UC-AnMap or 'synthetic climate function map') and **Climate Recommendation Map** (UC-ReMap). In late 1970's urban climate recommendation map was first started by German researchers 9Matzarakis,2005). The analytical map consists of data on physical geography of the space, climate information in form of climatopes. UC- ReMap consists on recommendations from planning perspective keeping in mind the climate knowledge. The climatopes are defined using climate information (layer 1 including data on climatic parameters such as air temperature, humidity, wind direction and velocity, precipitation and air pollution and air quality) , Physical geography (layer 2 using topography, slope, DEM models, soil) and land use (layer 3 using building density, greenery). The UC AnMap focus on the aspects of the site that may either have ventilation potential or have potential to cause heat trapping. With this input information required, sections of land can be classified based on urban climate conditions which is a product of the urban land use of the area or the surrounding area. These categories are called climatopes (VDI, 1997; Baumüller et al., 1992)[2].

Urban Climate AnMap of Hong Kong has eight climatopes classes based on distribution of PET. The draft Urban Climate map of Hong Kong included the thermal load map and the dynamic potential map without wind information and it was collated with thermal comfort conditions measured with the help of the Physiological Equivalent Temperature (PET) index for outdoor comfort conditions (Hoppe, 1993, 1999). The layers for the UC AnMap and the urban climate classes are given in Table 1 and Table 2 respectively (Feasibility Study FINAL REPORT School of Architecture, Planning Department: Urban Climatic Map and Standards for Wind Environment – CUHK Page 91 of 518).

[1] A Review of the historical development of urban climatic map study by Chao Ren (Ng and Ren, 2015)

[2] A Review of the historical development of urban climatic map study by Chao Ren (Ng and Ren, 2015)

Layer	Data	Basis for study	EFFECT ON THERMAL CONDITIONS	Tool
1	Building volume	Building density	Negative	THERMAL MAP
2	topography	Altitude	Positive	
3	Greenery	Bioclimate	Positive	
4	Ground coverage	Urban permeability	Negative	DYNAMIC POTENTIAL MAP
5	Natural landscape	Bioclimate	Positive	
6	Proximity to openness	Exchange of air mass	Positive	
7	Summer wind direction	Source of air flow through simulation	NA	WIND INFORMATION
8	Annual wind direction			

Table 2.11 Showing layers of the Urban climate map of Hong Kong source(Ng *et al.*, 2008)

Urban climate class	Thermal comfort	Urban climate zone	Action plan
Moderate Negative TL Good DP	Moderate	Climatically valuable	Preserve
Negative TL Good DP	Slightly neutral		
Low TL Good DP	Neutral	Climatically sensitive	Preserve and enhance
Some TL Some DP	Slightly moderate		
Moderate TL Some DP	Moderate to strong	Moderately sensitive	Action encouraged
Moderately High TL Low DP	Moderately strong	Highly sensitive	Action recommended
High TL Low DP	Strong		
Very high TL Low DP	Very strong	Very highly sensitive	Action necessary

Table 2.12 Description of the urban climate classes of HongKong Source(Ng *et al.*, 2008)

- Building Volume will reflect the elevated surface and air temperatures of urban areas both for trapped shortwave radiation and nightly released longwave radiation.
- Elevation -topographical height
- Green Space,
- Ground Coverage shows the amount of land occupied with buildings and affects the wind flow. High ground coverage with buildings will lower the Dynamic Potential.
- Natural Landscape includes Natural vegetation
- Proximity to Openness includes
  - Proximity to Water bodies which is a source of Land and sea breeze
  - Proximity to Open Space
  - Slope

In Bilbao, Spain thermal load use land-use data such as extent of urban development. Dynamic potential use ventilation characteristics to account for air exchange capacity and the removal of urban heat. The data required land-use, surface covered, location, height of buildings, urban vegetation, air circulation patterns and topography from DEM. The five layers for thermal load used were, building volume, building surface fraction, green areas, ventilation paths and slope of land.

In Arnhem, Holland, building volume and land use taken together to form an urban morphology which was classed based on percentage of building occupy to total floor area.In Arnhem, residential areas and traffic areas were seen as low ventilation zones with low dynamic potential and medium thermal load, commercial areas as low dynamic potential and high thermal load.[3]

In Freiburg, Germany, thermal maps include study of weather elements and ventilation potential analysis includes study of cool air flow direction. These primary maps along with bioclimate models and PET analysis helps to identify planning advice maps(Ng and Ren, 2015)[4].

[3] Urban climatic map studies in Arnhem, Holland Chao Ren, Tejo Spit, Lutz Katzschner and Anita Kokx

[4] Urban Climatic Map Studies In Freiburg, Andreas Matzarakis, Rainer Röckle, Helmut Mayer

In Kaohsiung, Taiwan, there are five layers for the thermal environment map. The layers are topography, population density, land use showing built surface area, intensity of UHI, and natural landscape. The wind environment includes water bodies, prevailing and local wind circulation. Based on the two environments, there are recommendations such as improve existing condition, mitigate existing condition, maintain or preserve exiting condition, strong recommendation for improving or maintaining existing conditions. The recommendation for improving or preservation greenery, shading, albedo, release of heat, air circulation and air pollution of the 11 districts. Areas with high thermal load and low dynamic potential were found to have high amount anthropogenic heat generation and release but with limited air circulation. These areas are suggested to have increased greenery. areas with medium thermal stress but high dynamic potential, greenery is suggested including restructuring of industrial activities to reduce air pollution. Areas with low thermal stress and high dynamic potential, the areas need to be preserved to encourage air exchange with surrounding areas.(Ren *et al.*, 2013). Finally, the study concludes with

- Consideration for waterfront, greenery and ventilation characteristics in urban climate-based planning.
- Bulk building position and size should be avoided or controlled along river fronts as this area is source of cool air and requires preservation to encourage the air circulation and exchange to combat the thermal environment.
- Green belts and urban green network linking parks and open spaces
- Buildings at pedestrian level should be permeable and permissive to wind flow.

In Greater Manchester, climatic events posing as hazards are mapped in hazard map. Exposure to air pollution or heat, flooding is represented in exposure map and vulnerability map. In heat exposure map, the layer used is summer temperature, surface cover, building density, building height and anthropogenic heat release(Ng and Ren, 2015)[5] . In Hong Kong, building volume should have site plot ratio of 5 or less than 5. Building permeability should involve 25% or 33% of the frontal elevation. Higher ground coverage at building site of more than70% should be mitigated. Large tree canopy with more than 6 leaf area index is recommended for shading. 20% to 30% tree vegetation near ground level and mixture of building heights is also suggested (Ng, E., Yau, R., Wong, Ks. Ren, C. and Katszchener, 2012).At micro scale climate

[5] Urban Climatic Map Studies in Greater Manchester, UK. Claire Smith, Gina Cavan and Sarah Lindley

intervention, surface material and building material and water retentive material will help control albedo, green corridors or green spaces will help enhance urban vegetation, and street orientation, building height, trees along roads will encourage shading.

2.5 STUDIES ON OUTDOOR THERMAL COMFORT INDICES

A single environmental parameter cannot account for conditions for thermal comfort. (Lin, 2011) Outdoor environment has more variation than the indoor environment. PET or Physiologically Equivalent Temperature is defined as 'the air temperature at which in a typical indoor setting, the heat balance of a human body is maintained with core and skin temperature equal to those under the conditions being assessed'(Hoppe,1999). In other words, it is the air temperature of a typical indoor room generating the same core and skin temperature as the actual complex outdoor conditions. (Lai, et al., 2014)

While Haldane was the first to introduce the use of wet bulb temperature in heat stress index in 1905, the parameters have widened to incorporate the combined effect of several factors. At the same time, a universal index cannot be applied to all regions due to the complex interactions of the different environmental and other factors, the intensity of which vary from place to place. (Epstein & Moran, Thermal Comfort and Heat Stress Indices, 2006) the predicted mean vote is one such index developed by Fanger (1972), and remained an important index in human biometeorology through the 1980's. It is based on the parameters of MEMI model and ASHRAE scale of thermal comfort. (Mayer & Hoppe, 1987). Physiologically Equivalent Temperature (PET) developed by Meyer and Hoppe(1987) is similar to Effective Temperature(ET) developed by Gagge(1980) except the conditions for standard room stated by Gagge differs from PET and the energy model used for PET is MEMI. (Mayer & Hoppe, 1987)

Physiologically Equivalent Temperature (PET) is more universally accepted to study outdoor thermal comfort conditions and is based on the MEMI model. PET can be calculated using the MEMI model which assumes Air Temperature ($Ta_{)}$ = Mean Radiant Temperature (Tmrt) for indoor thermal conditions. The Mean Radiant Temperature (Tmrt) becomes important in PET calculation during days with low wind velocity. (Matzarakis & Amelung, n.d.). Globe temperature (Tg) represents the **weighted average** between radiant energy and ambient convective energy and when T_g is in equilibrium, it represents the equilibrium between the two energy flows. (Thorsson, et al., 2007) (Tan, et al., 2013) (Johansson, et al., 2014)

Conventional globe thermometer consists of a thermometer with its thermal sensor at the centre of a black hollow sphere. Most commonly a copper globe, with 6-inch diameter, is used though it responds to the conditions of non-sweating environments. Kuehn, Stubbs and Weaver recommend choosing the emissivity value before selecting the diameter of the globe. There exists an inverse relation between emissivity and diameter of the globe where emissivity of 0.95 should need a black globe diameter of 6 inches (Kuehn, et al., 1970) . A smaller globe of 40 mm is suggested instead avoiding the inconvenience of the 6-inch globe in indoor conditions. (Humhreys, 1977) Globe thermometer may not be as accurate as the study involving radiation flux; however, it is cost effective in outdoor conditions. Globe with diameter less than 50 mm, have a faster response time but gives greater scatter due to increased wind velocity and solar radiation. (Khrita, et al., 2017) In other words, with increasing wind velocity, a small globe (smaller than 15cm diameter) may show more sensitivity by rapidly cooling down and Tg value becomes an underestimated value. (M.Budd, 2008) In order to minimise this effect an average of 10 minute readings of Va and 5 minute average of readings of Ta and Tg were taken respectively (Johansson, et al., 2018). **Black globe thermometer of 40mm diameter (or lesser) is used in several studies**. (Johansson, et al., 2018) (Huang, et al., 2014) (Johansson, Thorsson, Emmanuel, & Kruger, 2014) Only a significant difference between the mean radiant temperature and air temperature will reflect a difference in reading between a large and small globe thermometer in indoor conditions (Humhreys, 1977). Instrument standards such as ISO7726(1998) and ASHRAE Handbook of Fundamentals (ASHRAE,2001) recommend a grey 40 mm globe instead of a black globe as it reflects the radiation of outer clothing conditions of a person. The ellipsoid shape is more desirable as it helps give a better estimation of the Tmrt of a standing person; spherical globe thermometers are more appropriate for mid to higher latitudes. (Olesen, et al., 1989)

The calculation of Tmrt is followed by the calculation of PET. Verein Deutscher Ingenieure (VDI) has given a guideline 3787, part 2 “Methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning, part I: climate” recommending the use of PET index in the study of thermal comfort conditions in different climates of the world (Spagnolo & de Dear, 2003). The standard ranges of the PET index help us to evaluate the outdoor thermal comfort conditions. The values of thermal stress are comparable to Predicted Mean Vote (PMV) ranges (VDI 1998) and are derived from the studies of Fanger (1972). The subjective feeling of stress or comfort can be studied with a questionnaire schedule that inquiries about the thermal state of a person. The standard questions describe the thermal state of a person such as thermal perception, thermal comfort, thermal preference and personal acceptability and personal tolerance given by ISO10551 (1995) for working environment and ASHRAE 55 (2010) for indoor environment. Each of the questions adhere to a scale: thermal perception offers a 7-point scale to the question 'How are you feeling now?' Similarly, thermal comfort offers a 4-point scale, thermal preference offers a 7-point scale, personal tolerance offers a 5-point scale and personal acceptability is a two-category statement (Johansson, et al., 2014).

The thermal stress for Very Cold perception is Extreme cold stress, thermal stress for Cold is Strong Cold Stress, for cool it is Moderate cold stress, for Slightly cool it is Slight cold stress, for Comfortable it is No thermal stress, for Slightly warm it is Slight heat stress, for Warm it is Moderate heat stress, for Hot it is Strong heat stress and for Very hot the thermal stress is Extreme heat stress (Matzarakis, et al., 1999) (Mayer & Matzarakis, 1997). Thermal stress is determined by the extent of thermal load and dynamic potential. Thermal load considers the causes for increasing air temperature that may create thermal stress. It includes the 'stored or emitted heat intensity' in areas abound in built surface and other man-made features. Dynamic potential refers to the factors which encourage wind flow patterns and wind exchange depending on the proximity to open areas, waterfront and greenery (Ng, 2015). Therefore, urban surface properties showing proximity to open spaces and water bodies create a dynamic potential for wind circulation while artificial built features add to thermal load and greenery provides a cooling condition to the city and also softens the harsh urban landscape (Wong, et al., 2015) (Binte Ali & Patnaikb, 2018) (Wong & Yu, 2005) (Xu, et al., 2019) (Völker & Kistemann, 2011) (Taha, et al., 1991) (Szucs, 2013) (Ward & Grimmond, 2017).PET can be calculated on Envimet software developed by Micheal Bruse; and RayMAN software developed by Dr. Andreas Matzarakis. In this study, PET and mPET have been calculated on RayMan after calculating the Tmrt. The simulations were performed on Envimet software.

Modified PET (mPET)

mPET is most appropriate for hot humid regions (Lin *et al.*, 2019). There are several review papers (Lin *et al.*, 2019) that have applied this index. Several parameters have been studied using this index (Binarti *et al.*, 2020) ; such as wind facing surface,(Hadianpour *et al.*, 2019), seasonal variation in thermal comfort conditions (Sahabi Abed and Matzarakis, 2017), urban green surface and vegetation cover (Meili *et al.*, 2021)and subjective assessment (Cheung and Jim, 2018).

Sr. No.	Parameters and Indices	Author	Study	Year	Discussion
1	PET, THI, WBGT	Chow, Ali Akbar, Henga, & Roth	measured and perceived microclimates within tropical urban forest	2016	understand the impact of landcover on microclimate condition.
2	PET	Makaremi, Jaffar, & Salleh	outdoor thermal comfort in hot and humid context	2012	Vegetation surfaces improve comfort conditions
3	Tmrt	Walikewitz, et.al.	difference between the Tmrt and Ta within indoor summer conditions.	2015	Mean radiant temperature is an important parameter for most indices.
4	PMV, PET, and UTCI	Lai, Guo, Hou, & Lin	Outdoor Thermal Comfort in Northern China	2014	to understand the neutral temperature and the adaptation to cold conditions.
5	PET	Grigorieva & Matzarakis	assessment of extreme climate regions at the Russian Far East	2010	analysing the extreme conditions of Russian Far-East and to provide sufficient bioclimatic information.
6	PET, SET, PMV	HONJO	Thermal Comfort in Outdoor Environment	2009	appropriate heat stress indices to measure outdoor thermal comfort
7	TSV & PET	Deb & Ramachandra	thermal comfort in a rail terminal location in India	2010	Neutral temperature of 31.93 degree Celsius
8	PET	BinteAli & Patnaik	Thermal comfort in urban open spaces: in tropical city of Bhopal, India	2018	To find the PET values for different urban spaces such as Parks, lakefront, Market
9	PET	Amirtham, Horrison, & Rajkumar	Impact Of Urban Morphology on Microclimatic Conditions India	2015	Comparison of PET values show that nights are more comfortable than day.

10	PET	D & Meenatchi Sundaram	Influence Of Street Geometry on Urban Microclimate	2014	PET difference between Traditional streets vs Modern streets Of Srirangam
11	PET	A, Devadas, & Monsingh	Assessment Of Thermal Comfort in Urban Street Canyons	2019	PET calculation for Commercial areas
20	PET	Lutz Katzschner, Sabrina Campe	Urban Climate Map Studies in Germany: Frankfurt	2015	Positive and negative hotspots of the region during day hours of summer due to vegetation and built surface.
21	PET	Bjorn Holmer, Fredrik Lindberg, Sofia Thorsson	Impact of urban geometry on Tmrt and PET in summer and winter Sweden: Gothenburg	2015	resulting analysis of thermal bioclimate
14	PET	Thorsson, Honjo, Lindberg, Eliasson, & Lim	Difference in PET with surface cover	2007	Difference in PET between park and built spaces
15	India Model for Adaptive Comfort (IMAC)	Manu, Shukla, Rawal, Thomas, & de Dear	Thermal Comfort Across Multiple Climate Zones: India Model For Adaptive Comfort (IMAC)	2016	neutral temperatures and limits of acceptable conditions in different levels of ventilation in the Indian context.
16	PET	Edward Ng	human feeling in a city from aspect of bioclimatology;	2015	preparing an urban climate map of Hong Kong.
17	PET	Lutz Katzschner, Sebastian Kupski	analyse people’s perception bioclimate of the region as a climate; Hesse	2015	understand the level of stress on people’s health and model.

18	PET	Telma Andrade, Jussana Nery, Terezza Moura, Lutz Katzschner	Urban Climate Map Studies in Brazil: Salvador	2015	PET values over 24^0 C with peak values of 46 ^{0} C from 10 am to 4 pm.
19	PET	Maria Joao Alcoforado, Antonio Saraiva Lopes, Henrique Andrade	Urban Climate Map Studies in Portugal: Lisbon	2015	Mapping thermal comfort with PET values from 18-22 ^oC being mostly comfortable and thermal insulation with the help of clothing adjustments.
12	Effective Comfortabil ity Ratio (ECR)	(Mohan, Gupta, & Bhati	Thermal Comfort Classification	2014	Effective uncomfortability is higher in Kolkata than Chennai, Delhi, Mumbai and Hyderabad
13	Thermohygr ometric index, Relative Strain Index and WBGT	Bhattacharya , Biswas, & Guha	Summer Thermal Stress Over Kolkata from 1995 To 2009	2010	Heat stress is less in April than the other months and heat stress is maximum in 2009

Table 2.13 Showing studies using PET index and other indices in recent studies on Outdoor thermal comfort conditions.

2.6 STUDIES ON NUMERICAL SIMULATION MODELS- ENVIMET & RAYMAN

Urban location	Authors	Purpose	Result
Lisbon	Maria João Alcoforado, António Saraiva Lopes and Henrique Andrade	Study **wind characteristics** in the area	Synthesizes the main airflows in Telheiras and clearly indicates the areas were circulation is disturbed.
Germany, Berlin	Jörn Welsch	Micro-scale analysis of **urban open spaces**	Developed rating scale filtered positive and negative hotspots
Taiwan	Man Sing Wong, Janet E. Nichol*, Pui Hang To, Jingzhi Wang	Investigates **urban ventilation pathways** using the frontal area index model over a densely built urban area	Maps of ventilation paths facilitate the visualization of wind ventilation and show the specific locations in the city
European cities	Sebastian Huttner1, Michael Bruse1, Paul Dostal1	The micro climate simulation ENVI-met can be used to estimate the **effect of changing climate conditions** on the human thermal comfort within cities	While moist natural soils lead to a cooling of air temperature, very dry natural soils can reach nearly the same temperature as asphalt or concrete.
to experimental data	Ferdinando Salataa, ∗, Iacopo Golasia,1, Roberto de Lieto Vollarob,1, Andrea de Lieto Vollaro	**Assessment of the input parameters** based on the equations solved by ENVI-met.	The latest version of the software was tested and, in the conclusions, a general procedure to perform simulations in ENVI-met is suggested.
Phoenix Local Climate Zones	Ariane Middel, ∗, Kathrin Häbb, Anthony J. Brazel, Chris A. Martin, Subhrajit Guhathakurta	Analyze the **daytime microclimate** of typical Phoenix neighborhood types—xeric, mesic and oasis—to evaluate their cooling and warming potential related to landscaping and the built environment	Cooling is not only a function of vegetation and surface materials, but also dependent on the form and spatial arrangement of urban features

Table 2.14 Showing literature review on studies using Envimet to calculate PET and run simulations

Location of study	Authors	Purpose	Result
Freiburg, Germany	Jan Herrmann Andreas Matzarakis	Modifications of Mean Radiant Temperature Due to Urban Structures	variation of mean radiant temperature over a range of more than 30°C, which can correspond to three levels of thermal stress
Athens, Greece	Ioannis Charalampopoulos Ioannis Tsiros Aikaterini Chronopoulou-Sereli Andreas Matzarakis	The present study deals with human thermal comfort, as it is quantified by two well-known human biometeorological indices, Physiologically Equivalent Temperature (PET) and Humidex.	The analysis among the six selected sites suggests that the value of PET shows a strong relation with T_{mrt} value during the study period.
Freiburg, Germany	Hyunjung Lee Helmut Mayer	This study analyses previous T_{mrt} validations in a comparative manner. Their results are extended by a recent validation of T_{mrt} in an urban micro-environment in Freiburg (southwest Germany)	
in Urban Parks in Warm Weather Conditions	Priscilla L. D. David, Arch Thyssie O. Rioli, Arch Bruna B. Prado, Arch João R. G. Faria, Phd Maria S. G. C. Fontes, Phd	this pilot study aimed to characterize the thermal perception of users and changes of the range of PET (Physiological Equivalent Temperature) for thermal neutrality according to the age of visitors to a park in the city of Bauru, State of Sao Paulo, Brazil.	the differences between those thermal comfort limits and of the adult/elderly group (25.1-30.0 °C) were higher. This result shows higher tolerant to heat for that age group.
Freiburg, Modelling radiation fluxes	Andreas Matzarakis Frank Rutz Helmut Mayer	This paper presents the physical basis of the RayMan model	A comparison between measured and simulated values for global radiation and mean radiant temperature shows that the simulated data closely resemble measured data
Japanese Urban Public Places	Tsuyoshi Honjo, Fredrik Lindberg, Ingegard Eliasson, Sofia Thorson	Subjective thermal comfort and outdoor activity in a park and a square in a satellite city northeast of Tokyo were investigated through structured interviews, observations, and comprehensive micrometeorological measurements	Results showed that the park was on an average 1.1°C cooler than the square. The relatively warmer thermal conditions in the square in comparison to the park

Table 2.15 Showing literature review on studies using Rayman to calculate PET &mPET

2.7 STUDIES ON THERMAL PERCEPTION

Thermal perception study involves the study on thermal sensation, thermal acceptance, thermal tolerance, thermal satisfaction and thermal comfort [ASHRAE 55 (2010), ISO 10551 (1995)]

Thermal Sensation Vote (TSV) can be estimated using ASHRAE 7-point scale. The neutral PET for hot and cold season and PET was calculated to understand outdoor thermal comfort(Salata *et al.*, 2016). Refer Table 5.2 in Chapter 5.

Seasonal and regional differences create different outdoor neutral temperature(Liu, Zhang and Deng, 2016). A study in Shanghai shows that in winter months, TSV shows most strong positive relation with air temperature and solar radiation in winter during which neutral PET is calculated and thermal adaptation is reflected in duration of stay and residence (Chen *et al.*, 2015).

Thermal sensation is also related to urban geometry and SVF, high density buildings which may have moderate stress conditions, may create warm sensation but in open spaces where the heat stress is strong due to strong radiation may create warmer sensation (Chen *et al.*, 2015). A study in Guangzhou area showed that 90% acceptable thermal temperature limit is significantly higher than western/middle European limits' and a new thermal comfort index was constructed for the Guangzhou area(Zhao *et al.*, 2016).

Sudden change in temperature from air conditioned indoor to warm outdoor, may not only experience discomfort but may also have impact on human health (Zhao *et al.*, 2016). A study in Hongkong show examine the subjective perception under microclimate conditions of the eight LCZs in Hong Kong. High rise is associated with warm thermal sensation, mid-rise has inadequate shade, cooling effect due to vegetation and proximity to waterbody hence thermal sensation is different in different urban environment especially in sub-tropical high density cities.'(Tan *et al.*, 2019b).

Field surveys for monitoring microclimatic parameter as well as questionnaire for subjective assessment of thermal comfort was conducted in a study in Dhaka, where the microclimate conditions under defined urban geometry correlates with TSV. The same study calculated the neutral temperature and stated that people will be comfortable in outdoor conditions with higher range of PET (Sharmin, Steemers and Humphreys, 2019b).

A study in Brazil, having tropical climate zone, showed that neutral and preferred temperature both needs to be calculated to understand the thermal preference. The study also provides details of calibration of PET , strategies such as shading and wind exposure and findings related to thermal adaptation such as “environmental diversity”, “perceived control”, “thermal history” and “naturalness” The study is conducted in contrasting urban form with different SVF, height of buildings and “surface type” and “flow of people” (Hirashima, Assis and Nikolopoulou, 2016).

Shade and ventilation is important in creating comfort perception (Johansson *et al.*, 2018). Thermal sensation may vary with SVF and shaded conditions. High SVF allow more direct sunlight and create a warmed sensation as against a high-density location where the shade or ventilation may create a cooling sensation. Hence, ‘an open air site may feel strenuous while constricted area may feel less comfortable’(Krüger, Drach and Broede, 2017).

Tree canopy or building may offer shade or may limit the windspeed, both factors being important in tropical comfort conditions. Shading/exposure is more important than evapo-transpiration from urban greenery or water sources. In areas where evapotranspiration is important, humidity along with horizontal wins help in creating a cooling effect. however, in Low latitudes, high humidity and low windspeed do not make evapotranspiration an important influence on outdoor thermal comfort. In areas, where a water body may allow windspeed and evapotranspiration, in such cases, the exposure to sunlight may override the cooling effect by evapo-transpiration. So even though according to the Thermal index, sensation may show to be hot but in subjective perception of thermal comfort/ discomfort conditions may be acceptable and overall comfort conditions. this can be attributed to acclimatisation (Chow *et al.*, 2016).

Non meteorological factors like ‘adaptation, thermal comfort vote, thermal preference, gender, season and time of day’ is important. Neutral temperature, acceptable comfort range is calculated using thermal perception study and air conditioning improves comfort for conditions above the neutral temperature (Middel *et al.*, 2016). Thermal adaptation such as adjustment to clothing , time of activity and space of activity may improve comfort conditions and increase use of outdoor spaces (Middel *et al.*, 2016). Thermal factors along with Thermal adaptation play important role in assessing thermal comfort (Shooshtarian and Ridley, 2017). The physical environment and the psychological adaptation (naturalness, perceived control expectations, thermal history or experience, duration of exposure, and environmental stimulation) is said to be helpful (Nikolopoulou and Steemers, 2003).

Sr. No.	Author and year	Type of climate	City	Study	Methodology	Results
1	(Tsoka, Tsikaloudaki and Theodosiou, 2017)	Mediterranean	Thessaloniki, Greece	ENVI-met v.4		Higher surface reflectance material will reduce surface temperature but will increase Tmrt. Use of tree canopy will lead to reduced air temperature due to shade as well as lower Tmrt.
2	(Ewing and Handy, 2009)	Hot desert	Tempe, Arizona	human-biometeorological instrument platform MaRTy		Shade is important in creating thermal comfort, MCZ within LCZ suggested at 1-10m^2 range
3	(Shimazaki *et al.*, 2022)	Hot and Humid	Hong Kong	ENVImet		Grey areas of concrete generate thermally uncomfortable environment while green and blue areas have heat mitigation potential.
4	(Yang, Liu and Qian, 2020a) (Li and Ghosh, 2018)		USA	number of green pixels in google street vie images	Green View Index	Green view index has association with bmi among females.
5	(Luan *et al.*, 2019)	31 capital cities in China		REVIEW		Ambient air temperature has role in mortality
6	(Jin, Liu and Kang, 2019)(Wang, Berardi and Akbari, 2016)	Harbin, northeast China		MTSV	UTCI	Preferred, comfortable and neutral UTCI. People feel comfortable in warmer conditions of urban street during hot season.

7	(Sharmin and Steemers, 2020)	Hot and Humid	Dhaka, Bangladesh	TSV, Questionnaire	one-way ANOVA Kruskal-Wallis and Mann-Whitney test	People's neutral comfort range is found to be 30.6 °C ± 1.26. higher TSV higher TA, TG and Tmrt have association with higher TSV; low VA, RH have association with lower TSV
8	(Ma *et al.*, 2020)		China	ASHRAE Standard 55-2017	PPD, sensors	predicted percentage of dissatisfied data collection, processing.
9	(Galindo and Hermida, 2018)	highland subtropical climate	Ecuador	TSV, RAYMAN 1.2	mPET, Socio-Ecological Model	22.11–33.22 °C is the male Neutral temperature range, general acceptable range of temperature = 24.05–39.73 °C
10	(Shishegar, 2013)			Urban canyons	aspect ratio	Wider aspect ratio allows greater ventilation circulation
11	(Doick, Peace and Hutchings, 2014)	Cold-wer	London, England	Surface temperature, globe temperature	Data loggers	Cooling effect during low wind conditions are highest in small green and woody spaces instead of large open green spaces.
12	(Wong *et al.*, 2010)	Hot and Humid	Hong Kong	Least cost path analysis	GIS	Orientation and location of buildings can be reorganized in renewal of urban areas by identifying the blocks that obstruct wind ventilation. Ventilation path studies for human comfort instead of UHI analysis needs to be done at ground level not at boundary layer level. Winds passing over green spaces have greater cooling potential.

13	(Ma *et al.*, 2019)		Guang Dong province, China	PET	ENVI-met	Grass cover can reduce albedo and help in thermal comfort, increased building height may provide bigger shade and allow thermal comfort.
14	(Balslev, Potchter and Matzarakis, 2015)	subtropical climate	Tel-Aviv, Israel	PET	RAYMAN	Geddes' plan is perfect for the city "Climatic suitability of the urban structure to the various seasons, sustainability of climatic urban planning over time deter- mination of which factor (wind or shade) has a stronger influence on human thermal sensation"
15	(Wai, Xiao and Tan, 2021)	Hot and Humid	Hong Kong	PET	ENVI-met	Water spraying reduces ambient temperature Buildings oriented not parallel to wind direction reduce comfort conditions
16	(Yang, Liu and Qian, 2020b)	Model		CFD		Airflow in residential areas decreases due to blockages to ventilation. Air temperature among residential buildings is higher than around it. Windspeed over water surface is higher due to the temperature slope from water to surrounding built areas. Closer the water surface, greater is the effect of temperature lowering.
17	(Rebecchi *et al.*, 2019)	model		Milano Walkability Measurement		Making cities walkable is linked to street level comfort, safety, usefulness and design. Comfort includes lane width, street furniture and availability of trees.
18	(Priya and Senthil, 2021)	Review paper				Urban greenery like turfs, shrubs, trees, urban roofing will reduce air temperature.

Table 2.16 Literature study on Subjective Assessment in respect to Outdoor thermal comfort.

2.8 ADAPTIVE APPROACHES IN THERMAL COMFORT STUDIES

Urban agriculture or agroforestry is an important recommendation in reducing transport emissions associated with food supply to urban areas. It may also improve food security, economic development, improve urban microclimate, water management and soil conservation. It may also lead to over extraction of water or overuse of fertilizers as well as farming of crops that are not consumed by the farm households. Afforestation in 'climate smart forestry' and other forest-based solutions have strong evidence with 'medium agreement' to help adapt to climate change and improved management and regulation of microclimate. However, afforestation with non-native species may affect non-forest-based ecosystems like grasslands, shrubs, waterbodies. There is also debate about the extent of carbon sequestration rates between native forests versus new tree plantations.

One of the most important recommendations for combating local climate conditions is Urban and peri-urban adaptation to local climate conditions can include green parks, cooling pavement, green roofs and urban farming with richness of species. Urban forestry, urban wetlands and urban grassland are the three suggested measures of adaptation in urban and peri-urban areas. Urban forestry will help in improving air quality, heat mitigation and storm water absorption. Urban wetlands will help in heat mitigation, protection from coastal flooding and storm water absorption. Urban grassland will help in heat mitigation, storm water absorption and leisure. Trees have a cooling effect and not only for land but also around water bodies as riparian vegetation that will shade the fisheries. ecosystem-based adaptation or nature-based solutions include green and blue cover for urban and peri-urban areas.

Warm air has the capacity of holding more water and can cause higher rainfall. Therefore, restoring catchment areas, wetlands, lakes and ponds can help in management of storm water. There is strong evidence and strong agreement that both wetlands and green cover will help micromanage heat waves, increased rainfall and high temperature. At the same time, it will help to create a cooler microclimate and help manage excess storm water. (Chu *et al.*, no date; Lempert *et al.*, no date).

The different forms of adaptation also come with the problem of adaptation gaps and adaptation deficits. Adaptation gaps are the difference between societal goals and implemented policies or habits of adaptation, determined by preference for tolerated climate change, different competing priorities and resource limitations. Adaptation deficit is the insufficient adaptation to present conditions (UNEP2014, UNEP 2018). However, a maladaptation will be lowering of resilience of the green cover by the domination of a single exotic species in case of urban forests. Another challenge to urban green space will be the overuse of fertilizers and pesticides and over irrigation of species that may be non-resilient to drought conditions especially for urban grasslands.

2.9 SPATIAL PLANNING MEASURES IN URBAN PLANNING

Spatial planning measures in urban design include walkable pathways and residential sectors that will allow less emissions. Urban greenery (e.g green roofs, cool roofs, pervious surface material, rainwater harvesting, stormwater retention and tree afforestation), improved and local building materials and energy efficient building design. The intention is to combat a number of urban issues such as reduced air and noise pollution, storm water management, reduction in energy use, urban heat island effect, natura indoor lighting, improved air quality, increased physical activity and improved mental health. Spatial planning along with behavioural adaptation can include urban agriculture with rooftop gardening, community gardens in urban and peri-urban areas , organically procured farm products, rainwater harvesting, reduction in water wastage and water conservation policies (Reynaud, Aubert and Nguyen, 2013). Landuse changes using satellite data, ground installation of instruments for data collection on microclimate with portable sensors, modelling techniques using software and urban climate maps including ventilation maps, local climate zones, future LULC maps, can be used for risk assessment as well as for planning implementation. There is an inherent risk of heat waves in South Asia, (urban and non-urban sector) where the major constrains of adaptation are Economic constrains, Governance constraints, financial constraints and Informational constraints. Blue green infrastructure in urban areas are one of the recommendations of Climate related development pathways that also have positive implications on Sustainable Development Goals(Estoque et al., 2019; Mabon et al., 2019; Radhakrishnan et al., 2019)[6].

2.10 INFERENCE

Bibliometric analysis of Literature content has helped in the review of literature for different studies of Outdoor Thermal Comfort around the globe.

The level of Outdoor Thermal comfort is a reflection of the growing outdoor thermal stress conditions. Analysis of climate information involves identifying the thermal load and dynamic

[6] Sustainable Development Goals 3, 9, 11

potential of landcover. Such zones of thermal load and dynamic potential together with wind path and wind pattern will help identify climate zones. The defined zones of thermal comfort can be included in recommendation map with plans of preservation or restoration.

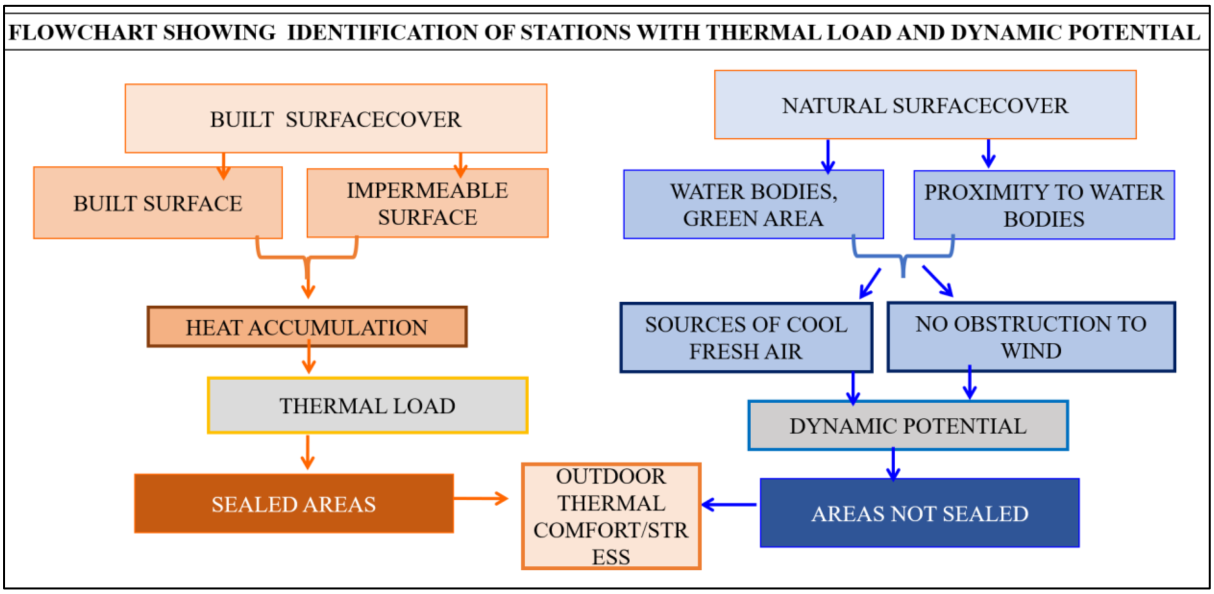


Figure 2.6 showing inference from literature review for identification of thermal load and dynamic potential

While natural systems present hard limits, human organisations and activities pose soft limits. Incremental adaptation strategies try to preserve the essence of the system unlike in transformational adaptation where there a change made to the system. The IPCC, 6th Assessment report, 2022 states that human health is at risk due to rising heat conditions, low lying cities are at risk of flooding, growing number of urban centres are at risk of climate hazards.

With intervention and proper planning, the risk of extreme heat stress may be monitored, evaluated and mitigated using micro-meteorological calculations and human response system.

2.11 RESEARCH GAP

1. Insufficient studies showing significant change in thermal comfort perception seasonally
2. Insufficient studies showing significance of surface cover on outdoor thermal comfort with changing seasons
3. Insufficient studies showing conditions for comfort based on comfort location and neutral temperature
4. Insufficient studies showing most relevant factors for classification of comfortable location with use of Principal Component Analysis.
5. Use of Plan Area Fraction to describe study area for analysis of outdoor thermal comfort studies
6. Planning at grassroot level with the involvement of people in climate-inclusive planning involves subjective assessment at microclimate scale. However, literature on inclusion of such assessment in urban planning is not found.
7. In SWOT analysis of City Development Plans in India, there is no mention of comfort and stress conditions of the city.

CHAPTER3: AIM & OBJECTIVES

The Research Gap has been discussed in Chapter 2. Based on the Research Gap, the research questions were constructed. Thereafter, Aim, Objectives, Research Hypothesis and research design is stated.

3.1 RESEARCH QUESTIONS

- Is Kolkata Comfortable?
- How does Outdoor Thermal Comfort change over space and seasons?
- What are the causes for variations in Thermal Comfort?
- How can people participate in Climate-Inclusive Urban Planning process?

3.2 AIM

To analyse and understand outdoor thermal comfort in different urban surface covers and microclimatic conditions

3.3 OBJECTIVES

i. To Study the influence of different surface covers such as water body, green area and open area on outdoor thermal comfort.

ii. To Classify comfort locations of city based on microclimatic and thermal perception study.

iii. To Calculate the Neutral mPET and acceptable range of comfort conditions in Kolkata

iv. To Recommend the overall conditions of comfort for sustainable urban planning.

3.4 RESEARCH HYPOTHESIS

Natural Landscape with Water Bodies, Vegetation and Open areas have a positive influence on Outdoor Thermal Comfort.

3.5 SCOPE OF WORK

- Outdoor Thermal Comfort- Objective Assessment
- Importance of water bodies in outdoor thermal discomfort
- Importance of Vegetation surface cover on outdoor thermal comfort.
- Importance of Open surface cover on outdoor thermal comfort.

- Subjective assessment- Perception studies on outdoor thermal comfort.
- Role of Thermal Load and Dynamic Potential
- Application of Outdoor Thermal Comfort in future Climate-oriented City Development Plans

3.6 RESEARCH DESIGN

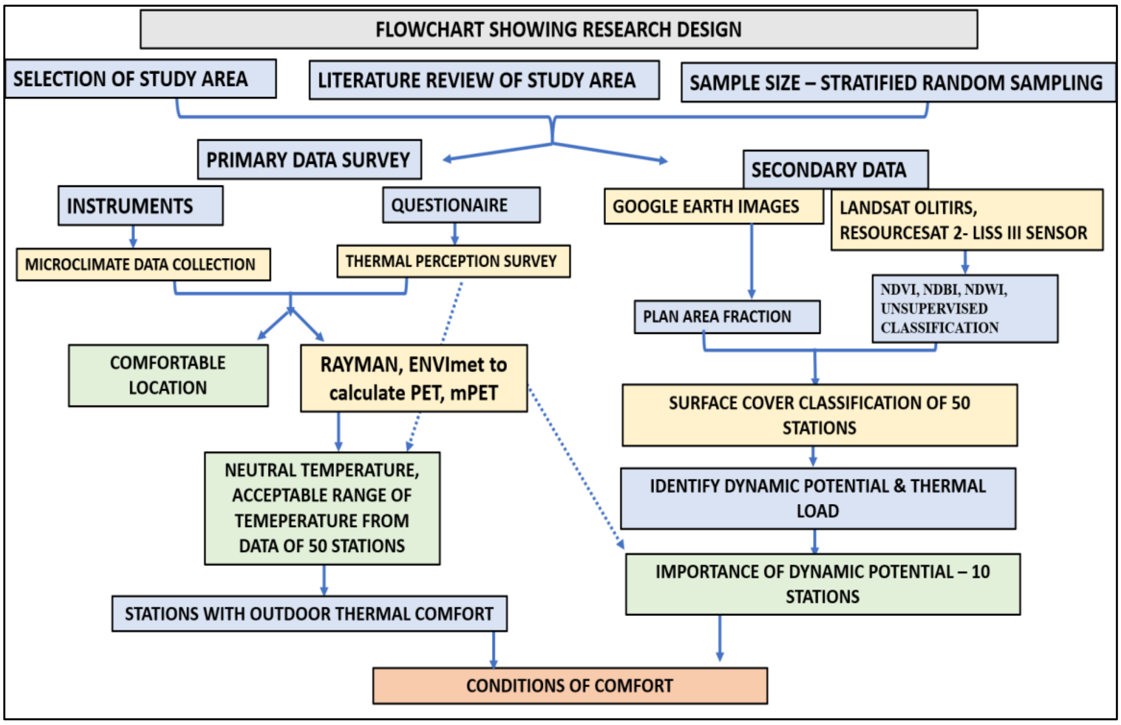


Figure 3.1 Flowchart showing Research Design

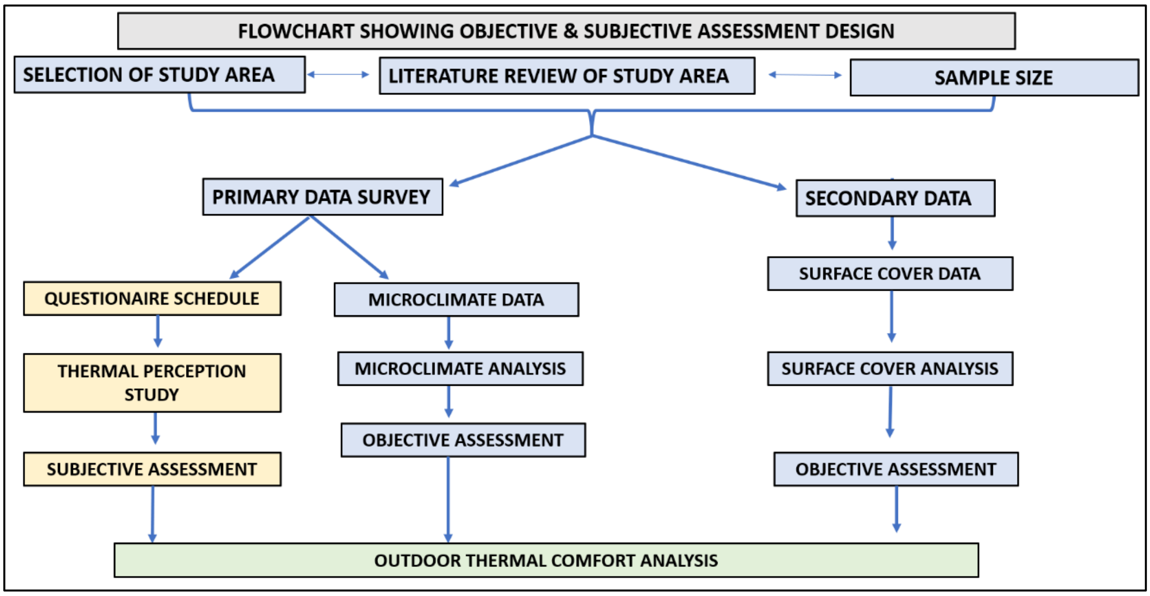


Figure 3.2 Flowchart showing Subjective and Objective Assessment Design

CHAPTER4: STUDY AREA

4.1 INTRODUCTION TO STUDY AREA

Kolkata has a rich history of more than 300 years. It served as the capital of India during the British Raj till 1911. Kolkata, capital of West Bengal state, was formerly known as Calcutta. Kolkata is located in eastern India at t 22° 33’ N88° 20’ E. the climate of Kolkata is tropical-wet-dry warm humid climate according to Köppen climate classification. With an area over 1800 square km, it has a population is near 15 million according to the 2001 census. Kolkata is the biggest urban core in Kolkata Municipal Area. as per 2011 census, the population of the state is 4.6 million people. It is an urbanised centre with a large commercial base and the population density 24, 760 persons per square kilometre as per Census, 2001. It is also a strong educational hub with three Central Business Districts- Dalhousie, Salt Lake and Rajarhat. However, the latter two are beyond the boundaries of the Kolkata Municipal Area since they are separate township and satellite town respectively.

The five administrative divisions of the city are the Kolkata CBD, Kolkata district, Kolkata Police Area, the Kolkata Municipal Corporation area and the Kolkata Metropolitan Area. the Kolkata police area is a service area that covered 105 square kilometre in 2011 and since then has been extended to the entire KMC area. The city of Kolkata is not an official term. This is because, a district may consist of several urban as well as rural areas. In the new plan of 2010, the House of Councillors in KMC, passed the delimitation plan in which ward 71 and 73 in borough 8 is included in borough 9 and instead the two wards will be replaced by ward 82 and ward 83. Ward 101 and 102 (borough 11) is included in borough 12 and these wards will be replaced by wards 103 and ward 104 of borough 12. The added area of Kolkata includes the southern, south-eastern and western fringes of the city. the east to west extent of the KMC area is from the river banks of river Hooghly to the Eastern Metropolitan Bypass (another name for Bongaon-Kulti Highway) (Banerji, 2020).But the district of Kolkata is the boundary of one of the largest urban areas of the country and the state. has grown organically from the banks of River Hooghly towards south, north, north-east and south-east. Kolkata Municipal Area is the largest agglomeration of eastern India and attracts workers, business, students and patients from the entire eastern flank of India. There is hardly any planned growth of the city and a diversified mix of commercial, residential zones in most areas. Informal settlements include linear settlements along railway tracks or along roadways as well as in areas of residential zones which offers employment to the people of informal settlement.

The Kolkata Municipal Corporation Area was once a wetland region with many swamps and marshy depressions that are the remnants of previous river channels. The height of the KMC area is between 1.5 to 9 m above mean sea level (msl) (SRTM data, NASA, 2000). It has the effect of the coast being located within 150 km of the city centre, the Bay of Bengal extends the high humidity and tropical depression up to the city region. With an annual mean temperature of 26-27 °C, the temperature range lies between 18 °C to 40 °C from summer to winter months. The monsoon season, from June to August or mid-September, brings most of the annual rainfall with the highest being 1600 mm.

There are nine drainage basins, with sewerage networks and pumping stations at terminal points. There is drainage of three basins into river Hooghly while remaining six drainage basins drain into Kulti drainage system. The Hooghly as eleven sluice gates and they prevent the high tide and tidal ingress during storms into the drainage of the city. (KMC, 2007). Kolkata Municipal area has a low relief and the proximity to the coast causes it to face many storms and tidal flooding. The main cause of flooding in Kolkata is due to heavy rainfall and lack of control of storm water drainage from sealed city areas where maintenance of water drainage is a challenge. Kolkata is not susceptible to flooding from storms but according to the IPCC 2022, 6th Assessment report, Kolkata is susceptible to flooding from sea level rise which is a direct consequence of global warming. People in the city have learnt to adapt to the annual flooding during monsoons. The 'adaptation deficit' is one of the main challenges during monsoon flooding whereby the sewerage system, the drainage system are insufficient to take the load of the population rise. Also, the institutional capacity has not evolved and not maintained adequately. Therefore, this adaptation deficit poses as a risk to the city in case of extreme flooding from climate change (Binarti et al., 2020).

According to the Koppen climate classification, Kolkata has a tropical wet and dry climate (Aw). On the banks of River Hooghly, Kolkata (22.34'N and 88.24'E) has elevation of 6m above msl. It a megacity with eastward southward expansion and a predominance of built surface. The Landcover of urban areas show which plays an important role in creating Urban Heat Islands (Oke). Open spaces, vegetation and waterbodies comprise of the natural surface, allowing cooling potential of the region. The number of open spaces and water bodies are on the decline as there is encroachment on wetlands and open spaces and continued urban expansion.

4.2 CLASSIFICATION OF STUDY AREA BASED ON SURFACE COVER

Unsupervised Classification showing Surface cover classification into categories of water bodies, vegetation, light vegetation, open areas, built surface and impermeable surface. SWIR with swath of 141 km and spatial resolution of 23.5 meter. The source of this data is IRS-Resourcesat-2. satellite with Linear Imaging and Self Scanning Sensor (LISS) sensor (Path 108 /Row 56) date of pass, 4th February 2019. Surface cover classification

Unsupervised classification was used to delineate landcover classes into built area, open space, water body and light vegetation using data from National Remote Sensing Centre, ISRO, Balanagar, Hyderabad. In this classification 39% of land surface is built surface cover followed by 21% of impermeable surfaces such as roads, streets, footpaths, road dividers; 19% is vegetation, 14% is light vegetation, 5% is water surface and 2% is open areas. Unsupervised classification was chosen over supervised classification because the source image has higher spatial resolution and lower spectral resolution compared to Landsat images with 11 spectral bands and 30m spectral resolution. So, the Beleghata canal could not be represented through repeated supervised classifications after Ortho correction and georectification. The Resourcesat LISS III image used is dated 4th February 2019, and unsupervised classification helped in showing larger number of water bodies.

Representation on map shows that along the north-south central axis, there is major share of built surface and impermeable surface with intermittent urban greenery including canopy along roads, along residential areas. A few among the 50 stations have been marked to show the extent of the spread of the stations. Light vegetation is found along the eastern margins, southern margins of the map as well as along the western green belt zone and Tollygunge golf turf zone. Water bodies are found intermittently along the storm water drainage canals, the Beleghata canal, the Rabindra Sarovar Lake in the middle of the KMC area, the western edges of the study area at the Hooghly estuary; the intermittent ponds and waterbodies in southern edges that lead to the south suburban region and the eastern marshes and swamps of the wetland regions of East Kolkata Wetland.

All maps in the following chapter have been made on Arc-GIS after ortho rectification and Georectification/ the maps are ma de using Spheroid Datum GCS, WGS-1984.

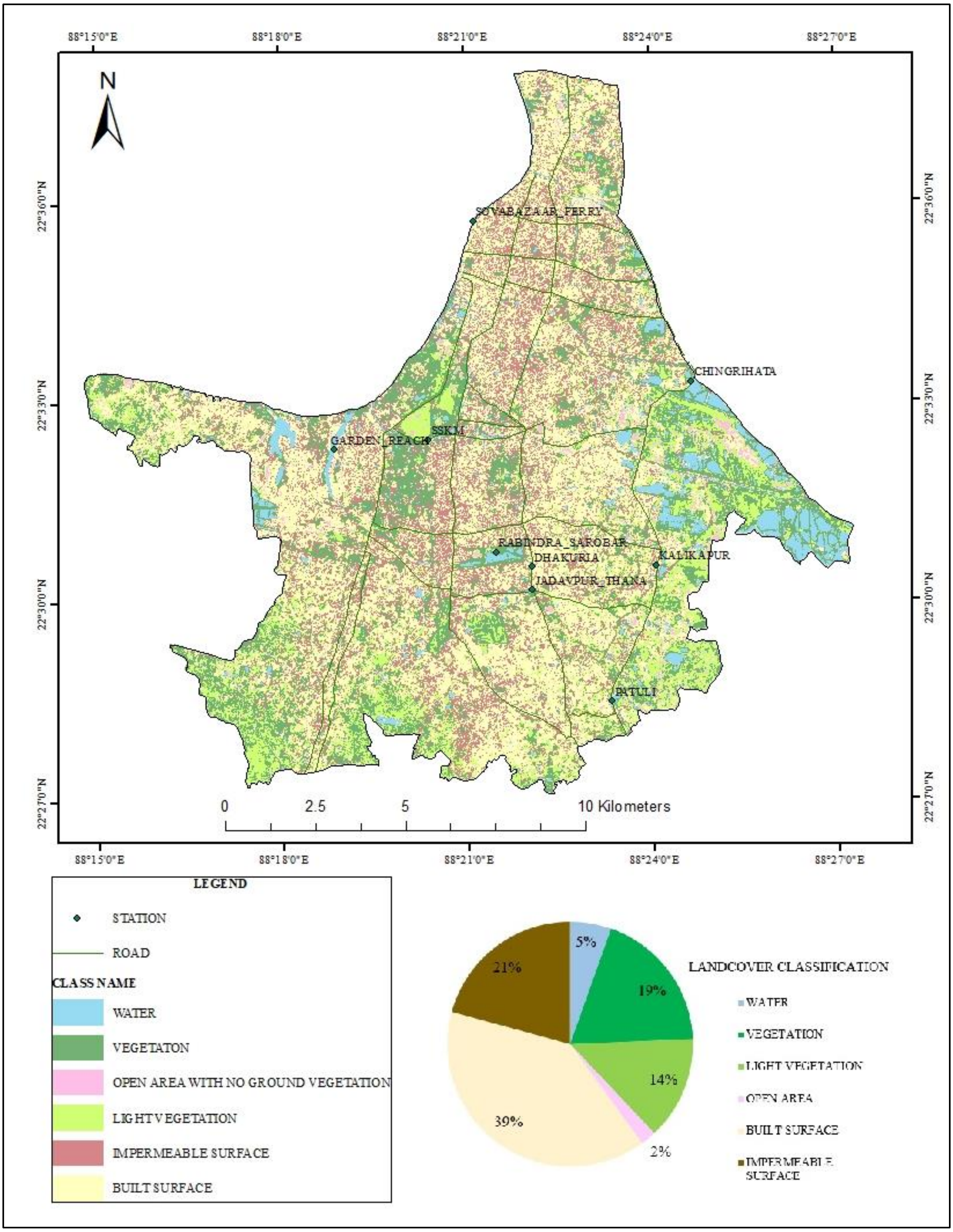


Figure 4.1 Unsupervised Classification showing Surface cover classification

Surface cover classification through Unsupervised Landcover classification show that water is 5%, vegetation 19%, Light vegetation 14%, Open surface -2%, Impermeable surface-21% and Built surface- 39%.

The centre of the study area shows most share of built and impermeable surface. Away from the centre region of the map, the amount of natural surface cover such as water bodies, vegetation and open areas increase. The E.M. Bypass, the easternmost arterial road shows the easternmost limit to most built surface. East of the highway, there is increased green and blue surface due to presence of larger extent of water bodies, vegetation and open areas. The quality of the vegetation cover, water bodies and built surface has been further seen through methods of band ratioing.

The accuracy details of the unsupervised classification are shown in Table 4.1. The overall accuracy is 84.74%. The producers and users' accuracy are provided for reference.

Class	Reference	Classified	Number	Producers	Users	Kappa Coefficient
Name	Totals	Totals	Correct	Accuracy	Accuracy	
	3	5	3	---	---	
UB_VEGETATION	93	80	73	78.49%	91.25%	90%
UB_WATERBODY	73	80	64	87.67%	80.00%	80%
UB_OPEN AREA	41	55	35	85.37%	63.64%	60%
UB_LIGHT VEGETATION	80	80	70	87.50%	87.50%	81%
IMPERMEABLE SURFACE	73	80	64	87.67%	80.00%	80%
BUILT SURFACE	90	80	77	85.56%	96.25%	92%
Overall Classification Accuracy = 84.74%						

Table 4.1 Showing accuracy result of unsupervised classification

The quality of surface is described using the mentioned band rationing methods already described in Materials and Methods. NDBI helps to understand the areas where water bodies are negative and predominantly built surface. NDVI show the vegetation areas and quality of its foliage. NDWI shows the quality of water in waterbodies. Figure 4b show that the study area is an urban area with dense built structure in most part of the study area. Where NDBI is low, marked by negative values in blue, the quality of vegetation is relatively high .. In NDWI, water surface is found only along the western flank along the estuary of River Hooghly and along the eastern flank where the East Kolkata Wetland marshes, fisheries and swamps and storm water drainage canals are found. . The Rabindra Sarovar area also shows high quality of water surface in the middle of the city.

From the above band ratioing, it is observed that the stations within the study area have high built surface in the core of the city. The map shows that vegetation is found along the eastern and southern part of the city. High quality vegetation is also seen in the golf turf of Tollygunge and in the Green Belt of Kolkata. Some water bodies covered in water hyacinth reflects as green surface. Water is found only along East Kolkata Wetlands, in Rabindra Sarovar and along the river Hooghly estuary.

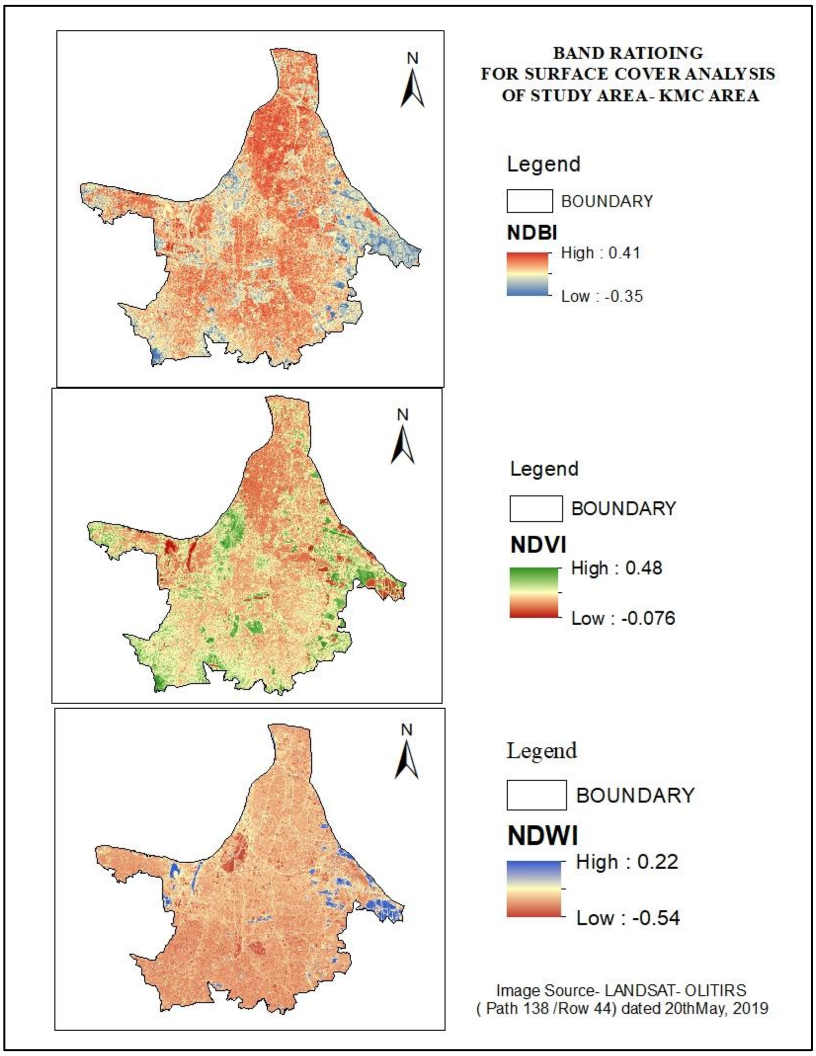


Figure 4.2 Showing NDBI, NDVI and NDWI for May, 2019

4.3 METHODOLOGY & JUSTIFICATION FOR SELECTION OF STATIONS

The following study aims to analyse the role of surface on outdoor thermal comfort condition. The built surface includes the impermeable surface comprise of 60% of landcover as found in landcover classification. The remaining 40 percent is divided between vegetation (trees), light vegetation (ground vegetation), open areas (without vegetation) and water surface. 50 stations have been considered at intersections of major east-west and north-south arterial roads. Kolkata The north-south arterial roads were selected since they serve as pathways for southerly wind ventilation.

Kolkata in South Bengal receives southerly and south-westerly winds in summer and north-easterly wind in winter, after retreat of south-west monsoons. as shown in Figure 4a. the Hence, the north-south arterial roads were selected as ventilation pathways and the cross sections of the roads with east-west arterial roads gives junctions or cross roads which are mostly the centre points for data collection. For some stations, the data points were taken close to natural surface cover to study the impact of natural surface. Few stations such as Dhapa, Bantola, Garden Reach are located on the eastern and western extreme ends of the east-west arterial limit in order to include the share of natural surface which is otherwise mostly absent in the city centre. This is because along the north-south arterial roadways mostly have high built and impermeable surface share.

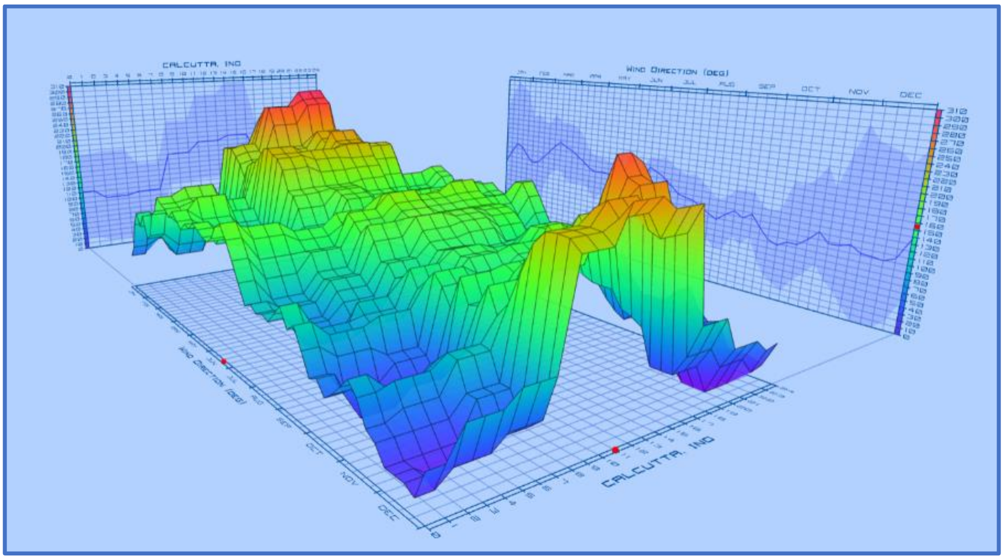


Figure 4.3 Showing Wind direction in Kolkata- Source-https://drajmarsh.bitbucket.io/weather-data.

The locations have different surface cover according to the Plan Area Fraction (PAF). In literature review, studies have considered areas with high built and impermeable surface to be contributors to heat accumulation and are termed as Thermal Load (TL). The areas that have high natural surface, lead to higher contribution to thermal comfort for being sources of cool, fresh air as found in the literature review. Areas, that have access to water bodies, open areas or vegetation cover have been sources of cool fresh air and are termed as Dynamic Potential (DP).

- 50 stations have been selected for collection of data over four seasons in 2019. the 50 stations are chosen based on two categories:

Category 1)- 25 stations in (>75% Built surface and Impermeable Surface) and Built surface includes all urban form and construction of buildings while impermeable surface refers to roads, lanes, by-lanes, footpath and road dividers. They may have some share of natural surface.

Category 2) - 25 stations in (<75% Built surface and Impermeable Surface). These stations will have certain share of built surface and impermeable surface. But they will also have a certain share of natural surface like water bodies, open areas and vegetation cover. In this category as built share will continue to fall below 50%, the share in natural surface will increase accordingly. The share in natural surface in combination with water bodies, open areas and vegetation cover, help us to understand that in a megalopolis urban area like Kolkata, stations with higher built share will be larger in number and there will be different stations with different share in built surface, but whether the presence of natural surface makes a difference in Outdoor thermal comfort is in the scope of this study.

- Selection of 10 stations for surface cover and microclimate analysis.

These 50 stations were then divided on basis of share of built surface and impermeable surface. The share of impermeable and built surface is varying for the 10 stations selected. Some have high share of built and impermeable surface and some have higher share of natural surface. The nature of the stations has been shown in the map below. In the subsequent topics, the stations have been described in detail and categorised based on the method of Plan Area Fraction. Plan Area Fraction is explained in detail in the following topic.

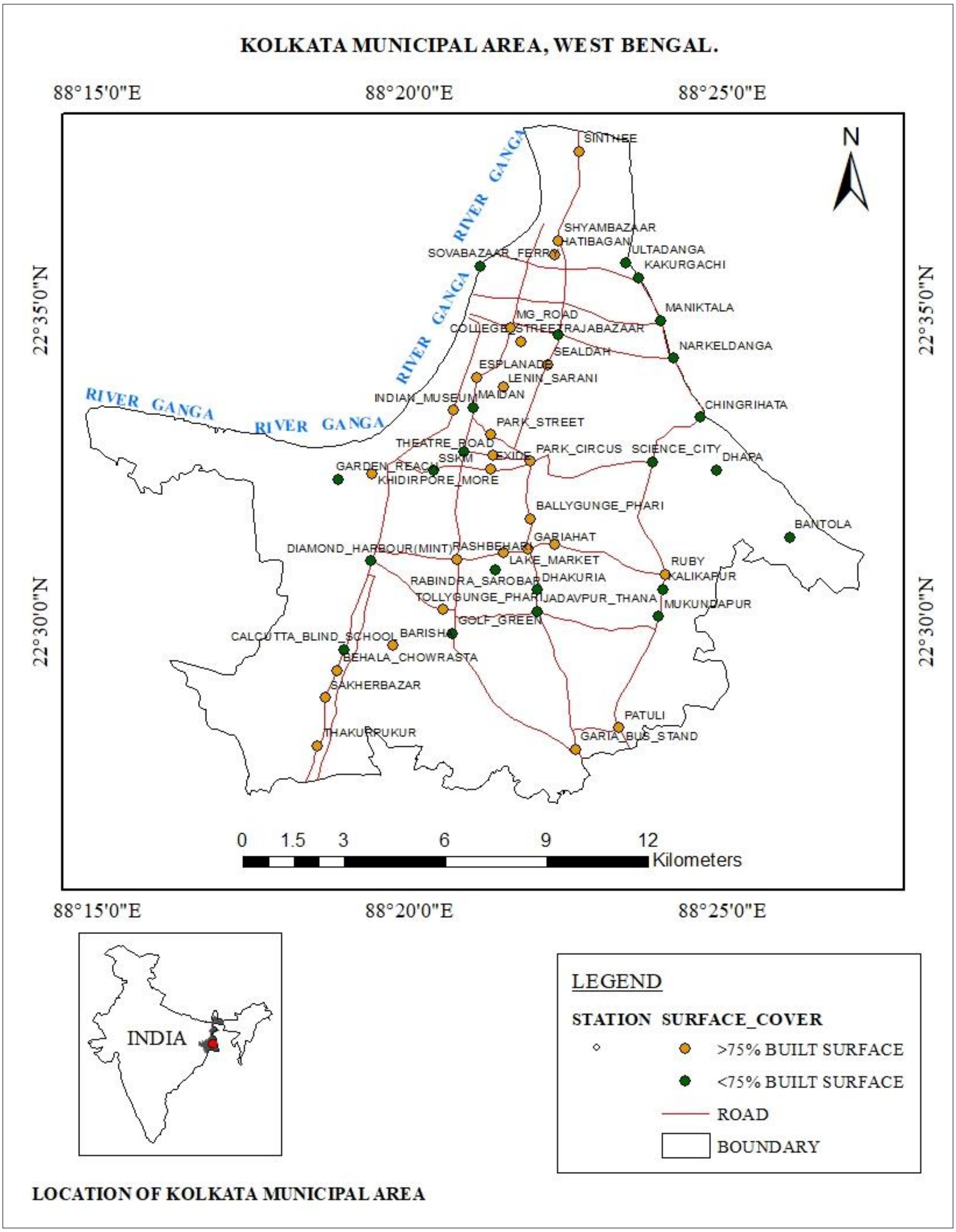


Figure 4.4 showing map with distribution of 50 data collection stations. the stations are divided in the map based on total built and impermeable surface taken together.

4.3.1 Plan Area Fraction for identifying Surface cover categories

Urban climate zones are characterized by distinct urban surface cover show distinct climatic behaviours.(Houet & Pigeon, 2011). The surface cover study is used to understand the quality of vegetation and water surface in the area and the share of built surface to natural surface. Considering that built features and impermeable surface features do not allow storm water percolation is contributory factor to heat accumulation (Oke, Mills, Christen, & Voogt, 2017), and natural surface contributes to comfort conditions (Binte Ali & Patnaikb, 2018)(Emmanuel & Johansson, 2006)(Emmanuel & Johansson, 2006)(Amirtham, Horrison, & Rajkumar, 2015), the share of natural surface to build surface in both stations will help us delineate the basic difference in surface character. Surface cover is calculated as a ratio of the area of a surface feature (Ax) to the total ground surface area (At), known as the Plan Area Fraction. (Oke, Mills, Christen, & Voogt, 2017). The surface cover showing greater share in open surface or water bodies, can create dynamic potential in an area (Ng, URBAN CLIMATIC MAPPING FOR PLANNING – AN EXPERIENCE FROM HONG KONG)(Urban climatic map studies in Vietnam: Ho Chi Minh City, 2015)(Welsch, 2015)(Wong, Kardinal Jusuf, Katzschner, & Ng, 2015)(Ren, Lun Lau, Ng, & Po Yiu, 2013). Built structures and built surface acting as obstruction to air flow can create thermal load. (Ng, URBAN CLIMATIC MAPPING FOR PLANNING – AN EXPERIENCE FROM HONG KONG). Thermal comfort conditions is a growing concern in India. Heat stress conditions can become acute especially for growing urbanized areas.(Amirtham, Lilly Rose; Horrison, Ebin; Rajkumar, Surya, 2015) In hot dry regions, dense canopy vegetation and water bodies can ameliorate thermal comfort (Binte Ali & Patnaikb, 2018).

The Plan area fraction provides the Landcover at neighbourhood level where the features were considered at scale of 1cm represents 100 km. One of the urban surface properties include surface cover which can be represented as a ratio of the area of a surface feature (A_x) to the total ground surface area (A_t). This is called Plan Area Fraction represented in Equation 6 where x stands for the surface cover of a feature which can be vegetation, built surface, waterbody etc as shown in Figure 2 [34].

$$\lambda_x = \frac{A_x}{A_t} \quad \text{Eq.6}$$

Equation 6 showing CALCULATION OF PAF, as ratio of the area of a surface feature (A_x) to the total ground surface area (A_t).

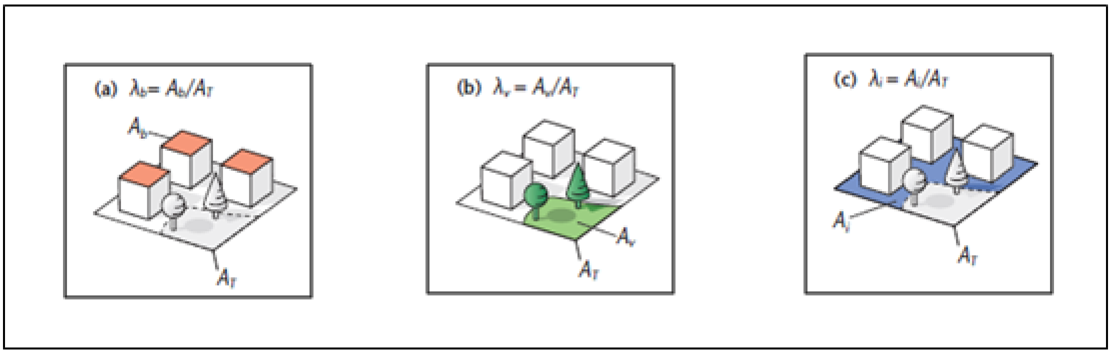


Figure 4.5 Showing Plan Area Fraction for Building (b), Vegetation (v) and Impervious surface (i) (Oke et al. 2017).

The Plan Area Fraction (PAF) was used to identify the total share of built surface and impermeable surface vs the total share of natural surface cover. From literature survey a number of factors have led to this result that higher share of built areas leads to less thermal comfort. However, areas with more natural surface cover or dynamic potential are a source of cool fresh air. For e.g., green belt, have a greater share of dynamic potential. Some station has greater share of open areas than water bodies such as Maidan. Since it is in the middle of the green belt it has access to some large canopy trees which may obstruct wind in one hand but may also provide shade and humidity. Some parts of the open areas are covered in light grass while in remaining portion of the surface there is little or no vegetation. Stations which have higher share in water surface than open areas or vegetation include Chingrihata, Garden reach, Patuli, Sova bazaar Ferry. Stations with higher share of vegetation with open areas are Dhapa, Rabindra Sarovar, SSKM, Bantola. Some stations such as Bantola, Garden reach lie on the extreme ends of the extensions of the east-west arterial road. They lie away from the city core and have proximity to sub-urban agricultural belt on the eastern end and the sluice gate and estuary of River Hooghly on the western end respectively.

Each station has been demarcated within a 100 m diameter. The radius has been drawn from the point where instruments are set. Area at a neighbourhood scale is taken from 10m to 200 m (T.R.OKE et.al.). Table 4.2 Showing a built fraction, impermeable surface fraction, vegetation fraction, open space fraction and water fraction fifty stations. (Plan Area Fraction for 50 stations)

Natural surface cover refers to water bodies, vegetation and open areas. The stations with higher natural surface cover are termed as Dynamic Potential as these stations do not accumulate heat nor cause extreme discomfort according to literature review. The stations with higher built and impermeable surface have greater heat accumulation and may cause higher discomfort; and are termed Thermal Load.

Plan area fraction has been calculated for built surface, impermeable surface, vegetation surface, open surface and water surface. the steps to identify the surface cover are as follows-

- First a buffer of diameter of 100m. was demarcated around the point of data collection and instrument set up.
- Then the surface cover categories were separately drawn with polygons which gave the area in km^2 as well as $m^{2.}$
- Each of the surface cover is represented as a ratio to the total area of the buffer of the respective station.
- With the help of the PAF, the surface cover of the stations within 100m diameter can be analysed.
- The stations with higher share of built and impermeable fraction are termed as Thermal Load.
- The stations with higher vegetation fraction, open space fraction and water fraction is considered a station with access natural surface cover; a Dynamic Potential.

The stations with higher dynamic potential are expected to have higher thermal comfort conditions than stations with higher thermal load. This is because the stations with higher thermal load will obstruct ventilation. Lack of urban greenery, water body will not help in absorption of the heat generated. In Urban Heat islands, the trapping of the longwave radiation at nighttime, addition to heat by emissions of indoor Heating Ventilation Air conditioning (HVAC), increase in suspended particulate matter (SPM) from fuel combustion led to increased reflection of longwave radiation back to surface.

Figure 4e and 4d, show examples of the 100m diameter area around the point of data collection, and calculating area of the surface cover using polygons.

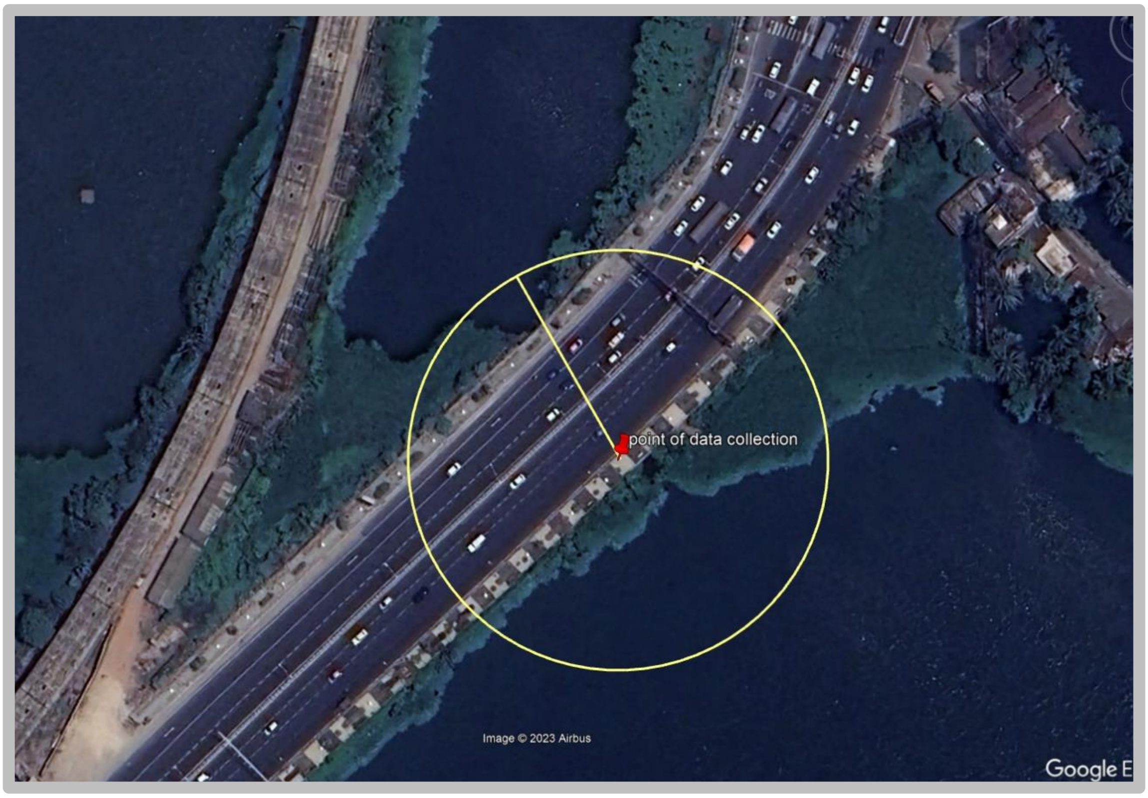


Figure 4.6 showing an example of 50m radius circle drawn around station Chingrihata

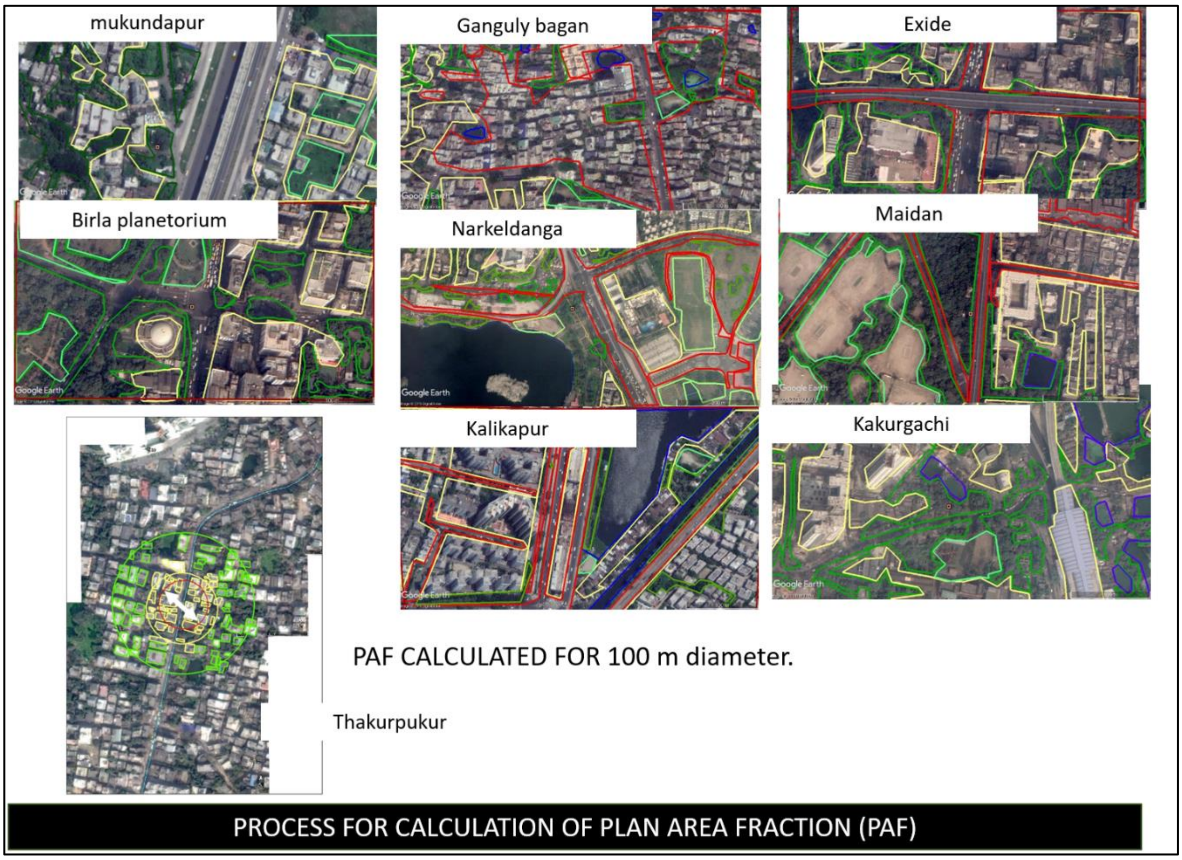


Figure 4.7 Showing calculating PAF with the help of polygons

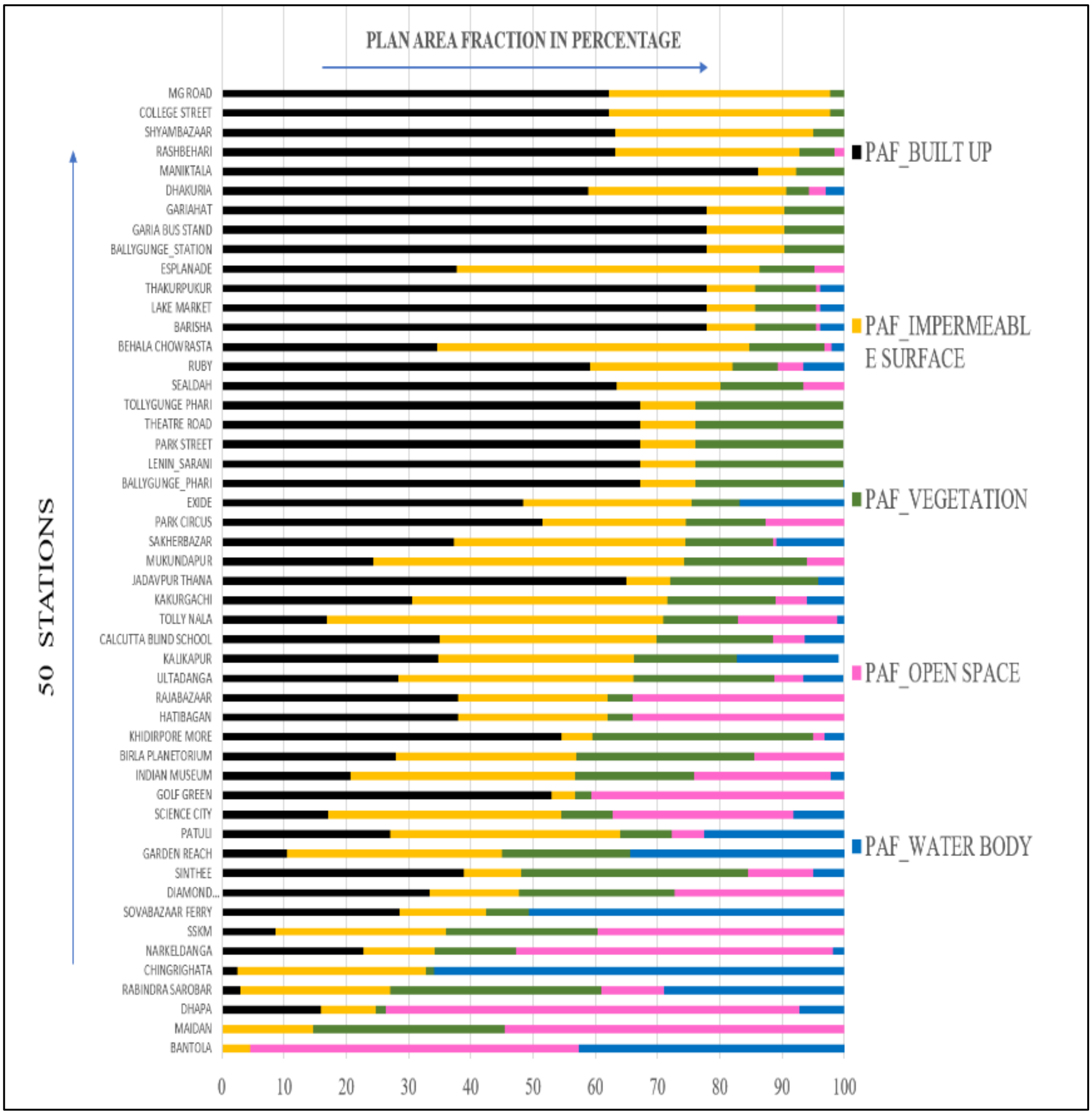


Figure 4.8 Showing Area fraction for different surface cover type for 50 stations, 2019

Plan area fraction calculated for 50 stations have been shown in Figure 4.h. in this figure, open areas (open space), vegetation cover and waster surface is considered together as Dynamic potential. In the figure above, it is seen that in stations with high thermal load, the share of built surface and share of impermeable surface is not equal. In some stations, built surface is more while in others impermeable surface is more.

Similarly, in case of dynamic potential, stations with higher share of natural surface have different share of water bodies, open areas and vegetation cover. Some stations have no water body and more open areas and vegetation cover like Maidan. Some stations have no open surface, but greater share of wate bodies like Chingrihata.

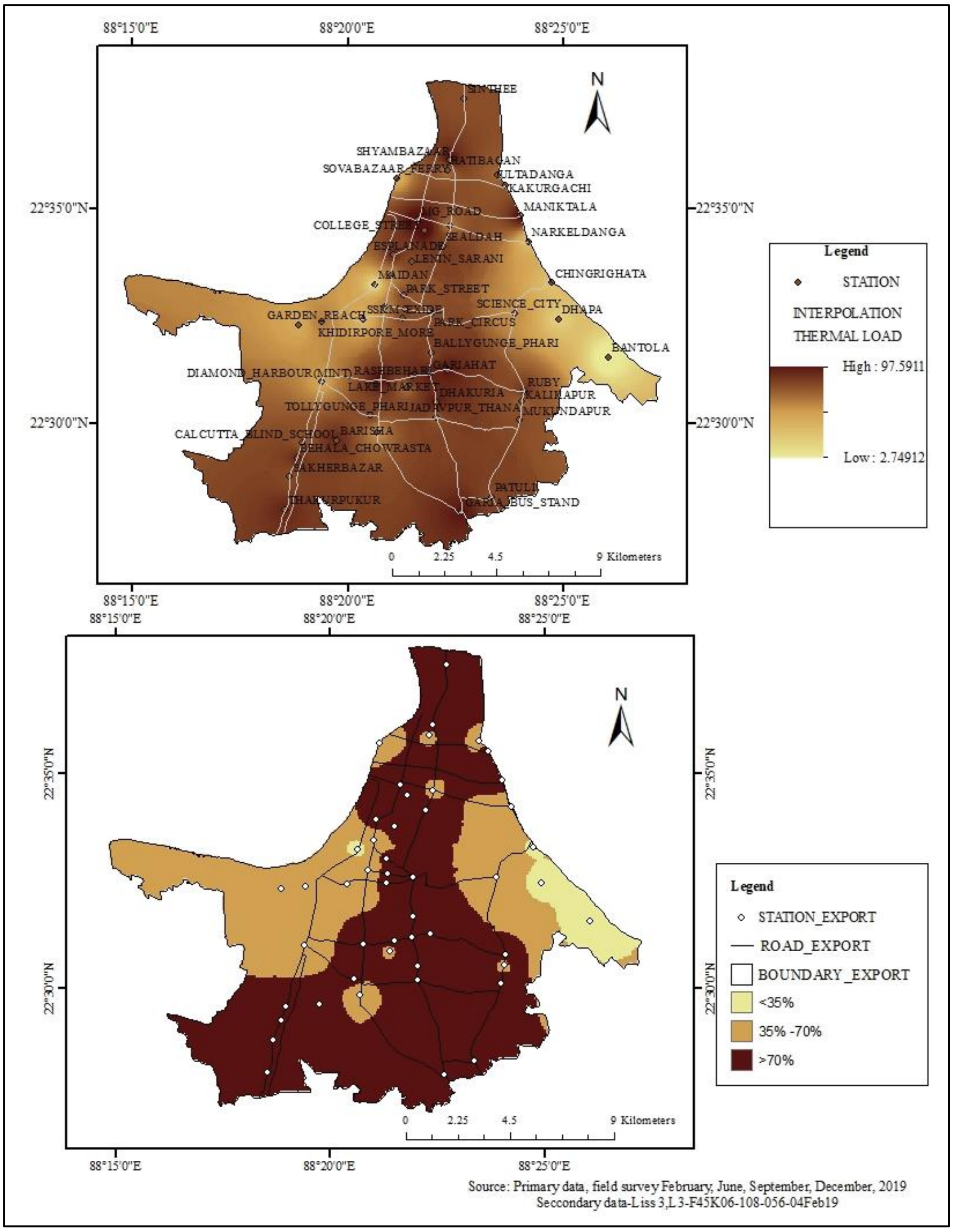


Figure 4.9 Showing map of areas with high thermal load over 70%

Figure 4.10 Image of Built surface over South Kolkata, image taken from Prajukti Bhawan rooftop, Jadavpur University

Figure 4.11 showing impermeable surface with vegetation canopy. a- Gariahat road, b- Khidirpore road, Garden Reach.

Figure 4.12 Showing impermeable and built surface in north and central Kolkata.

a-Central Avenue, b-M.G. Road, c- Dalhousie, d- Shyambazaar, e- College Street

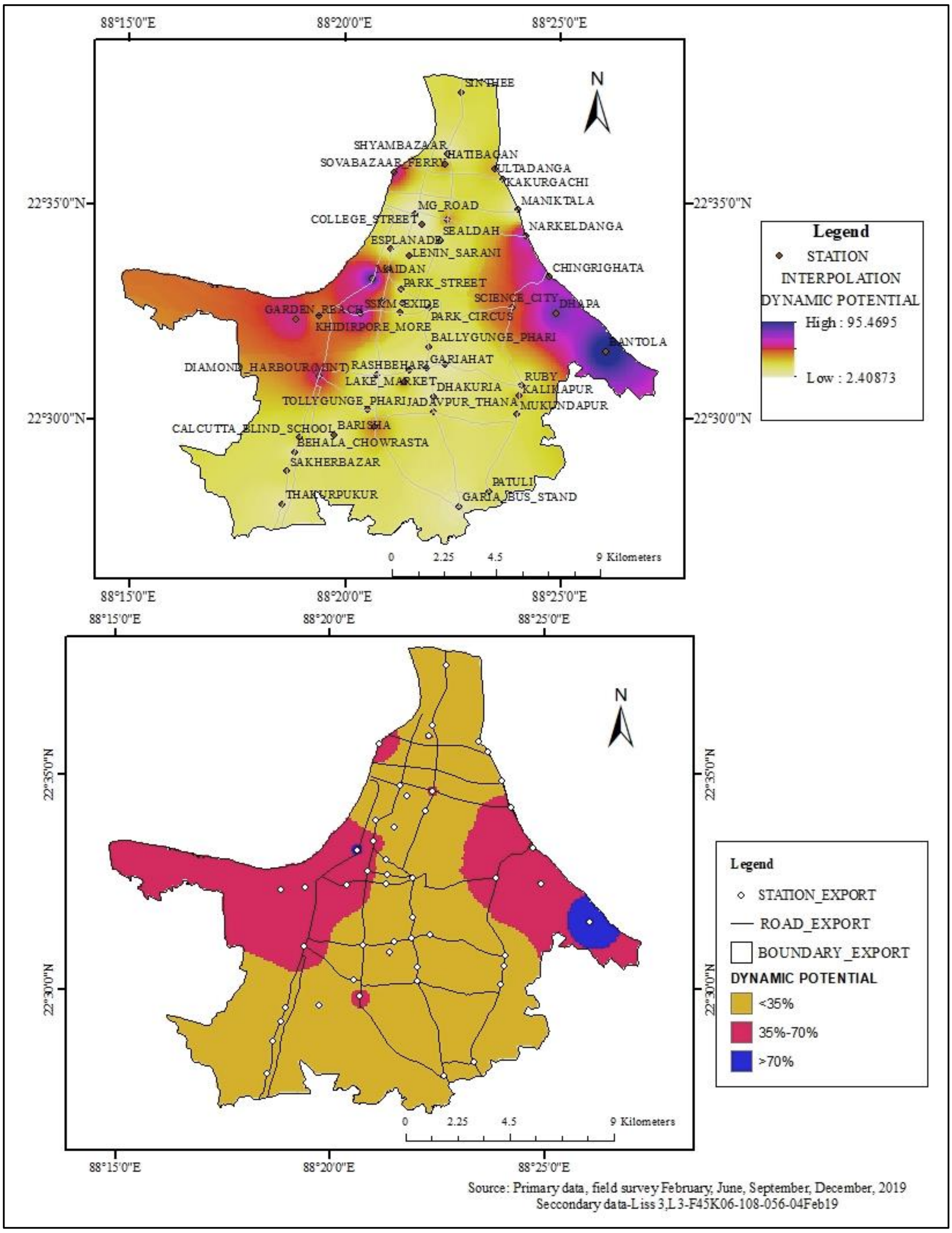


Figure 4.13 Showing map of areas with high thermal load over 70%

Figure 4.14 Showing Natural surface cover -DYNAMIC POTENTIAL

a-Rabindra Sarovar lake, b- Bantola, c- Dhapa, d- behind Ruby, Anandapur, e-Hooghly estuary at Garden Reach, f-Maidan green belt

PAF CATEGORY	Station	BUILT UP	IMPERMEABLE SURFACE	VEGETATION	OPEN SPACE	WATER BODY
1	BANTOLA	0.00	2.72	15	40	42
	MAIDAN	0.00	14.63	30.77	54.60	0.00
2	DHAPA	15.97	8.68	1.61	66.54	7.20
	RABINDRA SAROBAR	3.00	24.00	34.00	10.00	29.00
	CHINGRIGHATA	2.46	30.40	1.23	0.00	65.92
	NARKELDANGA	22.79	11.38	13.03	50.93	1.86
	SSKM	8.53	27.45	24.41	39.61	0.00
3	SOVABAZAAR FERRY	28.59	13.78	7.02	0.00	50.62
	GARDEN REACH	10.52	34.48	20.58	0.00	39.43
	DIAMOND HARBOUR(MINT)	33.31	14.41	24.97	27.30	0.00
	SINTHEE	38.86	9.17	36.44	10.53	5.00
	SCIENCE CITY	17.08	37.41	8.31	29.02	8.18
	GOLF GREEN	53.00	3.73	2.67	40.60	0.00
	INDIAN MUSEUM	20.68	36.08	19.08	21.97	2.19
	BIRLA PLANETORIUM	27.90	29.02	28.61	14.47	0.00
	KHIDIRPORE MORE	54.58	4.92	35.49	1.89	3.11
4	HATIBAGAN	37.90	24.05	4.04	34.01	0.00
	RAJABAZAAR	37.90	24.05	4.04	34.01	0.00
	PATULI	27.00	37.00	8.32	5.09	22.59
	ULTADANGA	28.30	37.81	22.62	4.73	6.38
	KALIKAPUR	34.70	31.57	16.50	0.01	16.32
	CALCUTTA BLIND SCHOOL	34.95	34.95	18.68	5.06	6.36
	TOLLY NALA	16.94	54.00	11.90	16.05	1.11
	KAKURGACHI	30.58	41.02	17.36	5.00	6.00
	JADAVPUR THANA	64.95	7.09	23.75	0.00	4.21
	MUKUNDAPUR	24.42	49.82	19.73	6.04	0.00
	SAKHERBAZAR	37.25	37.25	14.02	0.59	10.89

	PARK CIRCUS	51.49	23.06	12.81	12.65	0.00
	EXIDE	48.40	27.13	7.70	0.00	16.77
	BALLYGUNGE_PHARI	67.18	8.88	23.79	0.00	0.16
	LENIN_SARANI	67.18	8.88	23.79	0.00	0.00
	PARK STREET	67.18	8.88	23.79	0.00	0.00
	THEATRE ROAD	67.18	8.88	23.79	0.00	0.00
	TOLLYGUNGE PHARI	67.18	8.88	23.79	0.00	0.00
5	SEALDAH	63.48	16.58	13.40	6.54	0.00
	RUBY	59.17	22.86	7.23	4.19	6.56
	BEHALA CHOWRASTA	34.66	49.99	12.09	1.19	2.07
	BARISHA	77.90	7.71	9.86	0.66	3.88
	LAKE MARKET	77.90	7.71	9.86	0.66	3.88
	THAKURPUKUR	77.90	7.71	9.86	0.66	3.88
	ESPLANADE	37.76	48.59	8.79	4.86	0.00
	BALLYGUNGE_STATION	77.85	12.54	9.62	0.00	0.00
	GARIA BUS STAND	77.85	12.54	9.62	0.00	0.00
	GARIAHAT	77.85	12.54	9.62	0.00	0.00
	DHAKURIA	58.84	31.82	3.69	2.60	3.05
	MANIKTALA	86.16	6.14	7.70	0.00	0.00
	RASHBEHARI	63.26	29.56	5.62	1.56	0.00
	SHYAMBAZAAR	63.19	31.84	4.97	0.00	0.00
	COLLEGE STREET	62.17	35.57	2.26	0.00	0.00
	MG ROAD	62.17	35.57	2.26	0.00	0.00

Table 4.2 Station wise share of Built fraction, impermeable fraction, vegetation fraction, open space fraction and water fraction calculated by PAF method.

sr no	Station	TL	DP	sr.no.	Station	TL	DP
1	BALLYGUNGE_PHARI	76.057	23.943	26	LENIN_SARANI	76.057	23.787
2	BALLYGUNGE_STATION	90.384	9.616	27	MAIDAN	14.629	85.371
3	BANTOLA	2.727	95.491	28	MANIKTALA	92.298	7.702
4	BARISHA	85.603	14.397	29	MG ROAD	97.740	2.260
5	BEHALA CHOWRASTA	84.647	15.353	30	MUKUNDAPUR	74.234	25.766
6	BIRLA PLANETORIUM	56.915	43.085	31	NARKELDANGA	34.168	65.832
7	CALCUTTA BLIND SCHOOL	69.904	30.096	32	PARK CIRCUS	74.544	25.456
8	CHINGRIGHATA	32.852	67.148	33	PARK STREET	76.057	23.787
9	COLLEGE STREET	97.740	2.260	34	PATULI	54.487	45.513
10	DHAKURIA	90.658	9.342	35	RABINDRA SAROBAR	27.000	73.000
11	DHAPA	24.649	75.351	36	RAJABAZAAR	61.951	38.049
12	DIAMOND HARBOUR(MINT)	47.723	52.277	37	RASHBEHARI	92.823	7.177
13	ESPLANADE	86.352	13.648	38	RUBY	82.027	17.973
14	EXIDE	75.529	24.471	39	SAKHERBAZAR	74.496	25.504
15	GARDEN REACH	44.992	51.008	40	SCIENCE CITY	54.487	45.513
16	GARIA BUS STAND	90.384	9.616	41	SEALDAH	80.060	19.940
17	GARIAHAT	90.384	9.616	42	SHYAMBAZAAR	95.028	4.972
18	GOLF GREEN	56.730	43.270	43	SINTHEE	48.036	51.964
19	HATIBAGAN	61.951	38.049	44	SOVABAZAAR FERRY	42.367	57.633
20	INDIAN MUSEUM	56.763	43.237	45	SSKM	35.983	64.017
21	JADAVPUR THANA	72.040	27.960	46	THAKURPUKUR	85.603	14.397
22	KAKURGACHI	71.595	28.405	47	THEATRE ROAD	76.057	23.787
23	KALIKAPUR	66.266	33.734	48	TOLLY NALA	70.936	29.064
24	KHIDIRPORE MORE	59.501	40.499	49	TOLLYGUNGE PHARI	76.057	23.787
25	LAKE MARKET	85.603	14.397	50	ULTADANGA	66.114	33.886

Table 4.3 Showing Thermal Load (TL) and Dynamic Potential (DP) in each station

Thermal load of the stations is calculated by summing the built fraction and impermeable surface fraction. The dynamic potential is calculated by summing the open are fraction, Based on the concept of Thermal Load and Dynamic Potential taken from literature review, the stations have been categories into five categories of 1,2, 3, 4, 5. Category 1 having <20% Thermal Load, Category 2 having 20%-40% Thermal Load, Category 3 having 40%-60% Thermal Load, Category 4 having 60%-80% Thermal Load, Category 5 having >80%. Thermal Load.

In a congested urban area like Kolkata, the number of stations with higher share of TL is higher in frequency (Table 4.4). A few stations like Bantola, Maidan, Dhapa, Chingrihata have high share of DP and lie along the eastern margins of the city where the East Kolkata Wetlands begin.

The stations are arranged in ascending order of share of Thermal Load. Figure 4f show that the stations with highest share of TL have lowest share of DP. Conversely, stations with highest share of DP have lowest share of TL. Some stations have balanced share of TL and DP. The figure also shows the number of stations in each category and the representative graphs for these stations have also been shown.

PAF, CATEGORY	**STATIONS**	**FREQUENCY**
1	BANTOLA, MAIDAN	2
2	DHAPA, RABINDRA SAROBAR, CHINGRIGHATA. NARKELDANGA, SSKM	5
3	SOVABAZAAR FERRY, GARDEN REACH, DIAMOND HARBOUR(MINT), SINTHEE, PATULI SCIENCE CITY, GOLF GREEN, INDIAN MUSEUM, BIRLA PLANETORIUM, KHIDIRPORE MORE	10

4	HATIBAGAN, RAJABAZAAR, ULTADANGA, KALIKAPUR CALCUTTA BLIND SCHOOL, TOLL NALA, KAKURGACHI, JADAVPUR THANA, MUKUNDAPUR, SAKHERBAZAR, PARK CIRCUS, EXIDE, BALLYGUNGE_PHARI, LENIN_SARANI, PARK STREET, THEATRE ROAD, TOLLYGUNGE PHARI	17
5	SEALDAH, RUBY, BEHALA CHOWRASTA, BARISHA, LAKE MARKET, THAKURPUKUR, ESPLANADE, BALLYGUNGE_STATION, GARIA BUS STAND, GARIAHAT, DHAKURIA, MANIKTALA, RASHBEHARI, SHYAMBAZAAR, COLLEGE STREET, MG ROAD	16

Table 4.4 Showing frequency of stations in each PAF category

With the help of this figure, 10 stations have been chosen to study the importance of dynamic potential for outdoor thermal comfort. Table 4.5 and Table 4.6 show the surface cover and nature of water bodies around these stations. These selected 10 stations have been described in these tables in detail. the total area of these stations is A_T taken as 100%; λB - Built fraction, λ_V -Vegetation Fraction, λ_I – Impermeable fraction, λ_O - open area fraction and λ_W – water fraction.

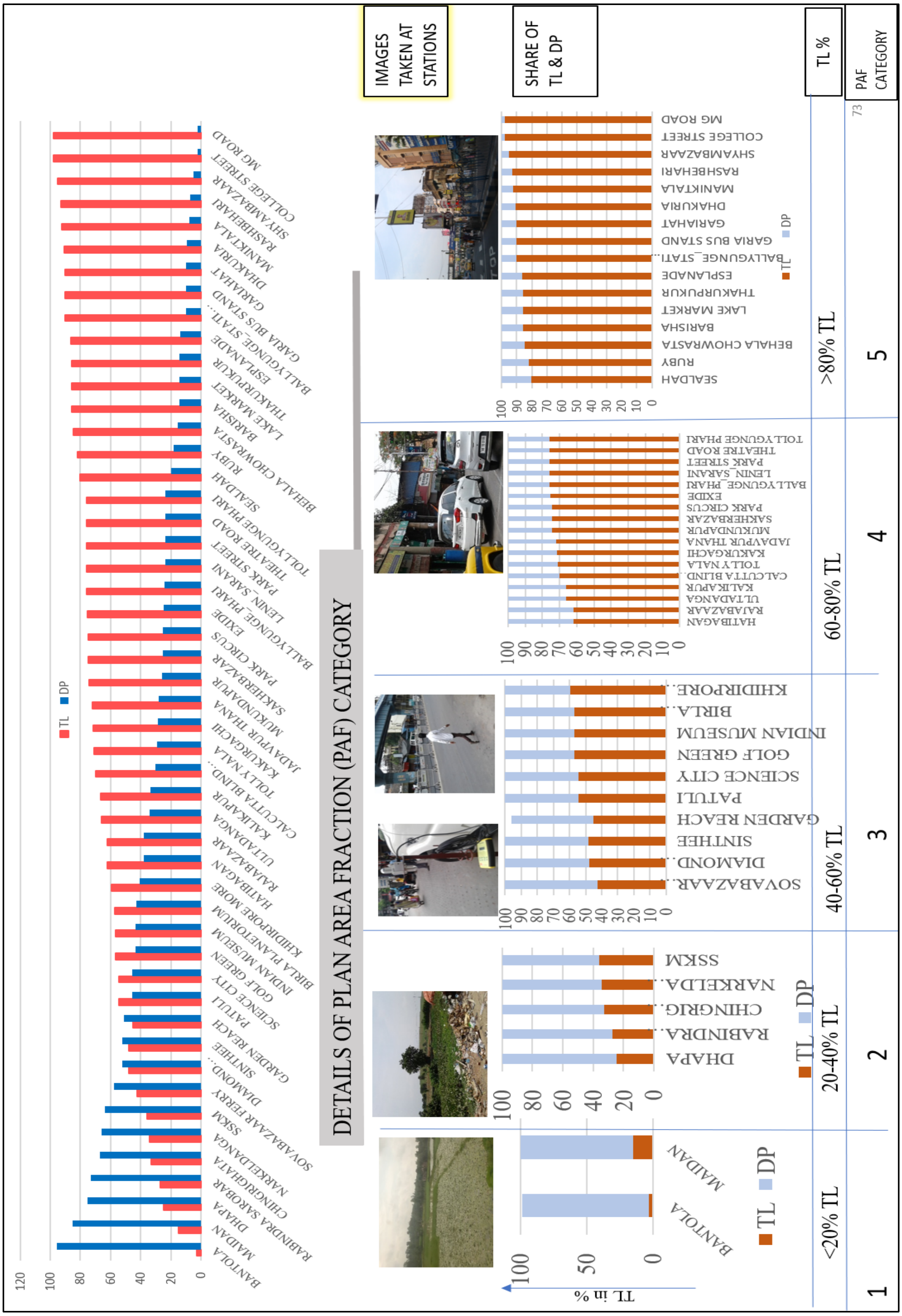
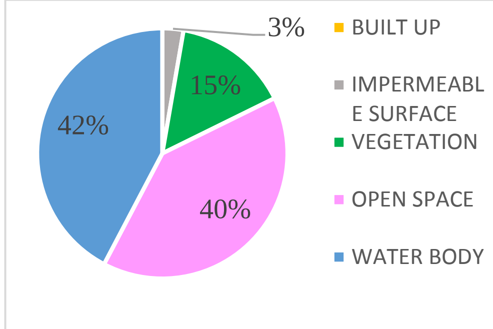
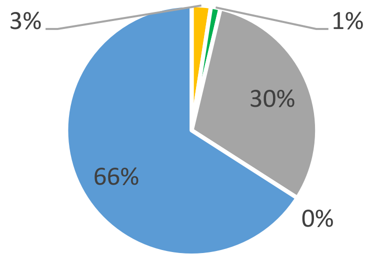
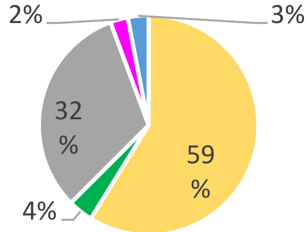
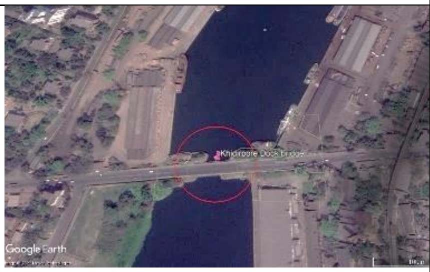
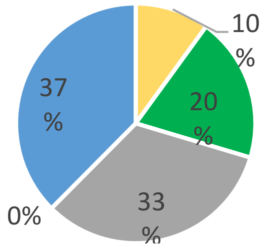
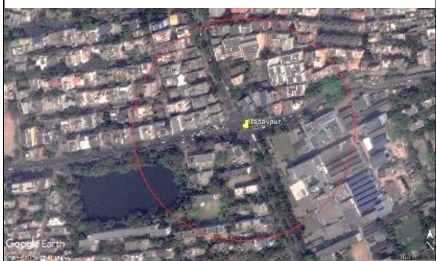
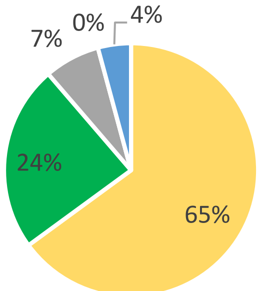


Figure 4.15 Showing station category based on share of thermal load (TL).

STATION	LANDCOVER IMAGE (GOOGLE EARTH, REFERRED 21ST APRIL,2019)	PLAN AREA FRACTION (km^2)	DIAGRAM SHOWING SHARE OF SURFACE COVER
BANTOLA	 100 m	λ_B = 0 λ_V=15 λ_I=2.72 λ_O=40 λ_W=42.3	
CHINGRIGHATA	 100m resolution	λ_B = 2.46 λ_V=1.23 λ_I=30.39 λ_O=0 λ_W=65.92	
DHAKURIA	 100m resolution	λ_B =58.84 λ_V=3.69 λ_I=31.82 λ_O=2.6 λ_W=3.05	
GARDEN REACH	 100m resolution	λ_B =10.52 λ_V=20.58 λ_I=34.48 λ_O=0 λ_W=39.43	
JADAVPUR THANA	 100m resolution	λ_B =64.95 λ_V=23.75 λ_I=7.09 λ_O=0 λ_W=4.21	

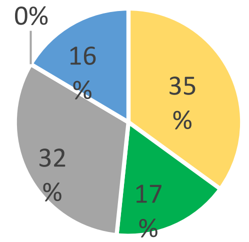
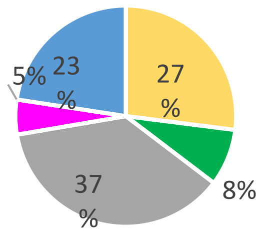
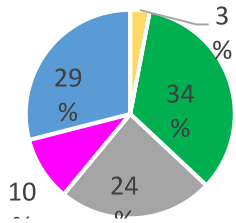
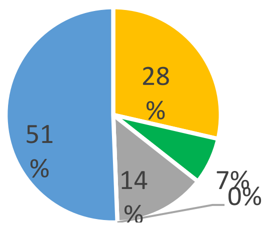
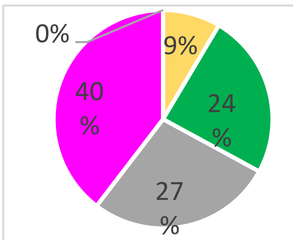
KALIKAPUR	 100 m resolution	λ_B =34.70 λ_V=16.50 λ_I=31.57 λ_O=0.01 λ_W=16.32	
PATULI	 100 m resolution	λ_B =27 λ_V=8.32 λ_I=37 λ_O=5.09 λ_W=22.59	
RABINDRA SAROBAR	 100m resolution	λ_B =3 λ_V=34 λ_I=24 λ_O=10 λ_W=29	
SOVABAZAAR FERRY	 100m resolution	λ_B =28.59 λ_V=7.02 λ_I=13.78 λ_O=0 λ_W=50.62	
SSKM	 300m resolution	λ_B =8.53 λ_V=24.41 λ_I=27.45 λ_O=39.61 λ_W=0	

Table 4.5 Showing plan area fraction of 10 stations in percentage. λB - Built fraction, λV - Vegetation Fraction, λI – Impermeable fraction, λO - open area fraction and λW – water fraction.

Sr.No.	PAF Category	Station Name	Size of Water Bodies	Distance Of Water Body (In Metres)	Type of Distribution	Canopy Size(m2)
A	1	Bantola	0.18km2	15m	Narrow feeder roads connecting agricultural and compost and industrial belt to the main city	25-50
B	2	Chingrihata	0.23km^2	50 m	Left bank-Right Bank separated by major arterial road	15
C		Rabindra Sarobar	0.31 km^2	50 m	Dugout waterbody surrounded with green park and open spaces and recreation centres and opens out into road and built surface	30-70
D		SSKM	4031m^2 3280m^2 3276m^2 0.042m^2	50m-300m	Scattered water bodies at distance of interspersed with green belt	30-80
E	3	Garden Reach	bridge over River Ganga estuary	0-10m	bridge over Ganga estuary	15-30
F		Patuli	0.003km^2 1265m^2 3181m^2 747m^2	100m	waterbodies along Left side and Right side of the road and high-density medium rise buidings flanking waterbody on left side	15-30
G		Sovabazaar Ferry	River Ganga	50 m	Riverfront	15-50
H	4	Jadavpur Station	0.1 km^2 & 0.01km^2	150 m	road junction connecting north-south and east-west part of the city. with two water bodies not visible from main road.	20-40
I		Kalikapur	0.043 km^2	100-300m	waterbody on right bank of road and high rise on left bank of road with broad passages evening breeze to pass through.	15-30
J	5	Dhakuria	0.1 km^2 +influence from Rabindra sarovar	250-300m & 450m	Mid-rise dense residential, with limited vegetation canopy and no waterbodies in visible range, high percentage of built and impermeable surface.	15-30

Table 4.6 Showing plan area fraction of 10 stations in percentage. λB - Built fraction, λ_V - Vegetation Fraction, λ_I – Impermeable fraction, λ_O - open area fraction and λ_W – water fraction.

I. Distance of water bodies from data collection points -

a. Stations like Bantola, Chingrihata, Garden reach, Sova bazaar Ferr, Patuli have large water bodies within very short distance. The water surface is easily seen from the data collection point.

b. Stations like Jadavpur, Dhakuria, SSKM have water bodies nearby, which cannot be seen from data collection points. However, the effect of water breeze is felt at evening time.

c. Stations like Kalikapur, have high rise buildings on side of the road and on the other side of the road is a sizeable water body which provides water breeze at evening time.

d. Station like Rabindra Sarovar; the data collection point is on the street and the open areas and vegetation surface and canopy can be seen from the data collection point. The water body cannot be seen from the data collection point. The natural surface is a sizeable share though the data collection point could not be centred around the water body because it would minimise the share of built surface around it. The study intends to find the importance of dynamic potential in an urban environment.

II. Arrangement of water bodies from data collection points-

a. Large water body on one side of road and low-density high rise on other side of road- Kalikapur

b. Large water body on one side of road and high-density low rise on other side of road- Sovabazaar Ferry

c. Large water body (storm water drainage canal) on one side of feeder road and open agricultural surface on the other side- Bantola

d. Water bodies on both side of road- Patuli, Chingrihata, Garden Reach (bridge over Hooghly estuary)

e. Scattered water bodies, none can be seen from the data collection point – SSKM

f. Water breeze from water bodies – Dhakuria, Jadavpur thana

g. Large area of water body, open area and vegetation at residential area- Rabindra Sarovar.

4.4 INFERENCE

- Stations with higher share of built surface and impermeable surface have Thermal Load. Stations with higher share of natural surface: water bodies, open surface and vegetation surface, have higher Dynamic potential.
- Stations with less than 40% thermal load have high dynamic potential. Stations have been divided into five categories based on share of Thermal Load.
- 10 stations have been considered for study of importance of Dynamic Potential.

The following chapters analyse the materials and methods applied for analysis of microclimate conditions, surface cover and Outdoor Thermal Comfort Conditions.

CHAPTER5: MATERIALS & METHOD

5.1 INTRODUCTION TO METHODOLOGY

According to Fanger and other pioneers of the outdoor thermal comfort indices, the parameters can be divided into meteorological, physiological and behavioural. These data are for objective assessment of Outdoor thermal comfort The meteorological parameters were monitored with instruments that became the base for primary data. The physiological parameters included, age, sex, height, weight. People's opinion on the outdoor thermal comfort conditions are a part of the outdoor thermal perception study. It is a subjective assessment. Both physiological parameter and behavioural parameter were studied using questionnaire schedule for the respondents from the concerned stations.

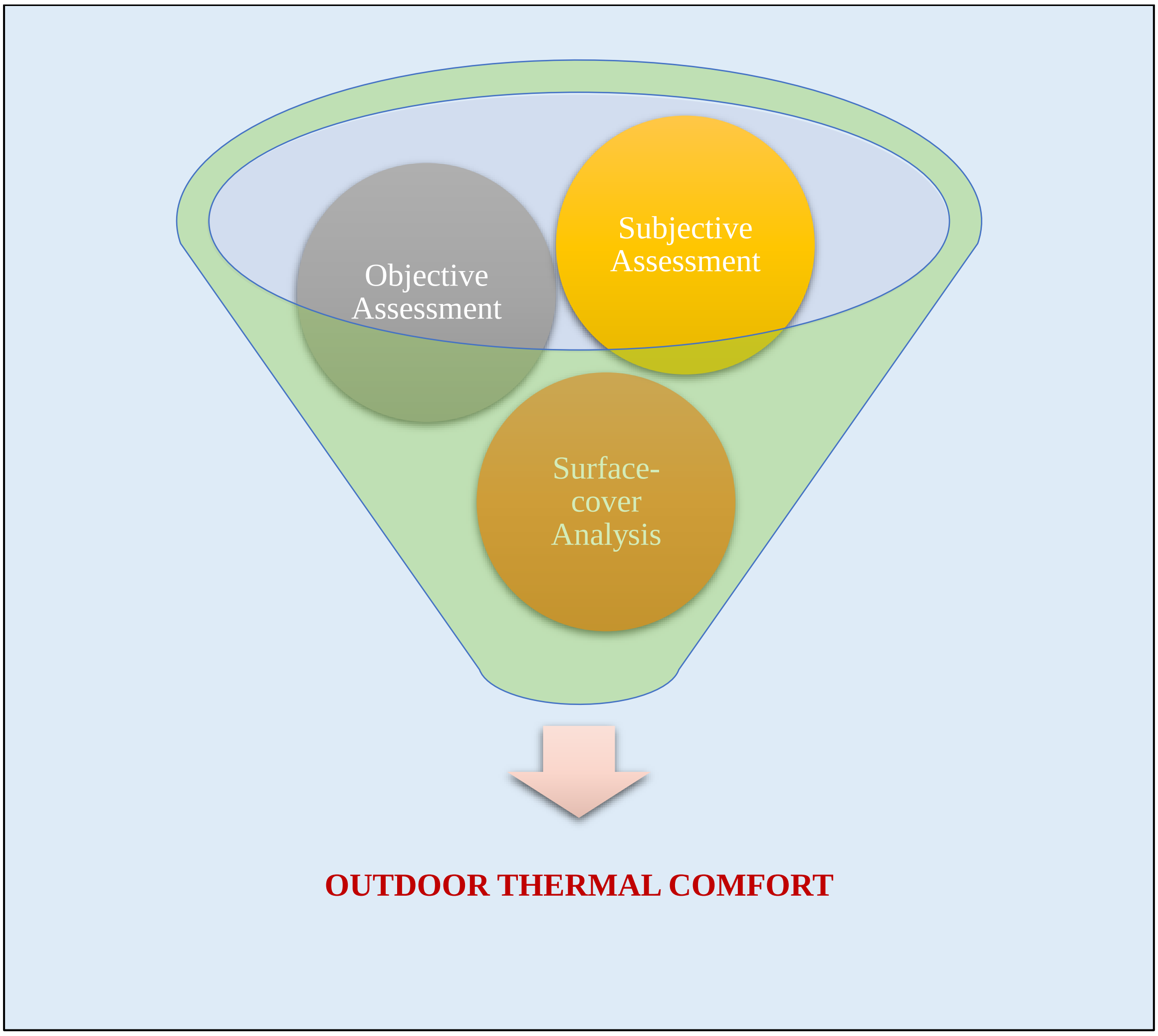


Figure 5.1 Showing different assessment in the study of Outdoor thermal comfort

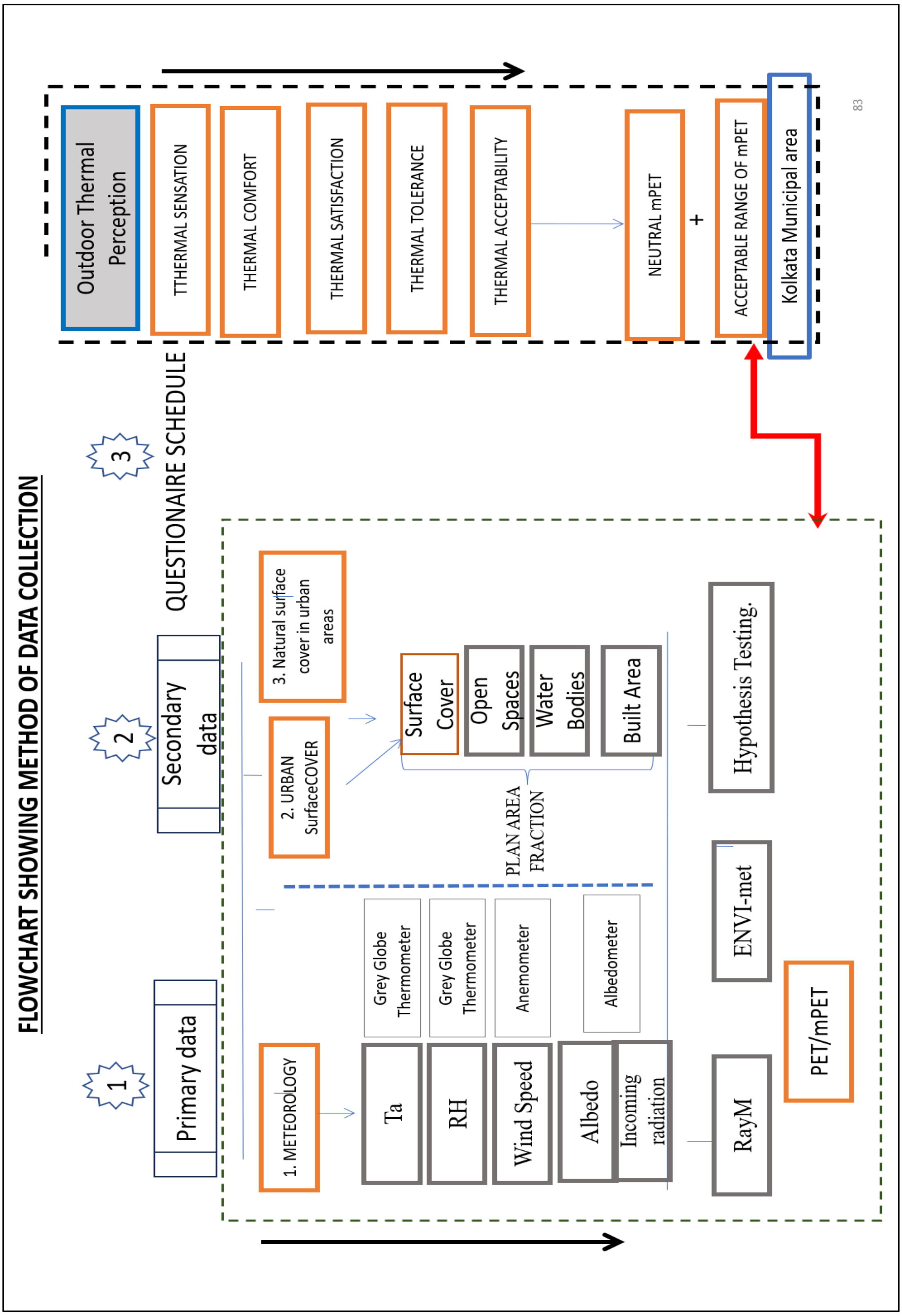


Figure 5.2 Flowchart showing Method of data collection

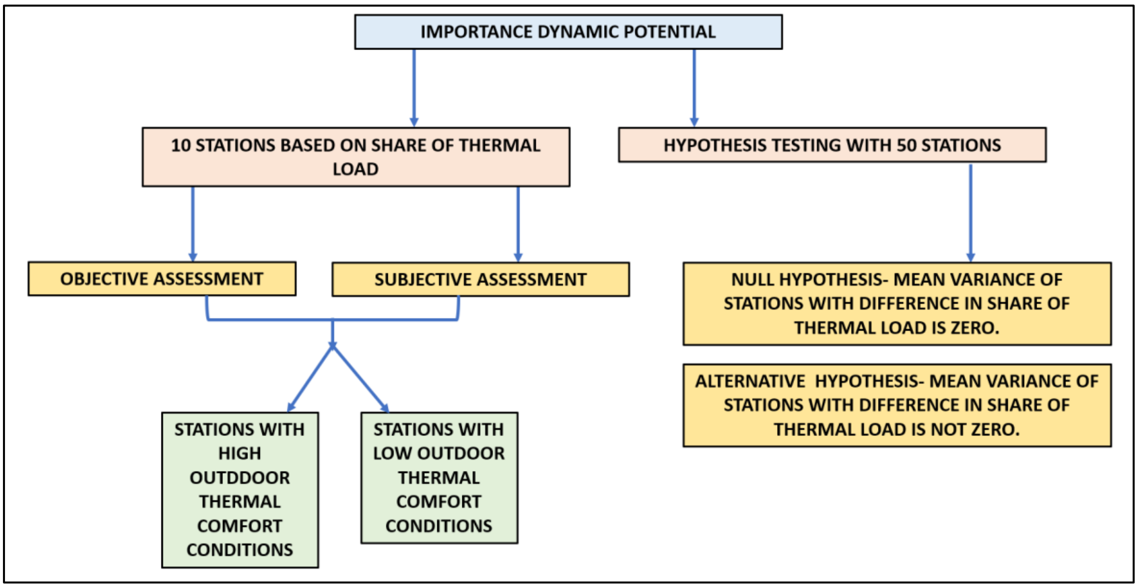


Figure 5.3 Flowchart showing methodology for analyzing importance of dynamic potential

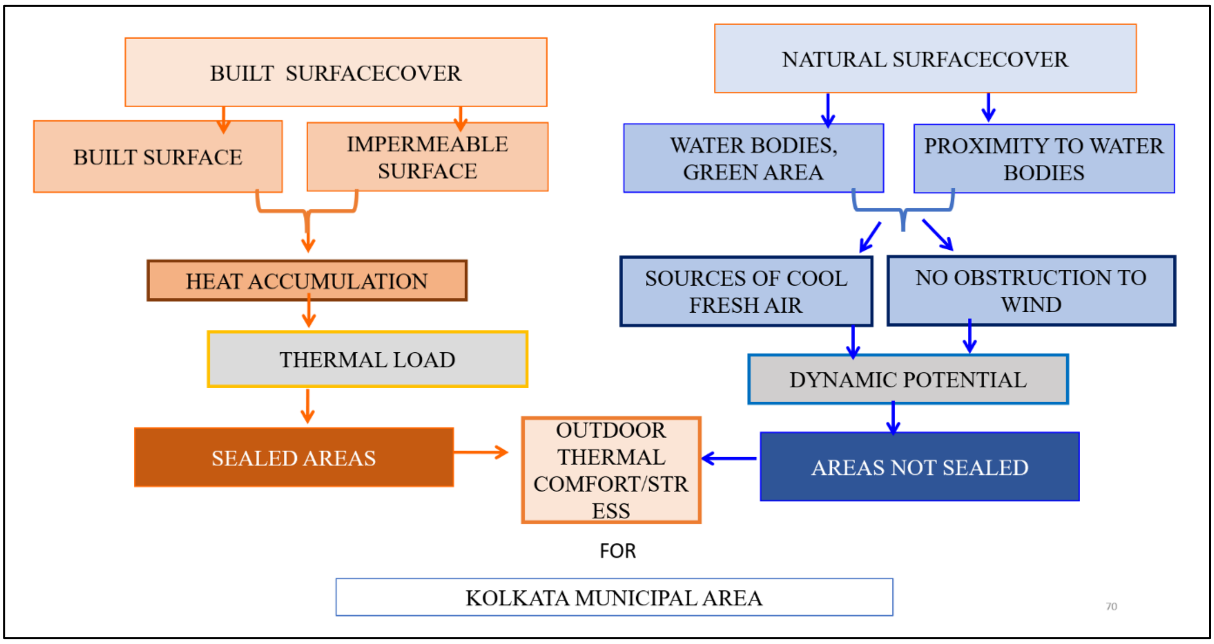


Figure 5.4 Flowchart showing analysis of outdoor thermal comfort for Kolkata Municipal Area

5.2 PRIMARY DATA COLLECTION

5.2.1 Instrument set-up

Instrument is used to calculate microclimate parameters which will help determine the calculation of Tmrt. Tmrt has been calculated using the formula used from literature review.

$$Tmrt = 4\sqrt{\frac{[(Tg + 273.15)4 + 1.1^{\times}108Va\ 0.6 \times (Tg-Ta)]}{\epsilon D\ 0.4}} - 273.15$$

Where va =wind velocity [m/s]; ε =emissivity of sphere (¼0.95); D =diameter of the sphere [mm]; Tg =globe temperature [C]; Ta =air temperature [C]. (Walikewitz, et al. 2015).

Mean radiant temperature can also be calculated based upon the ISO standard 7726 and computation of PET using RayMAN pro model, version 2.1 software. A station equipped with instruments was set to collect microclimate data at the respective stations. Mean Radiant Temperature (Tmrt) is measured at the locations with the help of a 40 mm black globe thermometer (emissivity=0.95) with a data logger that recorded Wet Bulb Globe Temperature (WBGT), Relative Humidity (RH), Air temperature (Ta) and Globe temperature (Tg) at 1.5-minute interval for 30 minutes. Kuehn has expressed Tmrt as a function of wind speed, air temperature and globe temperature. The anemometer and Black-Globe thermometer (measuring TA and TG) was set at 0.8 m above the ground while the albedometer was set at 1 above ground level. The recommended height given by ISO-7726 is between 0.6m to 1.1m above ground level. The air temperature and globe temperature are measured using EXTECH Heat stress WBGT Meter (HT30). It has a range of 0° to 50°C, accuracy of sensor of 1°C for Ta; range (0° to 80°C) and accuracy of sensor of 3°C for Tg; range (0-100%) and accuracy of sensor of +/-3% for Relative Humidity. The Metravi handheld anemometer with range of 0.80m/s to 30.0m/s range and accuracy of ± (0.05 + 0.05 Va) m/s for comfort levels and ± (0.1 + 0.05 Va) m/s for stress levels, is used to measure Va. The instrument was positioned not in direct sunlight nor in complete shade.

The details of the instruments are mentioned in Table 4a. The specifications for instrument setup were done in accordance to the regulations mentioned in ISO 7726: Thermal Environment—Instruments and Methods for Measuring Physical Quantities. This standard gives the explanations and definitions basic and derived parameters. It mentions ‘No specific instrument is standardized, only specifications.

Parameter measured	Instrument	Sensor details		
		Range	Accuracy	
			ISO7726	Sensor
Air Temperature	EXTECH Heat stress WBGT Meter (HT30)	0° to 50°C	+/- 0.5°C -40°C (Comfort) and 0°C -50°C (Stress)	1°C
Globe Temperature	EXTECH Heat stress WBGT Meter (HT30)	0° to 80°C		3°C
Relative Humidity	EXTECH Heat stress WBGT Meter(HT30)	0-100%		+/-3%
Wind Speed	Metravi handheld anemometer	0.80m/s to 30.0m/s	±(0.05 + 0.05 va) m/s (COMFORT); ±(0.1 + 0.05 va) m/s (STRESS)	
Global Solar Radiation & Albedo	Hukseflux SRA01 Second Class Albedometer (ISO 9060) Directional response < ± 25 W/m^{2}Spectral selectivity < ± 5 % (0.35 to 1.5 x 10-6 m)Temperature response < ± 3 % (-10 to +40 °C)Tilt response < ± 2 % (0 to 90 ° at 1000			

Table 5.1 showing instrument specifications for primary data collection, 2019

Figure 5.5 Showing data collection at different junctions of arterial roads. ;left to right- Ruby Golpark, Ballygunge Phari, Tollygunge Phari

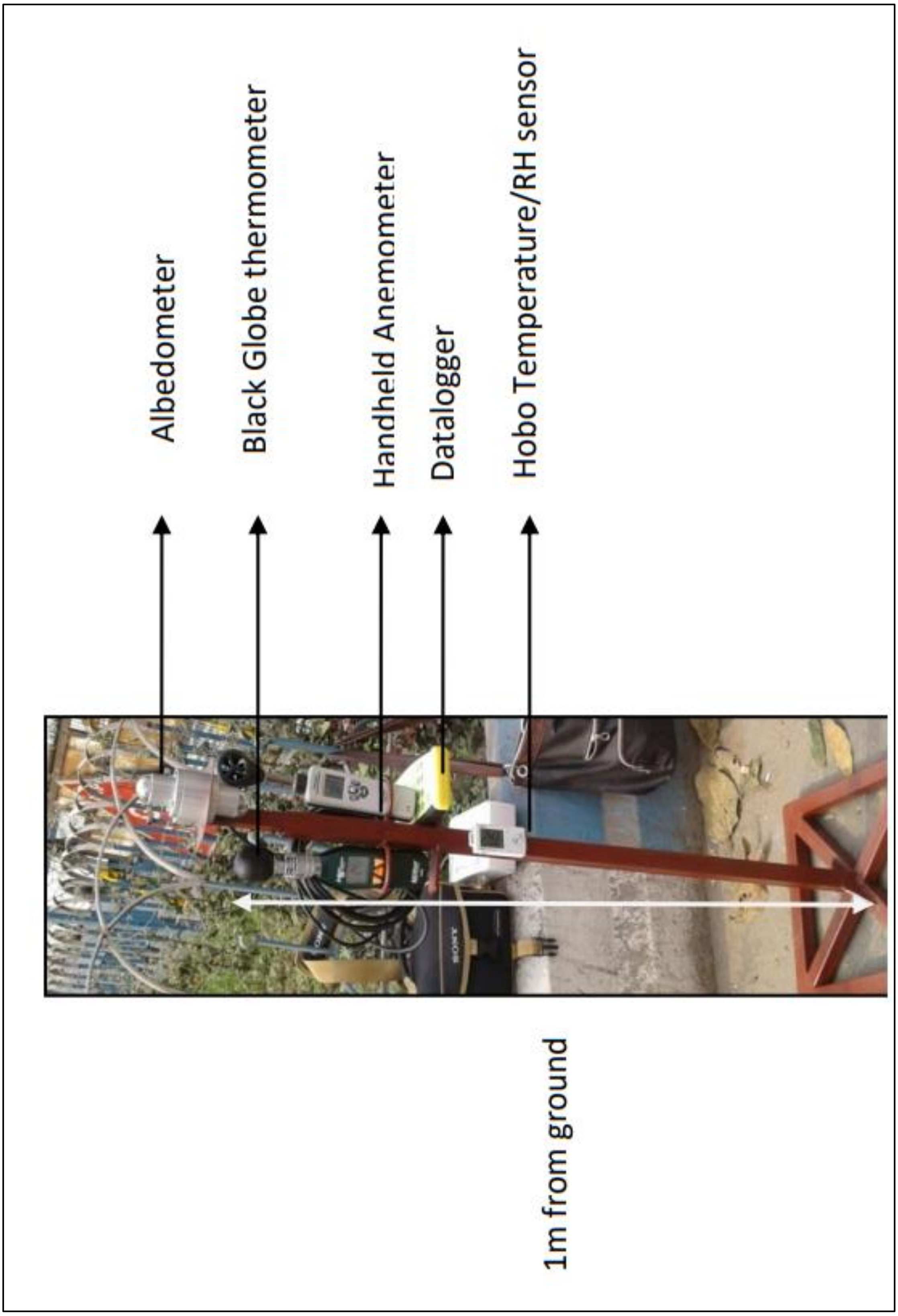


Figure 5.6 showing instrument for primary data collection of micrometeorological parameters, 2019

Figure 5.7 instrument on built surface, Hati Bagan.

Figure 5.8 instrument on green belt area, Maidan

Figure 5.9 instrument set at Chingrihata

The PET index was calculated using the RayMAN pro model, version 2.1 where data was put with an average Clo value of 0.9 (loose half sleeve shirt with a trouser) and the metabolic activity was put according to the respondent's activity level for PET calculation. For mPET calculation, Clo values of 0.7, 0.5, 0.9 and 1.0 were considered for spring, summer, autumn and winter respectively. The software considers meteorological conditions, geographical conditions as well as personal information. Average Clo value of 0.23-0.5 (loose half sleeve shirt with a trouser or an Indian sarong for male/saree for female) and the activity level determined the metabolic activity. According to ISO 8996, 110 W metabolic rate and for a standard man of 1.75m height , 70 kg weight is considered for calculating PET [43]. Wind (Va), Globe Temperature (Tg), Relative Humidity (RH) and Air temperature (Ta) were recorded for one hour between 11 to 2:30 pm for all the stations for the four mentioned seasons of 2019 to calculate Tmrt followed by calculation of PET and mPET for the four seasons of 2019. Primary data collected in 2019 is arranged in Master table. Refer Chapter 6 Table 6.2, 6.3, 6.4, 6.5 for spring, summer, autumn and winter records respectively. Statistical tests such as regression, Pearsons's correlation, Z-test, normal probability distribution was used for analysis. All calculation is performed on SPSS software.

5.2.2 Questionnaire Schedule

The respondents were selected in stratified random sampling manner. In each station, the instruments were set and allowed to sensitize to the environment for thirty minutes. Within that period two or three questionnaires were filled from respondents mostly in standing condition and few in sitting position. 50 stations were divided into two categories of 25 stations each. One category has high share of thermal load while the other category has high dynamic potential. Questionnaire schedule is prepared to gather response to questions covering thermal perception, thermal comfort, thermal preference, thermal acceptability and thermal tolerance. Several other questions have been constructed to gather information on personal perception of the environment and personal preference of the thermal condition including their perception of humidity, wind and sun based on three/ five/seven/nine-point scale. The questionnaire schedule is based on the ASHRAE 55 (2010) and the ISO 10551 (1995) guidelines which provide a detailed response to the questions formulated on an ordinal scale. The questionnaire schedule included questions on age, gender, time of response, place of response, date of response, season, station name, station type while temperature, humidity and the windspeed was simultaneously noted. Station name included names of station such as Ballygunge Phari, Gariahat etc. Station type included descriptives such as natural surface or built area. Questions on age are classified into age-groups, from <13 years to >65 year. Thermal sensation question is ‘How are you feeling now?’ the response is on a 7-point scale from very cold to very hot, 0 being neutral. Thermal comfort question is ‘How do you find this environment?’ the response is on a 7-point scale from extremely uncomfortable to extremely comfortable, 0 being comfortable. Personal acceptability question includes response 2-point scale, 0 being unacceptable and 1 being unacceptable. Question on thermal preference includes response on 7-point scale from very satisfied to very unsatisfied; 0 being neutral. Question on personal tolerance includes answer on 5-point scale, 0 being perfectly tolerable while 4 being intolerable. Refer Chapter 7, Table 7.8.

STATION NAME	SEASON-
DATE-	TEMPERATURE-
TIME	HUMIDITY-
STATION- TYPE-	WINDSPEED-

•Age Group : (in years)
□ <13 □ 13-18 □ 19-24 □ 25-34 □ 35-44 □ 45-54 □ 55-64 □ >65

•Clo value- 0.7, 0.5, 0.9, 1.0

•How are you feeling now? ISO 10551 (1995)/ What is your general thermal sensation? ASHRAE 55 (2010)
□ Very cold □ cold □ slightly cool □cool □neutral □ slightly warm □ warm □hot □very hot

•How do you find this environment comfortable? ISO 10551(1995)
□very comfortable □slightly comfortable □Comfortable □slightly uncomfortable □uncomfortable □very uncomfortable

•‘Please state how you would prefer it to be now’ ISO 10551 (1995)
□ Much cooler □cooler □slightly cooler □neither warmer nor cooler □little warmer □warmer □much warmer

•On a personal level, this environment is for me...... ISO 10551 (1995)
□ acceptable rather than unacceptable □ unacceptable rather than acceptable

How satisfied are you with the temperature in your space ? ASHRAE 55 (2010)
□ very satisfied □satisfied □ slightly satisfied □ neutral □ slightly dissatisfied □dissatisfied □ very dissatisfied

•Is it tolerable?ISO 10551 (1995)□perfectly tolerable □slightly difficult to tolerate □fairly difficult to tolerate □very difficult to tolerate □intolerable

Figure 5.10 Questionaire Schedule used in Primary Survey, 2019

A total of 100 responses were collected in each season with a stratified random sampling of 2 questionnaires per station per season. in most cases, the responses matched in their preference for cooler or warmer conditions. most of the respondents were in standing position. the questionnaire was conducted between 11 to 2:30 pm for four seasons. The responses did not stand in shade as this study did not include effect of shade as a parameter. The responses were not recorded during drag of wind caused by vehicles passing. Foreign visitors were excluded from this survey as well as visitors who have recently arrived into the city to avoid exaggeration. Also, people who have shifted recently from colder regions were not questioned. People who walked outdoors after a long period in indoor air-conditioned offices were not included in the questionnaire. Responses to the questionnaire schedules was recorded for four seasons, spring, summer, autumn and winter of 2019. Data collection in spring was conducted from 15th February -25th March, around the time of vernal equinox. and Data collection in summer was conducted from 15th May – 20th June 2019; during time of summer solstice, in Autumn the data collection was done from 15th October– 15th November 2019 and during of Autumnal Equinox and in Winter data collection was done from 15th December 2019 to 15th January 2019. During summer data collection, Norwester or Kal Baisakhi stormy days, monsoon season, day of Fani Cyclonic storm were avoided. One or two days after cyclonic depressions were also avoided since these days did not show the usual discomfort conditions of high temperature and high humidity that are otherwise prevalent in the season of summer. After averaging the responses from each station, the 400 questionnaires were reduced to 100 comprehensive survey responses for analysis and calculation purpose.

Figure 5.11 location marking with coordinates.

Figure 5.12 Showing primary data collection

THERMAL SENSATION	**STANDARD**	**DESCRIPTION**	**(Thorsson *et al.*, 2006)**
Thermal perception	ISO 10551 (1995)	'How are you feeling now?	7 Point scale: cold (3), cool (2), slightly cool (1), neutral (0), slightly warm (+1), warm (+2) and hot (+3) or 9-point scale: above plus 'Very cold' (4) and 'Very hot' (+4) (mainly for use in extreme environmen
	ASHRAE 55 (2010)	'What is your general thermal sensation?	the 7- point ASHRAE scale
Thermal comfort (affective evaluation)	ISO 10551 (1995)	'How do you find this environment?	4-Point: comfortable (0) as the point of origin followed by slightly uncomfortable (1), uncomfortable (2), very uncomfortable (3
Personal acceptability	ISO 10551 (1995)	On a personal level, this environment is for me ...'	acceptable rather than unacceptable (0) and unacceptable rather than acceptable
Thermal preference	ISO 10551 (1995)	'Please state how you would prefer it to be now'	7 POINT-much cooler (3), cooler (2), slightly cooler (1), neither warmer nor cooler (0), a little warmer (+1), warmer (+2) and much warme
Personal tolerance-	ASHRAE 55 (2010)	How satisfied are you with the temperature in your space?	7-Point: very satisfied (+3) and very dissatisfied (3) with neutral (0) in the middle (votes from 0 to +3 are considered acceptable)
	ISO 10551 (1995)	'Is it ...?	5-Point: perfectly tolerable (0), slightly difficult to tolerate (1), fairly difficult to tolerate (2), very difficult to tolerate (3) and intolerable (4)

Table 5.2 Thermal sensation question ASHRAE 55(2010) / ISO 10551 (1995)

Seasonal Clo values	Garment Description	Clo values
Spring 0.6 to 0.68 0.7	Long sleeved shirt + Trousers	0.61
	Same as above+ t-shirt	0.96
	Saree+shoes	0.78+1=0.88
	Salwar kameez scarf/dupatta+light shawl+socks+shoes	0.18+0.08+0.26+0.06+0.1
Summer 0.2-0.57 0.5	Short pants +short sleeved shirt+socks	0.36+0.02
	Trousers + short sleeved shirt	0.57
	Knee length skirt, short sleeved shirt, sandals	0.54
	Salwar kameez+scarf/dupatta+shoes	(0.13+0.04) +0.1=0.27
	Light saree	0.56
Autumn 0.56-0.96 0.7	Long sleeved shirt + Trousers	0.61
	Same as above + t-shirt	0.96
	Saree+shoes	0.78+1=0.88
	Salwar kameez+scarf/dupatta+light shawl+socks+shoes	0.18+0.08+0.26+0.06+0.1
Winter 0.9-2.55 0.9	Trousers, long sleeved shirt, long sleeved sweater, t shirt	1.01+0.12+0.40=1.53
	Sweatshirts sweatpants, t shirt, shoes, socks	0.34+0.28+0.12+0.06+0.1= 0.9
	Jeans, full sleeve t-shirt, sweater, socks, shoe, woollen cap	0.24+0.25+0.36+0.06+0.1+0.03
	Salwar kameez+scarf/dupatta, shawl/cardigan, shoes, socks	0.22+0.13+0.06+0.1=
	Saree, cardigan, socks	0.24+0.54+0.36+0.06=
	(OUTERWEAR)+Thermal innerwear	OUTERWEAR + 1.37

Table 5.3 Clo values calculated for study area according to the Indian subcontinent (Nicol *et al.*, 1999).

The results of the questionnaire survey were arranged in master table from which seasonal responses were arranged for further analysis. The table2 is provided for reference. It shows the ASHRAE and ISO standard followed to prepare a questionnaire schedule. A sample Questionnaire Schedule is also provided in the Appendix.

5.3 SECONDARY DATA COLLECTION

5.3.1 Remote-Sensing and Geographic Information System

Unsupervised classification used to delineate landcover classes into built area, open space, water body and light vegetation. Vegetation amd impermeable surface on Erdas Imagine. The author of this information is National Remote Sensing Centre, ISRO, Balanagar, Hyderabad. It is a first edition image.

The Spheroid Datum is GCS, WGS-1984. the data is prepared by NRSC and tile name is F45K06 and F45K07respectively. The source of this data has three spectral bands NIR (VNIR, Band2, Band3 and Band4) and Band5 from SWIR with swath of 141 km and spatial resolution of 23.5 meter. The source of this data is IRS-Resourcesat-2. satellite with Linear Imaging and Self Scanning Sensor (LISS) sensor (Path 108 /Row 56) date of pass, 4th February 2019 with metadata stamp of 2021-03-23 was used. It is an Ortho Corrected Imagery from IRS-Resourcesat-2. the file format is in Geotiff. Rectification of image performed with WGS, 1984 DATUM and UTM ZONE 45N projection system. For radiometric image rectification Nearest neighbor sampling was used. After geometric and radiometric correction, the image was worked upon in pseudocolour with signatures generated, maximum likelihood classifier, recoding and accuracy assessment (Error matrix, Descriptive Statistics and Kappa coefficient). The final product is subjected to spatial and thematic error with an accuracy assessment. Vector analysis and overlay analysis was performed on ArcMap. To prepare a map, signatures were collected for separate categories and for each of the categories, classification was first performed on ERDAS Imagine software. The classified image was then cropped within limits of the study area, Kolkata Municipal Corporation area. The classified image was then reclassed according to the signatures provided and grouped them into categories of Built Surface, Impermeable surface, Vegetation, Light Vegetation, open areas and water bodies. In this study vegetation is taken as a single parameter. However, in order to differentiate between open areas and light vegetation areas with similar reflectance, separate signatures were considered. In final study, light vegetation includes light grass covered surface whereas vegetation refers to area with tree canopies. Light vegetation and vegetation share of surface cover are later considered in a single category by adding their surface areas.

5.3.2 Google Earth Images

Details of Plan Area Fractionhas been discussed in Chapter 4. The source of all images for Plan Area Fraction is Google Earth, 2019.

5.3.3 Band ratioing

The quality of surface cover can be described using band ratioing. Built areas can be differentiated from barren land using the NDBI index where ratioing of band 4 an band 5 will result in negative pixel values for water bodies and positive for built area pixels. Similarly, NDVI helps to distinguish the large vegetation areas and its quality of foliage by ratioing bands 4 and band 3. NDWI is used to identify the quantity of water in waterbodies using the Green band and Near Infra-Red(NIR) band (McFeeters,1996).NDBaI is also a high speed mapping technique used to identify bare lands as a ratio between band6 and band 5. (As-syakur, Sandi Adnyana, Arthana, & Nuarsa, 2012)(Zha, Gao, & Ni, 2003)(Bhatta, 2011) NDVI, NDBI, NDWI.

The original approach to NDBI was developed by Zhaet al.(2003) by arithmetic techniques and recoding of bands3, 4 and 5. Once the continuous image is derived, recoding for positive and negative values are performed to make it a binary image (XU, 2006).

$$NDVI = \frac{band5 - band4}{band5 + band4} \ldots\ldots\ldots\ldots 7$$

$$NDBI = \frac{band6 - band5}{band6 + band5} \ldots\ldots\ldots\ldots 8$$

Similarly, the binary image is generated for NDBI by recoding the *continuous* image. The built surface is then extracted by the subtraction of NDVI from NDBI in equation 9 (XU, 2006).

BU=NDBI-NDVI………………………9

$$NDWI = \frac{band3 - band6}{band3 + band6} \ldots\ldots\ldots 10$$

Band ratioing performed using Landsat 8(sensor id.: OLI-TIRS) image (Path 138 /Row 44) dated 20thMay, 2019 having 11 bands with resampling option of 'cubic convolution' and band resolution of 30 m. The data is acquired from USGS Earth Explorer map base. NDVI, NDBI, BU and NDWI is performed on ArcMap with further reclassing and recoding

For radiometric image rectification Nearest neighbor sampling was used. of image preprocessing (Guindon et al. 2004). The Landsat ETM image was corrected geometrically following the Universal Transverse Mercator projection at 30-m resolution and using second-order polynomial and bilinear interpolation. The image is a rectified image having WGS, 1984 DATUM and UTM (zone45) projection system. After geometric and radiometric correction, the image was subjected to spatial and thematic error with an accuracy assessment. Again vector and overlay analysis was performed on ArcMap. Band Ratioing or spectral ratioing helps to enhance the gradient of two spectral reflectance curves. Normalized differential Vegetation Index, Normalized difference built index, Normalised difference bareness index and Normalized difference water index were used to show the surface cover conditions using Landsat 8 image dated 6th May,2019 (Worldwide Reference System Path 138 /Row 44) with 11 bands from sensors OLI (B, G,R,NIR,SWIR,PAN, CIRRUS) and TIRS (LIR). The Multispectral bands have resolution of 30m. To delineate the quality of landcover classes and cover classes into built area, open space, water body and vegetation on Erdas Imagine.

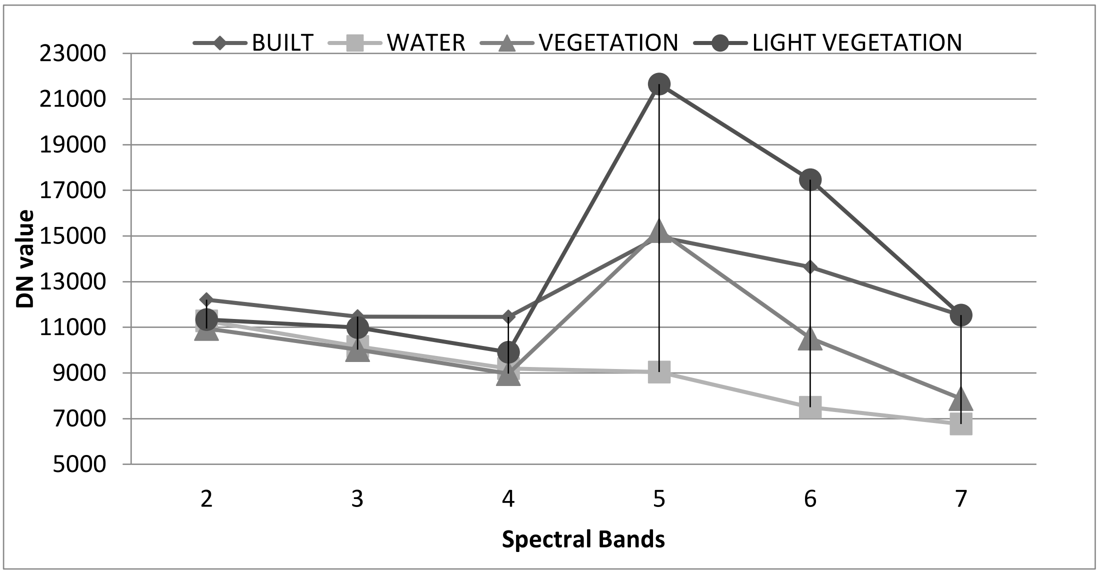


Figure 5.13 showing Spectral reflectance curve. Dn value of the spectral bands and the band which is used to denote the respective surface cover in the present image processing method.

In order to select the appropriate spectral band to study the surface cover, the spectral reflectance curve has been plotted. The relation between EMG spectrum and surface reflectance of a material plotted as frequency of the wave length is the Spectral reflectance curve. Spectral disparity is found maximum in band numbers 5, 6, 7. Light vegetation shows more reflective than water and built area. Subtracting band 4 from band 5 will give positive pixel values for light vegetation comprising of grass in open surface. This way reflectivity of all the categories was checked and finally image processing was carried forth.

5.4 SOFTWARE – CALCULATION OF PET AND MPET

5.4.1 Envi-met for calculation of PET and simulation

Surface cover of an urban area plays an important role in influencing the microclimate of a region. Along with microclimate parameters such as temperature, humidity, wind speed and direction; the urban form and geometry also plays a defining role in the creation of urban heat islands. Urban surface cover creates warmer nights than the surrounding non-urbanized areas due to greater share in built surface that prevent the outgoing radiation from escaping the surface [1] [2]. The interaction between natural and built surface within the lower urban boundary layer creates varying microclimate conditions at local level [3]. Such variations can be studied with the help of simulations using ENVI-met 4.4.3 where the Envi guide help to create. SIMX simulation files and forcing files using primary data and reference data. ENVI-met is a holistic model having a atmospheric model, vegetation model, soil model and built model.

In Envi-met the sapces in basic setting can be changed and a new model domain can be created. The nesting grid increases the stability of the model. If input of x by y is 100 by 100 then the nesting grid is 5 by 5. Z- grid is the height of the model divided by number of grids which gives the concept of telescoping. The z grid can be made equidistant when each 2m is divided into 5 grids each of 0.4m and then telescoping becomes zero. Soil properties, wall/ roof properties are kept default, , in geographic properties name of location, grid north, is provided. A new .INX file is made with building information while .SIM file is made with climate information.

Other information such as pollutant sources, vegetation, meteorologic data, soil wetness are giveb, simple forcing of the meteorology information is set. Initial temperature is set at 2m height from the weather station and specific humidity is taken from the Regional Meteorological Office.

Once the run is complete, data navigator allows the position of the view plane to be k=1.4 m.

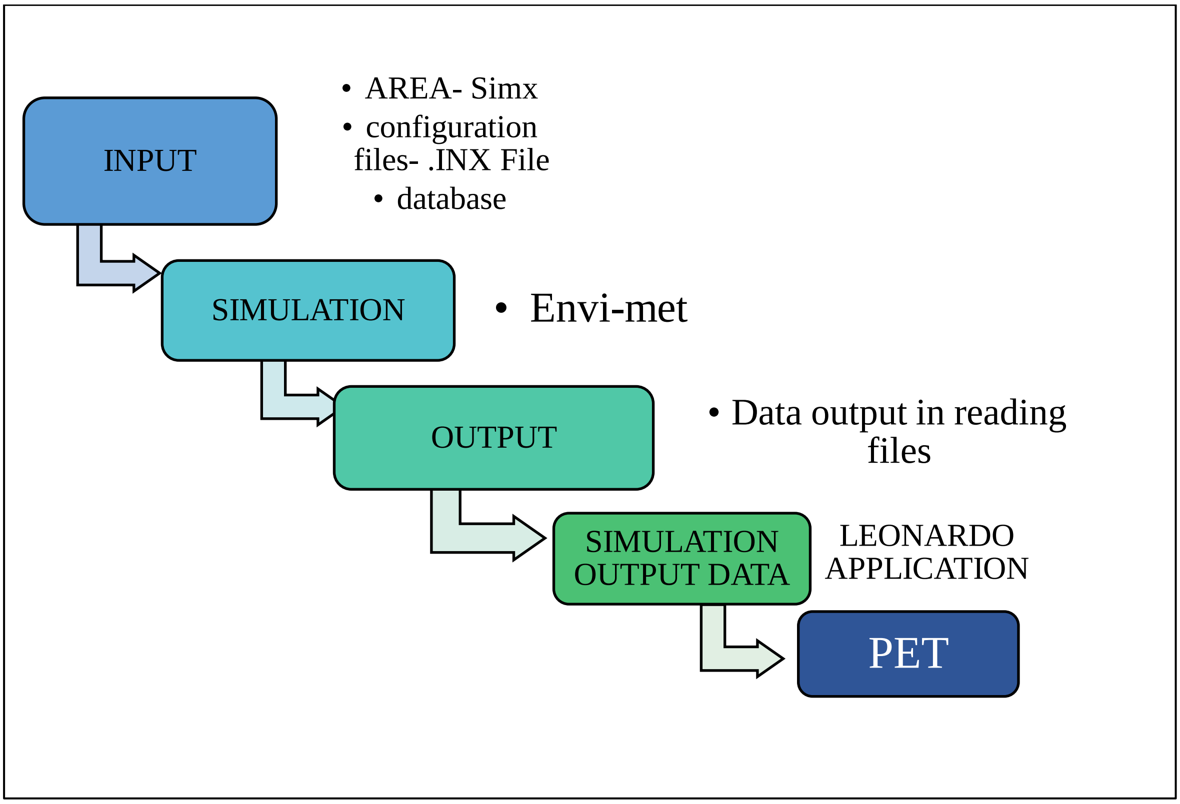


Figure 5.14 calculation of PET in Envi-met software.

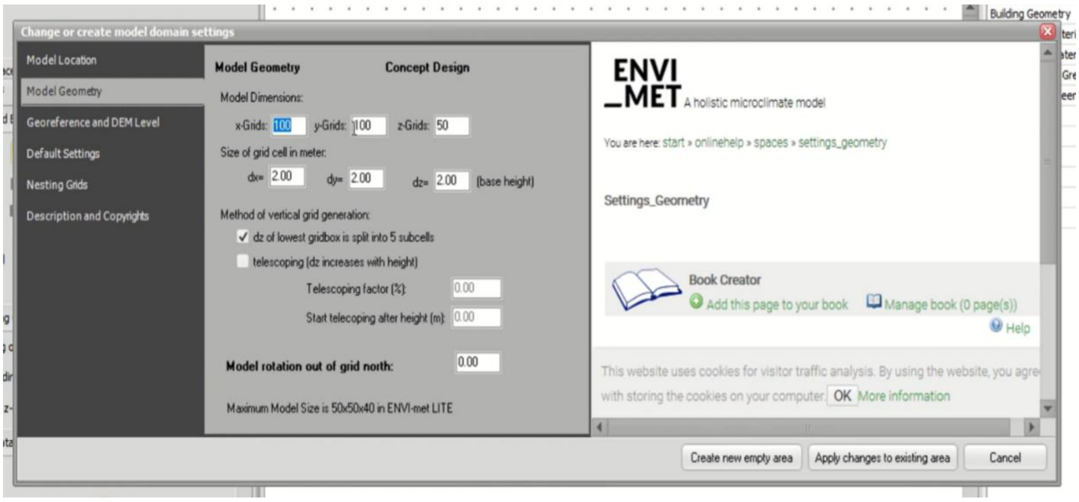


Figure 5.15 Model dimensions data entry- Envimet Software

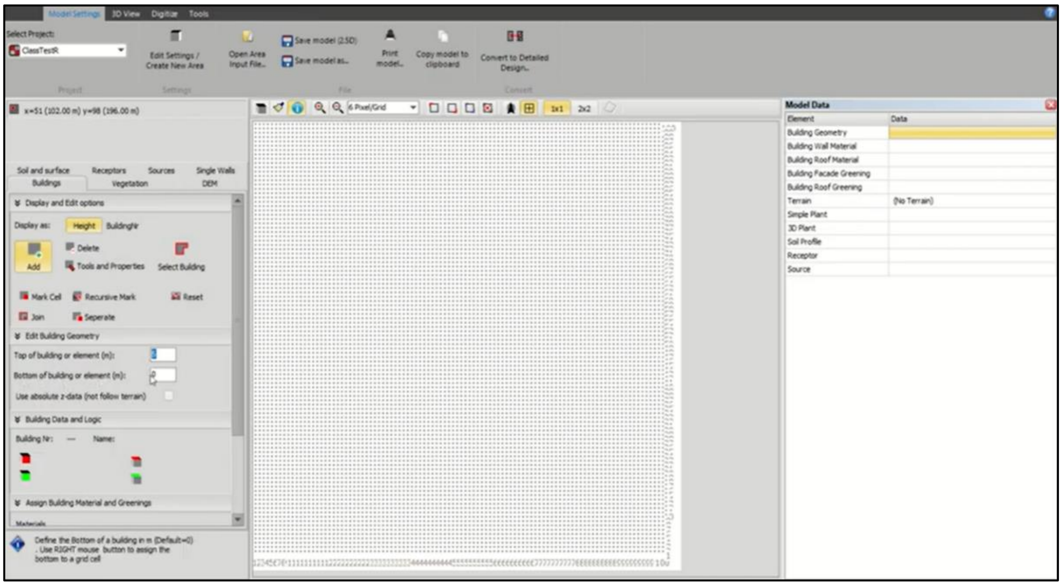


Figure 5.16 showing area for digitizing on Envi-met after data input

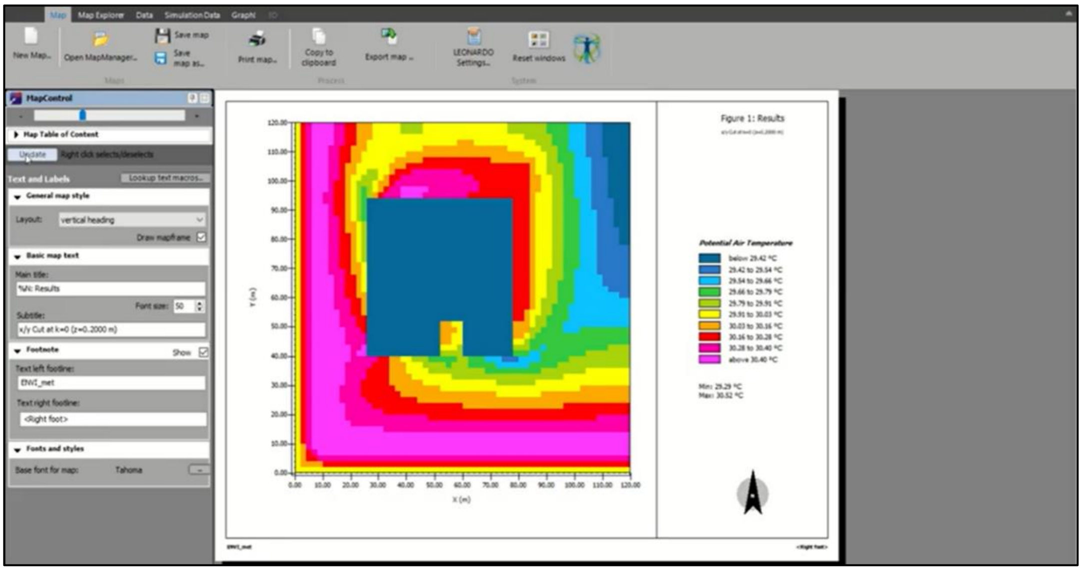


Figure 5.17 Visualization for simulated data on Leonardo; Envimet software

<table>
<tr><td></td><td>Station name</td><td>1</td><td>2</td><td>Source</td></tr>
<tr><td></td><td>Canyon orientation</td><td>North-south</td><td>North-south</td><td>Field</td></tr>
<tr><td rowspan="5">Model Area</td><td>Main model area</td><td>21000 sq.m</td><td>22500 sq.m</td><td rowspan="5">EnviMET</td></tr>
<tr><td>Grid size in meter</td><td>30*30*20</td><td>30*30*20</td></tr>
<tr><td>Dx= size of x grid</td><td>2</td><td>2</td></tr>
<tr><td>Dy= size of y grid</td><td>2</td><td>2</td></tr>
<tr><td>Dz= size of z grid</td><td>2</td><td>2</td></tr>
<tr><td rowspan="2">Construction material</td><td>Building material</td><td>Concrete</td><td></td><td>Field</td></tr>
<tr><td>Soil</td><td>Asphalt, clayey loam</td><td>Asphalt,clayey loam</td><td>ENVI-met</td></tr>
<tr><td>Position</td><td>Longitude
Latitude</td><td>22.33’17.59N
88,24’40.53E</td><td>22,30’30.46N
88,22’2.40E</td><td>ArcMap</td></tr>
<tr><td>Start and Duration of model</td><td>• Date of simulation
• Start time
• Total simulation time</td><td colspan="2">• 23.06.2019
• 12:00 pm
• 12 hours</td><td>ENVIMET</td></tr>
<tr><td rowspan="7">Initial meteorological conditions</td><td rowspan="2">• Roughness length at measurement site
• Initial temperature of atmosphere</td><td>0.7</td><td>0.01</td><td rowspan="2">Field</td></tr>
<tr><td>36.5</td><td>43.5</td></tr>
<tr><td rowspan="2">• Simple Forcing: Air temperature (K)
• Simple Forcing: Relative Humidity (%)</td><td>38.2 (c)</td><td>36.1 (c)</td><td rowspan="2">Field</td></tr>
<tr><td>64%</td><td>49%</td></tr>
<tr><td>• Specific humidity at model top (2500mg/kg)</td><td></td><td></td><td>IMD</td></tr>
<tr><td>• Wind speed at 10 m height (m/s)
• Wind direction</td><td>7m/s
South</td><td>7 m/s
South</td><td>IMD</td></tr>
</table>

Table 5.4 Showing input details to run simulation on EnviMet

With the help of Leonardo application, the representation of the simulated model is created. ENVI-met allow to overcome the limitations of recording continuous data over a long period of time and instrument security at measuring stations [4]. Envi-met also helps us to calculate the Physiological Equivalent Temperature (PET) as a thermal index to quantify thermal conditions in outdoor environment, using important microclimate parameters such as air temperature, mean radiant temperature, relative humidity and wind speed. [5]. Along with simulation the thermal comfort conditions are calculated using the Physiological Equivalent Temperature (PET) index.

The different ranges of thermal stress in the PET index were defined by Fanger. However, the question remains if the perception and sensation remain similar worldwide especially for tropical areas where people have greater adaptability and greater threshold to stressful heat conditions. however stressful conditions may aggravate and the adaptability of people may reduce owing to heating and cooling systems. PET considers the thermoregulatory mechanisms in the human body, the microclimate parameters and the adaptation mechanisms such as clothing conditions and metabolic activity (VDI). Verein Deutscher Ingenieure (VDI) guideline 3787, part 2 "Methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning, part I: climate" recommend PET index as a universal index for different parts of the world(VDI).

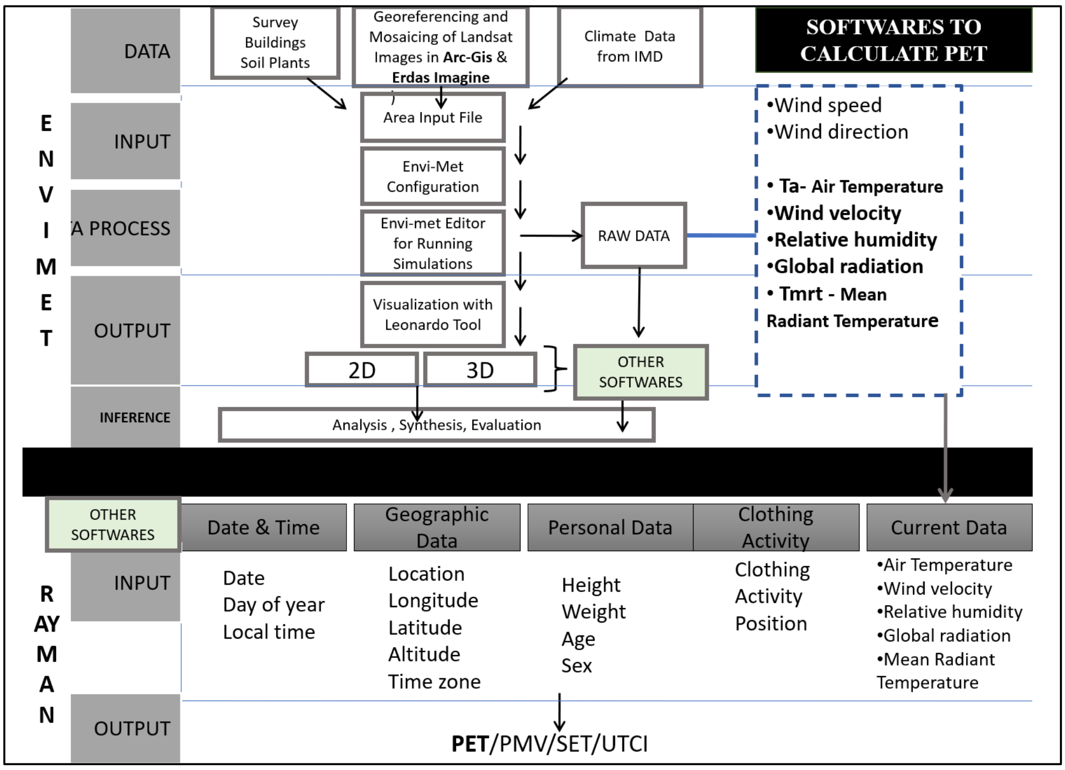


Figure 5.18 Flowchart showing the use of Envimet and Rayman software

5.4.2 RayMan for calculation of PET and mPET

PET and mPET both have been calculated on RayMan Pro 1.2. software. The software requires temporal, geographic, meteorological, physiological and behavioral data. Physiological data is labeled under personal data, behavioral adaptative data under clothing and activity while meteorological data under current data. Air temperature (Ta), Relative Humidity (RH), Surface Temperature (Ts), Radiation (G) have been measured with instrument. Cloud cover data is taken from Accu-weather website on the day and time of data collection. Temporal and geographic data is put according to study location. Personal data and clothing and metabolic activity is entered according to questionnaire survey. The required Outdoor thermal indices were PET and mPET. PET was defined by Dr. Peter Hoppe, mPET was defined by Prof.T.P. Lin, and RayMan Pro software was developed by Dr. Andreas Matzarakis. While there are studies with PET defining Outdoor Thermal comfort for tropical and temperate regions; mPET is solely regarded for sub-tropical and tropical hot, humid regions where the clothing pattern gives significant results.

The day, month and year is placed according to the study period, location time is provided by the time of data collection. Day of year is calculated as per the circadian chart. Location is provided in the drop-down menu. The latitude and longitude is automatically calculated with the provision of the location. Time zone and altitude is also automatically calculated.

The current data is entered one after the other and Vapour Pressure is calculated by the software on provision on Ta and RH. Mean radiant temperature can be calculated by the software but instead calculated mean radiant temperature, using the formula discussed, was added in the software.

The height weight age and gender were added according to the physiology of the respondents observed. Clothing Clo value was calculated for the Indian subcontinent region based on a paper that discussed South Asian dressing pattern. Activity was automatically calculated on provision of sitting or standing posture.

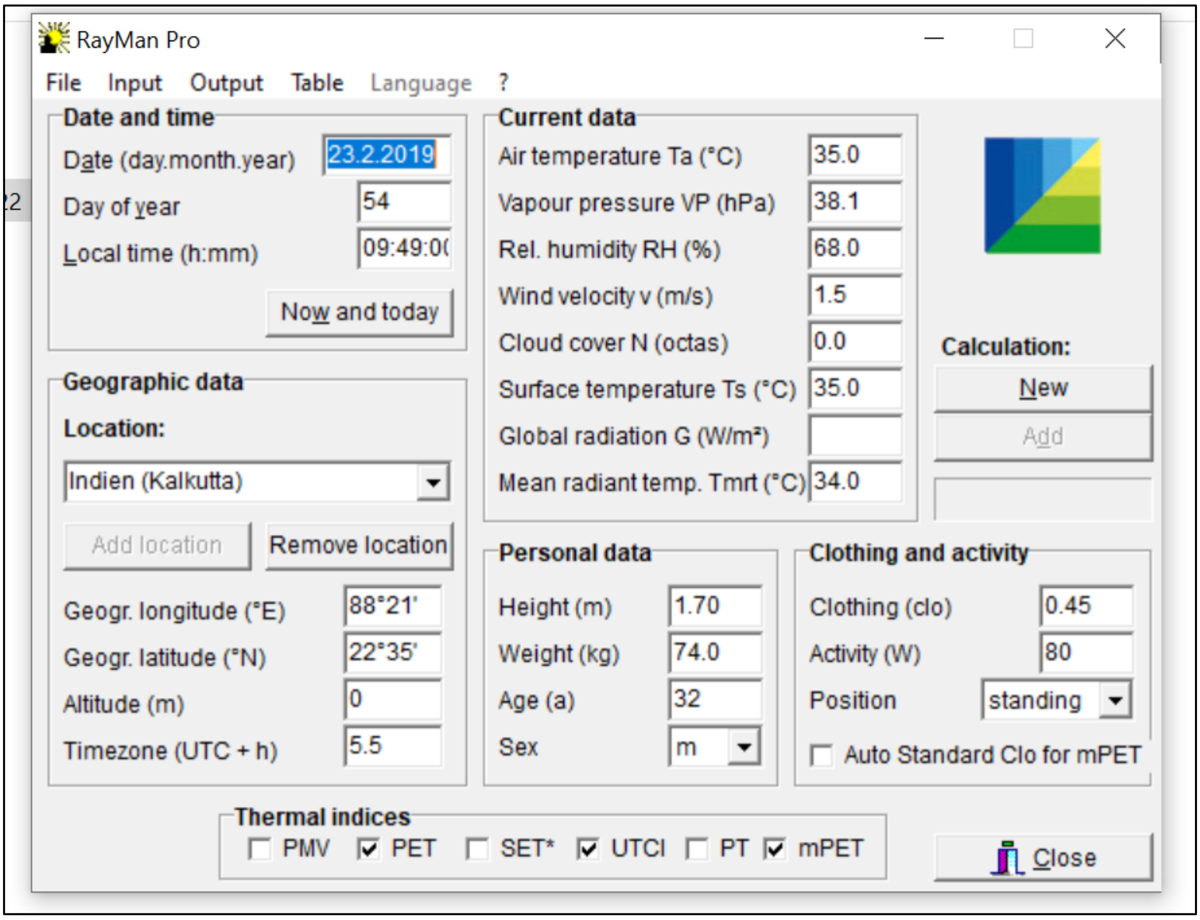


Figure 5.19 showing main window of RayMan Pro where all input details are put to calculate the mPET and other indices of Outdoor Thermal Comfort.

5.5 METHOD FOR CALCULATION OF NEUTRAL MPET & ACCEPTABLE RANGE OF mPET

Neutral mPET is the outdoor thermal conditions where respondents prefer no change in conditions and feel perfectly comfortable. The neutral conditions are reflected by the Thermal Sensation Vote (TSV) given by the ASHRAE as well as ISO standards.

TPV	ISO-10551 (1995)
3	Much Warmer
2	Warmer
1	Little Warmer
0	Neither Warmer Nor Cooler
-1	Slightly Cool
-2	Cooler
-3	Much Cooler

Table 5.6 showing Thermal Preference Vote (TPV)

TSV	ASHRAE-55 (2010)/ ISO-10551 (1995)
3	Hot
2	Warm
1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Table 5.5 showing Thermal Sensation Vote (TSV)

Neutral votes are considered those that are voting the option of thermal conditions as neutral and their preference is neither warmer nor cooler. Such votes are calculated for each 1^{o} C mPET interval group and regression analysis is done for both Mean TSV and mPET values. From the linear regression equation, the y value for neutral thermal sensation vote is entered to find the x value for Neutral mPET conditions. Refer Table 6.5 and Table 6.6 in Chapter 6.

5.6 ACCEPTABLE RANGE OF mPET

The acceptable range of mPET are the outdoor thermal conditions where people feel comfortable and can accept the conditions. According to ASHRAE Standard 55 conditions have to be acceptable to a minimum of 90% respondents in that condition or space while 10% feel unacceptable and such conditions are ‘acceptable thermal conditions. De Dear and

Fountain suggested that a vote outside the three central categories of the TSV scale is ‘‘unacceptable’’ vote. To calculate the acceptability vote, Thermal Preference Vote or Thermal Sensation vote is considered. Any votes beyond -1, 0, +1 is considered unacceptable. 0 stands for neutral thermal sensation and no change in preference. -1 stands for slightly warm sensation and slightly cool preference, +1 stands for slightly cool sensation and slightly warm preference.

The percentage of unacceptability is calculated by for the interval group of each 1^{o} C PET with the help of second-degree polynomial fitted curves to show 90% acceptability limits. The 90% acceptability limit is congruent with the 10% unacceptability limit. The points at which the 90% acceptability line cuts the polynomial curve, gives the lower and upper range in acceptable thermal comfort conditions.

5.7 CALCULATION OF COMFORTABLE LOCATION

To find the comfortable location, microclimate parameters of the study area and thermal perception of respondents were considered. The variables are computed to 3 principal components together which accounts for 78.495% variances. The level of variance for each variable can be seen from the table of communalities where the variance for each is more than 0.5 and rotated component matrix shows that Tg, Ta and Ts has high correlation with component 1; Wind speed with component 2 and RH with component 3. Weightages were distributed as follows: Tg, Ta and Ts having 20% weightage each; Windspeed and RH having 10% each and 0.55 given each to thermal sensation, thermal preference, thermal tolerance and thermal acceptability. The calculation is performed on SPSS software. The weights once calculated were fed in Arc GIS for raster analysis along with the raster layers for the variables. The layers included both meteorological data as well as thermal sensation distribution. The raster image after raster calculation for site-suitability, delineates the area that meet the conditions provided for outdoor comfort conditions.

5.8 STATISTICAL TECHNIQUES APPLIED

Correlations are required to understand the significance of relation between two parameters. The following correlation matrix was prepared to understand the relation between the parameters at 95% and 99% confidence level. In correlation, independent values and dependent variable have been identified before calculation. Correlation has been done by the Pearson’s Correlation method.

- Correlation between microclimate parameters such as Ta, Ts, RH, Tg, Tmrt, Va. and outdoor thermal conditions vis PET and mPET.
- Correlation between microclimate parameters such as Ta, Ts, RH, Tg, Tmrt, Va. and surface cover categories vis-built fraction, impermeable fraction, vegetation fraction, open area fraction and water fraction.
- Correlation between surface cover categories vis-built fraction, impermeable fraction, vegetation fraction, open area fraction and water fraction and outdoor thermal conditions vis PET and mPET.

in the first correlation, microclimate parameters are independent variables, in the second and third correlation, surface cover is the independent variable.

All calculations and representations have been done on Microsoft Excel and SPSS software.

Statistical Hypothesis testing

Hypothesis testing was performed to check the significance of Dynamic potential or higher share of natural surface cover. Hypothesis testing was performed with z-test at 95% and 99% confidence level. It is a two-tailed test for normal distribution. the hypothesis testing was calculated on two categories of surface cover. The first category has high share of Dynamic potential (calculated through Plan Area Fraction). The first category of stations is 25 in number. The second category of stations have low share of dynamic potential and the stations are 25 in number. The stations have been arranged in descending order of share of dynamic potential after which they were divided into two categories. The null hypothesis is that the hypothesized mean difference in mPET values in a two-tailed test at 0.05% significance level (95% confidence) is zero. Alternative hypothesis states that there is mean difference due to different share in dynamic potential.

5.9 LIMITATIONS OF METHODOLOGY

Outdoor thermal comfort is a study that includes several parameters and variables working together. The limitations of the methodology are as follows:

- The instrument is not in large numbers and data cannot be collected at all points simultaneously.
- Data for monsoons have not been collected to protect instruments.

- Continuous data monitoring could not be performed due to lack of manpower and total stations.
- All the parameters known through literature review have not been included hence effect of some parameters have been left out.
- Surface material reflectance and albedo have not been considered and hence the significance of impermeable surface could not be explained in detail.
- Shade as a factor is beyond the scope of this study and many built areas have shade properties.
- Manpower to collect microclimate data for 50 stations across the municipal area is limited.
- For long simulation hours, Envimet simulations were run for 2 stations only.

CHAPTER6: SURFACE COVER, MICROCLIMATE & OUTDOOR THERMAL COMFORT

6.1 MICROCLIMATE ANALYSIS

50 primary stations have been selected on basis of intersection points of east-west and north-south arterial roads of Kolkata Municipal area. Windspeed (Va), Globe Temperature (Tg), Relative Humidity (RH) and Air temperature (Ta) were recorded at 11 2:30 pm the stations for the four mentioned seasons of 2019 to calculate Tmrt followed by calculation of PET.

Windspeed is measured in metres per second, Globe temperature, Air Temperature and Surface temperature is measured in degree Celsius. Relative Humidity is measured in percentage. The sources of data are primary data at Canopy level. The data available for reference at Indian (Regional) Meteorological Stations in Kolkata are set at 10m or above to observe the climatic conditions at boundary level. However, at microlevel the instrument is set at pedestrian level to observe the conditions of outdoor thermal comfort at pedestrian level.

In the following maps of data of microclimate parameters for 50 stations red shades reflect high values and blue shades reflect low values. For example, high Ta has high RH and high Ts and high TG is shown in red shade. Low air temperature, globe temperature and surface temperature are shown in shades of blue. high. The Tmrt in summer is shown in shades from blue to red even though the lower values are relatively higher than in other seasons. The blue area indicates relatively lower values of the parameter. In summer the lowest value of 37^{O}C mPET is shown in blue and reflects conditions of high outdoor thermal discomfort according to the levels of stress synonymous with the mPET values.

The distribution of microclimate data of each microclimate parameter is shown in the following maps. Data obtained from 50 stations are interpolated using the IDW method and within the boundary of the Kolkata Municipal Corporation area.

6.1.1 DISTRIBUTION OF MICROCLIMATE PARAMETERS IN SPRING

Maximum Ta is 31^{o} C, Minimum Ta is24 ^{o} C, and average Ta is 27.92 ^{o} C. maximum Tg is 31^{o}C, Minimum Tg is 27^{o} C, and average Tg is 28.84 ^{o} C. Maximum Tmrt is 31 ^{o} C, Minimum Tmrt is 27 ^{o} C, and Average Tmrt is 28.80 ^{o} C. Maximum RH is 69%, Minimum Humidity is 39% and average humidity is 52.18%. maximum windspeed is 5.5 m/s, minimum windspeed is 0 m/s and average windspeed is 1.85 m/s.

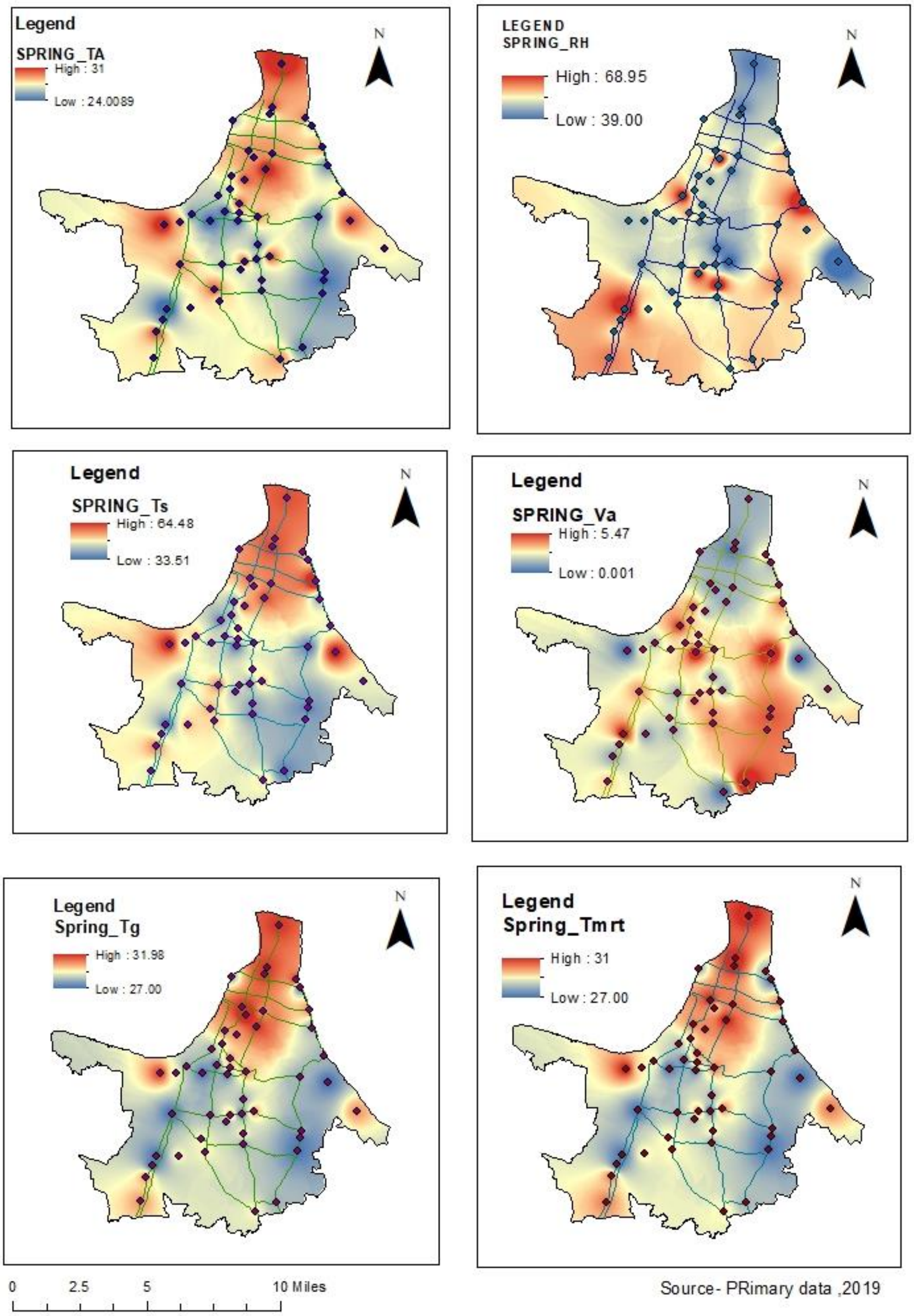


Figure 6.1 shows microclimate map of spring season, 2019, for air temperature (Ta), Surface temperature (Ts), Relative Humidity (RH), Globe Temperature (Tg), Wind speed (Va) and mean radiant temperature (Tmrt).

6.1.2 Distribution of microclimate parameters in summer

Maximum Ta in summer is 42 ° C, minimum Ta is 36.4 ° C and average Ta is 38.73 ° C. Maximum Tg is 53.6 ° C, minimum Tg is 37.0 ° C, Average Tg is 44.29 ° C. Maximum RH is 67%, minimum is 43% and average is 53.11%. Va is 4.6 m/s at maximum, minimum windspeed is 0 m/s and average windspeed is 1.81 m/s. Maximum Tmrt is 53.6 ° C, Minimum Tmrt is 34.3 ° Cand Average Tmrt is 44.09 ° C.

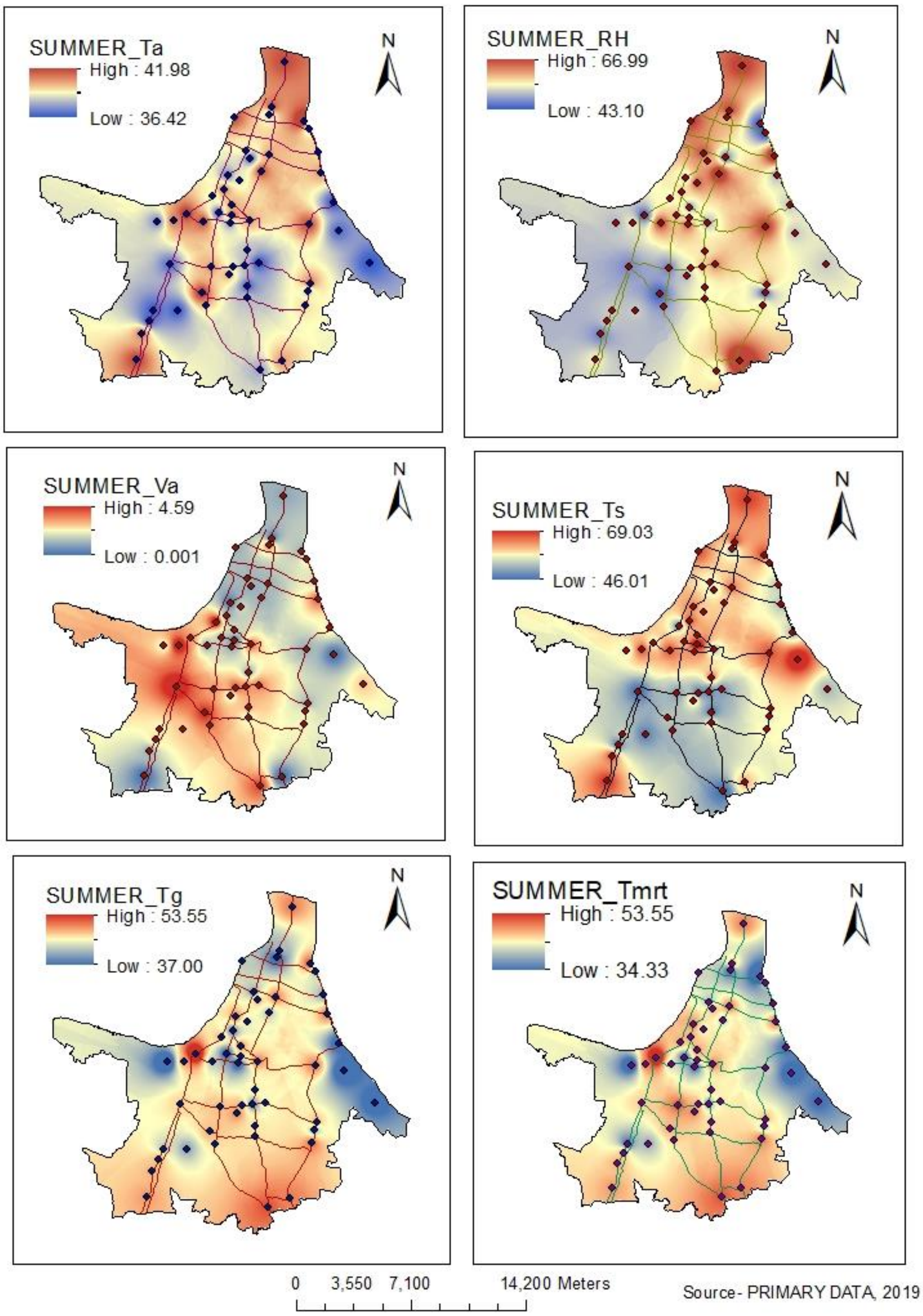


Figure 6.2 shows microclimate map of summer season, 2019, for air temperature (Ta), Surface temperature (Ts), Relative Humidity (RH), Globe Temperature (Tg), Wind speed (Va) and mean radiant temperature (Tmrt).

6.1.3 Distribution of microclimate parameters in autumn

Maximum Ta in summer is 30 ^{o} C, minimum Ta is 24 ^{o} C and average Ta is 27.30 ^{o} C. Maximum Tg is 35 ^{o} C, minimum Tg is 27.0 ^{o} C, Average Tg is 28.92 ^{o} C. Maximum RH is 76%, minimum is 61% and average is 67.70%. Va is 5.5 m/s at maximum, minimum windspeed is 0 m/s and average windspeed is 1.81 m/s. Maximum Tmrt is 35 ^{o} C, Minimum Tmrt is 25 ^{o} Cand Average Tmrt is 28.7 ^{o} C.

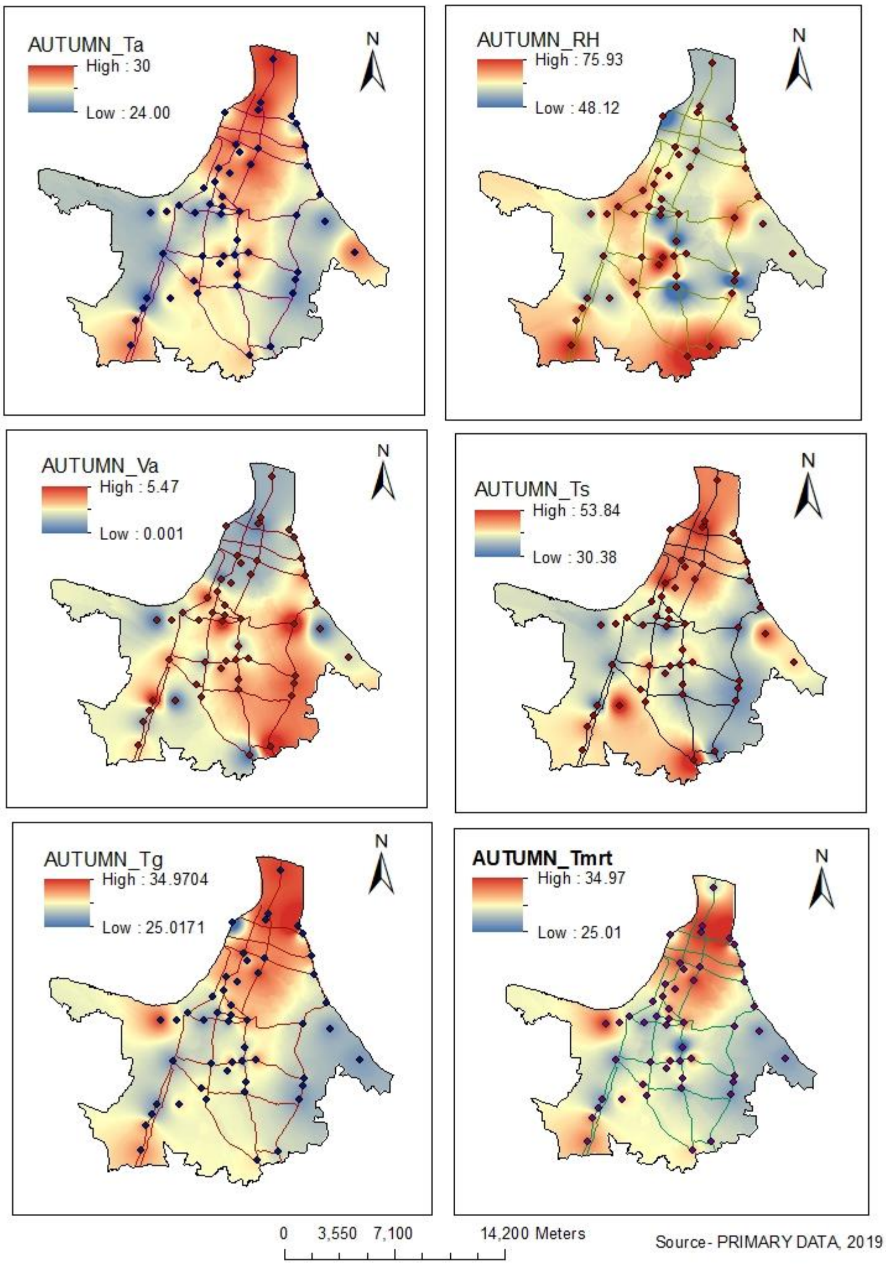


Figure 6.3 shows microclimate map of autumn season, 2019, for air temperature (Ta), Surface temperature (Ts), Relative Humidity (RH), Globe Temperature (Tg), Wind speed (Va) and mean radiant temperature (Tmrt).

6.1.4 Distribution of microclimate parameters in winter

Maximum Ta is 28 ^{o} C, Minimum Ta is 18 ^{o} Cand Average Ta is 24.34 ^{o} C. Maximum Tg is 29 ^{o} C, Minimum Tg is 19 ^{o} C, Average Tg is 25.97 ^{o} C. Maximum RH IS 51.9%, Minimum RH is 34% while average RH is 40.41%. Windspeed in winter is maximum at 5.32 m/s, Minimum windspeed is 28.37 m/s and average is 16.30 m/s. Maximum Tmrt is 29 ^{o} C, Minimum Tmrt is 19 ^{o} C and Average Tmrt is 25.47 ^{o} C.

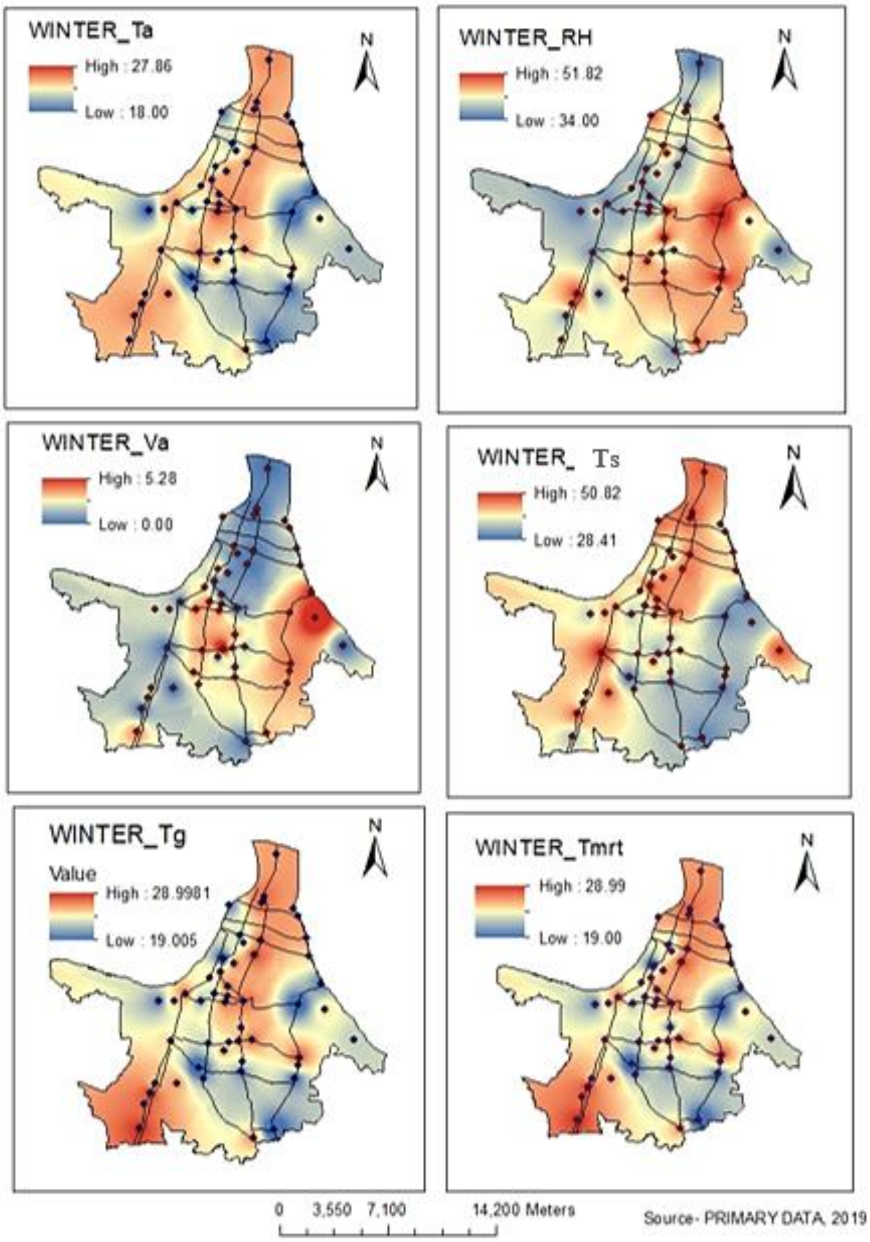


Figure 6.4 shows microclimate map of winter season, 2019, for air temperature (Ta), Surface temperature (Ts), Relative Humidity (RH), Globe Temperature (Tg), Wind speed (Va) and mean radiant temperature (Tmrt).

6.1.5 Trend of distribution of air temperature (ta), relative humidity (rh) and windspeed (va)

The trend in Ta, RH and wind for the four seasons is given as follows. In the following figures from 5-e to 5-h, stations are on the x-axis. On the y-axis is RH in percentage and Ta in degree Celsius. In spring, the average Ta is 29 ^{o} C; RH- 60-65% and VA- 1.88m/s. In summer, the a

verage Ta is 39-40^{o} C, RH- 75-80% and VA- 1.81 m/s.

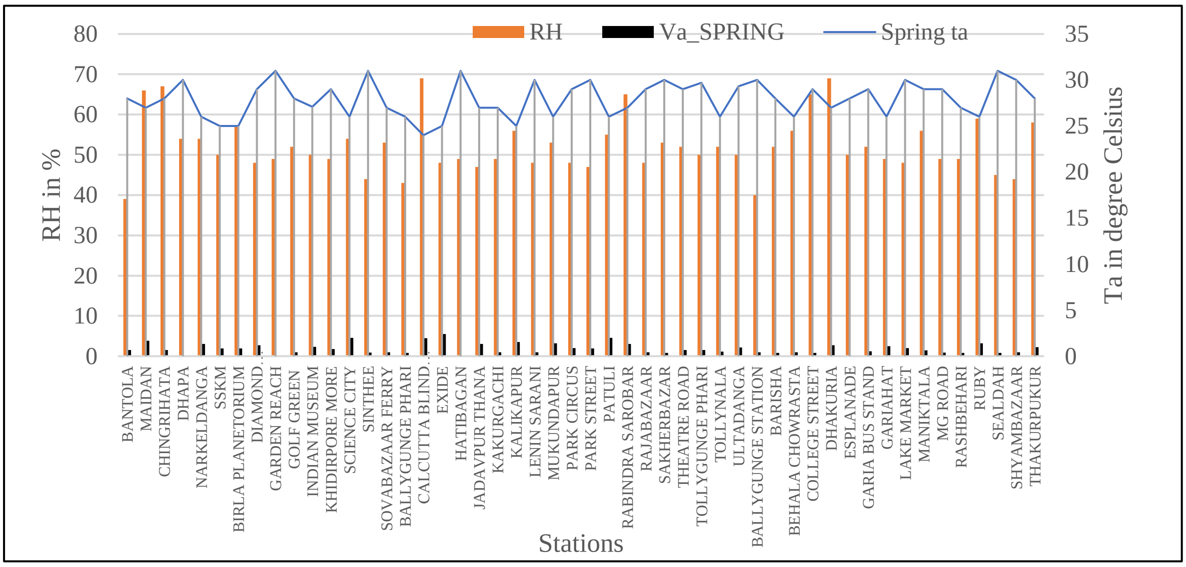


Figure.6.5 showing Ta, RH and Va in Spring, 2019

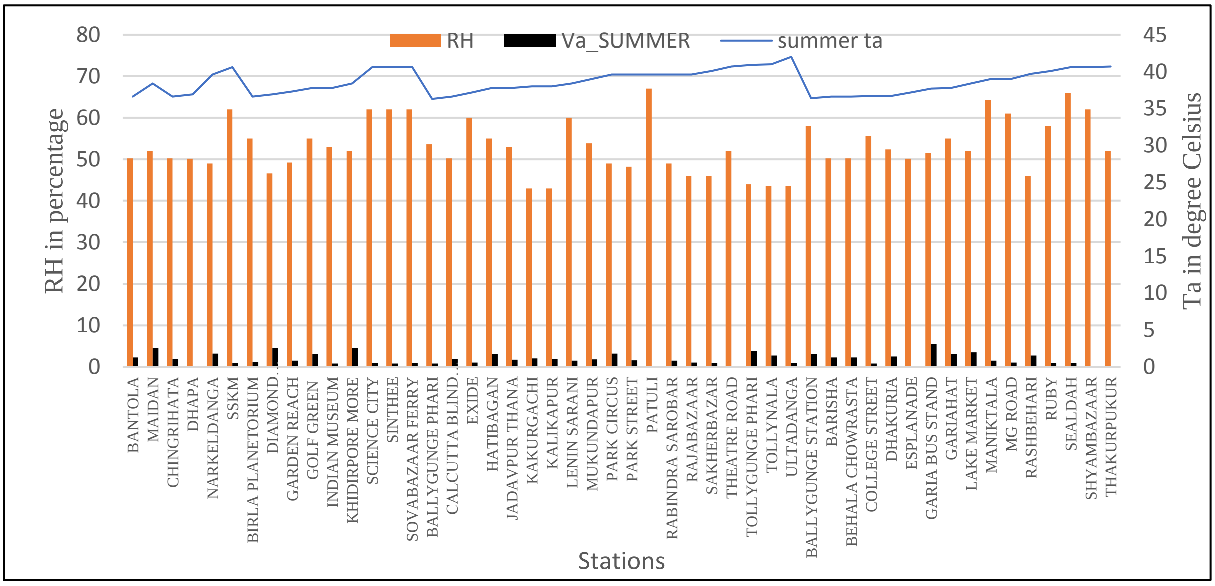


Figure 6.6 Ta, RH and Va in Summer, 2019

In spring, the average Ta is 27-28 ^{o}C; RH- 48-50% and VA- 1.8 m/s. In summer, the average Ta is 19-20^{o} C, RH- 39-50% and VA- 1.21 m/s. The air temperature and relative humidity conditions in summer exceeds the conditions in spring, autumn and winter.

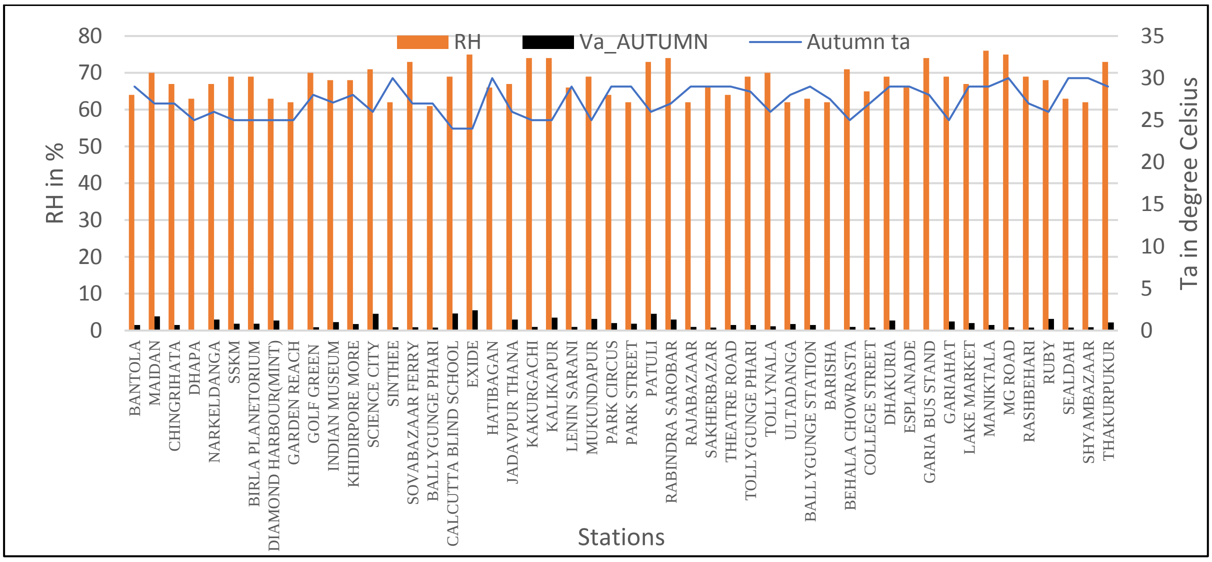


Figure 6.7 Ta, RH and Va in Autumn, 2019

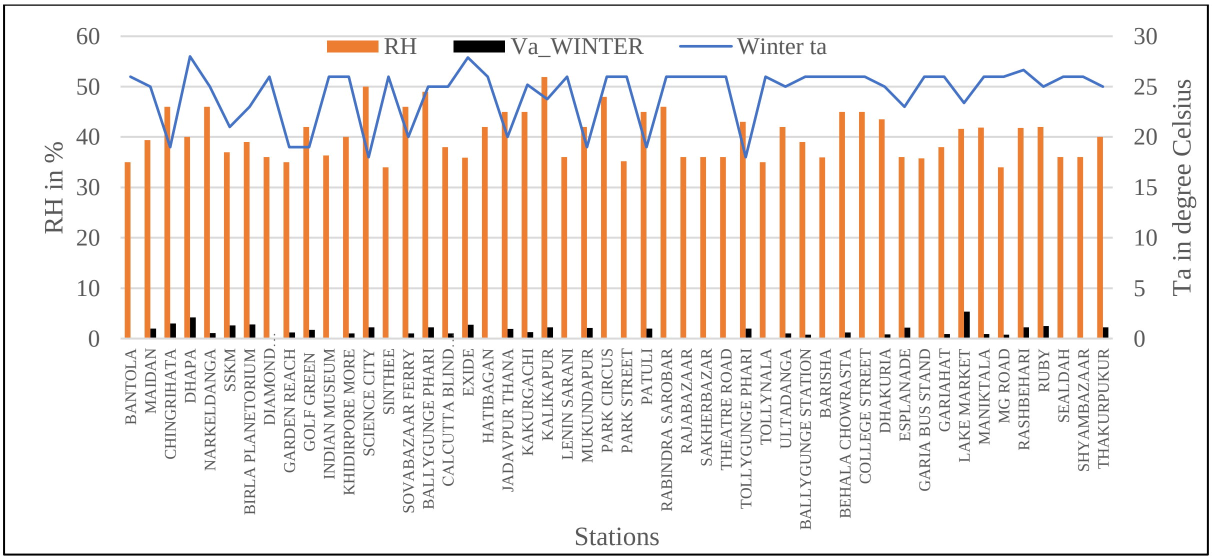


Figure 6.8 Ta, RH and Va in Winter, 2019

The wind speed in all the seasons is less than 10 m/s. in all the stations. The windspeed can be studied in the following graph where it is seen that windspeed is higher in Spring, summer and autumn than in winter. The median windspeed for spring is 1.5 m/s, for summer it is 1.6 m/s, for autumn it is 1.5 m/s and for winter it is 1.0 m/s.

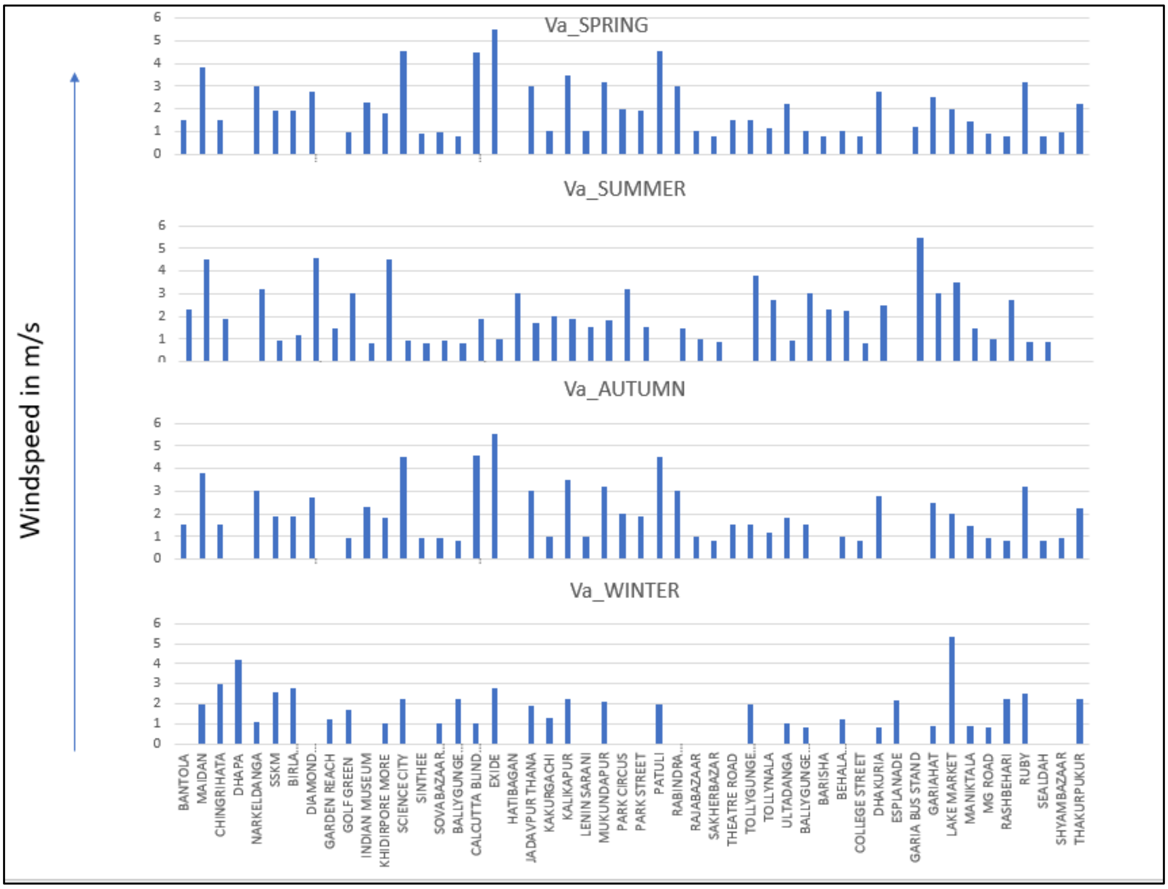


Figure 6.9 showing windspeed (Va) in m/s for four seasons, 2019.

Tmrt is a function of Ta and Tg as learnt from the literature review. Refer tables 6a, 6b, 6c, 6d for microclimate parameters in spring, summer, autumn and winter, 2019.

6.1.6 Inference from microclimate data

- The microclimate distribution in four seasons of the year 2019, show that areas that have high values of Ta, correspond with areas having high values of Tg and Tmrt. Refer Table 6.1, 6.2, 6.3, 6.4 in the subsequent pages.
- Same figures show that areas with high recorded windspeed at 1m level has low Ta, Tg, Tmrt.
- Summer has the highest temperatures compared to the other seasons.
- Wind speed is lowest in winter.

Sr no.	SITE	TA	TG	RH	VA	Ts	Ta	VP	RH	Tmrt
1	BALLYGUNGE_PHARI	26	28	43	0.8	48	26	14.4	42.9	28
2	BALLYGUNGE_STATION	30	30	40	1	50.4	30	16.9	39.9	30
3	BANTOLA	28	30	39	1.5	45.7	28	14.7	39	30
4	BARISHA	28	29	52	0.8	50	28	19.6	52	29
5	BEHALA_CHOWRASTA	26	27	56	1	46.7	26	18.8	56	27
6	BIRLA_PLANETORIUM	25	27	57	1.9	44.2	25	18	56.9	27
7	CALCUTTA_BLIND_SCHOOL	24	27	69	4.5	35.7	24	20.6	69.2	27
8	CHINGRIHATA	28	28	67	1.52	45.8	28	25.3	67.1	28
9	COLLEGE_STREET	29	32	65	0.81	50.9	29	26	65.1	29
10	DHAKURIA	27	29	69	2.75	40.1	27	24.6	69.1	29
11	DHAPA	30	27	54	0	59.8	30	22.9	54.1	27
12	DIAMOND_HARBOUR(MINT)	29	27	48	2.74	42.3	29	19.2	48	27
13	ESPLANADE	28	30	50	3	40.5	28	18.9	50.1	30
14	EXIDE	25	27	48	5.5	33.4	25	15.2	48.1	27
15	GARDEN_REACH	31	31	49	0	60.7	31	22	49.1	31
16	GARIA_BUS_STAND	29	29	52	0	48.3	29	20.8	52	29
17	GARIAHAT	26	27	49	2.5	39.9	26	16.4	48.9	27
18	GOLF_GREEN	28	29	52	0.94	49.2	28	19.6	52	29
19	HATIBAGAN	27	31	49	0	57.1	27	17.4	48.9	31
20	INDIAN_MUSEUM	27.1	29	50	2.29	41.6	27.1	17.9	50	29
21	JADAVPUR_THANA	27	28	47	3.02	39.5	27	16.7	46.9	28
22	KAKURGACHI	27	27	49	1	47.6	27	17.4	48.9	27
23	KALIKAPUR	25	27	56	3.5	36.5	25	17.7	56	27
24	KHIDIRPORE_MORE	29	29	49	1.8	45.3	29	17.4	43.5	29
25	LAKE_MARKET	30	30	48	2	45.5	30	20.3	48	30
26	LENIN_SARANI	30	30	48	1	54.4	30	20.3	48	30
27	MAIDAN	27	28	66	3.82	37.9	27	23.5	66	28
28	MANIKTALA	29	30	56	1.47	64.6	29	22.4	56.1	30
29	MG_ROAD	29	31	49	0.9	54.3	29	19.6	49	31
30	MUKUNDAPUR	26	27	53	3.18	40.5	26	17.8	53.1	27
31	NARKELDANGA	26	28	54	3.02	41	26	18.1	54	28
32	PARK_CIRCUS	29	30	48	2	47.6	29	19.2	48	30
33	PARK_STREET	30	30	47	1.9	49	30	19.9	47	30
34	PATULI	26	28	55	4.53	37.6	26	18.5	55.1	28
35	RABINDRA_SAROBAR	27	28	65	3	42	27	23.1	64.9	28
36	RAJABAZAAR	29	30	48	1	53.5	29	19.2	48	30
37	RASHBEHARI	27	28	49	0.8	53.2	27	17.4	48.9	28
38	RUBY	26	28	59	3.18	40.5	26	19.8	59	28
39	SAKHERBAZAR	30	30	53	0.8	53.5	29	19.2	48	30
40	SCIENCE_CITY	26	28	54	4.53	37.6	26	18.1	54	28
41	SEALDAH	31	31	45	0.8	56.9	31	20.2	45.1	31
42	SHYAMBAZAAR	30	31	44	0.94	55.2	30	18.6	43.9	31
43	SINTHEE	31	31	44	0.9	56.1	31	19.7	44	31
44	SOVABAZAAR_FERRY	27	28	53	0.94	52.4	27	18.9	53.1	28
45	SSKM	25	27	50	1.9	44.2	25	15.8	50	27
46	THAKURPUKUR	28	30	58	2.22	45.8	28	21.9	58.1	30
47	THEATRE_ROAD	29	30	52	1.5	50.1	29	20.8	52	30
48	TOLLYGUNGE_PHARI	29.7	29	50	1.52	50.8	29.7	20.8	50	29
49	TOLLYNALA	26	28	52	1.15	49.9	26	17.4	51.9	29
50	ULTADANGA	29.3	31	50	2.2	53	29.3	17.4	42.8	28

Table 6.1 showing microclimate data for Spring- air temperature (Ta) in o C, Globe temperature (Tg) in o 52C, Relative Humidity (RH) in%, windspeed (Va) in km/hr, calculated mean radiant temperature (Tmrt53) in o C.

Sr no.	SITE	TA	TG	RH	VA	Ts	Ta	VP	Tmrt
1	BALLYGUNGE_PHARI	38	45	53.6	0.8	59.2	38	35.4	45
2	BALLYGUNGE_STATION	36.4	44.9	58	3	48.7	36.4	35.1	44.9
3	BANTOLA	36.6	39.5	50.2	2.29	50.8	36.6	30.7	39.5
4	BARISHA	36.6	42	50.2	2.29	47.2	36.6	30.7	42
5	BEHALA_CHOWRASTA	36.6	46	50.2	2.22	47.2	36.6	30.7	46
6	BIRLA_PLANETORIUM	36.6	38.7	55	1.15	56	36.6	33.7	38.7
7	CALCUTTA_BLIND_SCHOOL	36.6	43	50.2	1.9	52.2	36.6	30.7	39.5
8	CHINGRIHATA	36.6	39.5	50.2	2	51.1	36.6	30.7	39.5
9	COLLEGE_STREET	36.7	46	55.6	0.8	52.6	36.6	34	46
10	DHAKURIA	36.7	45	52.4	2.5	46.7	36.6	32.1	45
11	DHAPA	36.9	38.2	50.1	0	65.8	36.9	31.2	38.2
12	DIAMOND_HARBOUR(MINT)	36.9	45.3	46.6	4.6	46.2	36.9	29	45.3
13	ESPLANADE	37.2	47	50.1	0	58.8	37	31.3	47
14	EXIDE	37.2	38.2	60	1	57.1	37.2	37.9	38.2
15	GARDEN_REACH	37.3	37	49.2	1.8	53.2	37.3	31.3	37
16	GARIA_BUS_STAND	37.7	48	51.5	3.5	46	37.7	33.4	48
17	GARIAHAT	37.8	41	55	3.02	46.9	37.8	35.9	41
18	GOLF_GREEN	37.8	39	55	3.02	50	37.8	35.9	39
19	HATIBAGAN	37.8	39	55	3.02	50	37.8	35.9	39
20	INDIAN_MUSEUM	40	41	54	0.8	61	40	39.7	46.1
21	JADAVPUR_THANA	38	45	53	1.68	54.3	38	35	45
22	KAKURGACHI	38	43	43	2	53.1	38	28.4	43
23	KALIKAPUR	38	42.6	43	1.9	53.1	38	28.4	42.6
24	KHIDIRPORE_MORE	40	46.1	52	4.53	60.9	40.6	47	47
25	LAKE_MARKET	38.4	46.1	52	3.5	46.7	38.4	35.1	46.1
26	LENIN_SARANI	38.4	44	60	1.52	55.6	38.4	40.5	44
27	MAIDAN	38.4	46.1	52	4.53	47.8	38.4	35.1	46.1
28	MANIKTALA	39	42.4	64.3	1.47	51.8	39	44.8	42.4
29	MG_ROAD	39	42	61	1	53.8	39	42.5	42
30	MUKUNDAPUR	39	47.3	53.8	1.8	54.8	39	37.5	47.3
31	NARKELDANGA	39.6	47	49	3.18	51.3	39.6	35.2	47
32	PARK_CIRCUS	39.6	47	49	3.18	51.3	39.6	35.2	47
33	PARK_STREET	39.6	47	48.2	1.53	56.7	39.6	34.7	47
34	PATULI	39.6	47	67	0	56.7	39.6	48.2	47
35	RABINDRA_SAROBAR	39.6	47	49	1.5	56.7	39.6	34.7	47
36	RAJABAZAAR	39.6	47	46	1	59.4	39.6	33.1	47
37	RASHBEHARI	39.7	45.9	46	2.74	49.3	39.7	33.3	48
38	RUBY	40.1	46	58	0.9	55.3	40.1	42.8	46
39	SAKHERBAZAR	40.1	46	46	0.9	60.5	40.1	33.1	46
40	SCIENCE_CITY	40.6	47	62	0.94	60.9	40.6	47	43
41	SEALDAH	40.6	43.1	66	0.9	55.8	40.6	50.1	43.1
42	SHYAMBAZAAR	40.6	43.1	62	0	62	40.6	47	46.4
43	SINTHEE	40.6	47	62	0.8	61.6	40.6	47	47
44	SOVABAZAAR_FERRY	40.6	43.1	62	0.94	60.9	40.6	47	43.1
45	SSKM	40.6	43.1	62	0.94	60.9	40.6	47	43.1
46	THAKURPUKUR	40.7	46.4	52	0	62.1	40.7	39.6	46.4
47	THEATRE_ROAD	40.7	46.4	52	0	69.1	40.7	39.6	46.4
48	TOLLYGUNGE_PHARI	40.9	45.9	44	3.82	51.4	40.9	33.9	45.9
49	TOLLYNALA	41	53.6	43.6	2.75	53.6	41	33.8	53.6
50	ULTADANGA	42	48	43.6	0.93	62.2	42	33.8	34.3

Table 6.2 showing microclimate data for Summer- air temperature (Ta) in o C, Globe temperature (Tg) in o C, Relative Humidity (RH) in%, windspeed (Va) in km/hr, calculated mean radiant temperature (Tmrt) in o C.

Sr no.	SITE	TA	TG	RH	VA	Ts	Ta	VP	Tmrt
1	BALLYGUNGE_PHARI	27	28	54	0.8	43	27	19.2	25
2	BALLYGUNGE_STATION	29	30	63	1.53	43.6	29	25.2	30
3	BANTOLA	29	27	64	1.5	42.3	29	25.6	27
4	BARISHA	27.5	29	62	0	52.6	27.5	22.7	29
5	BEHALA_CHOWRASTA	25	27	71	1	42.2	25	22.5	27
6	BIRLA_PLANETORIUM	25	27	69	1.9	37.1	25	21.8	27
7	CALCUTTA_BLIND_SCHOOL	24	27	59	4.6	31.2	24	17.6	27
8	CHINGRIHATA	27	28	67	1.52	35.2	27	24.9	28
9	COLLEGE_STREET	27	29	65	0.81	45.3	27	23.1	29
10	DHAKURIA	29	29	69	2.75	39.8	29	27.6	29
11	DHAPA	25	27	63	0	48.1	25	19.9	27
12	DIAMOND_HARBOUR(MINT)	25	27	63	2.74	35.1	25	19.9	27
13	ESPLANADE	29	30	66	0	53.9	29	26.4	29
14	EXIDE	24	27	54	5.5	30.3	24	16.1	27
15	GARDEN_REACH	25	31	62	0	35.1	25	19.9	31
16	GARIA_BUS_STAND	28	29	74	0	53	28	27.9	29
17	GARIAHAT	25	27	69	2.5	36.6	25	21.8	27
18	GOLF_GREEN	28	29	70	0.94	44	28	26.4	29
19	HATIBAGAN	30	31	67	0	52.6	30	28.4	31
20	INDIAN_MUSEUM	27.1	29	68	2.29	38	27.1	24.3	29
21	JADAVPUR_THANA	26	28	48	3.02	34.6	26	16.1	27
22	KAKURGACHI	25	27	62	1	40.7	25	19.6	27
23	KALIKAPUR	25	27	48	3.5	33.6	25	15.2	27
24	KHIDIRPORE_MORE	28	29	68	1.8	40.3	28	24.3	29
25	LAKE_MARKET	29	30	76	2	41.9	29	30.4	30
26	LENIN_SARANI	29	30	66	1	44.4	29	26.4	30
27	MAIDAN	27	28	70	3.82	40.4	27	23.8	28
28	MANIKTALA	29	30	64	1.47	43.6	29	25.6	30
29	MG_ROAD	30	31	65	0.9	47.5	30	27.5	31
30	MUKUNDAPUR	25	27	69	3.18	34.3	25	21.8	27
31	NARKELDANGA	26	28	67	3.02	35.5	26	22.5	28
32	PARK_CIRCUS	29	30	64	2	40.7	29	25.6	30
33	PARK_STREET	29	30	62	1.9	40.7	29	25.6	30
34	PATULI	26	28	73	4.53	33.3	26	24.5	28
35	RABINDRA_SAROBAR	27	28	74	3	36.4	27	26.3	28
36	RAJABAZAAR	29	30	62	1	44.4	29	24.8	30
37	RASHBEHARI	27	28	65	0.8	45.3	27	27.5	28
38	RUBY	26	28	68	3.18	36	26	22.8	28
39	SAKHERBAZAR	29	30	66	0.8	45.5	29	26.4	30
40	SCIENCE_CITY	26	28	71	4.53	33.3	26	23.8	28
41	SEALDAH	30	31	63	0.8	47.5	30	26.2	31
42	SHYAMBAZAAR	30	31	62	0.94	47.5	30	26.2	31
43	SINTHEE	30	31	62	0.9	45.9	30	26.2	28
44	SOVABAZAAR_FERRY	27	25	54	0.94	43	27	19.2	28
45	SSKM	25	27	69	1.9	37.1	25	21.8	27
46	THAKURPUKUR	29	30	73	2.22	41.3	29	29.2	30
47	THEATRE_ROAD	29	30	64	1.5	42.3	29	25.6	30
48	TOLLYGUNGE_PHARI	28.4	29	69	1.52	41.7	28.4	26.6	29
49	TOLLYNALA	26	28	70	1.15	42.6	26	23.5	28
50	ULTADANGA	28	35	62	1.8	41.6	28	23.4	35

Table 6.3 showing microclimate data for Autumn- air temperature (Ta) in o C, Globe temperature (Tg) in o C, Relative Humidity (RH) in%, windspeed (Va) in km/hr, calculated mean radiant temperature (Tmrt) in o C.

Sr no.	SITE	TA	TG	RH	VA	Ts	Ta	VP	Tmrt
1	BALLYGUNGE_PHARI	25	26	49	2.21	34.2	20	10.7	22
2	BALLYGUNGE_STATION	26	28	39	0.8	41	26	13.1	28
3	BANTOLA	22	24	35	0	47.1	22	9.2	24
4	BARISHA	26	27	35.99	0	46.6	26	12.1	27
5	BEHALA_CHOWRASTA	26	29	45	1.25	38.8	26	15.1	29
6	BIRLA_PLANETORIUM	23	23.2	39	2.8	33.8	23	10.9	23.2
7	CALCUTTA_BLIND_SCHOOL	25	26	48	1	39.1	25	15.2	26
8	CHINGRIHATA	19	22	46	3	28.4	18	9.5	22
9	COLLEGE_STREET	23	25	45	0	36	23	15.1	25
10	DHAKURIA	23	25	43.5	0.81	38.1	23	12.2	25
11	DHAPA	24	26	40	4.2	32.4	24	11.9	26
12	DIAMOND_HARBOUR(MINT)	25	26	36	0	50	25	11.4	26
13	ESPLANADE	23	19	36	2.2	33.1	23	10.1	19
14	EXIDE	27.88	28	35.9	2.75	36.9	27	18.5	26
15	GARDEN_REACH	19	22	35	1.2	35	19	7.7	22
16	GARIA_BUS_STAND	25	27	35.8	0	35	25	11.4	27
17	GARIAHAT	23	27	38	0.9	37.5	23	10.7	27
18	GOLF_GREEN	19	21	42	1.7	33	19	9.2	21
19	HATIBAGAN	26	28	42	0	46.7	26	14.1	28
20	INDIAN_MUSEUM	26	27	36.32	0	50.9	26	12.1	27
21	JADAVPUR_THANA	20	22	45	1.9	30.7	20	10.5	22
22	KAKURGACHI	25.2	27	45	1.3	37.7	25	10.5	27
23	KALIKAPUR	23.78	26	51.9	2.25	34	24	15.5	26
24	KHIDIRPORE_MORE	26	26	40	1	43	26	13.4	26
25	LAKE_MARKET	23.38	25	41.6	5.32	28.9	23	11.7	25
26	LENIN_SARANI	26	28	40	0	46.7	26	13.4	28
27	MAIDAN	24	25	39.4	1.97	36.9	24	11.7	25
28	MANIKTALA	26	27	41.9	0.9	40.5	26	14.1	27
29	MG_ROAD	22	24	42	0.8	37.1	22	11.1	24
30	MUKUNDAPUR	19	21	42	2.1	29.4	19	9.2	21
31	NARKELDANGA	25	26	46	1.12	41.6	25	14.5	26
32	PARK_CIRCUS	26	28	48	0	46.8	26	16.1	28
33	PARK_STREET	26	28	35.2	0	46.6	26	11.8	28
34	PATULI	19	20	45	2	29.7	19	9.9	20
35	RABINDRA_SAROBAR	26	27	46	0	46.8	26	15.4	27
36	RAJABAZAAR	26	28	36	0	46.6	26	12.1	28
37	RASHBEHARI	26.66	24	41.8	2.24	36.8	26.7	14.6	24
38	RUBY	25	29	42	2.5	34.5	25	13.3	29
39	SAKHERBAZAR	26	28	36	0	46.6	26	12.1	28
40	SCIENCE_CITY	18	20	50	2.26	30.2	18	10.3	20
41	SEALDAH	26	29	36.01	0	46.6	26	12.1	29
42	SHYAMBAZAAR	26	28	36	0	46.6	26	12.1	28
43	SINTHEE	26	27	34	0	46.5	26	11.4	27
44	SOVABAZAAR_FERRY	20	22	46	1	46.5	26	11.4	27
45	SSKM	21	23	37	2.6	33.8	23	10.9	23.2
46	THAKURPUKUR	25	29	40	2.26	34.9	25	12.6	29
47	THEATRE_ROAD	26	27	36	0	46.6	26	12.1	27
48	TOLLYGUNGE_PHARI	18	19	43	2	28.7	18	8.9	19
49	TOLLYNALA	26	28	35	0	42.1	26	0	28
50	ULTADANGA	25	27	42	1	39.1	25	13.3	27

Table 6.4 showing microclimate data for Winter- air temperature (Ta) in o C, Globe temperature (Tg) in o C, Relative Humidity (RH) in%, windspeed (Va) in km/hr, calculated mean radiant temperature (Tmrt) in o C (2019).

6.2 SURFACE COVER ANALYSIS

6.2.1 Classification of stations based on plan area fraction

The stations are arranged in descending order of dynamic potential. Dynamic potential refers to the natural surface cover including water bodies, vegetation cover and open areas. Refer Table 4.3 and Table 4. 4. In Figure 6.10, it is seen that the stations with high dynamic potential are the same stations that have either higher water fraction, vegetation fraction, open surface fraction or combination of three. Stations that have lower dynamic potential have lower water fraction, lower open space fraction and lower vegetation fraction. The hypothesis of this thesis is that stations showing difference in share of natural surface have difference in conditions of outdoor thermal comfort.

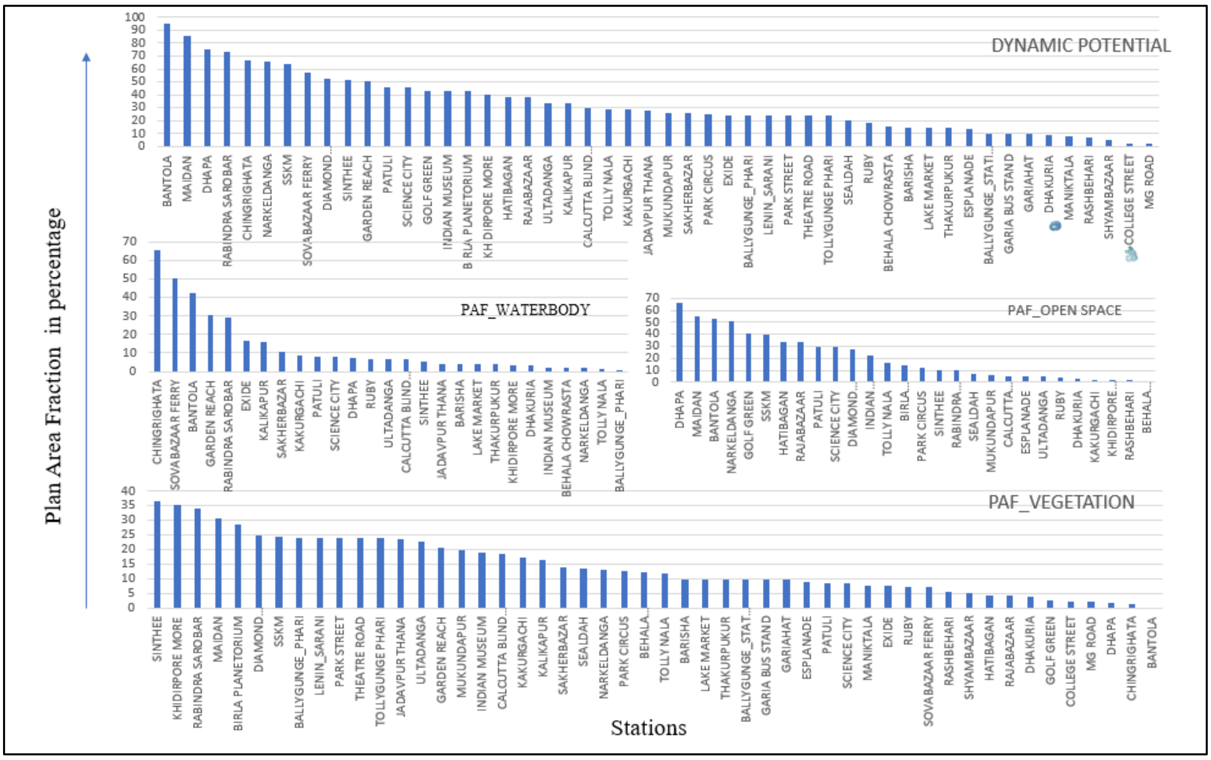


Figure 6.10 Plan Area Fraction showing stations with high dynamic potential

From NDBI, NDVI, NDWI it is seen that the centre part of the study area has high built surface and low quality of vegetation and water bodies. The intermittent water bodies are scattered. Thermal load is less along the greenbelt, along the east Kolkata wetland, along Rabindra Sarovar, around the golf turf and along the estuary and southern and eastern peri-urban region.

Figure 6.11 show stations arranged in descending order of thermal load. Thermal load refers to stations with higher built surface and higher impermeable surface. Stations with higher thermal load have higher built surface and higher impermeable surface. Stations with high thermal load have low share of natural surface cover. For example, college MG Road junction has 62.16% built surface and 35.57% impermeable surface. The same station has 2.26% natural surface cover.

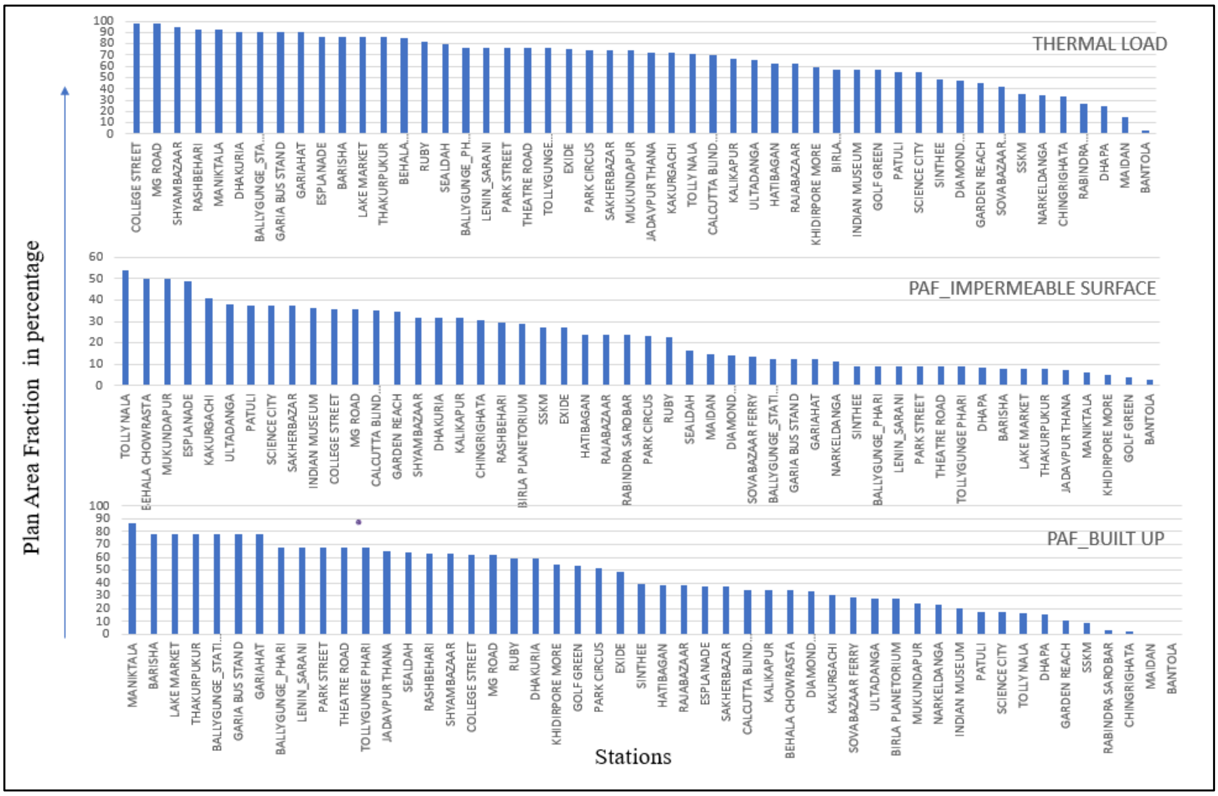


Figure 6.11 Plan Area Fraction showing stations with high thermal load

In the subsequent topic, outdoor thermal comfort conditions were calculated for each station. The stations were divided into two types- 1. High dynamic potential 2. Low dynamic potential. The stations were arranged in descending order of dynamic potential and the first 25 stations were included in type 1 and last 25 in type 2.

Due to difference in share of natural surface cover, a hypothesis test was conducted to see if difference in share of natural surface create a mean difference in mPET values between type 1 and type 2 stations.

Data for Plan Area Fraction for the stations is given in Chapter 4: Table 4.3 and Table 4.4.

6.2.2 Inferences from surface cover analysis

- Unsupervised classification show that 61% of KMC area is Built and Impermeable surface. The remaining 39% has natural landscape including open areas, water bodies and vegetation. Refer Figure 4.1.

- NDBI, NDVI, NDWI (refer Figure 4.2) show that the central part of the city and along the north-south arterial road way, there is dense built surface and the same area has low vegetation and low water bodies. Referring to Figures, 6.1, 6.2, 6.3, 6.4, the same central and northern part of the city have high values of Ta and high values of Tmrt.

- Based on Plan Aera Fraction, areas with thermal load will have higher share of built surface and impermeable surface. Areas with high dynamic potential will have high share of natural surface cover such as water surface, vegetation surface and open surface. Refer Figure- 5l and 5m.

- Maps showing distribution of outdoor thermal comfort conditions reflected in the values of PET and mPET show that the north and central part of KMC area that has high Ta, Tmrt, Tg, high built surface, low vegetation cover and low water bodies, also have high PET and high mPET values. (Refer Figure 6.11 distribution of PET for four seasons, 2019); (Figure 6.12 - distribution of mPET for four seasons, 2019).

6.3 ANALYSIS OF OUTDOOR THERMAL COMFORT

6.3.1 Calculation of PET & mPET.

The mPET and PET has been calculated using the microclimate parameters collected as primary data. The physiological and behavioural data was collected through questionnaire

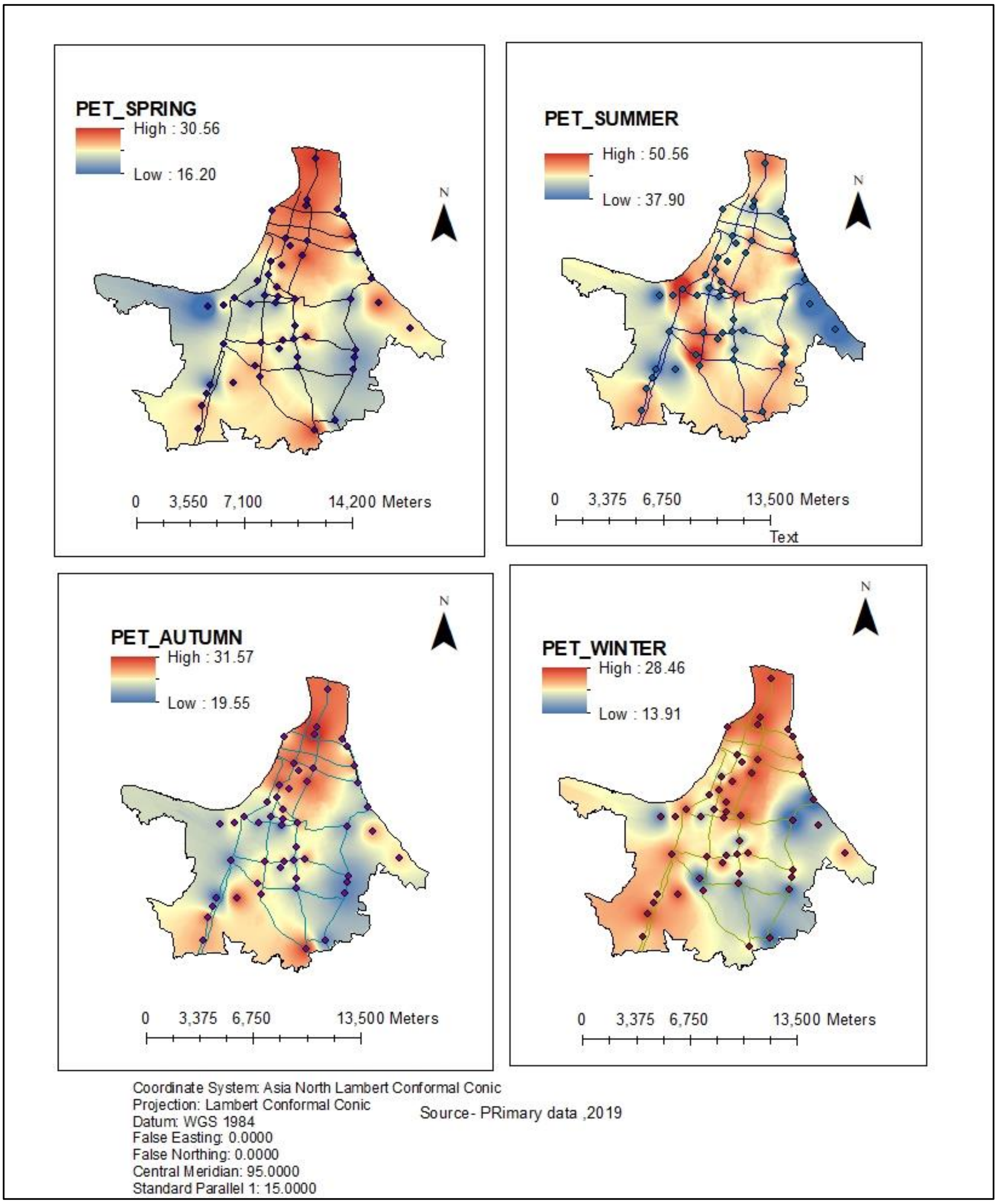


Figure 6.12 Maps showing Outdoor Thermal Comfort conditons- PET; four seasons, 2019

survey. The mPET and PET has been calculated on RayMan Pro Software. The calculated PET and mPET values can be found in table 6e and 6f.

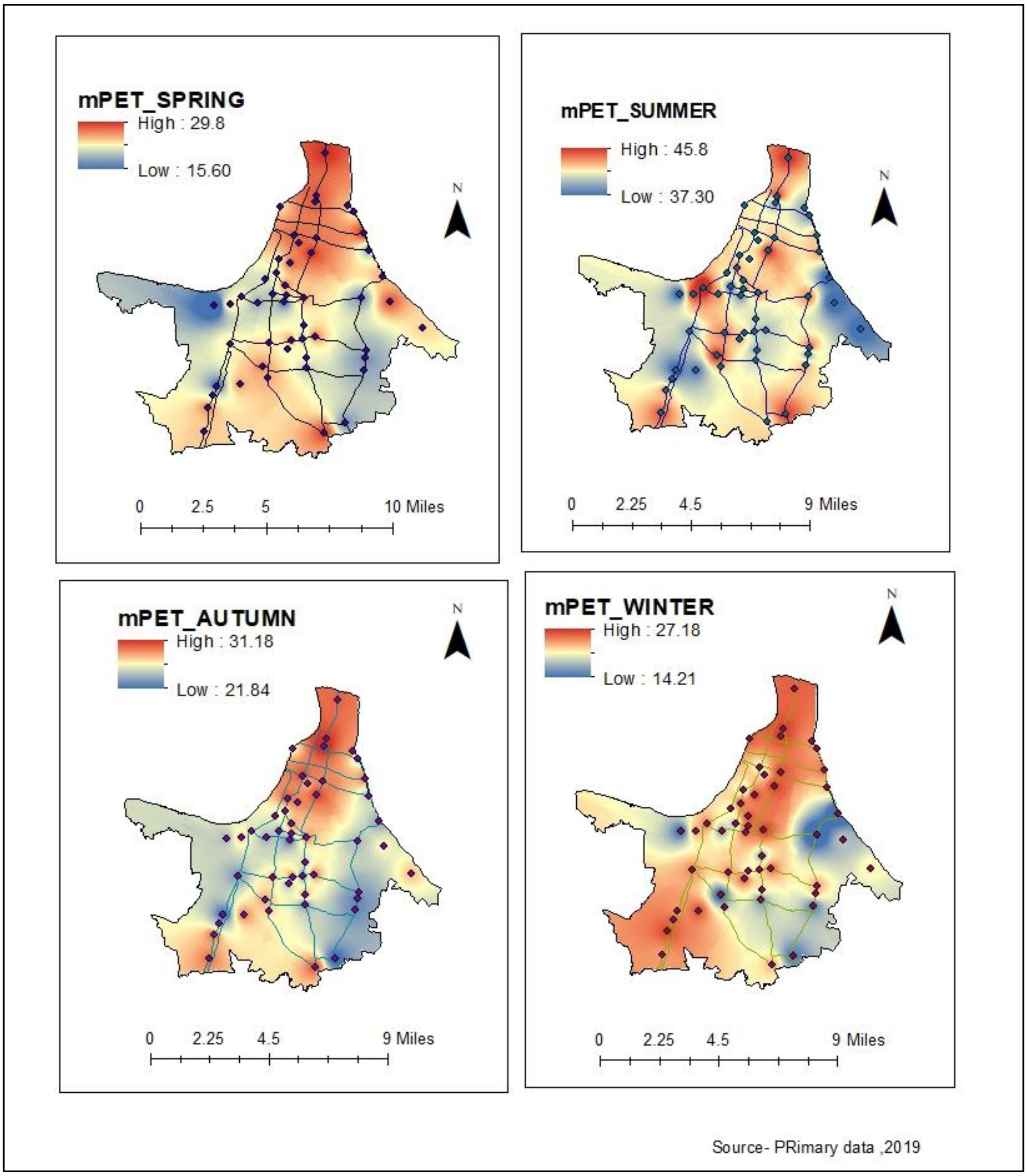


Figure 6.13 Maps showing Outdoor Thermal Comfort conditions- mPET; four seasons, 2019.

Figure 6.13 show that mPET conditions range from 16.20 to 30.56 degree Celsius. The areas that have low mPET values have higher outdoor thermal comfort. According to the grades of thermal perception (Jendritzky1990, Matzarakis et.al, 1997), outdoor thermal conditions reflected by 37.30^o C mPET to 45.80^o C mPET represent hot to very hot conditions. Spring outdoor thermal conditions reflected by 15.60^o C mPET to 29.8^o C mPET represent slightly cool to slightly warm conditions. By rule of acceptable votes (Lin et.al), the conditions in Spring are acceptable by meteorological and physiological calculation. Autumn is outdoor thermal conditions reflected by 21^o C mPET to 31^o C mPET represent comfortable to warm conditions. Winter outdoor thermal conditions reflected by 14^o C mPET to 27^o C mPET represent slightly cool to slightly warm conditions. Spring, winter are within acceptable limits. In autumn, apart from the warm conditions, other stations have acceptable conditions. In Fig.5-m, show that only in winter, the outdoor thermal conditions reflected by PET values, are acceptable. In spring, and autumn, conditions are reflected as much warmer than is shown in mPET. In recent years, studies have considered the use of mPET in hot humid sub-tropical regions.

Sr no.	SITE	PET_SP	PET_SU	PET_AU	PET_WI
1	BALLYGUNGE_PHARI	24.8	42.6	24.9	17.7
2	BALLYGUNGE_STATION	28.7	41	28.1	25.4
3	BANTOLA	26.1	38.8	26.2	24.2
4	BARISHA	27.3	39.8	29.4	27.3
5	BEHALA_CHOWRASTA	24.5	41.4	23.7	25.2
6	BIRLA_PLANETORIUM	21.9	38.6	22.8	18.7
7	CALCUTTA_BLIND_SCHOOL	19.5	39	19.8	23.5
8	CHINGRIHATA	26.2	39.1	23	13.9
9	COLLEGE_STREET	28.2	41.9	26.5	21.2
10	DHAKURIA	23.9	41	26.6	21.8
11	DHAPA	29.3	37.9	27.3	19.5
12	DIAMOND_HARBOUR(MINT)	24.8	41.3	22	26.5
13	ESPLANADE	24.7	43.5	30.1	18.4
14	EXIDE	20.4	38.9	19.5	24.3
15	GARDEN_REACH	16.2	38.5	23.2	16.5
16	GARIA_BUS_STAND	30	43.5	29.9	22.7
17	GARIAHAT	22.5	41	21.7	22.4
18	GOLF_GREEN	26.8	40.5	27.5	15.6
19	HATIBAGAN	30.3	40.5	31.6	28
20	INDIAN_MUSEUM	24.1	44.6	25.3	27.5
21	JADAVPUR_THANA	23.4	42.8	22.4	16.5
22	KAKURGACHI	24.8	41.9	23.9	23.4
23	KALIKAPUR	20.9	41.8	21.2	21.5
24	KHIDIRPORE_MORE	26.4	45.2	26.6	23.7
25	LAKE_MARKET	27.8	43.6	27.6	18.6
26	LENIN_SARANI	28.8	42.7	27.8	27.9

27	MAIDAN	23.4	44.3	24.6	20.5
28	MANIKTALA	30.6	42.3	27.8	24.9
29	MG_ROAD	28.6	41.9	29.8	20.6
30	MUKUNDAPUR	22.1	44.9	21.4	15.6
31	NARKELDANGA	22.5	45.9	23.3	22.7
32	PARK_CIRCUS	27	45.9	27.5	28
33	PARK_STREET	28.1	45.2	27.5	27.8
34	PATULI	21.9	44.6	21.8	15.4
35	RABINDRA_SAROBAR	23.5	45.2	23.4	27.4
36	RAJABAZAAR	28	44.9	27.8	27.9
37	RASHBEHARI	26	45.8	26.3	23.6
38	RUBY	22.4	44.5	22.4	23.1
39	SAKHERBAZAR	28.2	44.9	28.7	27.9
40	SCIENCE_CITY	21.9	43.4	22.5	14
41	SEALDAH	30.4	43.2	29.7	28.5
42	SHYAMBAZAAR	29.4	44.8	29.7	27.9
43	SINTHEE	30.3	45.2	28.7	27.3
44	SOVABAZAAR_FERRY	25.6	43.4	26	27.3
45	SSKM	22	43.4	22.8	18.7
46	THAKURPUKUR	25.8	44.6	27.4	23.2
47	THEATRE_ROAD	27.5	44.5	27.8	27.3
48	TOLLYGUNGE_PHARI	27.8	47.8	26.9	14.3
49	TOLLYNALA	24.7	50.6	24.8	27.3
50	ULTADANGA	27.3	41	28.3	23.9

Table 6.5 Station wise calculated PET values for four seasons, spring (SP), summer (SU), autumn (AU), winter (WI) for (2019).

Sr no.	SITE	mPET_SP	mPET _SU	mPET _AU	mPET _WI
1	BALLYGUNGE_PHARI	24.9	40.4	25.8	19.6
2	BALLYGUNGE_STATION	28.1	39.7	29	25.9
3	BANTOLA	26	37.7	27.6	22.7
4	BARISHA	27.1	38.4	28.8	26.4
5	BEHALA_CHOWRASTA	24.9	39.5	25.1	26
6	BIRLA_PLANETORIUM	22.9	37.5	24.7	19.6
7	CALCUTTA_BLIND_SCHOOL	20.2	37.4	22.3	24.5
8	CHINGRIHATA	26.8	37.4	24.6	14.2
9	COLLEGE_STREET	28.6	40.3	27.4	22.9
10	DHAKURIA	25	39.4	28.3	23.1
11	DHAPA	28.9	37.3	26.6	20.6
12	DIAMOND_HARBOUR(MINT)	25.6	39.4	24.1	25
13	ESPLANADE	25.3	41.2	29.8	20.4

14	EXIDE	19.7	38.1	21.8	25.7
15	GARDEN_REACH	15.6	37.6	25	17.1
16	GARIA_BUS_STAND	29.4	41.2	29.6	23.9
17	GARIAHAT	22.8	39.7	23.8	23.4
18	GOLF_GREEN	27	38.8	28.5	16.3
19	HATIBAGAN	28.8	38.8	31.2	26.9
20	INDIAN_MUSEUM	24.6	42.3	26.9	26
21	JADAVPUR_THANA	23.5	40.3	24.2	18.7
22	KAKURGACHI	25.2	39	25.1	24.3
23	KALIKAPUR	21.3	38.9	23.2	23.3
24	KHIDIRPORE_MORE	26.5	43.8	27.8	24.3
25	LAKE_MARKET	27.9	41.5	29.2	20.9
26	LENIN_SARANI	28.7	40.9	28.9	26.9
27	MAIDAN	23.9	41.1	26.1	21.5
28	MANIKTALA	29.8	41.8	28.8	25.6
29	MG_ROAD	28.4	41.3	30.3	22
30	MUKUNDAPUR	22.5	42	23.7	17.8
31	NARKELDANGA	22.9	42.2	25.3	23.7
32	PARK_CIRCUS	27	42.2	28.6	27.2
33	PARK_STREET	28	41.9	28.6	26.8
34	PATULI	21.9	43.5	22.5	17.7
35	RABINDRA_SAROBAR	24.4	41.9	24.9	26.7
36	RAJABAZAAR	27.9	41.6	28.7	26.8
37	RASHBEHARI	25.8	42.8	27.6	24.8
38	RUBY	23	43.2	24.7	24.5
39	SAKHERBAZAR	27.8	42.3	29.3	26.8
40	SCIENCE_CITY	21.9	42.5	25.1	14.5
41	SEALDAH	29.8	44	30.2	27.2
42	SHYAMBAZAAR	28.9	44	30.2	26.8
43	SINTHEE	29.8	43.7	29.4	26.1
44	SOVABAZAAR_FERRY	25.9	42.5	26.7	26.1
45	SSKM	22.6	42.5	24.7	19.6
46	THAKURPUKUR	26.3	43.1	29	24.5
47	THEATRE_ROAD	27.6	43.1	28.8	26.4
48	TOLLYGUNGE_PHARI	27.8	43.9	28.2	16.6
49	TOLLYNALA	25.1	45.9	26.1	25.4
50	ULTADANGA	27	39.5	29.1	24.8

Table 6.6 Station wise calculated mPET values for four seasons , spring (SP), summer (SU), autumn (AU), winter (WI) for (2019).

6.3.2 Inference from mPET calculation

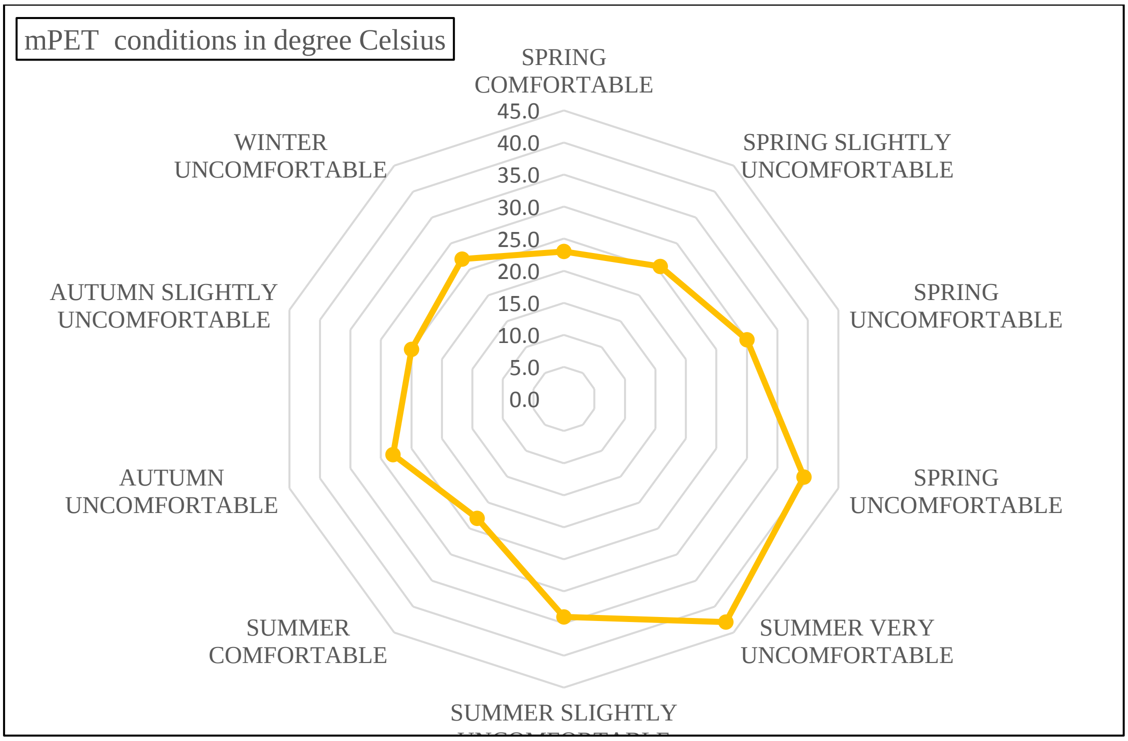


Figure 6.14 Radar chart showing Thermal mPET conditions in degree Celsius - clockwise from spring, summer, autumn and winter

In the study of Outdoor thermal comfort Conditions, the mPET temperature are given where Spring conditions are mostly comfortable, summer conditions are uncomfortable to very uncomfortable, Autumn is comfortable and Winter is comfortable to slight uncomfortable.

This is an inference from objective study which is followed by Surface cover analysis in the next pages.

6.4 IMPORTANCE OF DYNAMIC POTENTIAL

6.4.1 Microclimate surface cover and outdoor thermal comfort for selected 10 stations

Surface cover that has high share in natural surface has dynamic potential. In this study, these natural surfaces are a combination of water bodies, vegetation surface and open areas. In this analysis, the stations have been arranged in descending order of Dynamic Potential. Stations such as Bantola, Rabindra Sarovar, Chingrihata, SSKM, Sovabazaar Ferry, Garden Reach have more than 50% of natural surface. Patuli, Dhakuria, Kalikapur, Jadavpur thana have lower share of Dynamic Potential (Refer Table 6.6, 6.7, 6.8, 6.9).

In spring, the Ta is lower for Bantola, Rabindra Sarovar, SSKM, Sova bazaar Ferry, Garden reach and Patuli have Ta below 28.5° C but Dhakuria, Kalikapur, Jadavpur thana have Ta more than 28.5° C. The mPET for Dhakuria, Kalikapur, Jadavpur thana corresponds with slightly warm conditions or slight heat stress refer Figure 6.16 to Figure 6.20. The other stations having higher dynamic potential have comfortable conditions corresponding to the heat stress grade given by Mayer and Matzarakis, 1996.

Table 1 Ranges of the thermal indexes predicted mean vote (*PMV*) and physiological equivalent temperature (*PET*) for different grades of thermal perception by human beings and physiological stress on human beings; internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (according to Jendritzky et al. 1990; Matzarakis and Mayer 1997)

PMV	PET (°C)	Thermal perception	Grade of physiological stress
		Very cold	Extreme cold stress
–3.5	4		
		Cold	Strong cold stress
–2.5	8		
		Cool	Moderate cold stress
–1.5	13		
		Slightly cool	Slight cold stress
–0.5	18		
		Comfortable	No thermal stress
0.5	23		
		Slightly warm	Slight heat stress
1.5	29		
		Warm	Moderate heat stress
2.5	35		
		Hot	Strong heat stress
3.5	41		
		Very hot	Extreme heat stress

Figure 6.15 Showing the range of thermal perception or physiological stress given in accordance to thermal index PMV and PET (Matzarakis and Mayer, 1996).

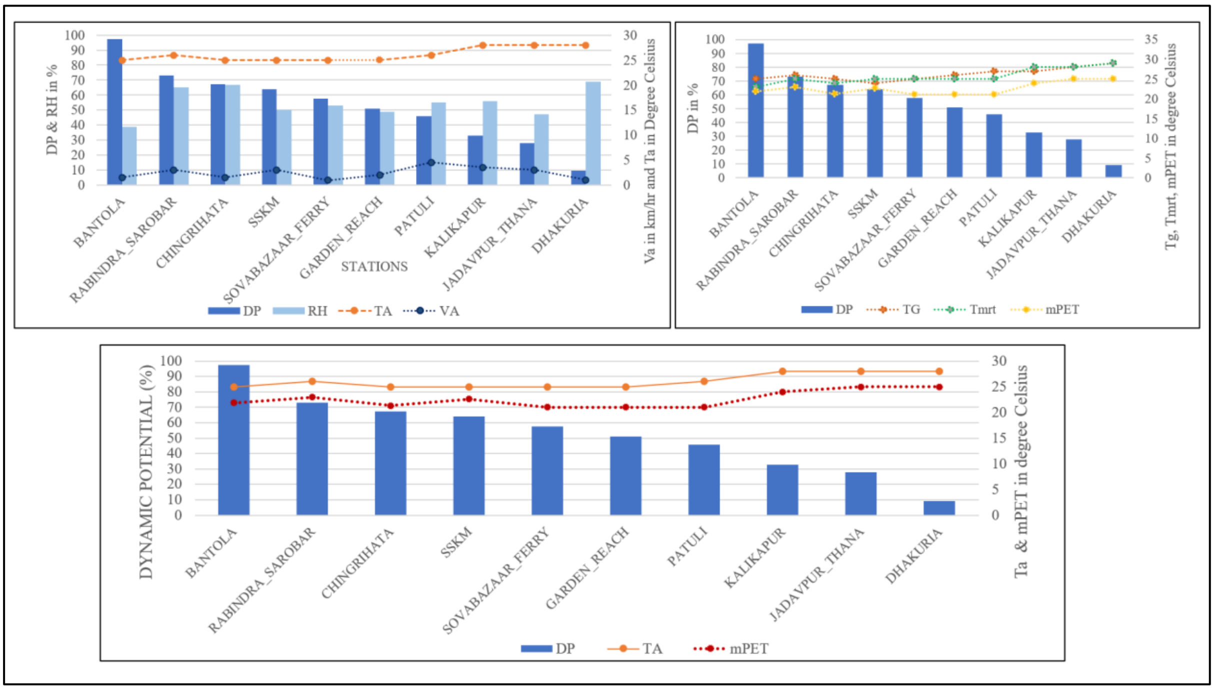


Figure 6.16 Showing mPET conditions in relation to Ta, RH, Va, Tg, Tmrt, DP- spring, 2019

In summer, the Ta varies between 35 °C and 40 °C. Stations with lower Dynamic Potential also has higher Ta as stations with lower Dynamic Potential. Some stations with high share of Vegetation or Open area have higher Ta. From literature review, this can be attributed to evapotranspiration or surface reflectivity. During daytime, the thermal conditions are warmer in stations with larger vegetation surface than areas with built surface. similar result has been derived in a study where, daytime Ta is higher in vegetated regions. In summer, surface cover do not have significant role in affecting the mPET values. However, mPET follows the trend of Ta. For stations with higher Ta, mPET values are higher and for stations having lower Ta, the mPET values are lower. Figure 6.16

In Autumn, Ta ranges between 25 °C to 28 °C. In some stations like Garden reach and Patuli, where temperatures are 25° C, the incoming solar radiation reaching the skin surface has higher temperature than the Ta. In such case, the Ta will be lower than Tg. Tmrt is a function of Ta and Tg. mPET has a significant relation with Tmrt. In this season, the difference in Ta and Tg is understood. However, for Dhakuria, the Ta is higher than Tg.

In autumn, Dhakuria has warm conditions compared to other stations. Refer Diagram 6. p.

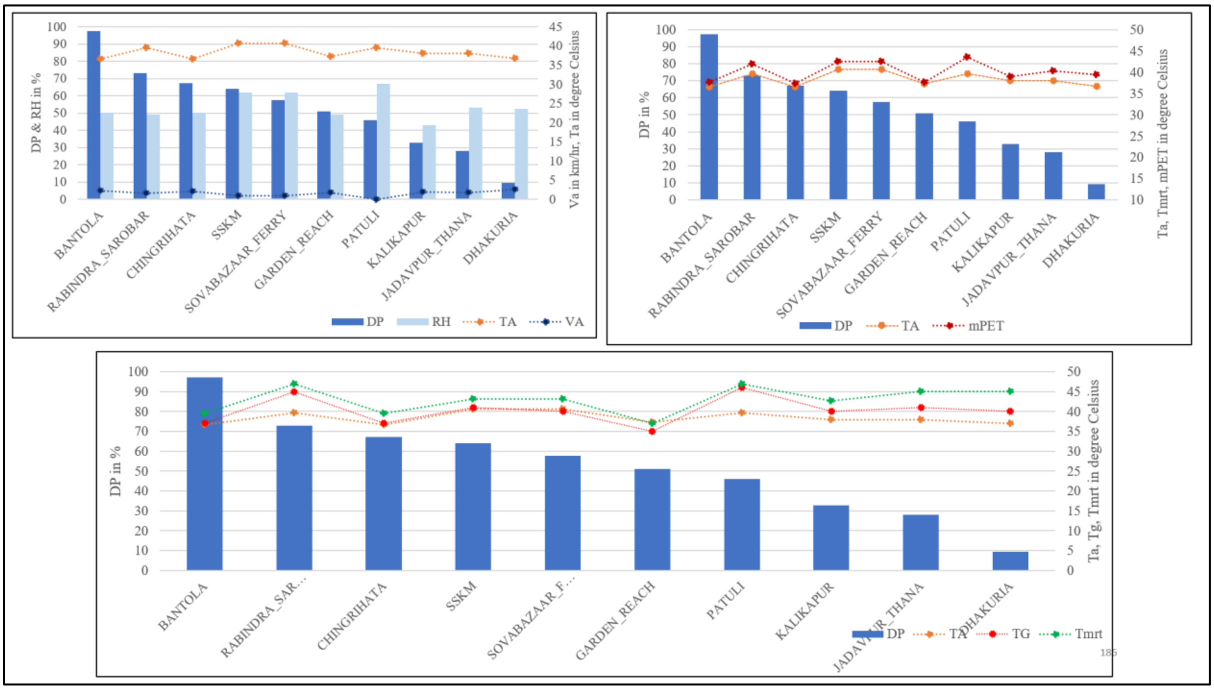


Figure 6.17 Showing mPET conditions in relation to Ta, RH, Va, Tg, Tmrt, DP- summer, 2019

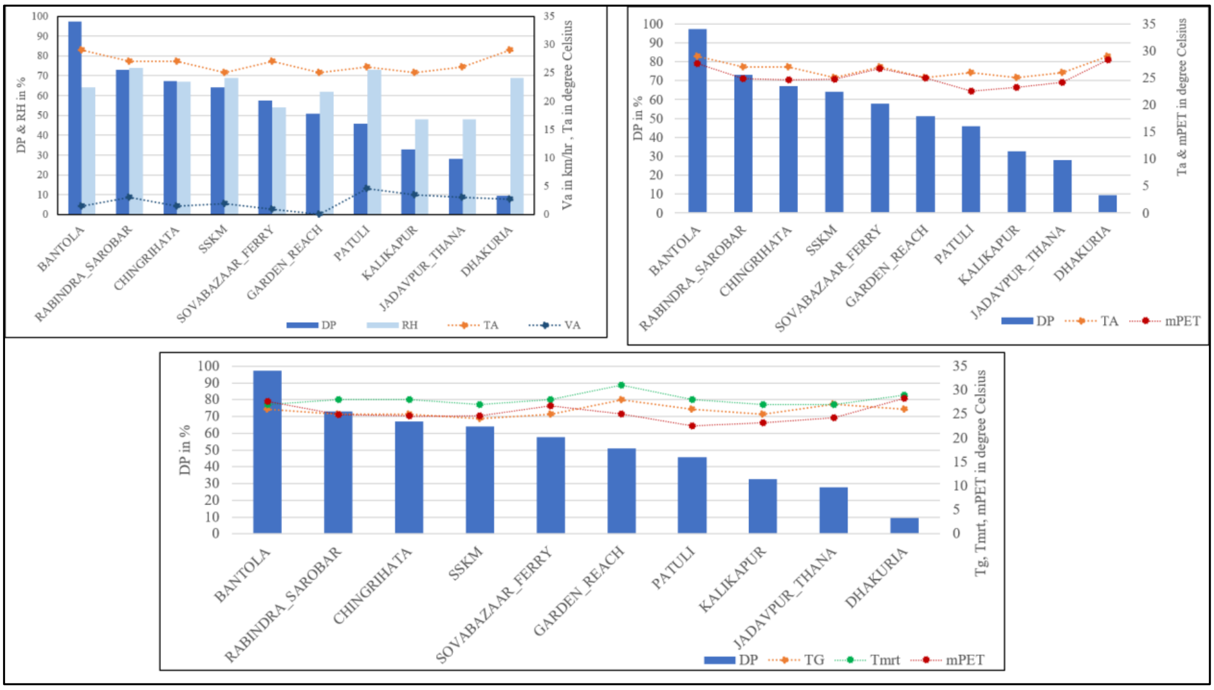


Figure 6.18 Showing mPET conditions in relation to Ta, RH, Va, Tg, Tmrt, DP- autumn, 2019

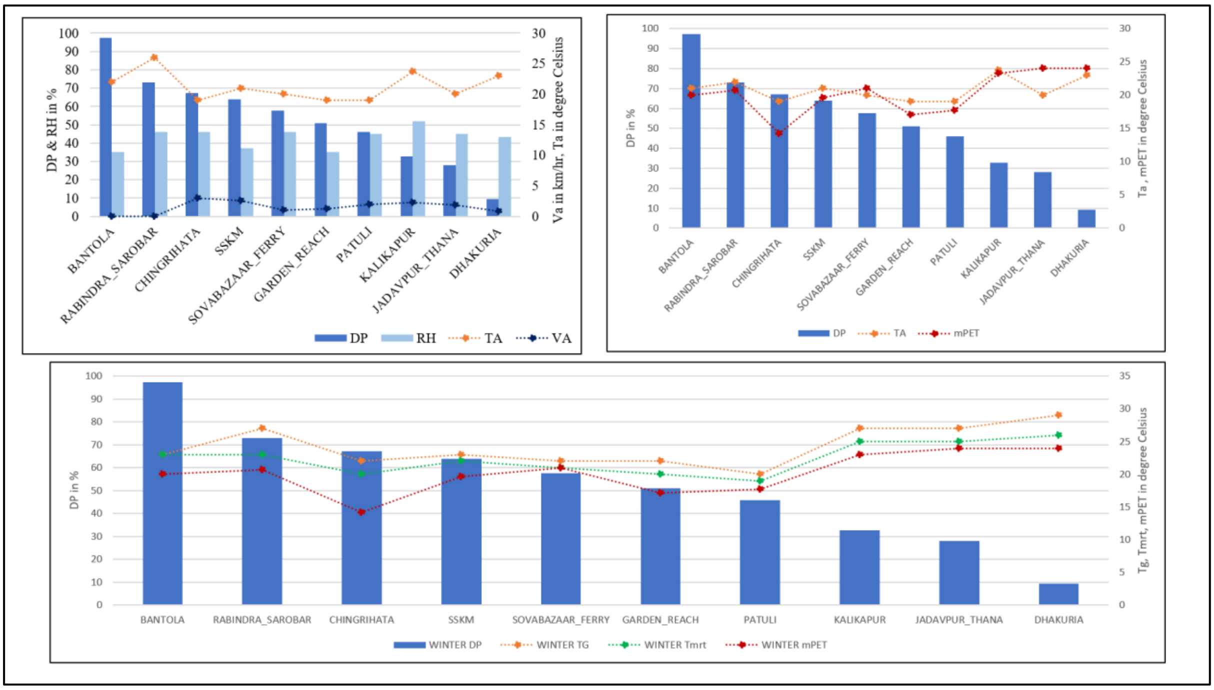


Figure6.19 Showing mPET conditions in relation to Ta, RH, Va, Tg, Tmrt, DP- winter, 2019

In Winter, the Ta is variable. For stations like Kalikapur and Dhakuria, the Ta is 25 to 28 ^{o} C. For other stations the range of Ta is from below 20^{o} C upto 20^{o} C. for stations having high Ta, the mPET is high. For stations having low Ta, mPET is low. Overall, mPET is higher for Jadavpur Thana, Kalikapur and Dhakuria. This can be attributed to the fall in windspeed as well as increased Built surface.

6.4.2 Inference from Study Of 10 Selected Stations

- SPRING- In spring, stations with high dynamic potential have outdoor thermally 'comfortable" conditions. Stations with low dynamic potential Kalikapur (40-60%), and Jadavpur Station(60-80%) Dhakuria(>80%) have 'slightly warm' conditions.
- SUMMER- In summer, all the stations have high thermal stress conditions. Stations with high dynamic potential have 'hot' conditions. Stations with low dynamic potential have 'very hot' conditions.
- AUTUMN- All stations have slightly 'warm' conditions, except for Dhakuria that has 'warm' conditions
- WINTER- All stations with high dynamic potential have low heat stress conditions, with conditions corresponding to 'cool', 'slightly cool' and stations with low dynamic potential have 'slightly warm' conditions.

	SPRING			
Sr.No.	SITE	DP	TA	mPET
A1	BANTOLA	97.30	25	21.9
B2	RABINDRA_SAROBAR	73.00	26	23
C2	CHINGRIHATA	67.15	25	21.3
D2	SSKM	64.02	25	22.6
E3	SOVABAZAAR_FERRY	57.63	25	21
F3	GARDEN_REACH	51.01	25	21
G3	PATULI	45.90	26	21
H4	KALIKAPUR	32.75	28	24
I4	JADAVPUR_THANA	27.96	28	25
J5	DHAKURIA	9.34	28	25
	SUMMER			
	SITE	DP	TA	mPET
A1	BANTOLA	97.30	36.6	37.7
B2	RABINDRA_SAROBAR	73.00	39.6	41.9
C2	CHINGRIHATA	67.15	36.6	37.4
D2	SSKM	64.02	40.6	42.5
E3	SOVABAZAAR_FERRY	57.63	40.6	42.5
F3	GARDEN_REACH	51.01	37.3	37.6
G3	PATULI	45.90	39.6	43.5
H4	KALIKAPUR	32.75	38	38.9
I4	JADAVPUR_THANA	27.96	38	40.3
J5	DHAKURIA	9.34	36.7	39.4
	AUTUMN			
	SITE	DP	TA	mPET
	BANTOLA	97.30	29	27.6
A1	RABINDRA_SAROBAR	73.00	27	24.9
C2	CHINGRIHATA	67.15	27	24.6
D2	SSKM	64.02	25	24.7
E3	SOVABAZAAR_FERRY	57.63	27	26.7
F3	GARDEN_REACH	51.01	25	25
G3	PATULI	45.90	26	22.5
H4	KALIKAPUR	32.75	25	23.2
I4	JADAVPUR_THANA	27.96	26	24.2
J5	DHAKURIA	9.34	29	28.3
	WINTER			
	SITE	DP	TA	mPET
A1	BANTOLA	97.30	22	22.7
B2	RABINDRA_SAROBAR	73.00	26	20.7
C2	CHINGRIHATA	67.15	19	14.2
D2	SSKM	64.02	21	19.6
E3	SOVABAZAAR_FERRY	57.63	20	21
F3	GARDEN_REACH	51.01	19	17.1
G3	PATULI	45.90	19	17.7
H4	KALIKAPUR	32.75	23.78	23.3
I4	JADAVPUR_THANA	27.96	20	18.7
J5	DHAKURIA	9.34	23	23.1

Table 6.7 Dynamic Potential, Ta and mPET for SPRING, SUMMER, AUTUMN AND WINTER

SPRING				
SITE	DP	TA	RH	VA
BANTOLA	97.30	25	39	1.5
RABINDRA_SAROBAR	73.00	26	65	3
CHINGRIHATA	67.15	25	67	1.52
SSKM	64.02	25	50	3
SOVABAZAAR_FERRY	57.63	25	53	0.94
GARDEN_REACH	51.01	25	49	2
PATULI	45.90	26	55	4.53
KALIKAPUR	32.75	28	56	3.5
JADAVPUR_THANA	27.96	28	47	3.02
DHAKURIA	9.34	28	69	1
SUMMER				
SITE	DP	TA	RH	VA
BANTOLA	97.30	36.6	50.2	2.29
RABINDRA_SAROBAR	73.00	39.6	49	1.5
CHINGRIHATA	67.15	36.6	50.2	2
SSKM	64.02	40.6	62	0.94
SOVABAZAAR_FERRY	57.63	40.6	62	0.94
GARDEN_REACH	51.01	37.3	49.2	1.8
PATULI	45.90	39.6	67	0
KALIKAPUR	32.75	38	43	1.9
JADAVPUR_THANA	27.96	38	53	1.68
DHAKURIA	9.34	36.7	52.4	2.5
AUTUMN				
SITE	DP	TA	RH	VA
BANTOLA	97.30	29	64	1.5
RABINDRA_SAROBAR	73.00	27	74	3
CHINGRIHATA	67.15	27	67	1.52
SSKM	64.02	25	69	1.9
SOVABAZAAR_FERRY	57.63	27	54	0.94
GARDEN_REACH	51.01	25	62	0
PATULI	45.90	26	73	4.53
KALIKAPUR	32.75	25	48	3.5
JADAVPUR_THANA	27.96	26	48	3.02
DHAKURIA	9.34	29	69	2.75
WINTER				
SITE	DP	TA	RH	VA
BANTOLA	97.30	22	35	0
RABINDRA_SAROBAR	73.00	26	46	0
CHINGRIHATA	67.15	19	46	3
SSKM	64.02	21	37	2.6
SOVABAZAAR_FERRY	57.63	20	46	1
GARDEN_REACH	51.01	19	35	1.2
PATULI	45.90	19	45	2
KALIKAPUR	32.75	23.78	51.9	2.25
JADAVPUR_THANA	27.96	20	45	1.9
DHAKURIA	9.34	23	43.5	0.81

Table 6.8 Dynamic Potential, Ta, RH, Va for SPRING, SUMMER, AUTUMN AND WINTER

SPRING				
SITE	DP	TG	Tmrt	mPET
BANTOLA	97.30	25	23	21.9
RABINDRA_SAROBAR	73.00	26	25	23
CHINGRIHATA	67.15	25	24	21.3
SSKM	64.02	24	25	22.6
SOVABAZAAR_FERRY	57.63	25	25	21
GARDEN_REACH	51.01	26	25	21
PATULI	45.90	27	25	21
KALIKAPUR	32.75	27	28	24
JADAVPUR_THANA	27.96	28	28	25
DHAKURIA	9.34	29	29	25
SUMMER				
SITE	DP	TG	Tmrt	mPET
BANTOLA	97.30	37	39.5	37.7
RABINDRA_SAROBAR	73.00	45	47	41.9
CHINGRIHATA	67.15	37	39.5	37.4
SSKM	64.02	41	43.1	42.5
SOVABAZAAR_FERRY	57.63	40	43.1	42.5
GARDEN_REACH	51.01	35	37	37.6
PATULI	45.90	46	47	43.5
KALIKAPUR	32.75	40	42.6	38.9
JADAVPUR_THANA	27.96	41	45	40.3
DHAKURIA	9.34	40	45	39.4
AUTUMN				
SITE	DP	TG	Tmrt	mPET
BANTOLA	97.30	26	27	27.6
RABINDRA_SAROBAR	73.00	25	28	24.9
CHINGRIHATA	67.15	25	28	24.6
SSKM	64.02	24	27	24.7
SOVABAZAAR_FERRY	57.63	25	28	26.7
GARDEN_REACH	51.01	28	31	25
PATULI	45.90	26	28	22.5
KALIKAPUR	32.75	25	27	23.2
JADAVPUR_THANA	27.96	27	27	24.2
DHAKURIA	9.34	26	29	28.3
WINTER				
SITE	DP	TG	Tmrt	mPET
BANTOLA	97.30	25	23	22.7
RABINDRA_SAROBAR	73.00	27	25	20.7
CHINGRIHATA	67.15	22	20	14.2
SSKM	64.02	23	22	19.6
SOVABAZAAR_FERRY	57.63	22	21	21
GARDEN_REACH	51.01	22	20	17.1
PATULI	45.90	20	19	17.7
KALIKAPUR	32.75	27	25	23.3
JADAVPUR_THANA	27.96	27	25	18.7
DHAKURIA	9.34	29	26	23.1

Table 6.9 Dynamic Potential, Tg, Tmrt, mPET for SPRING, SUMMER, AUTUMN AND WINTER

6.5 CORRELATION ANALYSIS USING PEARSON'S PRODUCT MOMENT

6.5.1 Correlaiton between microclimate and outdoor thermal comfort

Higher values of mPET reflect discomfort conditions; low values of mPET reflect comfort conditions. The comfortable conditions range between 18 ^{o} C to 23 ^{o} C. Ta and Ts have significant positive relation with mPET. In spring, increase in Ta, Ts, Tmrt causes increase in mPET. Refer Table 6.11, 6.12, 6.13, 6.14.

	Ta		Va		Ts		RH		VP		Tmrt	
SPRING mPET	✓	+	✓	-	✓	+					✓	+
SUMMER mPET	✓	+							✓	+	✓	+
AUTUMN mPET	✓	+	✓	-	✓	+			✓	+	✓	+
WINTER mPET	✓	+	✓	-	✓	+	✓	-	✓	+	✓	+

Table 6.10 show correlation between microclimate parameters and outdoor thermal conditions reflected by mPET.

➢ SPRING

PET shows a positive relation with TA (0.677) AT 99% confidence. MPET also has a positive relation with TA (0.642) at 99% confidence.

PET has negative relation with VA (-0.626) and MPET has negative relation with VA (-0.601) at 99% confidence.

PET has positive relation with TS (0.666) and MPET positive relation with TS (-0.609) at 99% confidence.

➢ SUMMER

PET shows a positive relation with TA (0.740) AT 99% confidence. MPET also has a positive relation with TA (0.826) at 99% confidence.

PET has positive relation with VP (0.325) at 95% confidence and MPET positive relation with VP (-0.634) at 99% confidence.

PET has positive relation with Tmrt (0.852) and MPET has positive relation with Tmrt (0.757) at 99% confidence.

- AUTUMN

In Autumn, PET shows a positive relation with TA (0.879) AT 99% confidence. MPET also has a positive relation with TA (0.642) at 99% confidence.

PET has negative relation with VA (-0.741) and MPET has negative relation with VA (-0.682) at 99% confidence.

PET has positive relation with TS (0.911) and MPET positive relation with TS (-0.845) at 99% confidence.

PET has positive relation with VP (0.707) at 95% confidence and MPET positive relation with VP (-0.760) at 99% confidence.

PET has positive relation with Tmrt (-0.662) and MPET has positive relation with Tmrt (-0.701) at 99% confidence.

- WINTER

PET shows a positive relation with TA (0.823) AT 99% confidence. MPET also has a positive relation with TA (0.874) at 99% confidence.

PET has negative relation with VA (-0.696) and MPET has negative relation with VA (-0.617) at 99% confidence.

PET has positive relation with TS (0.914) and MPET positive relation with TS (-0.825) at 99% confidence.

PET has positive relation with VP (0.328) at 95% confidence and MPET positive relation with VP (-0.443) at 99% confidence.

PET has positive relation with RH (-0.375) at 95% confidence and MPET positive relation with VP (-0.307) at 99% confidence.

PET has positive relation with Tmrt (0.875) and MPET has positive relation with Tmrt (0.890) at 99% confidence.

PET has positive relation with Tmrt (0.572) and MPET has positive relation with Tmrt (0.522) at 99% confidence.

		TA	TG	RH	VA	Ts	VP	RH	Tmrt	PET	mPET
TA	Pearson Correlation	1	.747**	-.389**	-.592**	.712**	.353*	-.417**	.725**	.677**	.642**
	Sig. (2-tailed)		.000	.005	.000	.000	.012	.003	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50	50
TG	Pearson Correlation	.747**	1	-.283*	-.465**	.608**	.259	-.313*	.907**	.592**	.548**
	Sig. (2-tailed)	.000		.047	.001	.000	.069	.027	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50	50
RH	Pearson Correlation	-.389**	-.283*	1	.347*	-.337*	.690**	.980**	-.375**	-.315*	-.243
	Sig. (2-tailed)	.005	.047		.014	.017	.000	.000	.007	.026	.089
	N	50	50	50	50	50	50	50	50	50	50
VA	Pearson Correlation	-.592**	-.465**	.347*	1	-.854**	-.126	.345*	-.483**	-.626**	-.601**
	Sig. (2-tailed)	.000	.001	.014		.000	.383	.014	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50	50
Ts	Pearson Correlation	.712**	.608**	-.337*	-.854**	1	.210	-.350*	.601**	.666**	.609**
	Sig. (2-tailed)	.000	.000	.017	.000		.143	.013	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50	50
Ta	Pearson Correlation	.997**	.746**	-.394**	-.589**	.709**	.357*	-.415**	.723**	.674**	.641**
	Sig. (2-tailed)	.000	.000	.005	.000	.000	.011	.003	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50	50
VP	Pearson Correlation	.353*	.259	.690**	-.126	.210	1	.698**	.184	.190	.237
	Sig. (2-tailed)	.012	.069	.000	.383	.143		.000	.202	.186	.098
	N	50	50	50	50	50	50	50	50	50	50
RH	Pearson Correlation	-.417**	-.313*	.980**	.345*	-.350*	.698**	1	-.364**	-.332*	-.260
	Sig. (2-tailed)	.003	.027	.000	.014	.013	.000		.009	.018	.068
	N	50	50	50	50	50	50	50	50	50	50
Tmrt	Pearson Correlation	.725**	.907**	-.375**	-.483**	.601**	.184	-.364**	1	.572**	.522**
	Sig. (2-tailed)	.000	.000	.007	.000	.000	.202	.009		.000	.000
	N	50	50	50	50	50	50	50	50	50	50

Table 6.11 showing correlation between microclimate parameters and outdoor comfort index ; PET & mPET (2019) in spring 2019 ; Ta- air temperature in o C, Tg- globe temeprature o C, RH- relative humidity in %, Ts- surface temperature o C, Tmrt- mean radiant temperature ^{o} C, Va- windspeed in m/s, VP-vapour pressure, PET- physiologically equivalent temperature ^{o} C, mPET- modified physiologically equivalent temperature ^{o} C.

		TA	TG	RH	VA	Ts	VP	Tmrt	PET	mPET
TA	Pearson Correlation	1	.502**	.113	-.241	.561**	.607**	.354*	.740**	.826**
	Sig. (2-tailed)		.000	.436	.092	.000	.000	.012	.000	.000
	N	50	50	50	50	50	50	50	50	50
TG	Pearson Correlation	.502**	1	-.212	.093	.064	.095	.787**	.792**	.689**
	Sig. (2-tailed)	.000		.139	.521	.659	.513	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
RH	Pearson Correlation	.113	-.212	1	-.373**	.192	.826**	-.083	-.100	.225
	Sig. (2-tailed)	.436	.139		.008	.182	.000	.565	.492	.116
	N	50	50	50	50	50	50	50	50	50
VA	Pearson Correlation	-.241	.093	-.373**	1	-.738**	-.339*	.123	.078	-.104
	Sig. (2-tailed)	.092	.521	.008		.000	.016	.396	.592	.473
	N	50	50	50	50	50	50	50	50	50
Ts	Pearson Correlation	.561**	.064	.192	-.738**	1	.460**	-.010	.189	.337*
	Sig. (2-tailed)	.000	.659	.182	.000		.001	.946	.189	.017
	N	50	50	50	50	50	50	50	50	50
VP	Pearson Correlation	.607**	.095	.826**	-.339*	.460**	1	.153	.325*	.634**
	Sig. (2-tailed)	.000	.513	.000	.016	.001		.287	.021	.000
	N	50	50	50	50	50	50	50	50	50
Tmrt	Pearson Correlation	.354*	.787**	-.083	.123	-.010	.153	1	.852**	.757**
	Sig. (2-tailed)	.012	.000	.565	.396	.946	.287		.000	.000
	N	50	50	50	50	50	50	50	50	50
**. Correlation is significant at the 0.01 level (2-tailed).										
*. Correlation is significant at the 0.05 level (2-tailed).										

Table 6.12 showing correlation between microclimate parameters and outdoor comfort index ; PET & mPET (2019) in summer 2019 ; Ta- air temperature in o C, Tg- globe temeprature o C, RH- relative humidity in %, Ts- surface temperature o C, Tmrt- mean radiant temperature ^{o} C, Va- windspeed in m/s, VP-vapour pressure, PET- physiologically equivalent temperature ^{o} C, mPET- modified physiologically equivalent temperature ^{o} C.

		TA	TG	RH	VA	Ts	VP	Tmrt	PET	mPET
TA	Pearson Correlation	1	.699**	.151	-.468**	.667**	.792**	.651**	**.879****	**.918****
	Sig. (2-tailed)		.000	.295	.001	.000	.000	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
TG	Pearson Correlation	.699**	1	.095	-.362**	.440**	.546**	.900**	**.680****	**.717****
	Sig. (2-tailed)	.000		.511	.010	.001	.000	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
RH	Pearson Correlation	.151	.095	1	-.033	.116	.688**	.148	.147	.183
	Sig. (2-tailed)	.295	.511		.819	.424	.000	.306	.307	.203
	N	50	50	50	50	50	50	50	50	50
VA	Pearson Correlation	-.468**	-.362**	-.033	1	-.831**	-.368**	-.333*	-.741**	-.682**
	Sig. (2-tailed)	.001	.010	.819		.000	.008	.018	.000	.000
	N	50	50	50	50	50	50	50	50	50
Ts	Pearson Correlation	.667**	.440**	.116	-.831**	1	.545**	.403**	**.911****	**.845****
	Sig. (2-tailed)	.000	.001	.424	.000		.000	.004	.000	.000
	N	50	50	50	50	50	50	50	50	50
VP	Pearson Correlation	.792**	.546**	.688**	-.368**	.545**	1	.546**	**.707****	**.760****
	Sig. (2-tailed)	.000	.000	.000	.008	.000		.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
Tmrt	Pearson Correlation	.651**	.900**	.148	-.333*	.403**	.546**	1	**.662****	**.701****
	Sig. (2-tailed)	.000	.000	.306	.018	.004	.000		.000	.000
	N	50	50	50	50	50	50	50	50	50
**. Correlation is significant at the 0.01 level (2-tailed).										
*. Correlation is significant at the 0.05 level (2-tailed).										

Table 6.13 showing correlation between microclimate parameters and outdoor comfort index ; PET & mPET (2019) in **autumn 2019** ; Ta- air temperature in o C, Tg- globe temperature o C, RH- relative humidity in %, Ts- surface temperature o C, Tmrt- mean radiant temperature ^{o} C, Va- windspeed in m/s, VP-vapour pressure, PET- physiologically equivalent temperature ^{o} C, mPET- modified physiologically equivalent temperature ^{o} C.

		TA	TG	RH	VA	Ts	VP	Tmrt	PET	mPET
TA	Pearson Correlation	1	.880**	-.304*	-.390**	.642**	.471**	.798**	**.823****	**.874****
	Sig. (2-tailed)		.000	.032	.005	.000	.001	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
TG	Pearson Correlation	.880**	1	-.246	-.419**	.610**	.397**	.942**	**.806****	**.838****
	Sig. (2-tailed)	.000		.085	.002	.000	.004	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
RH	Pearson Correlation	-.304*	-.246	1	.310*	-.399**	.291*	-.244	**-.375****	**-.307***
	Sig. (2-tailed)	.032	.085		.029	.004	.040	.088	.007	.030
	N	50	50	50	50	50	50	50	50	50
VA	Pearson Correlation	-.390**	-.419**	.310*	1	-.805**	-.025	-.468**	**-.696****	**-.617****
	Sig. (2-tailed)	.005	.002	.029		.000	.865	.001	.000	.000
	N	50	50	50	50	50	50	50	50	50
Ts	Pearson Correlation	.642**	.610**	-.399**	-.805**	1	.211	.681**	**.914****	**.825****
	Sig. (2-tailed)	.000	.000	.004	.000		.142	.000	.000	.000
	N	50	50	50	50	50	50	50	50	50
VP	Pearson Correlation	.471**	.397**	.291*	-.025	.211	1	.370**	**.328***	**.443****
	Sig. (2-tailed)	.001	.004	.040	.865	.142		.008	.020	.001
	N	50	50	50	50	50	50	50	50	50
Tmrt	Pearson Correlation	.798**	.942**	-.244	-.468**	.681**	.370**	1	**.875****	**.890****
	Sig. (2-tailed)	.000	.000	.088	.001	.000	.008		.000	.000
	N	50	50	50	50	50	50	50	50	50
**. Correlation is significant at the 0.01 level (2-tailed).										
*. Correlation is significant at the 0.05 level (2-tailed).										

Table 6.14 showing correlation between microclimate parameters and outdoor comfort index ; PET & mPET (2019) in winter 2019 ; Ta- air temperature in o C, Tg- globe temeprature o C, RH- relative humidity in %, Ts- surface temperature o C, Tmrt- mean radiant temperature ^{o} C, Va- windspeed in m/s, VP-vapour pressure, PET- physiologically equivalent temperature ^{o} C, mPET- modified physiologically equivalent temperature ^{o} C.

6.5.2 Correlation between microclimate and surface cover

Correlation between microclimate parameters such as Ta, Ts, RH, Tg, Tmrt, Va. and surface cover categories vis-built fraction, impermeable fraction, vegetation fraction, open area fraction and water fraction. In this correlation shown in the following table, surface cover is the independent variable and microclimate parameters is the dependent variable. The green colour corresponds to Spring, the yellow colour in the table correspond to summer, orange colour corresponds to Autumn and blue correspond to winter. Refer table 6.16, 6.17, 6.18, 6.19.

	Ta		Va		RH		VP		Tmrt	
BUILT-UP SURFACE									✓	+
WATER	✓	-							✓	-
VEGETATION COVER	✓	+								
BUILT-UP SURFACE	✓	+							✓	+
IMPERMEABLE	✓	+							✓	+
WATER	✓	-								
BUILT-UP SURFACE	✓	+							✓	+
IMPERMEABLE	✓	-							✓	-
WATER	✓	-								

Table 6.15 showing correlation between surface cover and microclimate parameters.

- *SPRING*

In spring, built up has a significant positive relation with Tmrt.

- SUMMER

In summer, water has a significant negative correlation with Ta and Tmrt.

Vegetation has a significant positive correlation with Ta.

- AUTUMN,

In Autumn, built surface has a significant positive relation with Ta and Tmrt.

Impermeable surface has a significant positive relation with Ta and Tmrt. However, Impermeable surface has a significant negative relation on surface temperature. Since the nature of surface and the reflectivity and albedo characteristics are not in the scope of this study, this particular correlation between Impermeable surface and surface temperature cannot be explained without further study. Water surface has a significant negative relation with Ta.

- WINTER

In winter, built surface has significant positive relation with Ta and Tmrt.

Water surface shows significant negative relation with Ta, Tmrt.

Impermeable surface shows significant positive relation with Ta.

		BUILT UP	IMPERMEABLE SURFACE	TL	VEGETATION	OPEN SPACE	WATER BODY	DP
TA	Pearson Correlation	.234	-.222	.116	-.034	-.074	-.054	-.124
	Sig. (2-tailed)	.101	.121	.422	.817	.608	.714	.392
	N	50	50	50	50	50	49	50
TG	Pearson Correlation	.309*	-.101	.274	-.164	-.165	-.115	-.282*
	Sig. (2-tailed)	.029	.484	.055	.255	.253	.431	.047
	N	50	50	50	50	50	49	50
RH	Pearson Correlation	-.238	.257	-.099	-.031	-.010	.195	.104
	Sig. (2-tailed)	.095	.071	.496	.830	.945	.180	.471
	N	50	50	50	50	50	49	50
VA	Pearson Correlation	-.248	.216	-.135	.154	.028	.033	.142
	Sig. (2-tailed)	.082	.131	.351	.285	.844	.824	.326
	N	50	50	50	50	50	49	50
Ts	Pearson Correlation	.239	-.191	.141	-.148	-.038	-.051	-.148
	Sig. (2-tailed)	.095	.185	.330	.305	.794	.726	.304
	N	50	50	50	50	50	49	50
VP	Pearson Correlation	-.036	.051	-.007	-.131	-.033	.157	.006
	Sig. (2-tailed)	.805	.727	.960	.365	.820	.281	.965
	N	50	50	50	50	50	49	50
Tmrt	Pearson Correlation	.343*	-.212	.241	-.145	-.141	-.106	-.250
	Sig. (2-tailed)	.015	.140	.092	.314	.327	.467	.080
	N	50	50	50	50	50	49	50
	N	50	50	50	50	50	49	50

Table 6.16 showing correlation between microclimate parameters and Surface cover in **spring 2019**; Ta- air temperature in o C, Tg- globe temperature o C, RH- relative humidity in %, Ts- surface temperature o C, Tmrt- mean radiant temperature ^{o} C, Va- windspeed in m/s, VP- vapour pressure.

		PAF_BUILT UP	PAF_IMPERMEABLE SURFACE	TL	PAF_VEGETATION	PAF_OPEN SPACE	PAF_WATER BODY	DP
TA	Pearson Correlation	.006	.016	.016	**.280***	-.061	-.140	-.011
	Sig. (2-tailed)	.968	.913	.910	.066	.676	.338	.937
	N	50	50	50	50	50	49	50
TG	Pearson Correlation	.207	.036	.248	.308*	-.224	-.345*	-.240
	Sig. (2-tailed)	.149	.806	.082	.029	.119	.015	.093
	N	50	50	50	50	50	49	50
RH	Pearson Correlation	.167	-.138	.095	-.140	-.060	-.027	-.093
	Sig. (2-tailed)	.247	.338	.512	.332	.678	.852	.523
	N	50	50	50	50	50	49	50
VA	Pearson Correlation	.020	-.206	-.107	.144	.168	-.104	.107
	Sig. (2-tailed)	.889	.152	.460	.319	.242	.477	.458
	N	50	50	50	50	50	49	50
Ts	Pearson Correlation	-.154	.021	-.155	.235	.033	.042	.158
	Sig. (2-tailed)	.285	.887	.282	.100	.822	.775	.273
	N	50	50	50	50	50	49	50
VP	Pearson Correlation	.133	-.144	.055	.089	-.080	-.090	-.050
	Sig. (2-tailed)	.358	.319	.707	.539	.583	.539	.730
	N	50	50	50	50	50	49	50
Tmrt	Pearson Correlation	.268	-.051	.260	.216	-.194	-.338*	-.253
	Sig. (2-tailed)	.060	.726	.068	.133	.176	.017	.076
	N	50	50	50	50	50	49	50
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 6.17 showing correlation between microclimate parameters and Surface cover in spring 2019; Ta- air temperature in o C, Tg- globe temperature o C, RH- relative humidity in %, Ts- surface temperature o C, Tmrt- mean radiant temperature o C, Va- windspeed in m/s, VP- vapour pressure.

		BUILT UP	IMPERMEABLE SURFACE	TL	VEGETATION	OPEN SPACE	WATER BODY	DP
TA	Pearson Correlation	.426**	-.284*	.286*	.204	-.149	-.368**	-.281*
	Sig. (2-tailed)	.002	.046	.044	.156	.303	.009	.048
	N	50	50	50	50	50	49	50
TG	Pearson Correlation	.442**	-.345*	.265	.120	-.154	-.268	-.262
	Sig. (2-tailed)	.001	.014	.063	.405	.285	.063	.066
	N	50	50	50	50	50	49	50
RH	Pearson Correlation	-.161	.252	-.018	-.119	-.066	.181	.025
	Sig. (2-tailed)	.264	.078	.904	.411	.651	.214	.864
	N	50	50	50	50	50	49	50
VA	Pearson Correlation	-.168	.108	-.116	-.150	.127	.120	.119
	Sig. (2-tailed)	.243	.456	.424	.300	.381	.410	.411
	N	50	50	50	50	50	49	50
Ts	Pearson Correlation	.115	-.305*	-.066	.210	.039	-.051	.066
	Sig. (2-tailed)	.426	.031	.649	.143	.788	.728	.648
	N	50	50	50	50	50	49	50
VP	Pearson Correlation	.105	.058	.151	-.076	-.057	-.089	-.144
	Sig. (2-tailed)	.470	.687	.296	.598	.692	.541	.318
	N	50	50	50	50	50	49	50
Tmrt	Pearson Correlation	.390**	-.345*	.208	.077	-.148	-.150	-.205
	Sig. (2-tailed)	.005	.014	.147	.596	.304	.303	.154
	N	50	50	50	50	50	49	50
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 6.18 correlation between outdoor thermal comfort and surface cover: built fraction, impermeable surface fraction, *vegetation fraction, open space fraction, water fraction. Autumn 2019*

		TA	TG	RH	VA	Ts	VP	Tmrt
PAF_BUILT UP	Pearson Correlation	.426**	.442**	-.161	-.168	.115	.105	.390**
	Sig. (2-tailed)	.002	.001	.264	.243	.426	.470	.005
	N	50	50	50	50	50	50	50
PAF_IMPERMEABLE SURFACE	Pearson Correlation	-.284*	-.345*	.252	.108	-.305*	.058	-.345*
	Sig. (2-tailed)	.046	.014	.078	.456	.031	.687	.014
	N	50	50	50	50	50	50	50
TL	Pearson Correlation	.286*	.265	-.018	-.116	-.066	.151	.208
	Sig. (2-tailed)	.044	.063	.904	.424	.649	.296	.147
	N	50	50	50	50	50	50	50
PAF_VEGETATION	Pearson Correlation	.204	.120	-.119	-.150	.210	-.076	.077
	Sig. (2-tailed)	.156	.405	.411	.300	.143	.598	.596
	N	50	50	50	50	50	50	50
PAF_OPEN SPACE	Pearson Correlation	-.149	-.154	-.066	.127	.039	-.057	-.148
	Sig. (2-tailed)	.303	.285	.651	.381	.788	.692	.304
	N	50	50	50	50	50	50	50
PAF_WATER BODY	Pearson Correlation	-.368**	-.268	.181	.120	-.051	-.089	-.150
	Sig. (2-tailed)	.009	.063	.214	.410	.728	.541	.303
	N	49	49	49	49	49	49	49
DP	Pearson Correlation	-.281*	-.262	.025	.119	.066	-.144	-.205
	Sig. (2-tailed)	.048	.066	.864	.411	.648	.318	.154
	N	50	50	50	50	50	50	50
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 6.19 correlation between outdoor thermal comfort and surface cover: built fraction, impermeable surface fraction, vegetation fraction, open space fraction, water fraction. Winter, 2019

6.5.3 Correlation between surface cover categories and outdoor thermal conditions

	SPRING				SUMMER				AUTUMN				WINTER			
	PET		mPET		PET		mPET		PET		mPET		PET		mPET	
BUILT-UP SURFACE	✓	+	✓	+					✓	+	✓	+			✓	+
IMPERMEABLE SURFACE	✓	-	✓	-												
VEGETATION																
OPEN AREAS																
WATER BODY					✓	+	✓	+								

Table 6.20 correlation between surface cover and mPET values of Outddoor Thermal Comfort

Table 6.h shows significant results in correlation between surface cover categories vis-built fraction, impermeable fraction, vegetation fraction, open area fraction and water fraction and outdoor thermal conditions vis PET and mPET. In this correlation, surface cover is the independent variable and mPET values are the dependent variable. Refer Table 6.21.

- Spring

Built surface has significant positive relation with mPET and PET.

Impermeable surface has significant negative relation with mPET and PET.

- SUMMER

Water shows significant positive relation with mPET and PET.

- AUTUMN

In autumn, built surface has significant positive relation with mPET and PET.

PLAN AREA FRACTION	CORRELATION	SPRING		SUMMER		AUTUMN		WINTER	
		PET	mPET	PET	mPET	PET	mPET	PET	mPET
PAF_BUILT UP	Pearson Correlation	.466**	.450**	.094	.181	.421**	.453**	.193	.297*
	Sig. (2-tailed)	.001	.001	.518	.207	.002	.001	.178	.036
	N	50	50	50	50	50	50	50	50
PAF_IMPERMEABLE SURFACE	Pearson Correlation	-.379**	-.368**	.083	.022	-.257	-.271	-.107	-.096
	Sig. (2-tailed)	.007	.009	.566	.880	.072	.057	.459	.505
	N	50	50	50	50	50	50	50	50
PAF_VEGETATION	Pearson Correlation	-.196	-.171	.259	.195	-.209	-.180	.072	.065
	Sig. (2-tailed)	.173	.234	.069	.175	.145	.212	.621	.655
	N	50	50	50	50	50	50	50	50
PAF_OPEN SPACE	Pearson Correlation	-.055	-.053	-.087	-.128	-.067	-.100	-.116	-.195
	Sig. (2-tailed)	.706	.712	.549	.377	.644	.489	.424	.176
	N	50	50	50	50	50	50	50	50
PAF_WATER BODY	Pearson Correlation	-.219	-.219	-.312*	-.309*	-.253	-.274	-.131	-.219
	Sig. (2-tailed)	.126	.126	.027	.029	.077	.054	.363	.126
	N	50	50	50	50	50	50	50	50
**. Correlation is significant at the 0.01 level (2-tailed).									
*. Correlation is significant at the 0.05 level (2-tailed).									

Table 6.21 Correlation between Surface cover fraction in percentage and Outdoor Thermal Index (PET & mPET) in degree Celsius, for four seasons, 2019.

6.5.4 Inferences from correlation analysis

(All data collected during daytime)

1. In spring, Ta, Tmrt significantly reduces comfort; in spring, higher share of built surface increases Tmrt; and Va increases comfort in spring.
2. In summer, Tmrt reduces comfort higher share of vegetation surface increases Ta in summer but higher share of water surface increases comfort by reducing Ta and Tmrt.
3. In Autumn, Ta, Tmrt reduces comfort. Built surface and Impermeable surface increases Ta, Tmrt; in autumn, higher share of Water surface reduces Ta, but Va increases comfort.
4. In winter higher share of built surface increases Ta and Tmrt, higher share of impermeable surface reduces Ta and Tmrt. higher share of water reduces Ta. In winter, Ta, Ts, Tmrt reduces comfort, Va and RH increases comfort.

- Air temperature and mean radiant temperature is most significant parameter affecting mPET causing discomfort Ta or Tmrt increases.
- Higher share of Built surface reduces comfort in spring, autumn, winter.
- Higher share of Water surface gives comfort by reducing Ta, Tmrt in all seasons except in summer. In summer, water surface reduces comfort.
- Higher share of Vegetation surface increases Ta in Summer.
- Wind speed significantly increases comfort in Spring, Autumn, Winter by reducing Ta and Tmrt.
- In summer, Ta is the most important parameter, built surface, water, vegetation contributes to discomfort during daytime.
- Clo value significantly increases mPET values in winter during daytime.

6.6 IMPORTANCE OF DYNAMIC POTENTIAL

6.6.1 Hypothesis testing

The Hypothesis test mentioned in previous topics 50 stations divided in to two categories on basis of dynamic potential (water fraction impermeable surface fraction open areas fraction). Category 1 has high dynamic potential and category 2 has low dynamic potential. Their mPET values compared with the hypothesis that the mean difference in mPET values and their variance is zero. Hypothesis testing was performed with Z-score statistical test where the mean difference in their mPET values were assumed to be zero. Two tailed tests at 95% confidence level were conducted on SPSS. Table 6.23 showing hypothesis testing for four seasons- green -spring, yellow-summer, orange- autumn and blue-winter: Null hypothesis stating that stations with different share in natural surface or dynamic potential have zero mean difference in their outdoor thermal conditions reflected by the value of calculated mPET ; short forms- DP-DYNAMIC POTENTIAL, TL- THERMAL LOAD.

z-Test: Two Sample for Means	SPRING	
	DP	TL
Mean	24.70	26.66
Known Variance	10.25	6.61
Observations	25.00	25.00
Hypothesized Mean Difference	0.00	
z	-2.34	
P(Z<=z) one-tail	0.01	
z Critical one-tail	1.64	
P(Z<=z) two-tail	0.02	
z Critical two-tail	1.96	

reject null hypothesis

z-Test: Two Sample for Means	SUMMER	
	DP	TL
Mean	40.56	41.50
Known Variance	5.45	3.44
Observations	25.00	25.00
Hypothesized Mean Difference	0.00	
z	-1.54	
P(Z<=z) one-tail	0.06	
z Critical one-tail	1.64	
P(Z<=z) two-tail	0.12	
z Critical two-tail	1.96	

accept null hypothesis

z-Test: Two Sample for Means	AUTUMN	
	DP	TL
Mean	26.04	27.90
Known Variance	5.17	5.44
Observations	25.00	25.00
Hypothesized Mean Difference	0.00	
z	-2.81	
P(Z<=z) one-tail	0.00	
z Critical one-tail	1.64	
P(Z<=z) two-tail	0.00	
z Critical two-tail	1.96	

reject null hypothesis

z-Test: Two Sample for Means	WINTER	
	DP	TL
Mean	21.87083	24.7125
Known Variance	16.8	6.75
Observations	25.00	25.00
Hypothesized Mean Difference	0	
z	-2.86869	
P(Z<=z) one-tail	0.002061	
z Critical one-tail	1.644854	
P(Z<=z) two-tail	0.004122	
z Critical two-tail	1.959964	

reject null hypothesis

Table 6.22 hypothesis testing

The result states that:

The null hypothesis is rejected that there is no difference in mPET values in a two-tailed test at 0.05% significance level (95% confidence).

- ❑ In summer, null hypothesis is accepted. The mean difference in mPET is zero. The difference in dynamic potential remains insignificant in this test.
- ❑ In spring, autumn and winter, null hypothesis is rejected. The mean difference in mPET is not zero. The difference in dynamic potential remains significant in this test.

6.6.2 Inference from hypothesis testing

Surface cover analysis in previous chapter-

- ➢ Natural surface cover such as open areas and vegetation surface did not show significant correlation with mPET conditions.
- ➢ water surface has shown to have significant positive correlation with Ta and Tmrt in Correlation analysis
- ➢ The role of open areas and vegetation surfaces will be included in our future scope.

Inference from Hypothesis testing

- ➢ It is concluded that natural surface cover as a combination of open areas, vegetation surface and water bodies taken together will have influence on thermal comfort conditions.
- ➢ Significant difference in Outdoor Thermal comfort conditions due to difference in share of Dynamic Potential.
- ➢ Natural surface as a combination of open areas, vegetation surface and water bodies is termed as Dynamic Potential.

6.7 IMPORTANCE OF WATER BODIES

6.7.1 Outdoor thermal comfort conditions of 10 selected stations

Ten stations have been selected on basis of their proximity to waterbodies or influence from water bodies. The locations have different landcover according to the Plan Area Fraction (PAF).

There are 3 stations in this study (PAF2), that have 20%-40% of built space. A2, is located on an arterial road, Eastern Metropolitan Bypass that connects the core of the city to the Salt Lake municipality as well as the satellite town of Rajarhat.

Almost at the eastern end of the city, along right and left bank of the road are wetlands and fisheries without any buildings. B2, is an artificial dug out water body that allows sport activities such as rowing. There is adjoining park surrounding the waterbody which on one side is the Safari Park, that allows morning evening walks, children's play area, sitting benches, open spaces to allow karate, yoga, laughing classes and many more. There is sufficient tree canopy that allows sitting in shade. Next to the waterbody, there is breeze that begins early evening. Early mornings are relatively cool and one may enjoy the variety of seasonal and migratory birds. This spot is combined of tree canopy, water surface, light vegetation with ground vegetation such as shrubs and grass; and open areas without ground vegetation.

C2, is lies between a hospital campus and the green belt. The Victoria Memorial Park is behind the road space and continues into the green belt of Maidan interspersed with fountains and waterbodies.

D3 is located on a bridge over Ganga estuary and near to the western end of the city. 3 stations in this study have 40% -60% built space (PAF3).

E3 is located along the southern part of the Eastern Metropolitan Bypass, water bodies that includes wetlands as well as artificial dug waterbodies. Beyond the waterbodies are low rise and mid-rise high-density buildings.

F3 is located on the left bank of the river, a ferry station, flanked by high density, mid-rise buildings with narrow lanes along the left bank.

There are 2 stations (PAF 4) with 60-80% built space. F4 and G4 both have water bodies within 200m of the study site.

At F4, the water bodies are behind buildings and not visible from the main road.

G4, have two large waterbodies along the right bank of the road. These waterbodies are easily visible from the road and also a source of evening breeze.

1 station (PAF 5) with built and impermeable surface and no visible waterbody or open space, yet receives evening breeze from the Rabindra Sarovar Lake and the Jodhpur Park Lake which people identify as lake breeze. When the pedestrian roadway is uncomfortable, many rail commuters and students from university nearby, climb the overbridge where breeze is more consistent and enjoyable.

The ten stations show difference in landcover and distribution of waterbodies. The stations having proximity to waterbodies or effect from water bodies show seasonal variation of air temperature (Ta), Relative Humidity (RH). Windspeed (Va), Mean radiant temperature (Tmrt) and PET. The stations based on their categories do not show any definite pattern of seasonal variation of microclimate parameters. During spring the temperature begins to rise and peaks during summer and during autumn the temperature begins to fall and reaches the minimum in winter. This is the trend for all the 9 stations and within these 9 stations there is not much variation (refer table a1). However, when the PET values of the 9 stations are compared, it is seen that the stations in category PAF 4 AND PAF5 have PET values higher than the average. G4, H4 and I5 have higher than average PET in spring, summer, autumn and winter. C2 has higher than average PET values in summer, autumn and winter.

Correlation with Spearman's Rho value, between PET values and microclimate parameters show that there is no significant relation with the individual parameters in spring and summer. In autumn and winter, the PET values show significant relation with TA at 99% confidence level. Correlation between PET and TMRT show positive relation during Spring, Summer and Autumn at 99% confidence level (refer Table 5.6). In order to understand the extent of variation in landcover, calculation of PAF identified built surface, impermeable surface (road), vegetation (tree canopy), open areas and water bodies. The percentage of built surface in categories PAF 4 and 5 is >60% and the PET in these categories is higher than the PAF1, PAF2, PAF3. Correlation between PAF values and individual microclimate parameters for the 9 stations showed no significant relation. However, correlation between PAF values and PET values showed significant relation only for the water bodies. In summer, autumn and winter, the PET values show negative relation with water bodies (refer Table a3) at 0.05 significance level. This shows that that instead of individual microclimate parameters, mean radiant temperature have a strong positive relation to PET values. Waterbodies show significant impact on PET values. The PET values of stations with more than 60% built surface have higher PET values.

		TA	Tg	RH	VA	TMRT
SPRING	Correlation Coefficient	.084	-.060	-.386	.046	**.966****
Sig. (2-tailed)		.830	.878	.305	.906	.572
SUMMER	Correlation Coefficient	.574	-.409	.207	-.424	**.899****
Sig. (2-tailed)		.106	.275	.594	.256	.001
AUTUMN	Correlation Coefficient	**.965****	**.969****	-.502	.085	**.970****
Sig. (2-tailed)		.000	.000	.168	.827	.000
WINTER	Correlation Coefficient	.928**	.050	-.111	.025	.017
Sig. (2-tailed)		.000	.898	.777	.949	.964

Table 6.23 showing correlation between PET values of spring, summer, autumn and winter and individual microclimate parameters

		PET Spring	**PET Summer**	**PET Autumn**	**PET Winter**
A1	Bantola	Comfortable	Hot	Cool	Cold
B2	Chingrihata	Slightly Warm	Hot	Slightly Cool	Cold
C2	Rabindra Sarobar	Slightly Warm	Hot	Slightly Cool	Cold
D2	SSKM	Slightly Warm	Very Hot	Slightly Cool	Cool
E3	Garden Reach	Slightly Warm	Hot	Cool	Cold
F3	Patuli	Neutral	Very Hot	Slightly Cool	Cool
G3	Sovabazaar Ferry	Slightly Warm	Very Hot	Slightly Cool	Cold
H4	Jadavpur Thana	Warm	Very Hot	Neutral	Slightly Cool
I4	Kalikapur	Warm	Very Hot	Neutral	Cool
J5	Dhakuria	Hot	Very Hot	Neutral	Slightly Cool

Table 6.24 showing thermal conditions with regard to mPET for four seasons in 2019. nine stations as case studies for effect of water fraction was taken. A2 , B2, C2 has 20-40% thermal load I 5 has >80% thermal load. With increasing thermal load, the thermal conditions change from warm to hot in summer and cold to slightly cool in winter.

The stations with higher categories of built surface are Jadavpur (G4), Kalikapur (H4) and Dhakuria(I5). These stations have 25% and 0% share of water surface within the study extent of area of 200m^2 per station. However, these stations also record noticeable water breeze from the surrounding lake area. Dhakuria may not have any water bodies in vicinity, however, the Rabindra Sarovar was originally the Dhakuria lake that is located at 1 km crow fly's distance. Hence, the lake breeze plays an important role in mitigating the heat conditions at evening.

Substituting the PET values with Thermal perception scale for sub-tropical regions (Lin, Matzarakis and Liu, 2009)(Ali and Patnaik, 2018)**,** Table 5 shows that in summer, all the 9 stations experience hot to very hot conditions. In summer, G4, H4 and I4 have warm and hot conditions whereas A2, B2, C2, D3, E3, F3 have neutral to slightly warm conditions. In autumn, the same stations (A2 TO F3) have slightly cool conditions whereas, G4, H4 I5 have neutral conditions. During this weather, there is a decrease in temperature, and the stations with higher built surface and lower or negligible share of water bodies feel 'neutral' but not 'slightly cooler'. In winter, the same stations (A2 TO F3), have cool or cold conditions. But G4, I5, that do not have waterbodies in plain view from the pedestrian level, have 'slightly cool' winter conditions. Stations with higher share of water surface have lower PET values and cooler conditions in autumn and winter when average temperature of the 9 stations is 23^0 C and 19^0 C respectively; and only 'slightly warm' conditions in spring when average temperature of the 9 stations together is 27^0 C.

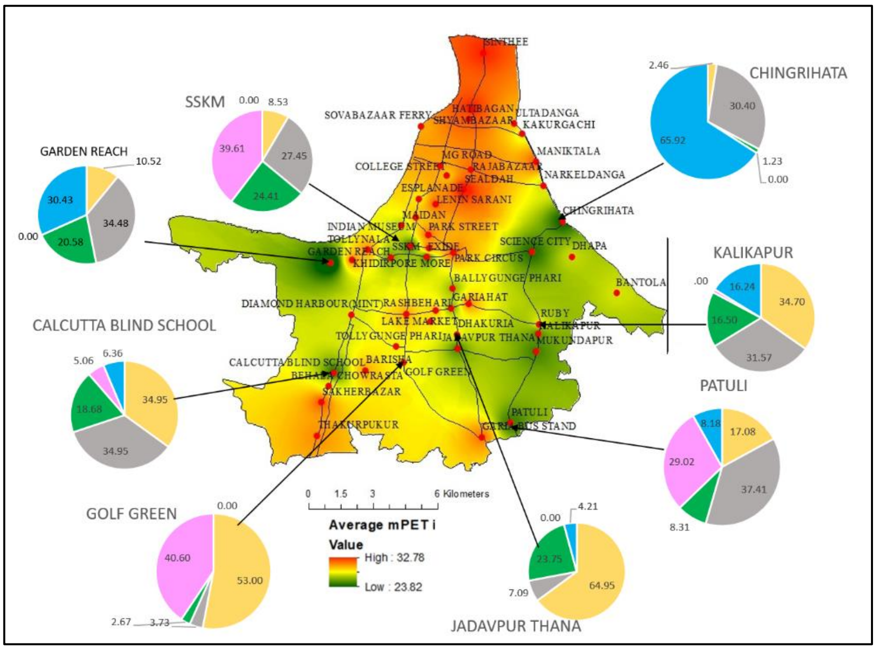


Figure 6.20 Showing stations with dynamic potential have low average mPET, water-blue, vegetation-green, open area- pink, built-yellow, impermeable-grey.

6.7.2 Inference from study of stations to understand the importance of water bodies.

- Mean radiant temperature have a strong positive relation to mPET values.
- Waterbodies show significant impact on mPET values. The stations with more than 60% built surface have higher mPET values. Higher mPET values reflect low levels of comfort.
- Dhakuria and Jadavpur have 98% and >86% built cover respectively, and the extent of water body is not visible from pedestrian level. Only a 100m radius area will include some of the water surface for some stations. Otherwise, all stations have been studied with a 50m radius.

6.7.3 Comparison of two stations with difference in surface cover characteristics and access to water breeze.

The two stations are (Station 1) Dhakuria and (Station2). Refer table 5.7 and 5.8 in this Chapter.

Station 1 - Dhakuria is a small junction along a main arterial roadway connecting the southern to the central city area. The road junction has an important bus stop, which is waking distance away from the railway station that connects the area and its surrounding to the suburban and rural areas. It has residential and commercial buildings. The residential buildings are mostly 2 or 4 storeyed depending on bungalows or multi-storeyed buildings. Station 1 is also a site of a popular shopping arcade along with shops occupying the ground floor of most buildings flanking the main Gariahat road. The Station 1 has hot and humid daytime conditions in warm season. It has lanes leading into residential areas from the main road. It is characterised by large number of vehicles, pedestrians, surrounding buildings and an over bridge.

Station 2- Chingrihata is located in the southern and eastern part of the city respectively on E.M. Bypass (Bongao-Kulti National Highway). The road is a major arterial road connecting the entire city to the Satellite town as well as the IT Sector or the new CBD of Kolkata. It also serves as a connector to the Northern areas of the city and the roadway is a bypass from the city proper. It is the. Chingrihata on the other hand lies along the eastern edge of the city flanked by the East Kolkata Wetlands (Ramsar Site) fisheries. Station 2 has water bodies on either side of the road. To be able to enjoy the water view, benches have been installed and footpaths repaired. There is sufficient street lights provided for people to enjoy the evening outdoors.

Station	Time	Ta (^{O}C)	Tg (^{O}C)	Va (m/s)	RH (%)	PET (^{O}C)
1. Dhakuria	Midday	38.2	48	0.95	64	51-53
	Early Evening	36.8	43	1.2-1.96	49	<39.46
2. Chingrihata	Midday	36.1	45.3	2.33- >2.42	49	36.71
	Early Evening	36.3	44.8	2.25- >2.42	51	<36.83

Table 6.25 Showing microclimate conditions of station 1 and station 2

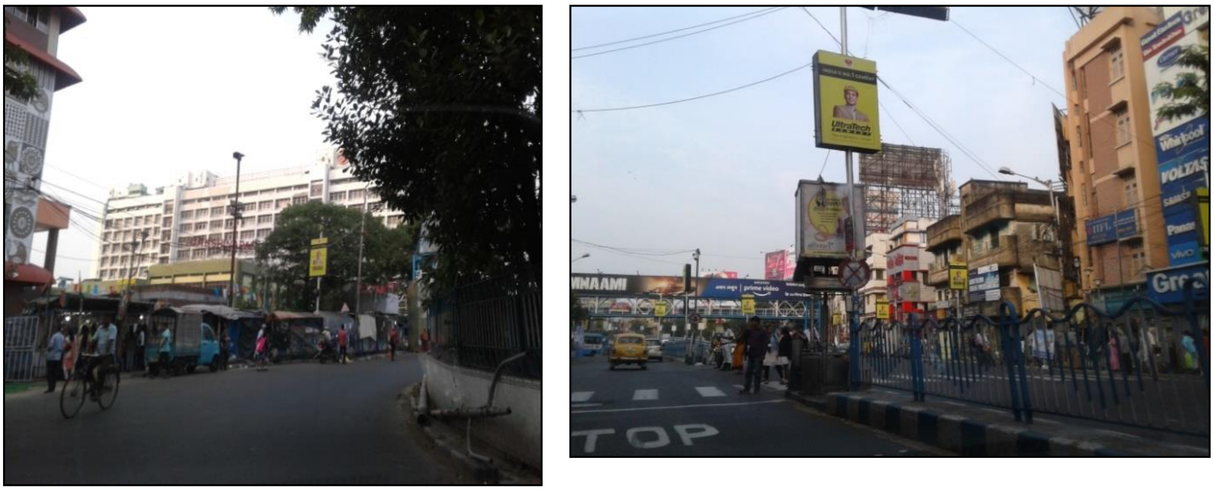


Figure 6.21 showing Station 1- Dhakuria

Figure 6.22 showing Station 2- Chingrihata

Station	PAF (%) *					NDVI	NDWI	NDBI	Number of	Average Building	Canyon Aspect	Mean Height	LCZ
	B	I	V	O	W								
Dhakuria	67.6	21.5	6	4.9	0	0.10	-0.05	0.4	25	11 m	0.75-2	10-25	2
Chingrihata	1.5	49.8	2.9	0	45.8	0.22	0.15	-0.10	1	2m	0.6-0.9	3-10	6

Table 6.26 surface characteristics of station 1- Dhakuria and station 2-Chingrihata (B-built fraction, I – Impermeable fraction, V-vegetation fraction, 0-open area fraction, W- water fraction). LCZ- Local Climate Zone (Stewart et.al)

Figure 6.23 – Showing Dhakuria (Station 1) top, and Chingrihata (Station 2) bottom- Google Earth Image, 2019.

	Station name	DHAKURIA	CHINGRIHATA	Source
	Canyon orientation	North-south	North-south	Field
Model Area	Main model area	21000 sq.m	22500 sq.m	EnviMET
	Grid size in meter	30*30*20	30*30*20	
	Dx= size of x grid	2	2	
	Dy= size of y grid	2	2	
	Dz= size of z grid	2	2	
Construction material	Building material	Concrete		Field
	Soil	Asphalt, clayey loam	Asphalt,clayey loam	ENVI-met
Position	Longitude Latitude	22.33’17.59N 88,24’40.53E	22,30’30.46N 88,22’2.40E	ArcMap
Start and Duration of model	• Date of simulation • Start time • Total simulation time	• 23.06.2019 • 12:00 pm • 12 hours		ENVIMET
Initial meteorological conditions	• Roughness length at measurement site • Initial temperature of atmosphere	0.7 36.5	0.01 43.5	Field
	• Simple Forcing: Air temperature (K) • Simple Forcing: Relative Humidity (%)	38.2 (c) 64%	36.1 (c) 49%	Field
	• Specific humidity at model top (2500mg/kg)			IMD
	• Wind speed at 10 m height (m/s) • Wind direction	7m/s South	7 m/s South	IMD

Table 6.27 showing data input details for EnviMet simulation

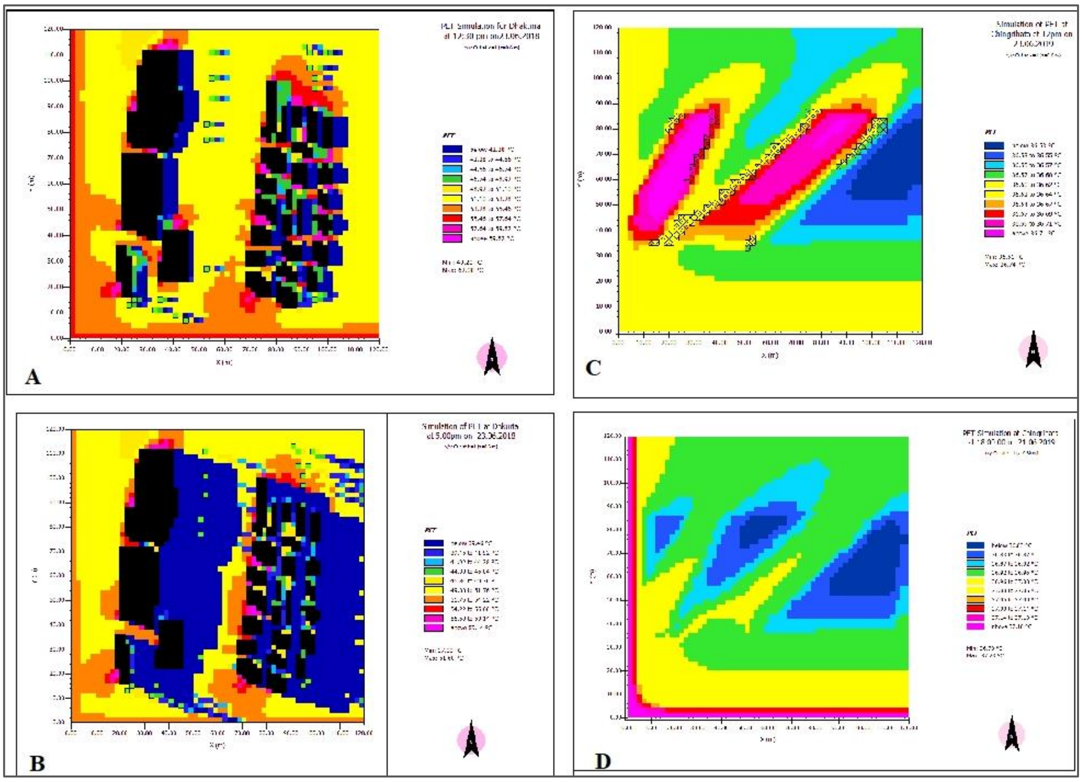


Figure 6.24 Showing simulation on EnviMET: A- daytime in station 1, B- evening breeze in station 1, C- daytime in station2, D- evening breeze in station 2

DHAKURIA (12:30-2:00 Pm)		Thermal Comfort: Very Uncomfortable		Thermal Comfort: Uncomfortable
		Thermal Sensation		
		Very Hot	Hot	Hot
Thermal Preference	Neutral	0	0	0
	Slightly Cooler	0	0	0
	Much Cooler	57.5	12.5	30
Thermal Tolerance	Perfectly Tolerable	0	0	0
	Fairly Difficult To Tolerate	5	5	7.5
	Very Diffficult To Tolerate	12.5	0	5
	Intolerable	40	7.5	17.5
Thermal Acceptance	Acceptbale Rather Than Unacceptable		12.5	30
	Unacceptable	23		
Thermal Satisfaction	Acceptable	0	0	0
	Dissatisfied	17.5	7.5	7.5
	Very Dissatisfied	40	5	22.5

CHINGRIHATA (12:30-2:00 Pm)		Thermal Comfort: SLIGHTLY UNCOMFO	Thermal Comfort: COMFORTABLE	
		THERMAL Sensation		
		WARM	WARM	NEUTRAL
Thermal Preference	Neutral	0	10	**75**
	Slightly Cooler	5	10	0
	Much Cooler	0	0	0
Thermal Tolerance	Perfectly Tolerable	5	20	75
	Fairly Difficult To Tolerate	0	0	0
	Very Difficult To Tolerate	0	0	0
	Intolerable	0	0	0
Thermal Acceptance	Acceptable Rather Than Unacceptable	5	20	75
Thermal Satisfaction	Acceptable	2.5	7.5	75
	Dissatisfied	2.5	5	0
	Very Dissatisfied	0	0	0

Table 6.28 Thermal sensation study at the two stations

The surface cover of the two stations shows a distinct difference in terms of share in natural surface and built surface. The NDVI index show a poor vegetation cover in both the stations with lack of dense of vegetation and barely any canopy. The NDWI index shows that Station 1 has a negative value showing lack of water surface than in Station 2 which show a higher positive value due to the presence of water bodies on either side of the roadway. The microclimate conditions also show that in Station 2, the Ta is lower than in station 1. Tmrt is a function of Ta and TG. So, with high Ta and Tg recorded in Station1 over station 2, the PET calculated is also higher for station 1. For both the stations, the simulation and data collection were done for summer season. So, for both stations, the PET value is very high. It corresponds with hot and very hot outdoor thermal conditions.

In both the stations, the PET values decrease in the evening but it is still very high as per PET thermal sensation grades of stress given by Matzarakis et. Al. The following simulations performed on EnviMET for morning and evening hours for 2 stations. PET is calculated in EnviMET. So, this analysis with simulations was performed using the PET index. In both stations there is a fall in Heat stress conditions marked by warm colours. During daytime, station 2 has higher windspeed than station1 so PET values are lower in daytime than in station 2. In the evening the PET values are lower in station2 than station 1, but in station 1 the drop in PET is from over 50^{o} C PET to <39.5^{o} C PET. This marked decrease in PET conditions reflect a change in outdoor thermal comfort conditions between daytime and evening time.

6.7.4 Inference on importance of water bodies

- Station 2 has acceptable votes in terms of thermal preference, tolerance and satisfaction. Station 1 has unacceptable votes for all the respondents during Thermal perception survey conducted between 12:30 pm to 2 pm.
- Share of water fraction is important for outdoor thermal comfort. The water breeze from water bodies improves outdoor comfort conditions.
- Station 1- daytime, outdoor thermal conditions are very hot with PET values of 51-53^{o} C. there is low windspeed. In the evening, the conditions are hot with PET value of <39.46^{o}C. there is water breeze from Rabindra Sarovar Lake. The breeze is appreciated by the respondents.

- Station 2 - During daytime, station 2 having access to water body has source to fresh breeze during daytime. In the evening, the breeze continues. The air temperature is high and so PET is 36.71^{o} C and in the evening, it is 36.83^{o} C. water bodies in an area extend a water effect whereby a uniformity in conditions are maintained. The breeze is appreciated by the respondents.

CHAPTER7: THERMAL PERCEPTION STUDY

7.1 THERMAL PERCEPTION STUDY

7.1.1 Nature of respondents- Age, Gender, Height, Weight, Clo, metabolic rate

The nature of the respondents is reflected in their age and physiological information. Most of the respondents were on way to work or peripatetic vendors or taxi drivers, rickshaw pullers and passersby. Some of the respondents were students in groups aged 20 to 22. The seniormost age was 70 to 73 while the maximum occurring age group was 35 to 40 and 40 to 45. The people showed easy adaptation to season. The average height and weight did not show much variation over the year. For some respondents a standard height weight for male and female respondents were used. The questionnaire schedule was conducted between 11 am to 2:30 pm on days with no overcast weather.

In Spring the people wear light clothing of Clo value ranging from 0.55 to 0.78. for a man wearing full sleeve shirt, trouser, shoes and socks, the Clo value will be (0.3+0.2+0.02+0.03). for jeans full sleeve shirt, shoes and socks, the Clo value is (0.3+0.3+0.02+0.02). for a woman, wearing sari with petticoat, blouse shoes and socks (0.15+0.35+0.12+0.02+0.03), for churidar, pyjama, dupatta, shoes, socks, scarf and in case of shawl (0.18+0.16+0.08+0.02+0.03+0.27+0.04).

In summer, half sleeved shirt with trousers, undershirt, socks, shoes will have clo values (0.19+0.15+0.06+0.03+0.02), for rickshaw pullers and mason workers the clo value is (0.06+0.13+0.21) wearing shorts, undershirt and sandals. For a student it is short sleeve, shorts, sandals (0.19+0.13+0.02). For a woman it is petticoat, Saree, Blouse, Shoes (0.15+0.3+0.12+0.02), churidar, salwar, dupatta, shoes (0.13+0.12+0,04+0.02).

In autumn, full sleeve shirts, trouser, undershirt, socks, shoes have Clo values as (0.03+0.24+0.06+0.02+0.1), full sleeve shirt, jeans, undershirt, socks and shoes have clo value of (0.3+0.3+0.06+0.02+0.1), churidar, salwar, shawl, shoes, socks will have Clo values as (0.18+0.16+0.3+0.06+0.05), saree, petticoat, blouse, light sweater or shawl, socks, shoes (0.15+0.35+0.16+0.18+0.04+0.06).

In winter, full sleeve shirt, jeans, full sweater, socks, shoes will have Clo values (0.3+0.3+0.36+0.06+0.1). full sleeve shirt, jacket, jeans, socks, shoes, cap will have Clo value of (0.3+0.3+0.4+0.05+0.1+0.1). saree, blouse, petticoat, full sweater, socks shoes will have Clo values as (0.15+0.39+0.19+0.36+0.02+0.03), churidar, salwar, full sleeve sweater, scarf, socks, shoes (0.18+ 0.16+ 0.3+0.13+0.06+0.05).

Apart from adaptive behaviour visible in changes in Clo value across seasons, the adaptive methods also include use of umbrella, caps, sunglasses, standing under tree, drinking water, cold drinks, fruit juices, lemonade etc, sitting on a bench, and so on. The respondents of the questionnaire also showed such behavioural adaptation but it is beyond the scope of this study.

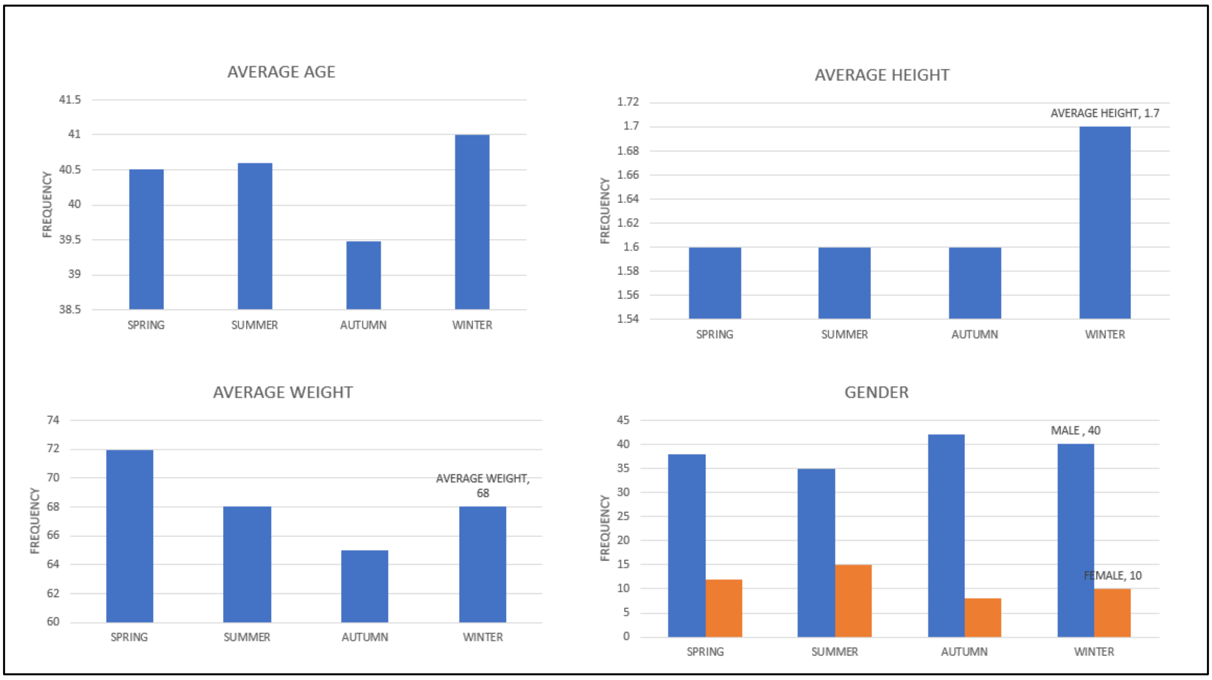


Figure 7.1 showing Physiological information collected during Questionnaire Survey, 2019.

The gender of the respondents show that most respondents are male in all the seasons for the given time of data collection. The metabolic rate has been followed in accordance to the standards provided in RayMan software. Metabolic activity is given by Met value calculated in the software based on standing, sitting posture. Since most of the respondents were in standing posture while responding to questionnaire schedule, the corresponding met value was chosen.

7.1.2 Thermal Sensation for Spring, Summer, Autumn Winter

Thermal sensation is graded on a 7-point scale with neutral, slightly cool and slightly warm as acceptable votes.

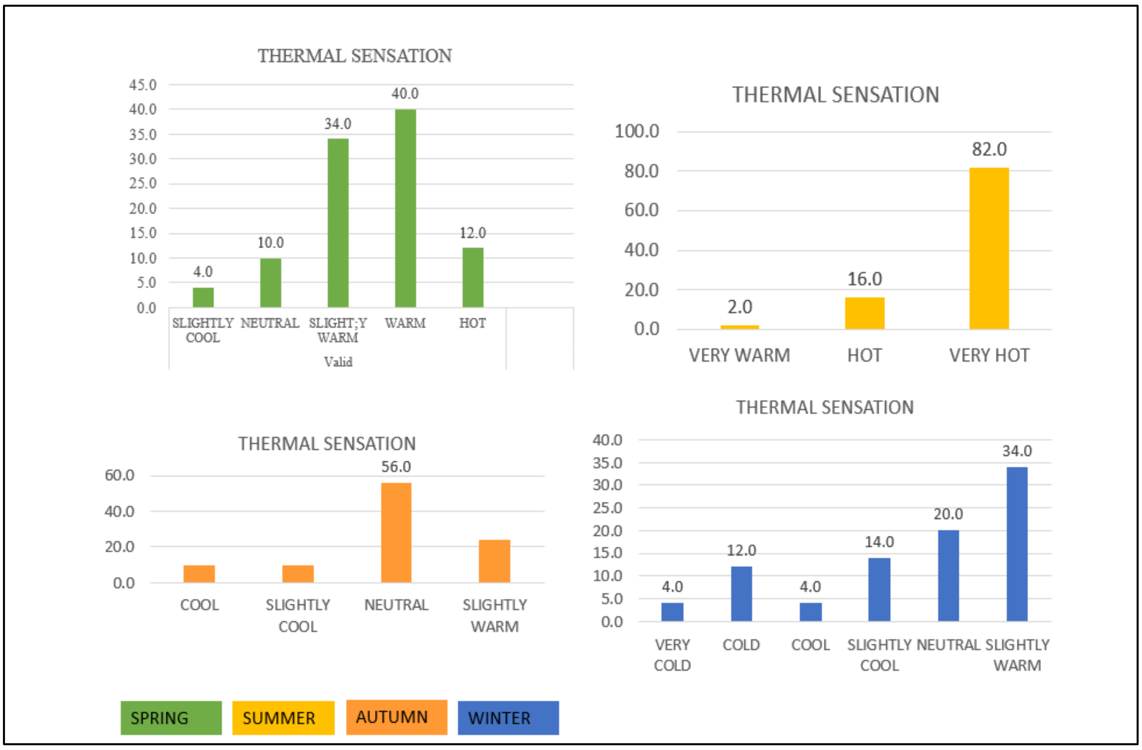


Figure 7.2 Thermal sensation 2019

➢ SPRING

4% feel slightly cool and 10% feel neutral 34-40% feel slightly warm and warm in spring, 12% feel hot. 52% unacceptable votes.

➢ SUMMER

2% feel very warm, 16% to 82% feel hot to very hot. 100% unacceptable votes.

➢ AUTUMN

56% feel neutral while 22% feel slightly warm in autumn, and 34% feel slightly warm in winter. 12% unacceptable votes.

➢ WINTER

14% feel slightly cool, 20% neutral, 34% slightly warm, 4% feel very cold., 12 % cold and 4% cool. 20% unacceptable votes.

7.1.3 Thermal acceptance for spring, summer, autumn winter

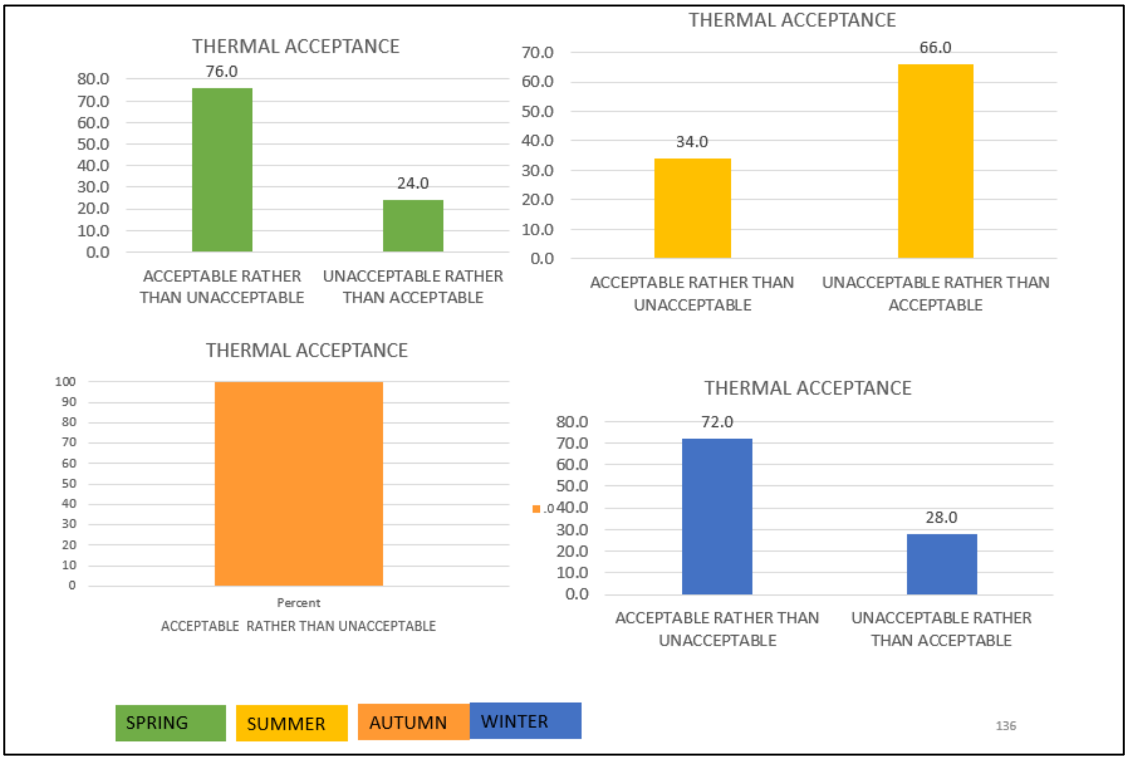


Figure 7.3 Thermal acceptability ,2019

Thermal acceptability is graded on a 2-point scale.

- SPRING

76% find the conditions acceptable.

- SUMMER

34% find conditions acceptable.

- AUTUMN

100% find conditions acceptable.

- WINTER

72% find conditions acceptable.

7.1.4 Thermal Satisfaction for Spring, Summer, Autumn Winter

Thermal satisfaction is measured on a 7-point scale where all forms of satisfaction and slightly dissatisfied are acceptable votes.

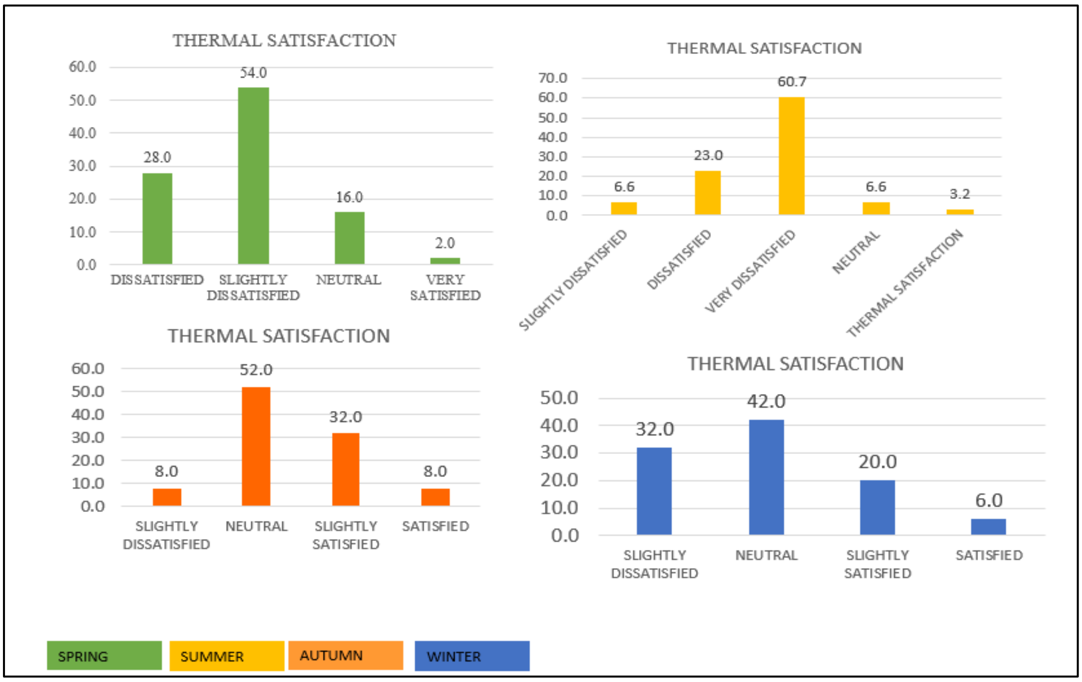


Figure 7.4 Thermal satisfaction 2019

- SPRING

16% feel feel neutral 2% feel very satisfied 545 slightly dissatisfied and 28% dissatisfied. unacceptable votes. 28% are unacceptable votes.

- SUMMER

60.7% feel very dissatisfied, 23% feel dissatisfied. 16.4% acceptable votes.

- AUTUMN

52% feel neutral while 32% feel slightly satisfied, 8% feel slightly dissatisfied and and 8% feel satisfied. 100% acceptable votes.

- WINTER

32% feel dissatisfied, 42% neutral, 20% slightly satisfied and 6% satisfied. 100% acceptable votes.

7.1.5 Thermal tolerance for spring, summer, autumn winter

Thermal tolerance is measured on a 5-point scale where tolerable and slightly intolerable are acceptable.

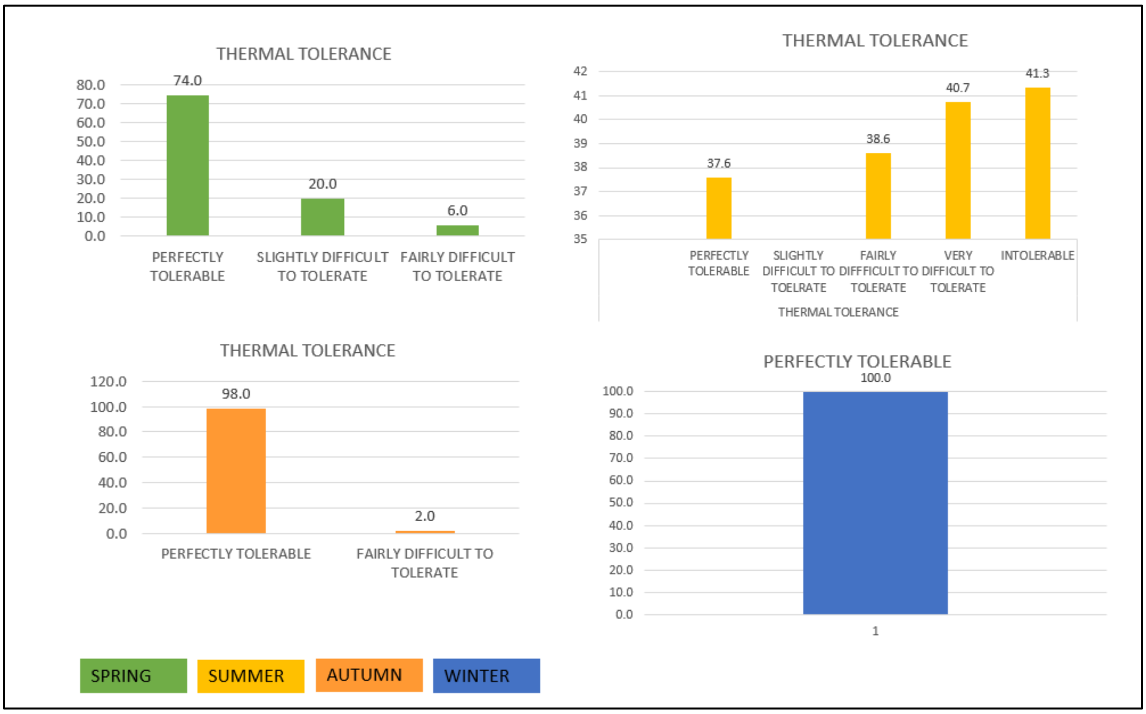


Figure 7.5 Thermal tolerance 2019

- SPRING

74% feel perfectly tolerable, 20% feel difficult to tolerate and 6% fairly difficult to tolerate. 6% are unacceptable votes.

- SUMMER

37.6% feel perfectly tolerable, 38.6% feel fairly difficult to tolerate, 40.7% very difficult to tolerate and 41.3% find it intolerable.

- AUTUMN

2% find conditions fairly difficult to tolerate. 98% acceptable votes.

- WINTER

100% acceptable votes.

7.1.6 Thermal Preference for Spring, Summer, Autumn Winter

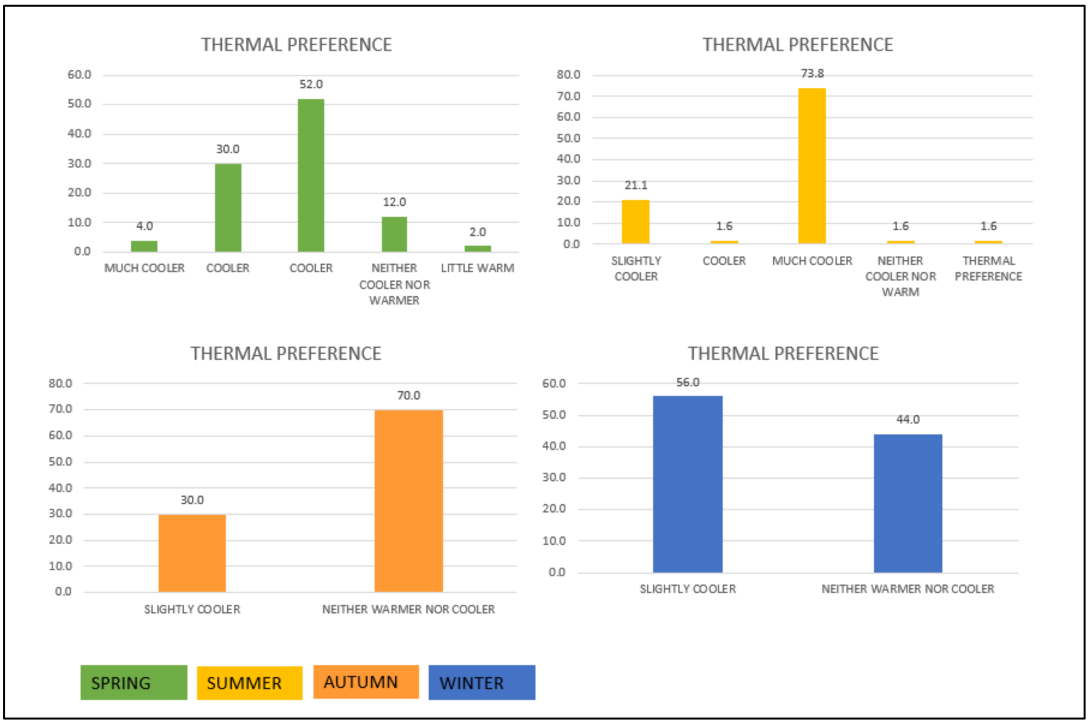


Figure 7.6 Thermal Preference 2019

Thermal preference is measured on a 7-point scale where neutral, slightly cooler and slightly warmer preferences are acceptable.

- SPRING

12% prefer no change, 2% little warm and 52% slightly cooler 30% cooler and 4% much cooler. 68% are acceptable votes.

- SUMMER

73.8% prefer much cooler conditions. While 1.6% prefer cooler conditions. 1.6 prefer neither cooler not warm conditions and 21.8% prefer slightly cooler conditions. Almost 75% are unacceptable votes.

- AUTUMN

30% prefer slightly cooler. 98% neither cooler nor warmer. 100% acceptable votes.

- WINTER

56% slightly cooler and 44% prefers no change. 100% acceptable votes.

7.1.7 Thermal Comfort for Spring, Summer, Autumn Winter

Thermal comfort is measured on a 7-point scale where neutral, slightly comfortable and slightly uncomfortable votes are acceptable.

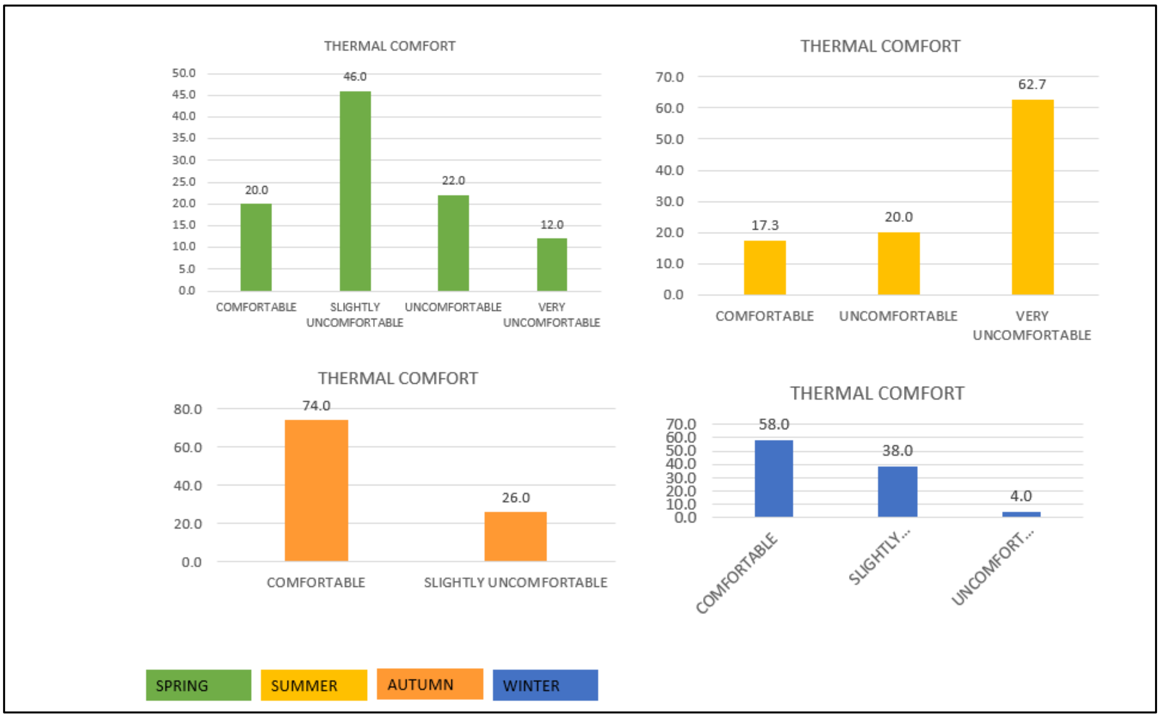


Figure 7.7 Thermal comfort 2019

- SPRING

20% comfortable, 46% slightly uncomfortable, 22% uncomfortable and 12% very uncomfortable.

- SUMMER

62.7% very uncomfortable, 20% uncomfortable, 17.3% comfortable. 82.7% unacceptable vote.

- AUTUMN

74% slightly uncomfortable. 26% comfortable. 100 acceptable votes.

- WINTER

4% Are Uncomfortable, 58% Comfortable, 38% Slightly Uncomfortable. 96 % Acceptable Votes.

THERMAL SENSATION		
	Frequency	Percent
SLIGHTLY COOL	2	4.0
NEUTRAL	5	10.0
SLIGHTLY WARM	17	34.0
WARM	20	40.0
HOT	6	12.0
TOTAL	50	100
THERMAL COMFORT		
	Frequency	Percent
COMFORTABLE	10	20.0
SLIGHTLY UNCOMFORTABLE	23	46.0
UNCOMFORTABLE	11	22.0
VERY UNCOMFORTABLE	6	12.0
Total	50	100.0
THERMAL PREFERENCE		
	Frequency	Percent
MUCH COOLER	2	4.0
COOLER	15	30.0
COOLER	26	52.0
NEITHER COOLER NOR WARMER	6	12.0
LITTLE WARM	1	2.0
Total	50	100.0
THERMAL ACCEPTANCE		
	Frequency	Percent
ACCEPTABLE RATHER THAN UNACCEPTABLE	38	76.0
UNACCEPTABLE RATHER THAN ACCEPTABLE	12	24.0
Total	50	100.0
THERMAL SATISFACTION		
	Frequency	Percent
DISSATISFIED	14	28.0
SLIGHTLY DISSATISFIED	27	54.0
NEUTRAL	8	16.0
VERY SATISFIED	1	2.0
Total	50	100.0
THERMAL TOLERANCE		
PERFECTLY TOLERABLE	37	74.0
SLIGHTLY DIFFICULT TO TOLERATE	10	20.0
FAIRLY DIFFICULT TO TOLERATE	3	6.0
Total	50	100.0

Table 7.1 Thermal Perception study- thermal sensation, thermal comfort, thermal preference, thermal acceptance, thermal satisfaction, thermal tolerance, spring 2019.

THERMAL SENSATION		
		Percent
VERY WARM		1.6
HOT		13.1
VERY HOT		67.2
Total	50	100.0
THERMAL COMFORT		
COMFORTABLE		17.3
UNCOMFORTABLE		20.0
VERY UNCOMFORTABLE		62.7
Total	50	100
THERMAL PREFERENCE		
SLIGHTLY COOLER		21.1
COOLER		1.6
MUCH COOLER		73.8
NEITHER COOLER NOR WARM		1.6
TOTAL	50	100
THERMAL ACCEPTANCE		
ACCEPTABLE RATHER THAN UNACCEPTABLE		34.0
UNACCEPTABLE RATHER THAN ACCEPTABLE		66.0
TOTAL	500	100
THERMAL SATISFACTION		
SLIGHTLY DISSATISFIED		6.6
DISSATISFIED		23.0
VERY DISSATISFIED		60.7
NEUTRAL		6.6
THERMAL SATISFACTION		3.2
TOTAL	50	100
THERMAL TOLERANCE		
PERFECTLY TOLERABLE		1.7
FAIRLY DIFFFICULT TO TOLERATE		5.0
VERY DIFFICULT TO TOLERATE		15.0
INTOLERABLE		61.7
TOTAL	50	100

Table 7.2 Thermal Perception study- thermal sensation, thermal comfort, thermal preference, thermal acceptance, thermal satisfaction, thermal tolerance, Summer, 2019.

THERMAL SENSATION		
	Frequency	Percent
COOL	5	10.0
SLIGHTLY COOL	5	10.0
NEUTRAL	28	56.0
SLIGHTLY WARM	12	24.0
Total	50	100.0
THERMAL COMFORT		
	Frequency	Percent
COMFORTABLE	37	74.0
SLIGHTLY UNCOMFORTABLE	13	26.0
Total	50	100.0
THERMAL PREFERENCE		
	Frequency	Percent
SLIGHTLY COOLER	15	30.0
NEITHER WARMER NOR COOLER	35	70.0
Total	50	100.0
THERMAL ACCEPTANCE		
	Frequency	Percent
ACCEPTABLE RATHER THAN UNACCEPTABLE	50	100.0
THERMAL SATISFACTION		
	Frequency	Percent
SLIGHTLY DISSATISFIED	4	8.0
NEUTRAL	26	52.0
SLIGHTLY SATISFIED	16	32.0
SATISFIED	4	8.0
Total	50	100.0
THERMAL TOLERANCE		
	Frequency	Percent
PERFECTLY TOLERABLE	49	98.0
FAIRLY DIFFICULT TO TOLERATE	1	2.0
Total	50	100.0
THERMAL PREFERENCE		
	Frequency	Percent
SLIGHTLY COOLER	15	30.0
NEITHER WARMER NOR COOLER	35	70.0
Total	50	100.0

Table 7.3 Thermal Perception study- thermal sensation, thermal comfort, thermal preference, thermal acceptance, thermal satisfaction, thermal tolerance, Autumn, 2019.

THERMAL SENSATION		
	Frequency	Percent
COOL	5	10.0
SLIGHTLY COOL	5	10.0
NEUTRAL	28	56.0
SLIGHTLY WARM	12	24.0
Total	50	100.0
THERMAL COMFORT		
	Frequency	Percent
COMFORTABLE	37	74.0
SLIGHTLY UNCOMFORTABLE	13	26.0
Total	50	100.0
THERMAL PREFERENCE		
	Frequency	Percent
SLIGHTLY COOLER	15	30.0
NEITHER WARMER NOR COOLER	35	70.0
Total	50	100.0
THERMAL ACCEPTANCE		
	Frequency	Percent
ACCEPTABLE RATHER THAN UNACCEPTABLE	50	100.0
THERMAL SATISFACTION		
	Frequency	Percent
SLIGHTLY DISSATISFIED	4	8.0
NEUTRAL	26	52.0
SLIGHTLY SATISFIED	16	32.0
SATISFIED	4	8.0
Total	50	100.0
THERMAL TOLERANCE		
	Frequency	Percent
PERFECTLY TOLERABLE	49	98.0
FAIRLY DIFFICULT TO TOLERATE	1	2.0
Total	50	100.0
THERMAL PREFERENCE		
	Frequency	Percent
SLIGHTLY COOLER	15	30.0
NEITHER WARMER NOR COOLER	35	70.0
Total	50	100.0

Table 7.4 Thermal Perception study- thermal sensation, thermal comfort, thermal preference, thermal acceptance, thermal satisfaction, thermal tolerance, Winter, 2019.

7.1.8 Inferences from Thermal Perception Study

In spring there are 52% unacceptable votes and in summer 100% unacceptable votes. The people have warm to very hot sensation.

In spring, summer, winter 70%-100% feel conditions to be acceptable. In summer only 34% finds conditions acceptable.

In summer, 28% have satisfaction votes. Summer has 83.6%unacceptable votes. Autumn and winter have 100% acceptable vote.

94% acceptable votes for tolerance in spring, 98% acceptable votes for tolerance in autumn and 100% acceptable vote for tolerance in winter. Summer has over 93% unacceptable votes for tolerance,

In Spring, there is preference for cooler conditions and 34% unacceptability vote. In summer over 90% have given unacceptability vote. In thermal preference for autumn and in winter there is 100% acceptability vote.

7.2 MEAN THERMAL SENSATION VOTE

Thermal sensation study is important to calculate the thermal sensation vote. Thermal sensation vote is the expression of thermal sensation of the respondents at mPET conditions. Thermal sensation at 0 is neutral. The mPET conditions where respondents feel neutral is given by the x-value of the linear equation. Mean Thermal Sensation Vote is thermal sensation for each mPET bin is taken as votes for mean thermal conditions for every 1 ^{o}C mPET. The MTSV helps to draw a regression analysis which will give us the linear equation. With the help of the MTSV, neutral temperature is calculated.

Mean mPET	22.9	23.3	24.9	24.9	25.5	26.4	33.5	41.4
Mean Thermal Sensation Vote (MTSV)	-4	-3	-2	-1	0	2	3	4

Table 7.5 Calculation with Mean Thermal Sensation Vote (MTSV)

TSV	Mean	Maximum	Median	Minimum	Range	Standard Deviation
VERY COLD	22.9	23.1	22.9	22.7	0.4	0.3
COLD	23.3	26.4	24	19.6	6.8	3
COOL	24.9	28.3	25.8	17.1	11.2	3.8
SLIGHTLY COOL	24.8	29	25.1	15.6	13.4	3.4
NEUTRAL	25.5	31.2	25.3	16.3	14.9	3.5
SLIGHTLY WARM	24.9	30.3	25.5	14.2	16.1	3.7
WARM	26.4	37.6	26.7	14.5	23.1	3.6
HOT	33.5	41.9	37.3	19.7	22.2	7.1
VERY HOT	41.4	45.9	41.8	37.4	8.5	2

Table 7.6 Mean Thermal Sensation Vote.

THERMAL SENSATION	THERMAL SENSATION GRADE	MEAN
VERY COLD	-4	22.9
COLD	-3	23.3
COOL	-2	24.9
SLIGHTLY COOL	-1	24.9
NEUTRAL	0	25.5
SLIGHTLY WARM	1	24.9
WARM	2	26.4
HOT	3	33.5
VERY HOT	4	41.4

Table 7.7 Mean Thermal Sensation Vote calculated for each grade of Thermal Sensation. Highlighted thermal sensation grade is the acceptable vote. Thermal sensation vote by Matzarakis et.al.

7.2.1 Neutral mPET

Neutral mPET in degree Celsius is the condition in which people feel neutral i.e. they neither prefer cooler nor warmer conditions. The mean sensation vote is calculated based on Thermal Sensation Vote (TSV). The votes are grouped into bins, for every 1° C change in mPET. TSV is a 7-point scale. In case of inclusion of extremely hot or extremely cold sensation, in such case it is a 9-point scale. At 0 Mean thermal Sensation Vote (MTSV), the corresponding mPET conditions is the neutral condition. Given below is the calculation of Neutral temperature.

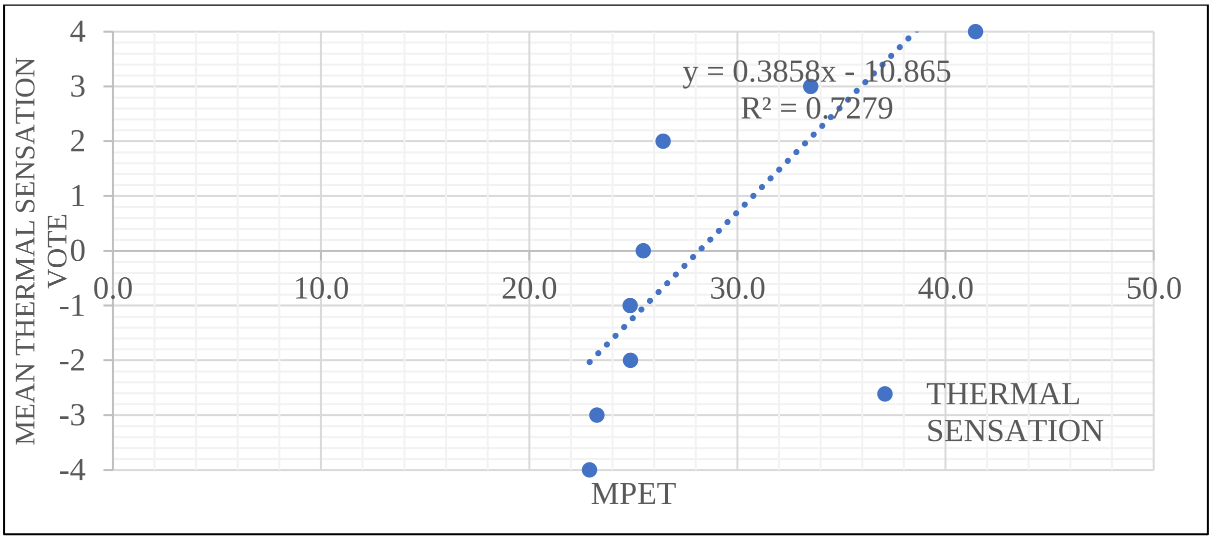


Figure 7.8 showing Neutral temperature calculation at neutral MTSV.

In the 7-point scale given by ASHRAE 55, 3 represents Hot, 2 represents Warm, 1 represents slightly warm, 0 represents neutral, -1 represents slightly cool, -2 represents cool and -3 represents cold. Refer Chapter 5 for Table 5.4 and Table 5.5.

The linear equation in this regression is **MTSV= 0.3858mPET - 10.865**

Neutral mPET was calculated using regression line equations **MTSV= 0.3858mPET - 10.865**

When MTSV=0, then neutral mPET = 28.16 ° C

Proposed Neutral temperature for the study area = 28.16 ° C

At 28.16 ° C people in Kolkata feel neutral, comfortable and prefer neither warmer nor cooler conditions.

7.2.2 Acceptable Range of mPET

Acceptable range of mPET refer to the range of temperature with 90% acceptability votes. The acceptability votes have been explained as the votes for neutral, slightly comfortable and slightly uncomfortable range. Acceptable votes also include, slightly warm and slightly cool preference. The **proposed acceptable range is 23º C to 29º C as shown below.**

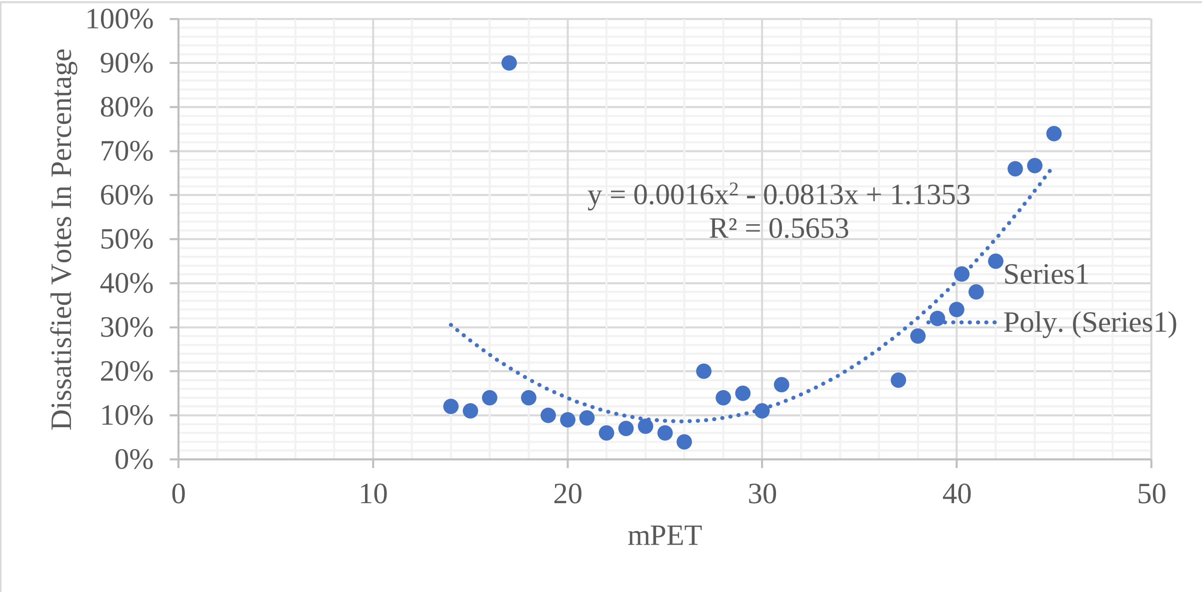
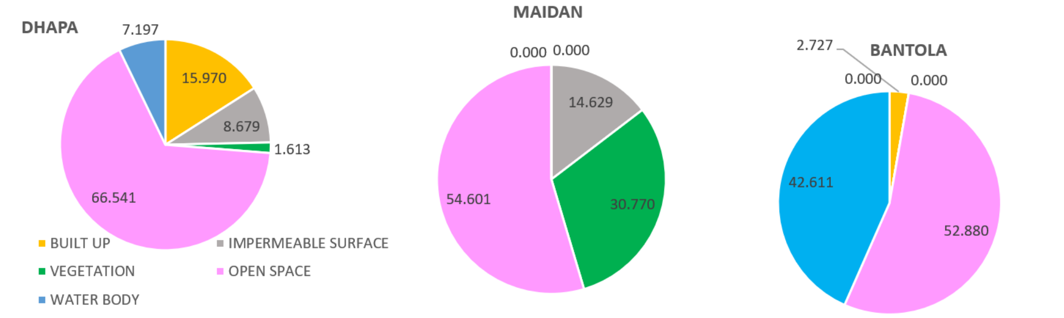


Figure 7.9 showing Acceptable range of temperature at 90% acceptability limits

mPET	unacceptable votes	mPET	unacceptable votes
14	0.12	27	0.2
15	0.11	28	0.14
16	0.14	29	0.15
17	0.9	30	0.11
18	0.14	31	0.17
19	0.1	37	0.18
20	0.09	38	0.28
21	0.094	39	0.32
22	0.06	40	0.34
23	0.07	41	0.38
24	0.075	42	0.45
25	0.06	43	0.66
26	0.04	44	0.667
		45	0.74

Table 7.8 Unacceptable votes calculated for every 1o C mPET bin.



mPET	28.15
Air temperature	29.35
Windspeed	3.53
Relative humidity	56.85
Tg	32.53

mPET	28.35
Air temperature	29.97
Windspeed	1.05
Relative humidity	51.77
Tg	30.05

mPET	28.5
Air temperature	29.9
Windspeed	1.32
Relative humidity	47.05
Tg	31.6

Figure 7.10 conditions of surface cover and microclimate conditions of stations with mPET values closest to proposed Neutral Temperature

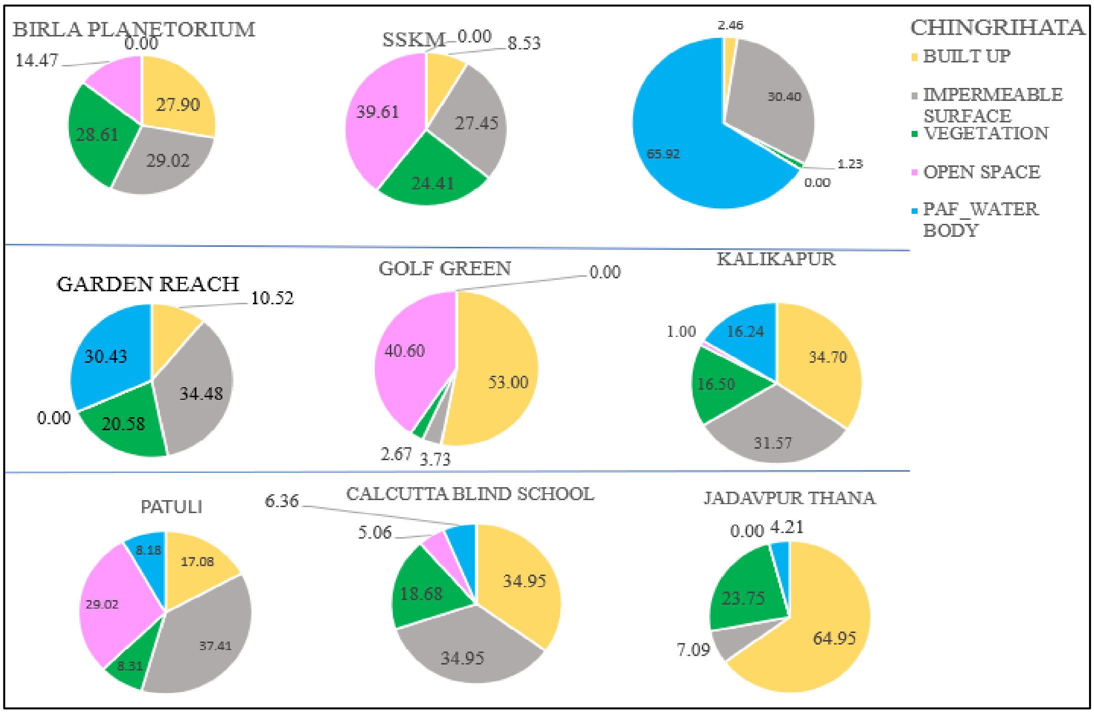


Figure 7.11 Stations with temperature between 23 to 28.1 degree Celsius.

The stations where the average mPET conditions are nearest to the neutral temperature of 28.1°C are Maidan, Dhapa and Bantola. The conditions in these stations are given in Figure 5.7.

7.2.3 Inference

PET	Thermal perception	Grade of physiological stress
	Very cold	Extreme cold stress
4°C	Cold	Strong cold stress
8°C	Cool	Moderate cold stress
13°C	Slightly cool	Slight cold stress
18°C	Comfortable	No thermal stress
23°C	Slightly warm	Slight heat stress
29°C	Warm	Moderate heat stress
35°C	Hot	Strong heat stress
41°C	Very hot	Extreme heat stress

Figure 7.12 Description of physiological stress, Matzarakis and Mayer, 1996)

- Three stations have neutral mPET conditions are Maidan, Dhapa, Bantola. Maidan and Bantola has less than 20% Thermal load and Dhapa have less than 255 Thermal load. According to the Thermal Stress Grade given by Matzarakis et al., the 28.1^{o} C mPET; conditions are slightly warm. These stations have conditions within 29 ^{o}C. The dynamic potential for these stations is 75% to >80% share of 100m diameter station area.

- Nine stations having mPET 23 ^{O}C to 28.1 ^{O}C. these stations have Dynamic potential from 30% to 65%. On an average, 45% of dynamic potential is required within an area of 100m diameter for thermal range to be withing 23 ^{O}C to 28.1 ^{O}C.

- Thermal Perception study is important to calculate the Neutral and Acceptable outdoor conditions.

7.3 THERMALLY NEUTRAL LOCATIONS IN RESPECT TO OUTDOOR THERMAL COMFORT

Comfort location was calculated by applying Site Suitability Analysis, Principal Component Analysis to understand the importance of each parameter to apply weights were applied. The parameters are the microclimate parameters and thermal perception study. The individual independent variables do not show a significant correlation.

The variables were reclassed with suitable weightage which helped extract the thermally preferred location. The weights applied for reclass of land use classification was based after the statistical technique of Exploratory Factor Analysis (EFA) in Principal Component Analysis.

It is a data reduction technique in which orthogonal rotation of Oblimin with Kaiser Normalisation was carried out. This being an exploratory analysis, Eigen values less than 1.0 was ignored. Communality of greater than 1.0 was considered significant.

The Kaiser Meyer Olkin (KMO) test of sampling accuracy is 0.65 which is above the recommended threshold of 0.5.

The Bartlett's test of sphericity is 0.0, which is less than 0.5 thus showing that the variables are highly correlated so that factor analysis may be performed and null hypothesis can be rejected

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.650
Bartlett's Test of Sphericity	Approx. Chi-Square	170.599
	df	15
	Sig.	.000

Communalities

	Initial	Extraction
TG	1.000	.732
TA	1.000	.689
RH	1.000	.898
Ts	1.000	.725
WINDSPEED	1.000	.880

Extraction Method: Principal Component Analysis.

Pattern Matrix

	Component 1	Component 2	Component 3
TG	.849		
TA	.830		
Ts	.490	-.486	.406
WINDSPEED		.944	
RH			-.935

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.[a]
a. Rotation converged in 8 iterations.

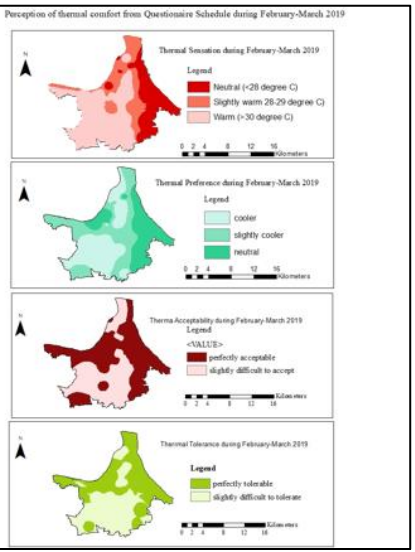


Figure 6.7.13 steps for Principal Component Analysis

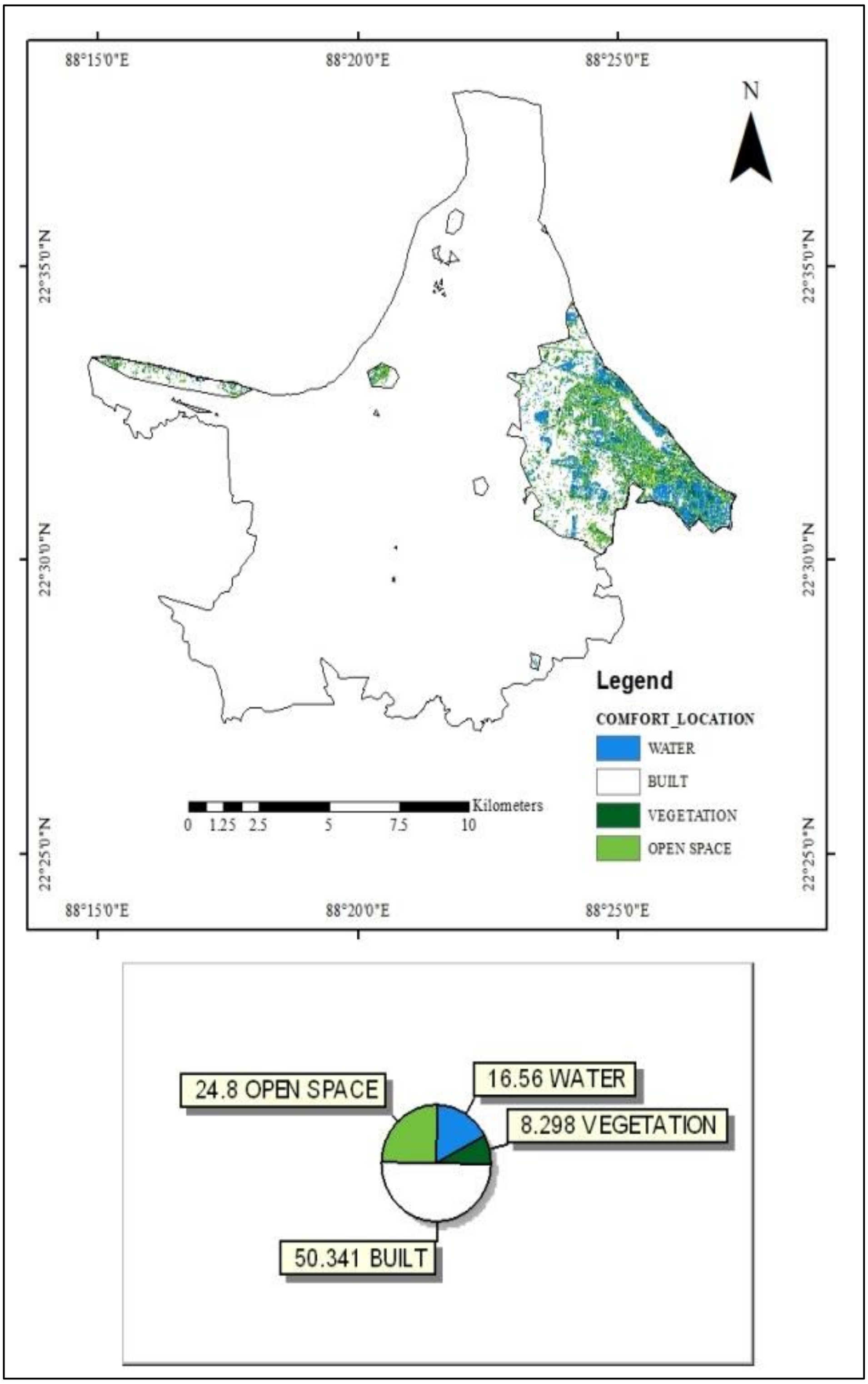


Figure 6.7.14 showing proposed Comfortable area after applying PCA and Site Suitability Analysis.

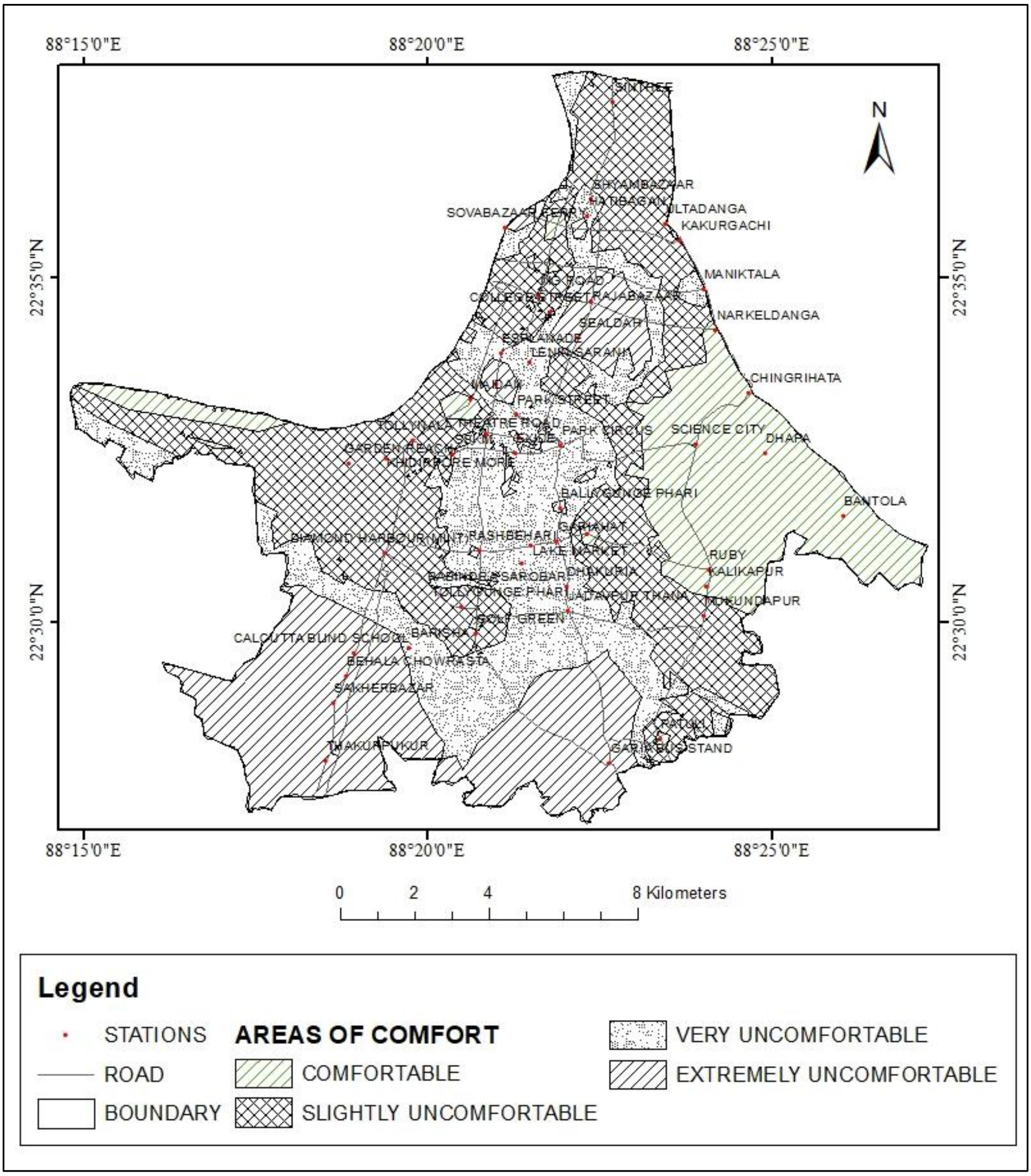


Figure 7.15 Identifying comfortable areas and uncomfortable areas within KMC area.

The results of the test are shown in Figure 5.y. The comfortable area also includes two of the three stations that have mPET conditions nearest to the proposed neutral temperature- Bantola and Maidan which fall within the comfortable zone. The surface cover of the proposed comfortable location is given in the following figure 5.z. the surface cover share is: 50.34% built surface, 24.8% open space, 15.56% water surface and 8.3% vegetation surface. After Site Suitability analysis, T proposed surface cover share was extracted unsupervised surface cover classification previously mentioned.

7.3.1 Inference from 7.2 and 7.3

- So, at 28.16 ^{o}C people feel neutral, comfortable and prefer neither warmer nor cooler conditions.
- The proposed acceptable range is 23^{o}C to 29^{o}C. Neutral range is within the acceptable range of temperature.
- There should be a combination of natural surface and built surface (Dynamic Potential and Thermal Load) in surface cover characteristics for a place to have comfortable outdoor thermal conditions.
- People’s perception of weather conditions is extremely important to calculate the neutral and acceptable outdoor thermal conditions. Without the Thermal Perception Study, such calculations cannot be performed. The mean thermal sensation vote implies the need for people’s participation in climate inclusive planning process.

CHAPTER8: DISCUSSION

8.1 IMPORTANCE OF MICROCLIMATE PARAMETERS

In microclimate analysis, most studies use microlevel data to understand the thermal conditions and to prescribe recommendations to improve the existing thermal conditions. In many studies. Data is collected for a single season while in some studies data is collected for several seasons in a year. Dat is collected at canopy level to study the contribution of the parameters in creating discomfort or comfort conditions. The discussion of such studies that analyse parameters, their importance, their effect on microclimate and people's perception, and provide recommendations for change are given as follows.

Data is collected for summer and winter for informal settlements in Kolkata, where Ta, Tg, RH and Va ae observed onsite. The microclimate data is observed at 1.1m from ground. Data is collected 11am to 5 pm at the informal settlements. Over 300 sample survey conducted. The microclimate data was used to calculate PET, neutral PET.(Banerjee, Middel and Chattopadhyay, 2020). Analysis of tree species and surface albedo for outdoor thermal comfort is conducted using Ta, Ts, Windspeed and Sky View Factor (SVF) and the result is that inspite of its use widely in previous studies, SVF does not act as an indicator of thermal comfort or surface radiation. (Mohammad *et al.,* 2021). Changes in albedo do not significantly affect thermal comfort conditions in hot regions (Mohammad *et al.*, 2021). Pedestrian level survey observe data on Ta and Va in cold winter conditions where acceptable conditions include higher Ta and lower Va (Kim, Lee and Kim, 2018). Wind is an important parameter for study in wind comfort around hi rise buildings(Janssen, Blocken and Van Hooff, 2013). To study the impact of draft in cold weather or the benefits of ventilation in hot weather using CFD and numerical simulations, Ta and Va are considered for study (Maher *et al.,* 2021). Study of thermal comfort in a high humidity , high temperature , low wind regions makes ta, RH, Va important parameters of observation in order to understand temperature sensation and wind sensation of the respondents (Lu *et al.*, 2016).microclimate studies for different seasons such as spring, autumn and winter are not as widely found. More studies are found for summer season (Tsoka *et al.*, 2020). Albedo is an important parameter that have been widely studied to understand the impact of surface material with high albedo(Tsoka *et al.,* 2020). Ta is an important parameter in hot and humid regions and water bodies and evapotranspiration are means to reduce Ta (Manteghi, Bin Limit and Remaz, 2015). In order to understand and implement adaptation strategies, it is important to have a strong climatic database involving the necessary microclimate parameters (Mauree *et al.*, 2019). Simulation and modelling requires onsite measurement of data (Lai *et al.*, 2019). For understanding of thermal comfort , both objective (meteorological data) and subjective (people's response to thermal conditions) need to be considered (Ali and Patnaik, 2018). Study of thermal conditions in different seasons to understand the favourable conditions for tourism (Sahabi Abed and Matzarakis, 2017). Wind can be a deterrent to comfort of a space not only in cold regions but also due to the microclimate conditions of wind turbulence caused by the built environment (Szucs, 2013; Cammelli and Stanfield, 2017). Adaptive measures to improve wind ventilation and to reduce heat load by evapotranspiration, or watered vegetation. (Müller, Kuttler and Barlag, 2014). Importance of parameters such as Ta, RH, solar radiation, wind speed and Tmrt can change with seasons. Study of people's responses to the microclimatic conditions such as temperature conditions , humidity conditions and wind conditions help in analysing the preferred temperature , perceived temperature , preferred sunshine level, preferred wind conditions and so one (Spagnolo and de Dear, 2003). Tmrt is one of the most important parameters in studies of microclimate. it can be calculated in RayMan software (Dai and Schnabel, 2013). Primary data is also important to understand the difference in values of the parameters between different regions such as urban and rural areas. the extent to which one parameter affects the other is studied through correlation analysis using Pearson's method can help identify the important parameter. In case of calculation of PET, Tmrt is the most important parameter (Krüger, Minella and Matzarakis, 2013).In outdoor thermal comfort analysis, parameters are used to calculate and measure the extent of comfort in many regions. Further on, with the extent of comfort or discomfort are already estimated, the studies go on to identify parameter that contributes most to such discomfort conditions. Methods to control such parameters with simulations, modelling and tunnel experiments are conducted. In such studies, secondary parameters, such as species of trees, surface material, building orientation, shade become important.

Some of the parameters discussed include the use of trees in unshaded areas and use of low albedo material will help lower surface temperature (Tan *et al.*, 2021). Shade and cool materials are good strategies, urban geometry and planting tree is an important component, Tmrt is an important parameter (Salman and Saleem, 2021). Shade areas have higher comfort, Open spaces with no shade have higher PET, Tree always do not guarantee comfort., Wind movement becomes unsteady with built environment (Ghaffarianhoseini *et al.*, 2019). Wind sheltering provides outdoor thermal comfort (Brozovsky *et al.*, 2021). High heat absorption material along with no vegetation and high humidity create heat stress (Kamel, 2021). Proposals for bioclimate based urban street designs to incorporate association between air pollution and thermal discomfort (Schaefer *et al.*, 2021). Temperature reduction for all scenarios from 100% , 50% green roofing to green walls (Herath, Halwatura and Jayasinghe, 2018). Low density buildings with shading allow for lower mean radiant temperature though overall share of urban cover should be less (Ferwati *et al.*, 2019). Tree alignment can have cooling effect on the city up to 1.2 degree Celsius (Bachir *et al.*, 2021). PET reduction up to 2.5 degree Celsius(Rossi *et al.*, 2020). Shading is more effective than wind in adding comfort but both together will create comfortable environment (Othman and Alshboul, 2020).

8.2 IMPORTANCE OF SURFACE COVER

8.2.1 Surface cover Classification

Unsupervised classification on Kolkata Metropolitan Area area gave result of 30% built surface, 9.73% vegetation and 9.73% vegetation, remaining fallow land, bare land, plantations make up almost 50%(Ray *et al.*, 2023). In this study surface classification of Kolkata Municipal area was performed where 60% of area is built surface, 5% water and 19% open area. The remaining area is vegetation and light vegetation. Another study shows the need to understand hyperspectral reflectivity to make surface cover classification using LISS III image. In this study, spectral reflectance curve has instrumental in surface cover classification(Raychaudhuri, Sarkar and Bhattacharyya, 2006) . a study shows that the northern and central part of KMC area has low NDVI(Chatterjee and Majumdar, 2022). The same result has been found in the NDVI performed for 2019 Landsat OLITIRS image, 2019.

8.2.2 Built surface cover

Urban climate zones are characterised by distinct urban surface cover show distinct climatic behaviours. (Houet & Pigeon, 2011). The surface cover study is used to understand the quality of vegetation and water surface in the area and the share of built surface to natural surface. Considering that built features and impermeable surface features do not allow storm water percolation is contributory factor to heat accumulation (Oke, Mills, Christen, & Voogt, 2017), and natural surface contributes to comfort conditions (Binte Ali & Patnaikb, 2018) (Emmanuel & Johansson, 2006) (Emmanuel & Johansson, 2006) (Amirtham, Horrison, & Rajkumar, 2015), the share of natural surface to built surface in both stations will help us delineate the basic difference in surface character. Surface cover is calculated as a ratio of the area of a surface feature (Ax) to the total ground surface area (At), known as the Plan Area Fraction. (Oke, Mills, Christen, & Voogt, 2017). The surface cover showing greater share in open surface or water bodies, can create dynamic potential in an area (Ng, 2015) (Urban climatic map studies in Vietnam: Ho Chi Minh City, 2015) (Welsch, 2015) (Wong, Kardinal Jusuf, Katzschner, & Ng, 2015) (Ren, Lun Lau, Ng, & Po Yiu, 2013). Built structures and built surface acting as obstruction to air flow can create thermal load. (Ng, 2015). Thermal load is a growing concern in India. Heat stress conditions can become acute especially for growing urbanised areas. (Amirtham, Lilly Rose; Horrison, Ebin; Rajkumar, Surya, 2015). Airflow in residential areas decreases due to to blockages to ventilation. Air temperature among residential buildings is higher than around it. Windspeed over water surface is higher due to the temperature slope from water to surrounding built areas. (Yang, Liu and Qian, 2020a)

8.2.3 Water surface cover

Studies have addressed the therapeutic role of water surface cover to combat heat stress conditions The water cycle and heat exchanges between atmosphere, land and water surface finds reflection in the air temperature and humidity conditions in what is known as ‘process-response system’. Water surface is considered as 'best absorber of radiation’ even though the thermal response is poor. (Wong, Tan, Nindyani, Jusuf, & Tan, 2012) Diffusion of absorbed energy, exchange of heat through convection, cooling through evaporation and large thermal capacity allows it to be a good urban heat sink (Oke T. , 2002). Due to convective evaporation, the water body may also contribute to warming of the surrounding during night time by increasing the humidity of the air. Water surface may also contribute to warming of the surrounding if the air temperature is lower than the surface water temperature and therefore counter the thermal conditions (Spronken- Smith, Oke, & Lowry, 2000) (Theeuwes, Solcerová, & Steeneve, 2013) (Imam Syafii, et al., 2016). Yet, water bodies serve as an important source of cooling for the surrounding microclimate, especially on sunny days (Wong, Tan, Nindyani, Jusuf, & Tan, 2012) in urban built fabric (Kruger & Pearlmutter). Areas closest to the water body show maximum reduced temperature than surrounding regions. (Coutts, Tapper, Beringer, Loughn, & Demuzere, 2012). Increasing distance from the water surface results in decreasing influence of water surface. The size of the water body also plays as vital a role as its location. A larger water body will influence the immediate surrounding but several water bodies will influence the greater percentage of the urban area. (Theeuwes, Solcerová, & Steeneve, 2013) Evaporation rates may increase the cooling effect if the surface area of the water body is large (Manteghi, limit, & Remaz, 2015). Built surface create a warming effect especially along a water body by absorbing radiation if the surface is dark coloured. (Hathway & Sharples, 2012) Wider road of 100 m with green belts will have more cooling effect from adjoining water bodies than roads with widths of 10m or 20m (Murakawa, Sekine, & Saburo, 1991). Features such as Vegetation and Shading (Hathway & Sharples, 2012) and Sea Breeze (Emmanuel & Johansson, 2006)play an important role in creating cool conditions from water's surface. Shallow water conditions in summer also do not aid much in 'sensible cooling' due to rise in water temperature (Hathway & Sharples, 2012). Water surface also adds up as a 'therapeutic landscape' (Völker & Kistemann, 2011) and spacious corridors to allow natural ventilation are necessary to guide the breeze from water surface into the urban interiors and therefore, improve comfort thermal conditions (Han, Chen, Yuan, Cai, & Han). Greater proximity to water surface and greater share of non-built landscape helps ameliorate the heat stress conditions. (Matzarakis & Amelung, Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans, 2008) Water bodies help to cool the environment and mitigate the heat stress conditions and improve dynamic potential and urban tourism (Binte Ali & Patnaikb, 2018) (Syafii, et al., 2016) (Wong, Kardinal Jusuf, Katzschner, & Ng, 2015). Water bodies help to cool the environment and mitigate the heat stress conditions and improve dynamic potential and urban tourism (Binte Ali & Patnaikb, 2018) (Syafii, et al., 2016) (Wong, Kardinal Jusuf, Katzschner, & Ng, 2015). Closer the water surface, greater is the effect of temperature lowering (Yang, Liu and Qian, 2020a).

8.2.4 Vegetation cover

In hot dry regions, dense canopy vegetation and water bodies can ameliorate thermal comfort (Binte Ali & Patnaikb, 2018). Higher surface reflectance material will reduce surface temperature but will increase Tmrt. Use of tree canopy will lead to reduced air temperature due to shade as well as lower Tmrt (Tsoka, Tsikaloudaki and Theodosiou, 2017). Shade is important in creating thermal comfort, MCZ within LCZ suggested at 1-10m^2 range Ewing and Handy, 2009). Grey areas of concrete generate thermally uncomfortable environment while green and blue areas have heat mitigation potential (Shimazaki *et al.*, 2022) . Green view index has association with BMI among females (Yang, Liu and Qian, 2020b) (Li and Ghosh, 2018). Orientation and location of buildings can be reorganised in renewal of urban areas by identifying the blocks that obstruct wind ventilation. Ventilation path studies for human comfort instead of uhi analysis needs to be done at ground level not at boundary layer level. Winds passing over green spaces have greater cooling potential (Wong *et al.*, 2010). Grass cover can reduce albedo and help in thermal comfort, increased building height may provide bigger shade and allow thermal comfort (Ma *et al.*, 2019). Geddes plan is perfect for the city "climatic suitability of the urban structure to the various seasons, sustainability of climatic urban planning over time determination of which factor (wind or shade) has a stronger influence on human thermal sensation" (Balslev, Potchter and Matzarakis, 2015). Urban greenery like turfs, shrubs, trees, urban roofing will reduce air temperature (Priya and Senthil, 2021). Making cities walkable is linked to street level comfort, safety, usefulness and design. Comfort includes lane width, street furniture and availability of trees (Rebecchi *et al.*, 2019). Plan area fraction applied in the same way as coverage area of green and blue infrastructure. The same study show that a combination of green-blue infrastructure can help reduce Ta by preventing sunlight to reach water surface with the help of tree shade(Jing Li *et al.*, 2020). combination of water bodies, open areas and vegetation is seen in the correlation matrix, where individual water fraction, vegetation fraction and open area fraction do not show significant impact. But together, termed as Dynamic potential, they have significant impact on the thermal conditions of the study area.

8.3 ANALYSIS OF OUTDOOR THERMAL COMFORT

The extent of thermal comfort conditions can be evaluated using the thermal comfort index such as Physiological Equivalent Temperature (PET) (Matzarakis & Amelung, Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans, 2008) (Matzarakis, Rutz, & Mayer, Modelling radiation fluxes in simple and complex environments—application of the RayMan model, 2007) (Nikolopoulou, Baker, & Steem, 2001) (Theeuwes, Solcerová, & Steeneve, 2013). In India the extent of comfort range and neutral temperature has been calculated for a few stations. The studies have been mentioned as follows: In 2010, a study in Chennai Railway Station using TSV and PET in summer months of June, calculated the Neutral temperature of 31.93^{o} C (Deb & Ramachandraiah, 2010). In 2015, in Chennai, study was conducted in April to calculate PET values ; where traditional streets with PET conditions ranging from -22°C -42°C and for Modern streets-21°C -37°C (Amirtham, Horrison, & Rajkumar, 2015) .Similar study was conducted in Srirangam, Tamil Nadu in 2014 (D & Meenatchi Sundaram, 2014). Thermohygrometric index (THI), WBGT, Relative Strain Index (RSI) was used in a study published in 2010 for period (March, April, May 1995-2009) to conclude that Heat stress is less in April than the other months and heat stress is maximum in Kolkata (Mohan, Gupta, & Bhati, 2014). Neutral conditions calculated at Park to be at 38.8 °C, lakefront with 39.9 °C thermal conditions are considered to be Hot and in market, area the thermal conditions at 41.8 °C PET is also considered hot. This study was conducted in April-May in 2018 in Bhopal, Madhya Pradesh (BinteAli & Patnaik, 2018). Effective uncomfortability is higher in Kolkata than Chennai, Delhi, Mumbai and Hyderabad-found in a study conducted in Five-year period from 2004-2008 using Effective Comfortability Ratio (ECR) in 2014, in Kolkata, Chennai, Mumbai, Delhi, Hyderabad (Mohan, Gupta, & Bhati, 2014). Commercial areas have PET= 40°C, at 5:30 pm PET=28°C -32°C; studied in April,2019 in Chennai using PET index for outdoor thermal comfort (A, Devadas, & Monsingh). The proposed acceptable range of temperature in this study is 23^{o} C to 29^{o} C. the Neutral mPET conditions are at 28.1^{o}C.

Ambient air temperature has role in mortality as studied in 31 capital cities in China (Luan *et al.*, 2019). Preferred, comfortable and neutral UTCI was calculated and was observed that people feel comfortable in warmer conditions of urban street during cold season in Harbin, northeast China. The study used MTSV and UTCI methods to calculate outdoor thermal comfort (Jin, Liu and Kang, 2019)(Wang, Berardi and Akbari, 2016). PET analysis in Arizona give a neutral temperature of 28.6 °C and the acceptable comfort range is from 19.1 °C– 38.1 °C while the preferred temperature is 20.8 °C(Middel *et al.*, 2016). People's neutral comfort range is found to be 30.6 °C ± 1.26. higher TSV higher TA, TG and Tmrt have association with higher TSV; low VA, RH have association with lower TSV in a one-way ANOVA Kruskal-Wallis and Mann-Whitney test. This study used TSV, Questionnaire schedule method in Dhaka, Bangladesh (Sharmin and Steemers, 2020). predicted percentage of dissatisfied data collection, processing using PPD, with monitoring sensors attached on body. This study followed ASHRAE Standard 55-2017 in China (Ma *et al.*, 2020). Study of outdoor thermal comfort is appropriately performed with PET index (Staiger, Laschewski and Matzarakis, 2019).

8.4 IMPORTANCE OF THERMAL PERCEPTION STUDY

Thermal sensation, perception, thermal acceptability and tolerance are recorded on a 7 point or 5 point or 9-point scale based on the standards of ISO10551 (1995) for working environment and ASHRAE 55 (2010) for outdoor and indoor environment. The thermal sensation study is performed with the help of Thermal Sensation Vote (TSV). The TSV can be be given on perception of several parameters. The sensation of Va and Ta in a sun and wind comfort index. The study of these index is beyond the scope of this study. However, both Ta and Va are important indicators of comfort. In previous studies, from literature, review it is seen that Va can be a deterrent to comfort and there may be preference for higher Ta in colder regions. But in sub-tropical regions like in Kolkata, there is preference for breeze to provide relief from the hot humid regions. UTCI underestimates the function of Tmrt, Va at higher temperatures, but overestimates the role of Ta and RH on people's perception on comfort and hence sun wind comfort index was applied(Jianong Li *et al.*, 2020). Hence, PET and mPET helped calculate the comfort conditions in this study. In TSV, the adaptive behaviour and adaptive psychology plays a vey important role. Such behavioural pattern also depends on cultural conditions. Outdoor comfort conditions and its complexities with several parameters cannot be always be represented in simplified models, thus adaptation studies in hot humid regions become very important (Lin, Middel et. al). TSV considers only subjective assessment of comfort through questionnaire schedules (Brychkov, Garb and Pearlmutter, 2018). A study mentions that wind is effective in offsetting the uncomfortable conditions created by solar radiation only up to a temperature of 31^{o}C (Xie *et al.*, 2019). A similar result was found in this study; during high Ta conditions in summer, the correlation between mPET and other parameters are not significant. Only Ta as a function of Tmrt shows significant relation with mPET when Ta ranges between 35^{o} C to 41^{o}C. The neutral PET is 19.7 ^{o}C and acceptable PET range is 9.8–30.7 ^{o}C in sub-tropical hot humid and dry arid region of Xi'an, China (Mi *et al.*, 2020) . Higher wind and sunlight has negative impact on thermal sensation in oceanic temperate regions. However, people wanting high windspeed conditions for outdoor activity will have different response and sensation wot high windspeed. Behavioural adaptation play an important role in environment sensitivity that depend on understanding of the microscale environment which could in turn influence the level of acceptance and satisfaction.(Peng, Feng and Timmermans, 2019) Such behavioural adaptation and acceptance is seen in the study area where, even in high summer Ta, vote of acceptance inspite of discomfort show the understanding of urban heat stress environment . This study is an empirical analysis of meteorologic and subjective assessment of Outdoor thermal conditions that used multiple linear regression analysis. Subjective assessment can be studied through Ordinal Logistic regression since the ordinal scale of objective assessment is not continuous.

Thermal sensitivity reduces in winter and spring but with greater exposure and at higher temperature, the effect of thermal sensitivity to thermal conditions is attenuated. Also, at moderate Ta in summer, there is preference for cool conditions but with increasing Ta and exposure to higher Ta, and heat wave conditions, the acclimatization which was initially observed is lost (Krüger *et al.*, 2017). Similar results are found in TSV in this study where, the effect to acclimatization is noted at higher temperatures. With adaptation there is thermal acceptance of high Ta at microscale from some respondents while for others, there is reduction in acceptance and acclimatization. While PET and other indices show results in estimating the outdoor thermal comfort conditions, these indices do not include thermal perception (Golasi *et al.*, 2016). In this present study, thermal index has been applied to understand the grade of thermal stress or comfort and alongside thermal perception study has been conducted. There is importance of adaptation observed with changing Clo values. Similar adaptation is observed in this study where the correlation between Clo and mPET values show significant result. Preference for sunlit warm spaces in cold seasons and shade in warm season and indifference to space characteristics in spring season (Mi *et al.*, 2020) was similarly found in this study, where thermal conditions are more acceptable in spring and autumn (transition seasons) than in extreme hot summer. PET is not applicable in understanding the skin temperature of an environment where there is increased moisture due to artificial mist spraying environment conditioning (Oh *et al.*, 2019). However, in this study, in hot humid regions, where humidity is high, the Clo value show significance with changing humidity in mPET index.

The correlation between Ta and RH is significantly inverse; correlation between Va and Ta is inverse. Correlation between Ta and TSV is significant but not significant between Rh and TSV (Das, Das and Mandal, 2020). Correlation between microclimate parameters and TSV was not analysed but the correlation between Ta and RH and Ta and Va show that RH and Va are functional in reduction of Ta in the study area.

CHAPTER9: CONCLUSION & RECOMMENDATION

9.1 REVISITING THE OBJECTIVES

The aim of the study was to analyse and understand the outdoor thermal comfort conditions in different urban surface covers and microclimatic conditions. Analysis of surface cover of 50 stations based on Plan Area Fraction; and microclimatic analysis of the same stations along with the study of importance of Dynamic potential (DP) was conducted. The findings of the research based on the objectives of the study are revisited as follows:

Objective 1-To Study the influence of different surface covers such as water body, green area and open area on outdoor thermal comfort.

Dynamic potential shows significant effect on Outdoor thermal comfort. In summer, Air Temperature is the most significant parameter that affects Mean radiant temperature and Outdoor Thermal Comfort. In summer, both water surface, built surface do not significantly affect outdoor thermal comfort during daytime. However, built surface has a strong significant positive impact on Air temperature in all seasons. Vegetation cover shows significant positive correlation with mPET. Natural Surface or Dynamic Potential, in combination with water bodies, open areas and vegetation, have significant impact on Outdoor thermal comfort during daytime in Spring, Autumn and Winter. Share of water bodies is important for outdoor thermal comfort. Windspeed helps in improving Outdoor Thermal Comfort.

Objective 2-To Classify comfort locations of city based on microclimatic and thermal perception study.

The areas having at least 50% dynamic potential within a neighbourhood with radius of circle around each station being 50m, will have acceptable range of comfort conditions. For areas having at least >80% dynamic potential within a neighbourhood with radius of circle around each station being 50m, will have neutral conditions of comfort where people will feel comfortable with no change in preference for conditions of comfort. Thermal perception study has allowed the inclusion of people’s perception of outdoor microclimate and its impact on their thermal sensation.

Objective 3- To Calculate the Neutral mPET and acceptable range of comfort conditions in Kolkata

The Neutral mPET is 28.1 ^{o}C and acceptable range of comfort conditions is between 23 ^{o}C and 29^{o} C in Kolkata. The comfortable locations found within the Kolkata Municipal Area have acceptable range of conditions. Few stations have neutral conditions of comfort.

Objective 4-To Recommend the overall conditions of comfort for sustainable urban planning.

The recommendations for overall conditions of comfort are based on share of natural surface cover or dynamic potential. The areas with higher share of dynamic potential show comfort conditions that are different from areas having low dynamic potential. Areas that have Neutral mPET conditions reflect acceptable and comfort outdoor conditions. These areas are sources of cooler environment with larger share of natural surface. Natural surface provides a natural environment that needs to be preserved. The Comfortable location found in this study coincides with the East Kolkata Wetland area and Hooghly estuary near Garden Reach and open areas in the Green Belt of Maidan. The comfortable location includes cool sinks that are sources of cool fresh air.

Urban surface category	**Outdoor Thermal Sensation conditions**	**Comfort level**	**Urban climate type**	**Urban climate action**
>80% DP	Neutral	Neutral to Comfortable	Source of cool fresh air, potential for air circulation	Preserve source of Cool Sinks
50-80% DP	Acceptable	Comfortable	Less air circulation but source of cool fresh air to neighbourhoods. Also acts as buffer between congested areas.	Preserve linkages to cool areas.
<50% DP	Heat stress	Uncomfortable	High heat accumulation, with little vegetation or open surface. may receive water breezes from surrounding neighbourhood.	Areas with potential for improvement with urban greenery, urban water channels, open spaces
<20% DP	High heat stress	Very uncomfortable	Very high heat accumulation, some stations may receive water breeze in the evening.	Need for action plans to deal with high heat stress.

Table 9.1 Recommendations for preservation of cool sinks of the city.

9.2 RECOMMENDATION

Recommendation for comfortable outdoor environment is given as potential measures that can be looked into surface temperature and air temperature of areas with high Thermal Load . There should be ventilation corridors by reducing the barriers and obstructions in the direction of wind. Green walking lanes will not only allow soft lanes but also absorb the stormwater. Urban vegetation should include trees with canopy that will prevent overheating of roadways and water surface. However, maladaptation should be kept in mind as mentioned in IPCC 2022, 6th Assessment Report.

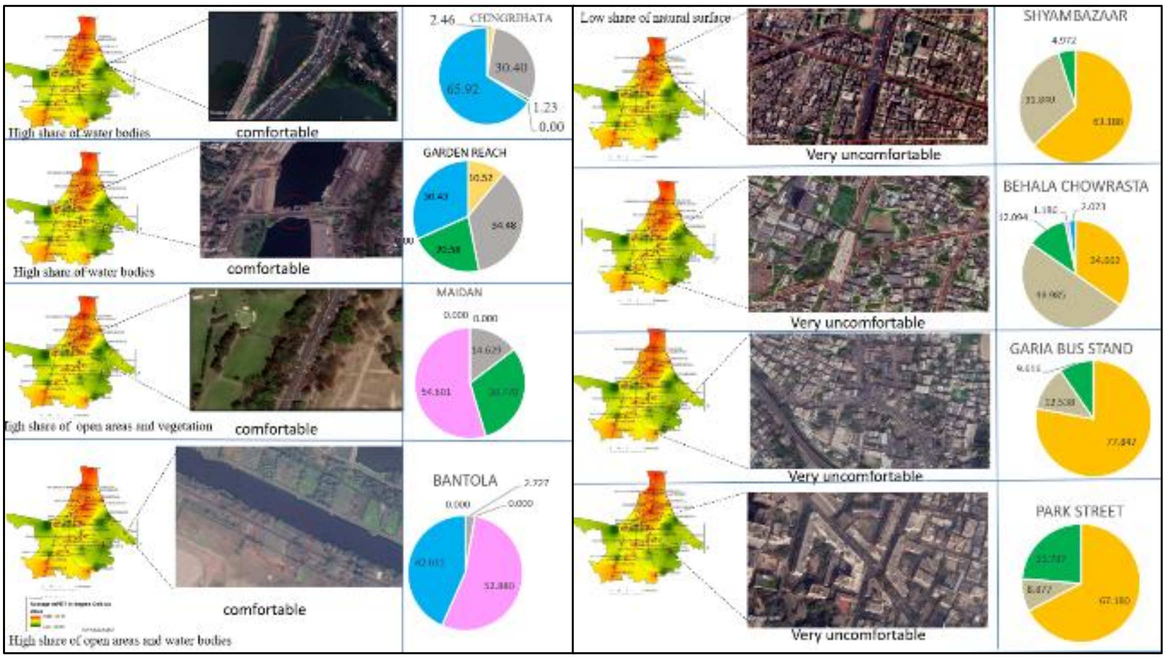


Figure 9.1Microclimate that needs to be maintained and areas that need to be improved.

- Stations with high natural surface reflected in the thermal comfort map of Kolkata.
- The stations correspond with the green coloured areas indicating low mPET conditions or high outdoor thermal comfort.
- The natural surface cover of such areas needs to be maintained.
- The stations correspond with the red coloured areas in Outdoor Thermal Comfort Map indicating high mPET conditions or low outdoor thermal comfort.
- The urban greenery needs to be enhanced through community participation and open spaces must be encouraged for air circulation.
- Stations with high natural surface reflected in the thermal comfort map of Kolkata.

- The stations correspond with the green coloured areas indicating low mPET conditions or high outdoor thermal comfort.
- The natural surface cover of such areas needs to be maintained.
- The stations correspond with the red coloured areas in Outdoor Thermal Comfort Map indicating high mPET conditions or low outdoor thermal comfort.
- The urban greenery needs to be enhanced through community participation and open spaces must be encouraged for air circulation.

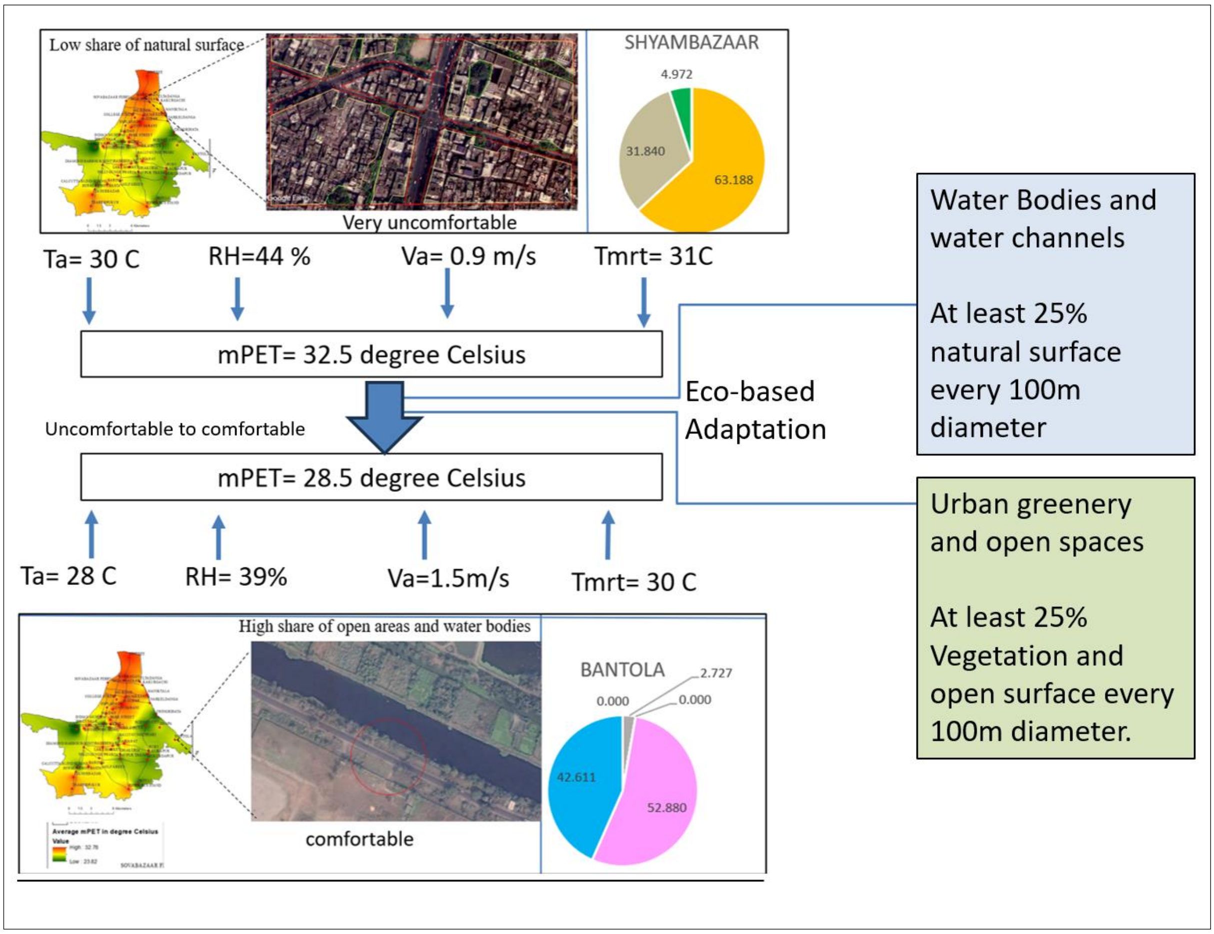


Figure 9.2 Showing need for eco-based adaptation in urban areas to improve thermal comfort

9.3 PROPOSAL OF PLAN AREA FRACTION FOR COMFORTABLE OUTDOOR CONDITIONS.

Dynamic potential of an area can be improved by maintaining linkages to the Cool sinks or cool islands. Water channels as seen in Freiburg, Germany, can be implemented with care that the water does not remain stagnant for breeding of mosquito larvae. If the storm water channels can be utilised to direct the monsoonal discharge as water channels or sources of cool fresh air across the city. In future planning of the city, more green blue spaces are recommended to allow for greater dynamic potential of the city. Outdoor thermal comfort can be improved by providing cool linkages across the urban heat island. Built surface should be supplemented with vertical greenery and fountain landscapes. New areas of planning should allow surface cover with greater natural surface.

Outdoor Thermal Sensation — Percentage of Surface cover

SITE	BUILT UP	IMPERMEABLE SURFACE	VEGETATION	OPEN SPACE	WATER BODY
NEUTRAL AND COMFORTABLE	9	8	24	7	52
NEUTRAL	15	9	2	66	8
SLIGHTLY UNCOMFORTABLE	29	27	28	14	2
UNCOMFORTABLE	80	15	5	0	0

Acceptable — Unacceptable

Table 9.2 Showing Proposed share (in percentage) of Thermal load and Dynamic Potential for Neutral and Comfortable conditions.

Outdoor Thermal Sensation — (Percentage)

	THERMAL LOAD	DYNAMIC POTENTIAL
NEUTRAL AND COMFORTABLE	17	83
NEUTRAL	24	76
SLIGHTLY UNCOMFORTABLE	56	44
UNCOMFORTABLE	95	5

Acceptable — Unacceptable

Table 9.3 Showing Proposed Plan Area Fraction, in percentage, for neutral and comfortable conditions.

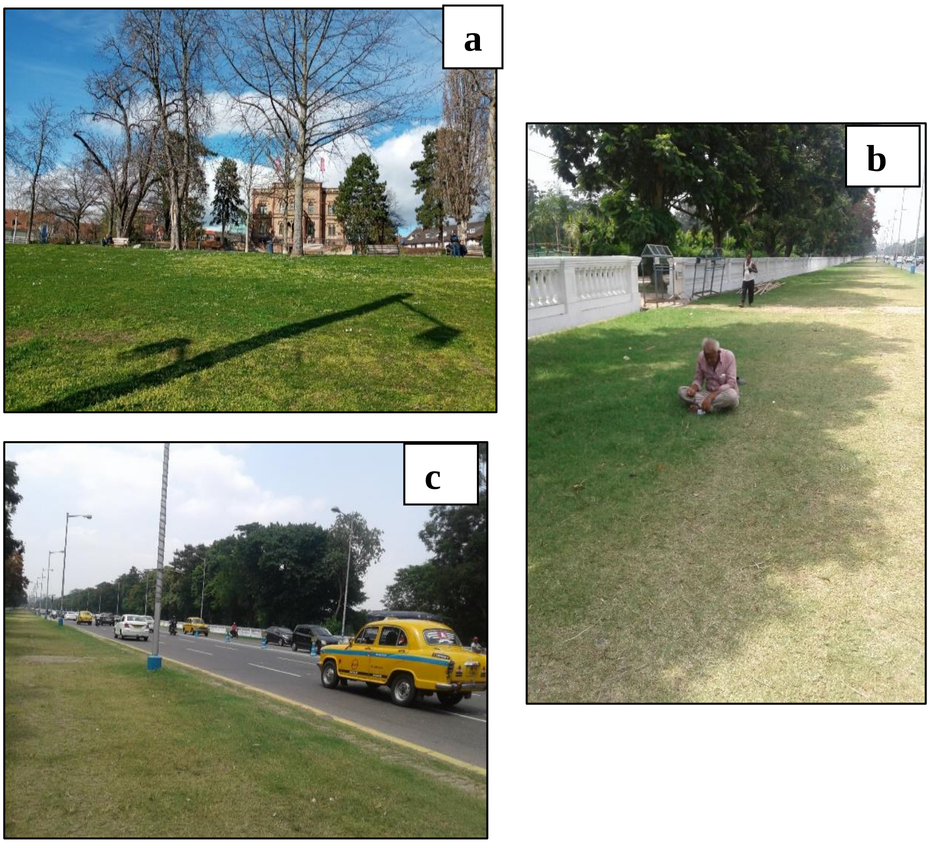


Figure 9.3showing open areas - a- Freiburg, Germany; b- Maidan, Kolkata- shade of vegetation canopy and open area, c- green belt, Kolkata, along impermeable surface.

Figure 9.4 Water channels, from River Rhine throughout the city of Freiburg, Germany. Pictures taken by author.

9.4 PROPOSAL FOR OUTDOOR MICRO-CLIMATE INFORMATION SYSTEM

Inclusion of People's perception of Outdoor thermal comfort is very essential in a sustainable neighbourhood habitat. Thermal perception study is used to calculate the neutral mPET conditions and the acceptable range of temperature. In analysing the Comfort location, thermal perception has been applied as a parameter in the Factor analysis method. Thermal perception study will allow grassroot participation in Climate-inclusive Urban Planning Process. It will allow the evaluation of outdoor conditions by different stakeholders and beneficiaries of a healthy sustainable outdoor environment at neighbourhood level, across the city.

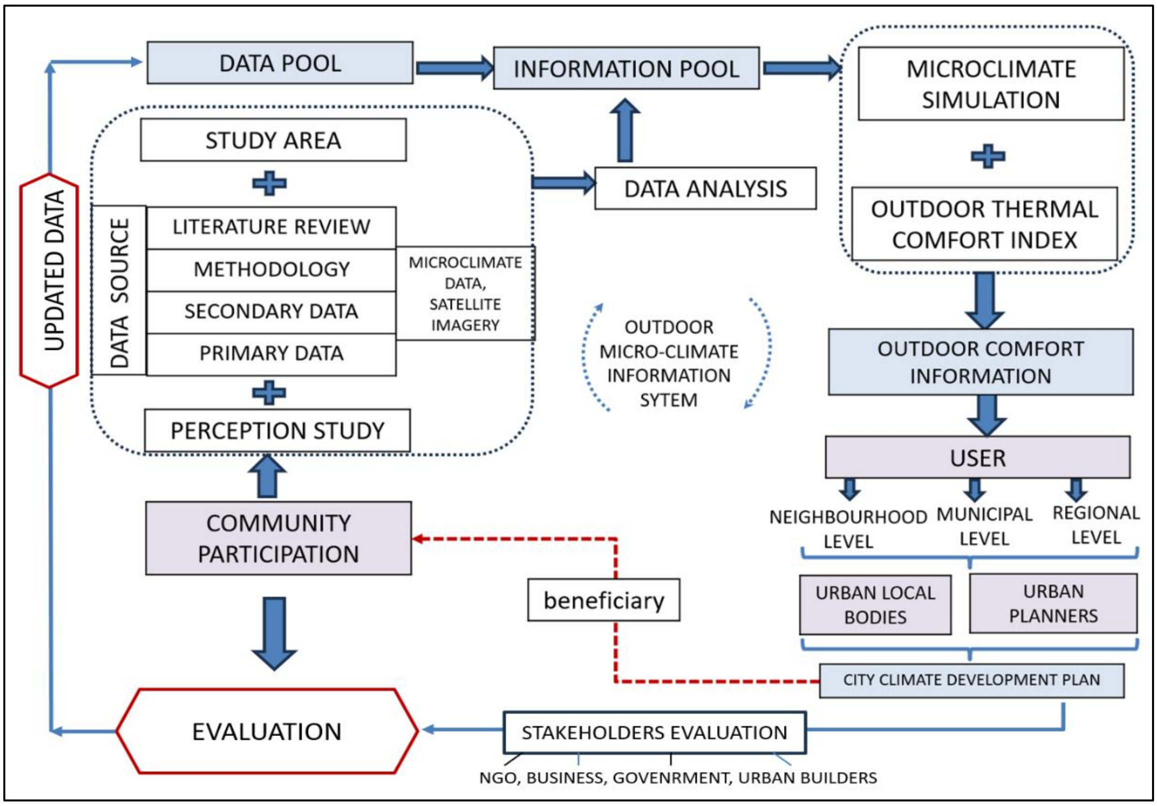


Figure 9.5: Proposed flowchart showing Outdoor Micro-climate Information System for the city of Kolkata having sub-tropical hot humid microclimate conditions.

OUTDOOR MICRO-CLIMATE INFORMATION SYSTEM

The pool of data consists of primary and secondary data collection for both objective and subjective assessment. Analysis of such data converts data into information. The information pool is used for simulation and calculation of outdoor thermal comfort conditions with the help of comfort index. The information on outdoor comfort conditions are used by urban local bodies and urban planners at various levels of planning in urban areas. The urban development report is evaluated by stakeholders and implemented for the benefit of the community. The plan becomes a new input in data pool after evaluation and update. The cyclical mechanism of use and re-use and updating of information will continue to maintain a sustainable urban planning process.

SWOT ANALYSIS

In the **JNnurm Toolkit for preparation of CDP**, Strength, Weakness, Opportunity and Threat were identified. In this study, the areas of High thermal load will represent weakness, high dynamic potential will represent Strength, conversion of natural surface to built surface is a threat and changes in land use- landcover as Eco-based adaptation is an opportunity.

STRENGTH	WEAKNESS	OPPORTUNITY	THREAT
Areas showing Dynamic Potential	Areas showing Thermal Load	Potential for Eco-Based Adaptation; Source of Cool Fresh Air	Reclamation Of Wetlands and Natural Surface

Table 9.4 showing SWOT analysis to include in Comfort-Oriented City Development Plan (CO-CDP).

Based on the SWOT Analysis, surface cover of a neighbourhood for every 50m radius is planned. Lewis Mumford, disciple of Ebenezer Howard had mentioned that Howard's Garden city concept is a combination or integration of both urban and rural characteristics to promote growth of satellite cities and towns. Von Thunen's Concentric Ring model also explains arrangement of landcover for based on economic activity. For new outgrowths, transitions towns (Louise Rooney), transit-oriented developments and satellite towns the following proposal is made. The layout at a neighbourhood scale show share of dynamic potential with dominant wind ventilation in South Bengal Region. Proposal for neighbourhood with 100m diameter.

Each concentric zone will represent a surface cover with overlapping transition zones at the border. There will be zones of preservation, development and development with maintenance.

Preservation- water surface and vegetation cover

Development- Built surface and impermeable surface such as roadways

Development with Maintenance- encourages development but maintaining the extent of open areas to prevent barriers to wind circulation.

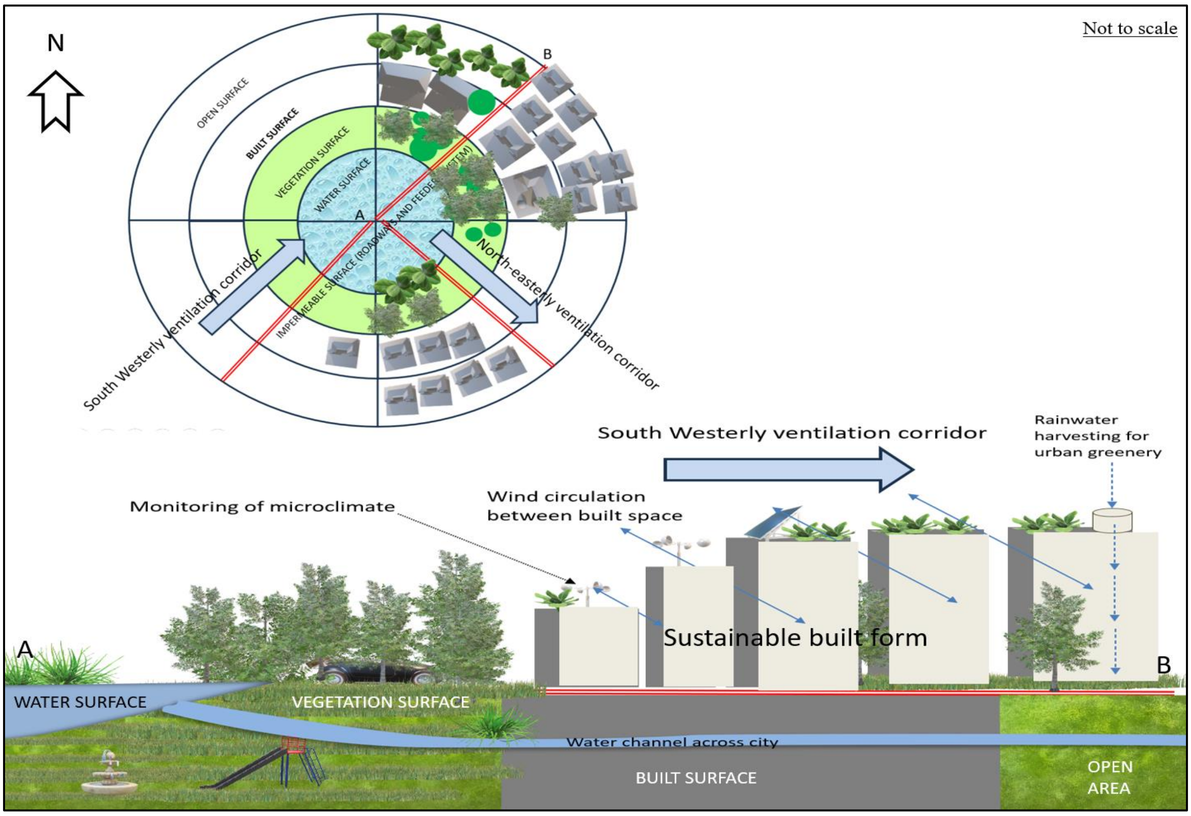


Figure 9.6 Proposal for Dynamic Potential at a neighbourhood level for improving outdoor microclimate conditions.

9.5 CONTRIBUTION FROM RESEARCH WORK

In the review of literature, there was absence of microclimate work in the city of Kolkata at neighbourhood level for large number of stations showing seasonal variation.

The objective and subjective assessment was performed for four seasons showing seasonal variation in Outdoor thermal comfort and adaptation changes in terms of Clo value.

The Neutral mPET conditions and Acceptable range of mPET were calculated for 50 stations across the city, spanning across the major arterial roads of the city.

Comfortable location was extracted using Factor Analysis, Principal Component Analysis and Raster Analysis.

The Comfortable location coincides with the Green Belt of Kolkata, the East Kolkata Wetlands and the Hooghly estuary within the limits of the Kolkata Municipal Area. Comfortable areas and very uncomfortable areas were identified.

The importance of water breeze was analysed between two stations, one having high dynamic potential with large share of water surface; the other having high Thermal load and outdoor heat stress conditions.

The importance of Dynamic potential was analysed with the microclimatic data analysis of 10 stations with varying share of Thermal load.

The importance of subjective assessment through Outdoor Thermal Perception study is recognised in calculation of comfortable and acceptable conditions. Such assessment assures climate inclusive planning with grassroot participation.

The areas of comfort can become the strength of a city and the sources to cool fresh air can be an opportunity for sustaining well-being. Kolkata is near to the Bay of Bengal, located on the levee of the mighty River Ganges; with the Kolkata wetlands extending its marshes and swamps in southern and eastern portion of the city. The city has wealth of water bodies that can be a source of comfort for the cities. The sewage system and stormwater drainage system can be utilised as linkages of cool fresh air across the city

9.6 CONCLUSION

Objective study included the analysis of microclimate variation over the seasons on 2019 and the influence of surface cover as an independent variable. The surface cover with high Dynamic potential provides greater outdoor comfort than areas with thermal load. Dynamic potential of an area is recognised with different combinations of water surface, vegetation surface and open areas. Perception of weather conditions is extremely important to calculate the neutral and acceptable outdoor thermal conditions. Without the Thermal Perception Study, such calculations cannot be performed. The mean thermal sensation vote implies the need for people's participation in climate inclusive planning process. Neutral range is within the acceptable range of temperature. There should be a combination of natural surface and built surface (Dynamic Potential and Thermal Load) in surface cover characteristics for a place to have comfortable outdoor thermal conditions. The average share of dynamic potential is required to be 45% for every 100m diameter circular area in order to keep the thermal range within 23 ^{O}C to 28.1 ^{O}C for a subtropical hot-humid city, Kolkata.

In conclusion, the importance of comfortable microclimate is essential for good health and well-being of the people. With eco-based adaptations in urban areas and proper linkages of cool sources of air, the urban microclimate can be improved and in turn will ensure a sustainable approach to Human Biometeorology.

CHAPTER10: LIMITATIONS OF STUDY & FUTURE SCOPE

10.1 LIMITATIONS OF STUDY

Outdoor thermal comfort is a study that includes several parameters and variables working together. The limitations of the methodology are as follows:

I. Multiple points of data collection could not be collected simultaneously.

II. Many parameters work together in this study some of which have been included in future scope.

III. Data could not be collected post 2019 seasons due to Covid 19 lockdown.

IV. Envimet simulations are limited in number.

V. Distance of the water bodies and proximity analysis could be done in more detail

10.2 FUTURE SCOPE

Aerosol pollutants and its relation to thermal comfort and thermal environment is an important parameter in recent times with large emission in urban areas (Wai *et al.*, 2017). However, such impact is beyond the scope of this study.

Body movement and metabolic rate and its relation with comfort conditions was analysed with regression analysis. Metabolic rate and PET was the independent variable and MTSV is the dependent variable. Regression analysis show that the independent variable can predict the independent variable. Metabolic rate of human body can be determined on inhaled oxygen, exhaled carbon dioxide (CO2) , heart rate or even calculated in an equation (Zhang *et al.*, 2020). However, PET and mPET calculation requires the activity of the respondent to be chosen from a list of options given in RayMan software, as applicable for the input response.

Sensitivity analysis is an important part of thermal perception study. The perception of trees and water bodies is important than perception to solar radiation and Ta in summer, while in winter thermal perception to solar radiation and Ta is important in winter. Thermal perception is an important evaluation for outdoor thermal comfort(Chan and Chau, 2019) (Chow *et al.*, 2016). In this study, subjective sensation has been taken into consideration based on questions from ISO and ASHRAE standards. In future scope, the perception to trees, solar radiation, Ta and other parameters needs to be included in detail.

Study on age group and sensitivity to thermal conditions show that old age group show less sensitivity to thermal conditions. Exposure to thermal conditions for longer period increase sensitivity to thermal conditions (Xue *et al.*, 2020)(Yung, Wang and Chau, 2019). Gender wise neutral PET was derived by calculating separate PET bins for male and female MTSV (Galindo and Hermida, 2018). In this study, Gender wise thermal sensation was not conducted since the number of female respondents at the time of survey was insufficient.

Tests on cognitive performance can improve indoor thermal comfort(Ko *et al.*, 2020). Similar cognitive tests can help understand the outdoor scenery that can improve outdoor thermal sensation.

Future scope also involve the type of outdoor economic activity and outdoor thermal comfort(Lam and Lau, 2018; Banerjee, Middel and Chattopadhyay, 2020; Baruti, Johansson and Yahia, 2020).

Tourism Climate Index involves rating of Ta and RH in PET index. This will help understand the comfortable conditions for tourism. PET helps to find comfortable range of temperature and neutral temperature and acceptable range of temperature. (Binte Ali & Patnaikb, 2018) (Syafii, et al., 2016) (Wong, Kardinal Jusuf, Katzschner, & Ng, 2015)(Kovács *et al.*, 2016).

Photographic comparison to study thermal perception offer a range of possibilities to compare outdoor spaces on basis of exhibit of behavioural and spatial characteristics (Cortesão, Brandão Alves and Raaphorst, 2020).

BIBLIOGRAPHY

Abaas, Z.R. (2020) 'Impact of development on Baghdad's urban microclimate and human thermal comfort', *Alexandria Engineering Journal*, 59(1), pp. 275–290. doi:10.1016/j.aej.2019.12.040.

ADB (2013) *Investing in Resilience: Ensuring a Disaster-Resistant Future*. Available at: www.adb.org.

Ahmedabad Municipal Corporation; Ahmedabad Urban Development Authority; CEPT (2012) 'Jawaharlal Nehru National Urban Renewal Mission: CITY DEVELOPMENT PLAN Ahmedabad 2006-2012', p. 180.

Ahmedabad Municipal Corporation (2016) 'Ahmedabad Heat Action Plan 2016 - Guide to extreme heat planning in Ahmedabad, India', p. 24.

Ali, S.B. and Patnaik, S. (2018a) 'Thermal comfort in urban open spaces: Objective assessment and subjective perception study in tropical city of Bhopal, India', *Urban Climate*, 24, pp. 954–967. doi:10.1016/J.UCLIM.2017.11.006.

Allegrini, J., Dorer, V. and Carmeliet, J. (2015) 'Influence of morphologies on the microclimate in urban neighbourhoods', *Journal of Wind Engineering and Industrial Aerodynamics*, 144, pp. 108–117. doi:10.1016/j.jweia.2015.03.024.

Amirtham, L.R., Horrison, E. and Rajkumar, S. (2014) 'Study on the microclimatic conditions and thermal comfort in an institutional campus in hot humid climate', *30th International PLEA Conference: Sustainable Habitat for Developing Societies: Choosing the Way Forward - Proceedings*, 2(December), pp. 361–368.

Bachir, N. *et al.* (2021) 'The simulation of the impact of the spatial distribution of vegetation on the urban microclimate: A case study in Mostaganem', *Urban Climate*, 39(September), p. 100976. doi:10.1016/j.uclim.2021.100976.

Balslev, Y.J., Potchter, O. and Matzarakis, A. (2015) 'Climatic and thermal comfort analysis of the Tel-Aviv Geddes Plan: A historical perspective', *Building and Environment*, 93(P2), pp. 302–318. doi:10.1016/j.buildenv.2015.07.005.

Banerjee, S. and Chattopadhyay, S. (2020) 'A meta-analytical review of outdoor thermal comfort research: Applications, gaps and a framework to assess low-income settlements in Indian megacities', *Urban Climate*, 33(May), p. 100641. doi:10.1016/j.uclim.2020.100641.

Banerjee, S., Middel, A. and Chattopadhyay, S. (2020) 'Outdoor thermal comfort in various microentrepreneurial settings in hot humid tropical Kolkata: Human biometeorological assessment of objective and subjective parameters', *Science of the Total Environment*, 721. doi:10.1016/j.scitotenv.2020.137741.

Banerjee, S., Middel, A. and Chattopadhyay, S. (2022) ‘A regression-based three-phase approach to assess outdoor thermal comfort in informal micro-entrepreneurial settings in tropical Mumbai’, *International journal of biometeorology*, 66(2), pp. 313–329. doi:10.1007/S00484-021-02136-7.

Banerji, A. (2020) ‘The city of Kolkata’, *Contemporary Group Theatre in Kolkata, India*, pp. 15–20. doi:10.4324/9780429261954-3.

Baruti, M.M., Johansson, E. and Yahia, M.W. (2020) ‘Urbanites’ outdoor thermal comfort in the informal urban fabric of warm-humid Dar es Salaam, Tanzania’, *Sustainable Cities and Society*, 62. doi:10.1016/j.scs.2020.102380.

Best, M.J. and Grimmmmond, C.S.B. (2015) ‘Key conclusions of the first international urban land surface model comparison project’, *Bulletin of the American Meteorological Society*, 96(5), pp. 805–819. doi:10.1175/BAMS-D-14-00122.1.

Bherwani, H. *et al.* (2021) ‘Establishing influence of morphological aspects on microclimatic conditions through GIS-assisted mathematical modeling and field observations’, *Environment, Development and Sustainability*, 23(11), pp. 15857–15880. doi:10.1007/S10668-021-01320-4.

Bherwani, H., Singh, A. and Kumar, R. (2020) ‘Assessment methods of urban microclimate and its parameters: A critical review to take the research from lab to land’, *Urban Climate*, 34(August), p. 100690. doi:10.1016/j.uclim.2020.100690.

Bianchi, C. *et al.* (2020) ‘Quantifying effects of the built environment on solar irradiance availability at building rooftops’, *Journal of Building Performance Simulation*, 13(2), pp. 195–208. doi:10.1080/19401493.2019.1679259.

Binarti, F. *et al.* (2020) ‘A review of outdoor thermal comfort indices and neutral ranges for hot-humid regions’, *Urban Climate*, 31(July 2019), p. 100531. doi:10.1016/j.uclim.2019.100531.

Broadbent, A.M. *et al.* (2018) ‘The cooling effect of irrigation on urban microclimate during heatwave conditions’, *Urban Climate*, 23, pp. 309–329. doi:10.1016/j.uclim.2017.05.002.

Brozovsky, J. *et al.* (2021) ‘Evaluation of sustainable strategies and design solutions at high-latitude urban settlements to enhance outdoor thermal comfort’, *Energy and Buildings*, 244, p. 111037. doi:10.1016/j.enbuild.2021.111037.

Brychkov, D., Garb, Y. and Pearlmutter, D. (2018) ‘The influence of climatocultural background on outdoor thermal perception’, *International Journal of Biometeorology*, 62(10), pp. 1873–1886. doi:10.1007/s00484-018-1590-7.

Cammelli, S. and Stanfield, R. (2017) 'Meeting the Challenges of Planning Policy for Wind Microclimate of High-rise Developments in London', *Procedia Engineering*, 198(September 2016), pp. 43–51. doi:10.1016/j.proeng.2017.07.163.

Chan, F.K.S. *et al.* (2018) '"Sponge City" in China—A breakthrough of planning and flood risk management in the urban context', *Land Use Policy*, 76(May 2017), pp. 772–778. doi:10.1016/j.landusepol.2018.03.005.

Chan, S.Y. and Chau, C.K. (2019) 'Development of artificial neural network models for predicting thermal comfort evaluation in urban parks in summer and winter', *Building and Environment*, 164. doi:10.1016/j.buildenv.2019.106364.

Chatterjee, U. and Majumdar, S. (2022) 'Impact of land use change and rapid urbanization on urban heat island in Kolkata city: A remote sensing based perspective', *Journal of Urban Management*, 11(1), pp. 59–71. doi:10.1016/j.jum.2021.09.002.

Chatzidimitriou, A. and Yannas, S. (2017) 'Street canyon design and improvement potential for urban open spaces; the influence of canyon aspect ratio and orientation on microclimate and outdoor comfort', *Sustainable Cities and Society*, 33(May), pp. 85–101. doi:10.1016/j.scs.2017.05.019.

Chen, L. *et al.* (2015) 'Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai', *Building and Environment*, 94, pp. 644–653. doi:10.1016/j.buildenv.2015.10.020.

Chen, Z. *et al.* (2009) 'Field measurements on microclimate in residential community in Guangzhou, China', *Frontiers of Architecture and Civil Engineering in China*, 3(4), pp. 462–468. doi:10.1007/s11709-009-0066-6.

Cheung, P.K., Fung, C.K.W. and Jim, C.Y. (2020) 'Seasonal and meteorological effects on the cooling magnitude of trees in subtropical climate', *Building and Environment*, 177(December 2019), p. 106911. doi:10.1016/j.buildenv.2020.106911.

Cheung, P.K. and Jim, C.Y. (2019a) 'Differential cooling effects of landscape parameters in humid-subtropical urban parks', *Landscape and Urban Planning*, 192. doi:10.1016/j.landurbplan.2019.103651.

Cheung, P.K. and Jim, C.Y. (2019b) 'Effects of urban and landscape elements on air temperature in a high-density subtropical city', *Building and Environment*, 164. doi:10.1016/j.buildenv.2019.106362.

Chow, W.T.L. *et al.* (2016a) 'Assessment of measured and perceived microclimates within a tropical urban forest', *Urban Forestry and Urban Greening*, 16, pp. 62–75. doi:10.1016/j.ufug.2016.01.010.

Chow, W.T.L. and Brazel, A.J. (2012) 'Assessing xeriscaping as a sustainable heat island mitigation approach for a desert city', *Building and Environment*, 47(1), pp. 170–181. doi:10.1016/j.buildenv.2011.07.027.

Cortesão, J. *et al.* (2016) 'Retrofitting public spaces for thermal comfort and sustainability':, *http://dx.doi.org/10.1177/1420326X16659326*, 25(7), pp. 1085–1095. doi:10.1177/1420326X16659326.

Cortesão, J., Brandão Alves, F. and Raaphorst, K. (2020) 'Photographic comparison: a method for qualitative outdoor thermal perception surveys', *International Journal of Biometeorology*, 64(2), pp. 173–185. doi:10.1007/s00484-018-1575-6.

Coutts, A.M. *et al.* (2013) 'Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context', *Progress in Physical Geography*, 37(1), pp. 2–28. doi:10.1177/0309133312461032.

Dai, Q. and Schnabel, M.A. (2013) 'Relationship between mean radiant temperature and building type for pedestrians in rotterdam', *Communications in Computer and Information Science*, 369 CCIS(June), pp. 306–314. doi:10.1007/978-3-642-38974-0_29.

Das, M., Das, A. and Mandal, S. (2020) 'Outdoor thermal comfort in different settings of a tropical planning region: A study on Sriniketan-Santiniketan Planning Area (SSPA), Eastern India', *Sustainable Cities and Society*, 63. doi:10.1016/j.scs.2020.102433.

De, B. and Mukherjee, M. (2018) *"Optimisation of canyon orientation and aspect ratio in warm-humid climate: Case of Rajarhat Newtown, India", Urban Climate*. doi:10.1016/j.uclim.2017.11.003.

Deb, C. and Ramachandraiah, A. (2010) 'Evaluation of thermal comfort in a rail terminal location in India', *Building and Environment*, 45(11), pp. 2571–2580. doi:10.1016/j.buildenv.2010.05.023.

Dimoudi, A. and Nikolopoulou, M. (2003) 'Vegetation in the urban environment: Microclimatic analysis and benefits', *Energy and Buildings*, 35(1), pp. 69–76. doi:10.1016/S0378-7788(02)00081-6.

Doick, K.J., Peace, A. and Hutchings, T.R. (2014) 'The role of one large greenspace in mitigating London's nocturnal urban heat island', *Science of the Total Environment*, 493, pp. 662–671. doi:10.1016/j.scitotenv.2014.06.048.

Dulal, H.B. (2019) 'Cities in Asia: how are they adapting to climate change?', *Journal of Environmental Studies and Sciences*, 9(1), pp. 13–24. doi:10.1007/s13412-018-0534-1.

Efthymiou, C. *et al.* (2016) 'Development and testing of photovoltaic pavement for heat island mitigation', *Solar Energy*, 130, pp. 148–160. doi:10.1016/j.solener.2016.01.054.

Emmanuel, R. and Johansson, E. (2006) 'Influence of urban morphology and sea breeze on hot humid microclimate: The case of Colombo, Sri Lanka', *Climate Research*, 30(3), pp. 189–200. doi:10.3354/cr030189.

Ep-Bellara, S.L. and Abdou, S. (2016) 'Vegetation Effects on Urban Street Microclimate and Thermal Comfort during Overheated Period under Hot and Dry Climatic Conditions', *Journal of New Technology and Materials*, 6(2), pp. 87–94. doi:10.12816/0043938.

Estoque, R.C. *et al.* (2019) 'The future of Southeast Asia's forests', *Nature Communications*, 10(1), pp. 1–12. doi:10.1038/s41467-019-09646-4.

Ferrari, A. *et al.* (2020) 'The use of permeable and reflective pavements as a potential strategy for urban heat island mitigation', *Urban Climate*, 31(September 2019), p. 100534. doi:10.1016/j.uclim.2019.100534.

Ferwati, S. *et al.* (2019) 'A comparison of neighborhood-scale interventions to alleviate urban heat in Doha, Qatar', *Sustainability (Switzerland)*, 11(3). doi:10.3390/su11030730.

Fünfgeld, H. (2015) 'Facilitating local climate change adaptation through transnational municipal networks', *Current Opinion in Environmental Sustainability*, 12, pp. 67–73. doi:10.1016/j.cosust.2014.10.011.

Galindo, T. and Hermida, M.A. (2018) 'Effects of thermophysiological and non-thermal factors on outdoor thermal perceptions: The Tomebamba Riverbanks case', *Building and Environment*, 138, pp. 235–249. doi:10.1016/j.buildenv.2018.04.024.

Ghaffarianhoseini, Amirhosein *et al.* (2019) 'Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia', *Science of the Total Environment*, 666(xxxx), pp. 1327–1345. doi:10.1016/j.scitotenv.2019.01.284.

Golasi, I. *et al.* (2016) 'Thermal perception in the mediterranean area: Comparing the mediterranean outdoor comfort index (moci) to other outdoor thermal comfort indices', *Energies*, 9(7), pp. 1–16. doi:10.3390/en9070550.

Gutiérrez, E. *et al.* (2015) 'A Mechanical Drag Coefficient Formulation and Urban Canopy Parameter Assimilation Technique for Complex Urban Environments', *Boundary-Layer Meteorology*, 157(2), pp. 333–341. doi:10.1007/S10546-015-0051-7.

Han, G. *et al.* (2011) 'Field measurements on micro-climate and cooling effect of river wind on urban blocks in Wuhan city', *2011 International Conference on Multimedia Technology, ICMT 2011*, pp. 4446–4449. doi:10.1109/ICMT.2011.6003331.

Hao, Y. *et al.* (2015) ‘On the relationship between traffic noise resistance and urban morphology in low-density residential areas’, *Acta Acustica united with Acustica*, 101(3), pp. 510–519. doi:10.3813/AAA.918848.

Hao, Y., Kang, J. and Krijnders, J.D. (2015) ‘Integrated effects of urban morphology on birdsong loudness and visibility of green areas’, *Landscape and Urban Planning*, 137, pp. 149–162. doi:10.1016/J.LANDURBPLAN.2015.01.006.

Hathway, E.A. and Sharples, S. (2012) ‘The interaction of rivers and urban form in mitigating the Urban Heat Island effect: A UK case study’, *Building and Environment*, 58(December 2012), pp. 14–22. doi:10.1016/j.buildenv.2012.06.013.

He, B.J., Ding, L. and Prasad, D. (2020) ‘Relationships among local-scale urban morphology, urban ventilation, urban heat island and outdoor thermal comfort under sea breeze influence’, *Sustainable Cities and Society*, 60(April), p. 102289. doi:10.1016/j.scs.2020.102289.

Herath, H.M.P.I.K., Halwatura, R.U. and Jayasinghe, G.Y. (2018) ‘Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy’, *Urban Forestry and Urban Greening*, 29(March 2017), pp. 212–222. doi:10.1016/j.ufug.2017.11.013.

Hirashima, S.Q. da S., Assis, E.S. de and Nikolopoulou, M. (2016) ‘Daytime thermal comfort in urban spaces: A field study in Brazil’, *Building and Environment*, 107, pp. 245–253. doi:10.1016/j.buildenv.2016.08.006.

IPBES (2019) ‘Report of the plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on the work of its seventh session. Addendum: Summary for policymakers of the global assessment report on biodiversity and ecosystem services of ’, *Report of the Plenary*, 7(1), p. 56.

IPCC (2022) ‘Key Risks Across Sectors and Regions’, *IPCC WGII Sixth Assessment Report*, pp. 20–22.

Janssen, W., Blocken, B. and Van Hooff, T. (2013) ‘Use of CFD simulations to improve the pedestrian wind comfort around a high-rise building in a complex urban area’, *Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association*, pp. 1918–1925.

Jiang, J. and Tian, G. (2010) ‘Analysis of the impact of Land use/Land cover change on Land Surface Temperature with Remote Sensing’, *Procedia Environmental Sciences*, 2(5), pp. 571–575. doi:10.1016/j.proenv.2010.10.062.

Jin, H., Liu, S. and Kang, J. (2019) ‘Thermal comfort range and influence factor of urban pedestrian streets in severe cold regions’, *Energy and Buildings*, 198, pp. 197–206. doi:10.1016/j.enbuild.2019.05.054.

JnNURM (2012) ‘City development plan of Pune city - 2041, volume I’, pp. 1–326. Available at: http://punecorporation.org/informpdf/CDP/Executive_Summary-Revised CDP.pdf.

Johansson, E. *et al.* (2018) ‘Outdoor thermal comfort in public space in warm-humid Guayaquil, Ecuador’, *International Journal of Biometeorology*, 62(3), pp. 387–399. doi:10.1007/s00484-017-1329-x.

Kamel, T.M. (2021) ‘A new comprehensive workflow for modelling outdoor thermal comfort in Egypt’, *Solar Energy*, 225(April), pp. 162–172. doi:10.1016/j.solener.2021.07.029.

Kannamma, D. and Sundaram, A.M. (2014) ‘Influence of Street Geometry on Urban Microclimate – a Comparison of Traditional and Modern Streets of Srirangam’, *International Journal of Innovation and Scientific Research*, 3(1), pp. 27–39.

Karakounos, I., Dimoudi, A. and Zoras, S. (2018) ‘The influence of bioclimatic urban redevelopment on outdoor thermal comfort’, *Energy and Buildings*, 158, pp. 1266–1274. doi:10.1016/j.enbuild.2017.11.035.

El Kenawy, A.M. *et al.* (2021) ‘The impact of COVID-19 lockdowns on surface urban heat island changes and air-quality improvements across 21 major cities in the Middle East’, *Environmental Pollution*, 288(June). doi:10.1016/j.envpol.2021.117802.

Kim, H., Lee, K. and Kim, T. (2018) ‘Investigation of pedestrian comfort withwind chill during winter’, *Sustainability (Switzerland)*, 10(1). doi:10.3390/su10010274.

Kittas, C. *et al.* (2015) ‘Measurements and simulation of microclimatic effects of a horizontal hydroponic pergola’, *CEUR Workshop Proceedings*, 1498, pp. 255–262.

Klein, R.J.T. *et al.* (2015) ‘Adaptation opportunities, constraints, and limits’, *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects*, pp. 899–944. doi:10.1017/CBO9781107415379.021.

Ko, W.H. *et al.* (2020) ‘The impact of a view from a window on thermal comfort, emotion, and cognitive performance’, *Building and Environment*, 175. doi:10.1016/j.buildenv.2020.106779.

Kovács, A. *et al.* (2016) ‘Adjustment of the thermal component of two tourism climatological assessment tools using thermal perception and preference surveys from Hungary’, *Theoretical and Applied Climatology*, 125(1–2), pp. 113–130. doi:10.1007/s00704-015-1488-9.

Krüger, E., Drach, P. and Broede, P. (2017) ‘Outdoor comfort study in Rio de Janeiro: site-related context effects on reported thermal sensation’, *International Journal of Biometeorology*, 61(3), pp. 463–475. doi:10.1007/s00484-016-1226-8.

Krüger, E.L. *et al.* (2017) 'Short- and long-term acclimatization in outdoor spaces: Exposure time, seasonal and heatwave adaptation effects', *Building and Environment*, 116, pp. 17–29. doi:10.1016/j.buildenv.2017.02.001.

Krüger, E.L., Minella, F.O. and Matzarakis, A. (2013) 'Analysis of Different Input Data for Assessing Mean Radiant Temperature as Relevant Human-Biometeorological Factor in Thermal Comfort Issues', *PLEA 2013: Sustainable Architecture for a Renewable Future* [Preprint], (September).

Kumar, P. and Sharma, A. (2022) 'Assessing the outdoor thermal comfort conditions of exercising people in the semi-arid region of India', *Sustainable Cities and Society*, 76. doi:10.1016/J.SCS.2021.103366.

Lai, A., Maing, M. and Ng, E. (2017) 'Observational studies of mean radiant temperature across different outdoor spaces under shaded conditions in densely built environment', *Building and Environment*, 114, pp. 397–409. doi:10.1016/j.buildenv.2016.12.034.

Lai, D. *et al.* (2014) 'Studies of outdoor thermal comfort in northern China', *Building and Environment*, 77, pp. 110–118. doi:10.1016/j.buildenv.2014.03.026.

Lai, D. *et al.* (2019) 'A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces', *Science of the Total Environment*, 661, pp. 337–353. doi:10.1016/j.scitotenv.2019.01.062.

Lam, C.K.C. and Lau, K.K.L. (2018) 'Effect of long-term acclimatization on summer thermal comfort in outdoor spaces: a comparative study between Melbourne and Hong Kong', *International Journal of Biometeorology*, 62(7), pp. 1311–1324. doi:10.1007/s00484-018-1535-1.

Lan, H. *et al.* (2021) 'Improved urban heat island mitigation using bioclimatic redevelopment along an urban waterfront at Victoria Dockside, Hong Kong', *Sustainable Cities and Society*, 74(June), p. 103172. doi:10.1016/j.scs.2021.103172.

Lempert, R. *et al.* (no date) 'AC TO E N IO IT IT'.

Li, Jing *et al.* (2020) 'An integrated strategy to improve the microclimate regulation of green-blue-grey infrastructures in specific urban forms', *Journal of Cleaner Production*, 271. doi:10.1016/j.jclepro.2020.122555.

Li, Jianong *et al.* (2020) 'Exploration of applicability of UTCI and thermally comfortable sun and wind conditions outdoors in a subtropical city of Hong Kong', *Sustainable Cities and Society*, 52. doi:10.1016/j.scs.2019.101793.

Li, X. and Ghosh, D. (2018) 'Associations between Body Mass Index and Urban "Green" Streetscape in Cleveland, Ohio, USA', *International Journal of Environmental*

Research and Public Health 2018, Vol. 15, Page 2186, 15(10), p. 2186. doi:10.3390/IJERPH15102186.

Lin, B.S. and Lin, C.T. (2016) 'Preliminary study of the influence of the spatial arrangement of urban parks on local temperature reduction', *Urban Forestry and Urban Greening*, 20, pp. 348–357. doi:10.1016/J.UFUG.2016.10.003.

Lin, T., Matzarakis, A. and Liu, Y. (2009) 'Outdoor thermal comfort acceptable range and campus microclimate in hot-humid region', *Urbanclimate.Net*, pp. 247–252. Available at: http://www.urbanclimate.net/matzarakis/papers/BMIUF_18_2009_Linetal.pdf%0Ahttp://www.urbanclimate.net/matzarakis1/papers/BMIUF_18_2009_Linetal.pdf.

Liu, B., Lian, Z. and Brown, R.D. (2019) 'Effect of landscape microclimates on thermal comfort and physiological wellbeing', *Sustainability (Switzerland)*, 11(19). doi:10.3390/su11195387.

Liu, W., Zhang, Y. and Deng, Q. (2016) 'The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate', *Energy and Buildings*, 128, pp. 190–197. doi:10.1016/j.enbuild.2016.06.086.

Lu, S. *et al.* (2016) 'Analysis of the differences in thermal comfort between locals and tourists and genders in semi-open spaces under natural ventilation on a tropical island', *Energy and Buildings*, 129, pp. 264–273. doi:10.1016/j.enbuild.2016.08.002.

Luan, G. *et al.* (2019) 'Associations between ambient high temperatures and suicide mortality: a multi-city time-series study in China', *Environmental Science and Pollution Research*, 26(20), pp. 20377–20385. doi:10.1007/s11356-019-05252-5.

Ma, R. *et al.* (2020) 'Measurement of personal experienced temperature variations in rural households using wearable monitors: A pilot study', *International Journal of Environmental Research and Public Health*, 17(18), pp. 1–21. doi:10.3390/ijerph17186761.

Ma, X. *et al.* (2019) 'The evaluation of outdoor thermal sensation and outdoor energy efficiency of a commercial pedestrianized zone', *Energies*, 12(7). doi:10.3390/en12071324.

Mabon, L. *et al.* (2019) 'Fukuoka: Adapting to climate change through urban green space and the built environment?', *Cities*, 93(August 2018), pp. 273–285. doi:10.1016/j.cities.2019.05.007.

Maher, D. *et al.* (2021) 'Effect of inlet/outlet on thermal performance of naturally ventilated building', *International Journal of Low-Carbon Technologies*, 16(4), pp. 1348–1362. doi:10.1093/ijlct/ctab055.

Makaremi, N. *et al.* (2012) 'Study on outdoor thermal comfort in hot and humid context', *International Conference on Urban Climates*, (August), pp. 8–11.

Manavvi, S. and Rajasekar, E. (2020) 'Estimating outdoor mean radiant temperature in a humid subtropical climate', *Building and Environment*, 171(January), p. 106658. doi:10.1016/j.buildenv.2020.106658.

Manteghi, G., Bin Limit, H. and Remaz, D. (2015) 'Water bodies an urban microclimate: A review', *Modern Applied Science*, 9(6), pp. 1–12. doi:10.5539/mas.v9n6p1.

Mauree, D. *et al.* (2019) 'A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities', *Renewable and Sustainable Energy Reviews*, 112(May), pp. 733–746. doi:10.1016/j.rser.2019.06.005.

Meili, N. *et al.* (2021) 'Vegetation cover and plant-trait effects on outdoor thermal comfort in a tropical city', *Building and Environment*, 195(February), p. 107733. doi:10.1016/j.buildenv.2021.107733.

Mi, J. *et al.* (2020) 'Outdoor thermal benchmarks and their application to climate–responsive designs of residential open spaces in a cold region of China', *Building and Environment*, 169. doi:10.1016/j.buildenv.2019.106592.

Middel, A. *et al.* (2016) 'Impact of shade on outdoor thermal comfort—a seasonal field study in Tempe, Arizona', *International Journal of Biometeorology*, 60(12), pp. 1849–1861. doi:10.1007/s00484-016-1172-5.

Mohammad, P. *et al.* (2021) 'Evaluating the role of the albedo of material and vegetation scenarios along the urban street canyon for improving pedestrian thermal comfort outdoors', *Urban Climate*, 40(October), p. 100993. doi:10.1016/j.uclim.2021.100993.

Mohan, M., Gupta, A. and Bhati, S. (2014) 'A Modified Approach to Analyze Thermal Comfort Classification', *Atmospheric and Climate Sciences*, 04(01), pp. 7–19. doi:10.4236/acs.2014.41002.

Monam, A. and Rückert, K. (2013) 'The Dependence of Outdoor Thermal Comfort on Urban Layouts', *Young Cities – Developing Urban Energy Efficiency* [Preprint].

Morabito, M. *et al.* (2016) 'The impact of built-up surfaces on land surface temperatures in Italian urban areas', *Science of the Total Environment*, 551–552, pp. 317–326. doi:10.1016/j.scitotenv.2016.02.029.

Mughal, M.O. *et al.* (2021) 'Detailed investigation of vegetation effects on microclimate by means of computational fluid dynamics (CFD) in a tropical urban environment', *Urban Climate*, 39(April). doi:10.1016/j.uclim.2021.100939.

Müller, N., Kuttler, W. and Barlag, A.B. (2014) 'Counteracting urban climate change: Adaptation measures and their effect on thermal comfort', *Theoretical and Applied Climatology*, 115(1–2), pp. 243–257. doi:10.1007/s00704-013-0890-4.

Murakawa, S. *et al.* (1991) 'Study of the effects of a river on the thermal environment in an urban area', *Energy and Buildings*, 16(3–4), pp. 993–1001. doi:10.1016/0378-7788(91)90094-j.

Nazarian, N., Acero, J.A. and Norford, L. (2019) 'Outdoor thermal comfort autonomy: Performance metrics for climate-conscious urban design', *Building and Environment*, 155(November 2018), pp. 145–160. doi:10.1016/j.buildenv.2019.03.028.

Ng, E., Yau, R., Wong, Ks. Ren, C. and Katszchener, L. (2012) 'Urban Climatic Map and Standards for Wind Environment Feasibility Study Final Report', *Hong Kong Planning Department.*, (November), p. 518. Available at: https://doi.org/10.13140/RG.2.1.5165.0000.

Ng, E. *et al.* (2008) 'Working Paper No. 1A: draft urban climatic analysis map--urban climatic map and standards for wind environment--feasibility study', p. 156.

Ng, E. and Ren, C. (2015) *The urban climatic map: A methodology for sustainable urban planning*, *The Urban Climatic Map: A Methodology for Sustainable Urban Planning*. doi:10.4324/9781315717616.

Nicol, J.F. *et al.* (1999) 'Climatic variations in comfortable temperatures: The Pakistan projects', *Energy and Buildings*, 30(3), pp. 261–279. doi:10.1016/S0378-7788(99)00011-0.

Nikolopoulou, M. and Steemers, K. (2003) 'Thermal comfort and psychological adaptation as a guide for designing urban spaces', in *Energy and Buildings*, pp. 95–101. doi:10.1016/S0378-7788(02)00084-1.

Oh, W. *et al.* (2019) 'Environmental index for evaluating thermal sensations in a mist spraying environment', *Building and Environment*, 161. doi:10.1016/j.buildenv.2019.106219.

Oke, T.R. (2007) 'Siting and Exposure of Meteorological Instruments at Urban Sites', *Air Pollution Modeling and Its Application XVII*, 1, pp. 615–631. doi:10.1007/978-0-387-68854-1_66.

Othman, H.A.S. and Alshboul, A.A. (2020) 'The role of urban morphology on outdoor thermal comfort: The case of Al-Sharq City – Az Zarqa', *Urban Climate*, 34(November 2019), p. 100706. doi:10.1016/j.uclim.2020.100706.

Parida, B.R. *et al.* (2021) 'Impact of COVID-19 induced lockdown on land surface temperature, aerosol, and urban heat in Europe and North America', *Sustainable Cities and Society*, 75(September), p. 103336. doi:10.1016/j.scs.2021.103336.

Peng, S.L. and Ye, Y.H. (2007) ‘The influence of urban heat island on urban planning’, *Zhongshan Daxue Xuebao/Acta Scientiarum Natralium Universitatis Sunyatseni*, 46(5), pp. 59–63.

Peng, Y., Feng, T. and Timmermans, H. (2019) ‘A path analysis of outdoor comfort in urban public spaces’, *Building and Environment*, 148, pp. 459–467. doi:10.1016/j.buildenv.2018.11.023.

Pereira, C.T., Masiero, É. and Bourscheidt, V. (2021) ‘Socio-spatial inequality and its relationship to thermal (dis)comfort in two major Local Climate Zones in a tropical coastal city’, *International Journal of Biometeorology*, 65(7), pp. 1177–1187. doi:10.1007/s00484-021-02099-9.

Perera, T.A.N.T. *et al.* (2021) ‘Modelling of vertical greenery system with selected tropical plants in urban context to appraise plant thermal performance’, *Ecological Indicators*, 128(January), p. 107816. doi:10.1016/j.ecolind.2021.107816.

Pontes, R.H. *et al.* (2022) ‘Adapting the Olgyay bioclimatic chart to assess local thermal comfort levels in urban regions’, *Clean Technologies and Environmental Policy*, 24(2), pp. 661–675. doi:10.1007/s10098-021-02158-0.

Priya, U.K. and Senthil, R. (2021) ‘A review of the impact of the green landscape interventions on the urban microclimate of tropical areas’, *Building and Environment*, 205(July), p. 108190. doi:10.1016/j.buildenv.2021.108190.

Qaid, A. and Ossen, D.R. (2015) ‘Effect of asymmetrical street aspect ratios on microclimates in hot, humid regions’, *International Journal of Biometeorology*, 59(6), pp. 657–677. doi:10.1007/s00484-014-0878-5.

Qian, Y. *et al.* (2022) ‘Urbanization Impact on Regional Climate and Extreme Weather: Current Understanding, Uncertainties, and Future Research Directions’, *Advances in Atmospheric Sciences*, 39(6), pp. 819–860. doi:10.1007/s00376-021-1371-9.

Radhakrishnan, M. *et al.* (2019) ‘Development of context specific sustainability criteria for selection of plant species for green urban infrastructure: The case of Singapore’, *Sustainable Production and Consumption*, 20(August), pp. 316–325. doi:10.1016/j.spc.2019.08.004.

Ray, R. *et al.* (2023) ‘Quantitative Analysis of Land Use and Land Cover Dynamics using Geoinformatics Techniques: A Case Study on Kolkata Metropolitan Development Authority (KMDA) in West Bengal, India’, *Remote Sensing*, 15(4), pp. 1–23. doi:10.3390/rs15040959.

Raychaudhuri, B., Sarkar, A. and Bhattacharyya, S. (2006) ‘Semi-Supervised Classificationoif Land Cover Based on Spectral Reflectance Date Extracted from LISS IV Image’, (Table 1).

Rebecchi, A. *et al.* (2019) 'Walkable environments and healthy urban moves: Urban context features assessment framework experienced in Milan', *Sustainability (Switzerland)*, 11(10). doi:10.3390/SU11102778.

Reed, S.O. *et al.* (2015) 'Resilience projects as experiments: implementing climate change resilience in Asian cities', *Climate and Development*, 7(5), pp. 469–480. doi:10.1080/17565529.2014.989190.

Ren, C. *et al.* (2013) 'The application of urban climatic mapping to the urban planning of high-density cities: The case of Kaohsiung, Taiwan', *Cities*, 31, pp. 1–16. doi:10.1016/j.cities.2012.12.005.

'Revised Toolkit for Preparation of City Development Plan, JNNURM: Executive Summary' (2009). Available at: http://p2.mpcdp.com/PDF/JnNURMRevisedCDP-Toolkit-Summary.pdf.

Reynaud, A., Aubert, C. and Nguyen, M.H. (2013) 'Living with floods: Protective behaviours and risk perception of vietnamese households', *Geneva Papers on Risk and Insurance: Issues and Practice*, 38(3), pp. 547–579. doi:10.1057/gpp.2013.16.

Rossi, F. *et al.* (2020) 'Outdoor thermal comfort improvements due to innovative solar awning solutions: An experimental campaign', *Energy and Buildings*, 225, p. 110341. doi:10.1016/j.enbuild.2020.110341.

Rosso, F. *et al.* (2018) 'On the impact of innovative materials on outdoor thermal comfort of pedestrians in historical urban canyons', *Renewable Energy*, 118, pp. 825–839. doi:10.1016/j.renene.2017.11.074.

Sahabi Abed, S. and Matzarakis, A. (2017) 'Seasonal Regional Differentiation of Human Thermal Comfort Conditions in Algeria', *Advances in Meteorology*, 2017. doi:10.1155/2017/9193871.

Salata, F. *et al.* (2015) 'Evaluation of different urban microclimate mitigation strategies through a PMV analysis', *Sustainability (Switzerland)*, 7(7), pp. 9012–9030. doi:10.3390/su7079012.

Salata, F. *et al.* (2016) 'Outdoor thermal comfort in the Mediterranean area. A transversal study in Rome, Italy', *Building and Environment*, 96, pp. 46–61. doi:10.1016/j.buildenv.2015.11.023.

Salman, A.M. and Saleem, Y.M. (2021) 'The effect of Urban Heat Island mitigation strategies on outdoor human thermal comfort in the city of Baghdad', *Frontiers of Architectural Research*, 10(4), pp. 838–856. doi:10.1016/j.foar.2021.07.002.

Sanagar Darbani, E. *et al*. (2021) ‘Impacts of urban form and urban heat island on the outdoor thermal comfort: a pilot study on Mashhad’, *International Journal of Biometeorology*, 65(7), pp. 1101–1117. doi:10.1007/s00484-021-02091-3.

Sangkertadi, S. and Syafriny, R. (2016) ‘Pair influence of wind speed and mean radiant temperature on outdoor thermal comfort of humid tropical environment’, *Journal of Urban and Environmental Engineering*, 10(2), pp. 177–185. doi:10.4090/juee.2016.v10n2.177185.

Schaefer, M. *et al.* (2021) ‘Assessing local heat stress and air quality with the use of remote sensing and pedestrian perception in urban microclimate simulations’, *Science of the Total Environment*, 794, p. 148709. doi:10.1016/j.scitotenv.2021.148709.

Sharma, D. and Tomar, S. (2010) ‘Mainstreaming climate change adaptation in Indian cities’, *Environment and Urbanization*, 22(2), pp. 451–465. doi:10.1177/0956247810377390.

Sharmin, T. and Steemers, K. (2020) ‘Effects of microclimate and human parameters on outdoor thermal sensation in the high-density tropical context of Dhaka’, *International Journal of Biometeorology*, 64(2), pp. 187–203. doi:10.1007/s00484-018-1607-2.

Sharmin, T., Steemers, K. and Humphreys, M. (2019a) ‘Outdoor thermal comfort and summer PET range: A field study in tropical city Dhaka’, *Energy and Buildings*, 198, pp. 149–159. doi:10.1016/j.enbuild.2019.05.064.

Sharmin, T., Steemers, K. and Humphreys, M. (2019b) ‘Outdoor thermal comfort and summer PET range: A field study in tropical city Dhaka’, *Energy and Buildings*, 198, pp. 149–159. doi:10.1016/j.enbuild.2019.05.064.

Shi, Y. *et al.* (2016) ‘Mapping the urban microclimatic spatial distribution in a sub-tropical high-density urban environment’, *Architectural Science Review*, 59(5), pp. 370–384. doi:10.1080/00038628.2015.1105195.

Shimazaki, Y. *et al.* (2022) ‘Improving outdoor human-thermal environment by optimizing the reflectance of water-retaining pavement through subjective field-based measurements’, *Building and Environment*, 210. doi:10.1016/J.BUILDENV.2021.108695.

Shojaei, P. *et al.* (2017) ‘Effect of different land cover/use types on canopy layer air temperature in an urban area with a dry climate’, *Building and Environment*, 125, pp. 451–463. doi:10.1016/j.buildenv.2017.09.010.

Shooshtarian, S. and Ridley, I. (2017) ‘The effect of physical and psychological environments on the users thermal perceptions of educational urban precincts’, *Building and Environment*, 115, pp. 182–198. doi:10.1016/j.buildenv.2016.12.022.

Spagnolo, J. and de Dear, R. (2003) 'A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia', *Building and Environment*, 38(5), pp. 721–738. doi:10.1016/S0360-1323(02)00209-3.

Staiger, H., Laschewski, G. and Matzarakis, A. (2019) 'Selection of appropriate thermal indices for applications in human biometeorological studies', *Atmosphere*, 10(1). doi:10.3390/atmos10010018.

Stewart, I.D. (2011) 'Redefining the urban heat island. Unpublished doctoral dissertation.', *Buildings*, (October), pp. 1–11.

Subhashini, S. and Thirumaran, K. (2020) 'CFD simulations for examining natural ventilation in the learning spaces of an educational building with courtyards in Madurai', *Building Services Engineering Research and Technology*, 41(4), pp. 466–479. doi:10.1177/0143624419878798.

Syafii, N.I. *et al.* (2016) 'Experimental Study on the Influence of Urban Water Body on Thermal Environment at Outdoor Scale Model', *Procedia Engineering*, 169, pp. 191–198. doi:10.1016/j.proeng.2016.10.023.

Szucs, Á. (2013) 'Wind comfort in a public urban space-Case study within Dublin Docklands', *Frontiers of Architectural Research*, 2(1), pp. 50–66. doi:10.1016/j.foar.2012.12.002.

Taleghani, M. and Berardi, U. (2018) 'The effect of pavement characteristics on pedestrians' thermal comfort in Toronto', *Urban Climate*, 24, pp. 449–459. doi:10.1016/j.uclim.2017.05.007.

Taleghani, M., Sailor, D. and Ban-Weiss, G.A. (2016) 'Micrometeorological simulations to predict the impacts of heat mitigation strategies on pedestrian thermal comfort in a Los Angeles neighborhood', *Environmental Research Letters*, 11(2). doi:10.1088/1748-9326/11/2/024003.

Tan, J.K.N. *et al.* (2021) 'The urban heat island mitigation potential of vegetation depends on local surface type and shade', *Urban Forestry and Urban Greening*, 62(April), p. 127128. doi:10.1016/j.ufug.2021.127128.

Tan, Z. *et al.* (2019a) 'Design for climate resilience: influence of environmental conditions on thermal sensation in subtropical high-density cities', *Architectural Science Review*, 62(1), pp. 3–13. doi:10.1080/00038628.2018.1495612.

Tan, Z. *et al.* (2019b) 'Design for climate resilience: influence of environmental conditions on thermal sensation in subtropical high-density cities', *Architectural Science Review*, 62(1), pp. 3–13. doi:10.1080/00038628.2018.1495612.

Tan, Z., Lau, K.K.L. and Ng, E. (2016) 'Urban tree design approaches for mitigating daytime urban heat island effects in a high-density urban environment', *Energy and Buildings*, 114, pp. 265–274. doi:10.1016/j.enbuild.2015.06.031.

Theeuwes, N.E., Solcerová, A. and Steeneveld, G.J. (2013) 'Modeling the influence of open water surfaces on the summertime temperature and thermal comfort in the city', *Journal of Geophysical Research Atmospheres*, 118(16), pp. 8881–8896. doi:10.1002/jgrd.50704.

Tong, S. *et al.* (2017) 'Impact of urban morphology on microclimate and thermal comfort in northern China', *Solar Energy*, 155, pp. 212–223. doi:10.1016/j.solener.2017.06.027.

Tsoka, S. *et al.* (2020) 'Urban warming and cities' microclimates: Investigation methods and mitigation strategies—A review', *Energies*, 13(6). doi:10.3390/en13061414.

Tsoka, S., Tsikaloudaki, K. and Theodosiou, T. (2017) 'Urban space's morphology and microclimatic analysis: A study for a typical urban district in the Mediterranean city of Thessaloniki, Greece', *Energy and Buildings*, 156, pp. 96–108. doi:10.1016/j.enbuild.2017.09.066.

Vaishnani, Y. *et al.* (2020) 'Thermal performance analysis of a naturally ventilated system using PMV models for different roof inclinations in composite climatic conditions', *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 42(3). doi:10.1007/S40430-020-2219-4.

Völker, S. *et al.* (2013) 'Evidence for the temperature-mitigating capacity of urban blue space - A health geographic perspective', *Erdkunde*, 67(4), pp. 355–371. doi:10.3112/erdkunde.2013.04.05.

Völker, S. and Kistemann, T. (2011) 'The impact of blue space on human health and well-being - Salutogenetic health effects of inland surface waters: A review', *International Journal of Hygiene and Environmental Health*, 214(6), pp. 449–460. doi:10.1016/j.ijheh.2011.05.001.

Völker, S. and Kistemann, T. (2013) '"I'm always entirely happy when I'm here!" Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany', *Social Science and Medicine*, 78(1), pp. 113–124. doi:10.1016/j.socscimed.2012.09.047.

Wai, K.M. *et al.* (2017) 'Aerosol pollution and its potential impacts on outdoor human thermal sensation: East Asian perspectives', *Environmental Research*, 158, pp. 753–758. doi:10.1016/j.envres.2017.07.036.

Wang, Y., Berardi, U. and Akbari, H. (2016) 'Comparing the effects of urban heat island mitigation strategies for Toronto, Canada', *Energy and Buildings*, 114, pp. 2–19. doi:10.1016/j.enbuild.2015.06.046.

Wniosku, R. (2013) 'S E N Io K Ro', pp. 20–22.

Wong, G.K.L. and Jim, C.Y. (2017) 'Urban-microclimate effect on vector mosquito abundance of tropical green roofs', *Building and Environment*, 112, pp. 63–76. doi:10.1016/j.buildenv.2016.11.028.

Wong, M.S. *et al.* (2010) 'A simple method for designation of urban ventilation corridors and its application to urban heat island analysis', *Building and Environment*, 45(8), pp. 1880–1889. doi:10.1016/j.buildenv.2010.02.019.

Xie, Y. *et al.* (2019) 'Outdoor thermal sensation and logistic regression analysis of comfort range of meteorological parameters in Hong Kong', *Building and Environment*, 155, pp. 175–186. doi:10.1016/j.buildenv.2019.03.035.

Xu, X. *et al.* (2017) 'The cooling and energy saving effect of landscape design parameters of urban park in summer: A case of Beijing, China', *Energy and Buildings*, 149, pp. 91–100. doi:10.1016/j.enbuild.2017.05.052.

Xu, X. *et al.* (2019) 'Evaluation of energy saving potential of an urban green space and its water bodies', *Energy and Buildings*, 188–189, pp. 58–70. doi:10.1016/j.enbuild.2019.02.003.

Xuan, Y. *et al.* (2016) 'Outdoor thermal environment for different urban forms under summer conditions', *Building Simulation*, 9(3), pp. 281–296. doi:10.1007/s12273-016-0274-7.

Xue, F., Gou, Z. and Lau, S.S.Y. (2017) 'Green open space in high-dense Asian cities: Site configurations, microclimates and users' perceptions', *Sustainable Cities and Society*, 34, pp. 114–125. doi:10.1016/j.scs.2017.06.014.

Xue, J. *et al.* (2020) 'Outdoor thermal comfort at a university campus: Studies from personal and long-term thermal history perspectives', *Sustainability (Switzerland)*, 12(21), pp. 1–17. doi:10.3390/su12219284.

Yang, L., Liu, X. and Qian, F. (2020) 'Research on water thermal effect on surrounding environment in summer', *Energy and Buildings*, 207, p. 109613. doi:10.1016/j.enbuild.2019.109613.

Yang, W., Lin, Y. and Li, C.Q. (2018) 'Effects of Landscape Design on Urban Microclimate and Thermal Comfort in Tropical Climate', *Advances in Meteorology*, 2018. doi:10.1155/2018/2809649.

Yu, Y. *et al.* (2021) 'Impact of wind turbulence on thermal perception in the urban microclimate', *Journal of Wind Engineering and Industrial Aerodynamics*, 216(July), p. 104714. doi:10.1016/j.jweia.2021.104714.

Yung, E.H.K., Wang, S. and Chau, C. kwan (2019) ‘Thermal perceptions of the elderly, use patterns and satisfaction with open space’, *Landscape and Urban Planning*, 185, pp. 44–60. doi:10.1016/j.landurbplan.2019.01.003.

Zhang, Y. *et al.* (2020) ‘Analysis of thermal comfort during movement in a semi-open transition space’, *Energy and Buildings*, 225. doi:10.1016/j.enbuild.2020.110312.

Zhao, L. *et al.* (2016) ‘Study on outdoor thermal comfort on a campus in a subtropical urban area in summer’, *Sustainable Cities and Society*. Elsevier Ltd, pp. 164–170. doi:10.1016/j.scs.2016.02.009.

Zhao, T.F. and Fong, K.F. (2017a) ‘Characterization of different heat mitigation strategies in landscape to fight against heat island and improve thermal comfort in hot-humid climate (Part II): Evaluation and characterization’, *Sustainable Cities and Society*, 35, pp. 841–850. doi:10.1016/j.scs.2017.05.006.

Zhao, T.F. and Fong, K.F. (2017b) ‘Characterization of different heat mitigation strategies in landscape to fight against heat island and improve thermal comfort in hot–humid climate (Part I): Measurement and modelling’, *Sustainable Cities and Society*, 32, pp. 523–531. doi:10.1016/j.scs.2017.03.025.

APPENDIX-I

Questionnaire Schedule for Outdoor Thermal Comfort Survey

MONTH OF SURVEY:

Today's Air Temperature is........

Name :		Date:
Time:	Name of Location:	Gender: □**M** □**F**

Occupation: ....

1. **Age Group: (in years)**

   □ <13 □ 13-18 □ 19-24 □ 25-34 □ 35-44 □ 45-54 □ 55-6 □ >65

2. **Clo value-**

   0.7, 0.5, 0.9, 1.0

3. **How are you feeling now? ISO 10551 (1995)/ What is your general thermal sensation? ASHRAE 55 (2010)**

   □ Very cold □ cold □ slightly cool □cool □neutral □ slightly warm □ warm □hot □very hot

4. **How do you find this environment comfortable? ISO 10551(1995)**

   □very comfortable □slightly comfortable □Comfortable □slightly uncomfortable □uncomfortable □very uncomfortable

5. **'Please state how you would prefer it to be now' ISO 10551 (1995)**

   □ Much cooler □cooler □slightly cooler □neither warmer nor cooler □little warmer □warmer □much warmer

6. **On a personal level, this environment is for me...... ISO 10551 (1995)**

   □ acceptable rather than unacceptable □ unacceptable rather than acceptable

7. **How satisfied are you with the temperature in your space ? ASHRAE 55 (2010)**

   □ very satisfied □satisfied □ slightly satisfied □ neutral □ slightly dissatisfied □dissatisfied □ very dissatisfied

8. **Is it tolerable?ISO 10551 (1995)**

   □perfectly tolerable □slightly difficult to tolerate □fairly difficult to tolerate □very difficult to tolerate □intolerable

3. **How long have you been in this location** ?

□ <15 mins □ 15-30 mins □ 30-60 mins □ >60 mins

4. **Activity level (in last half hour)**

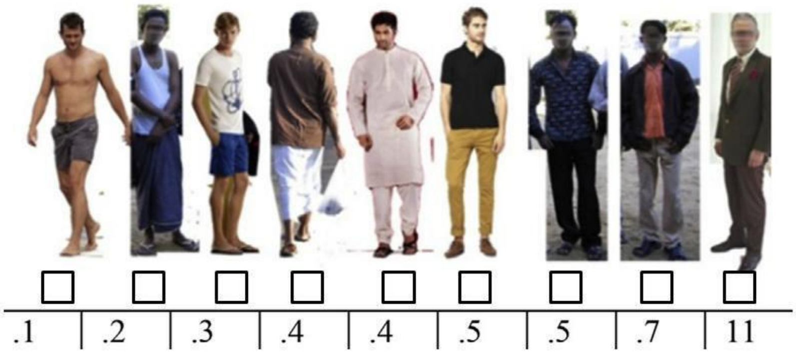
Walking slowly, walking fast, Running, Sitting, Standing.

7 **Were you in AIR CONDITIONING in last 15 minutes ?**

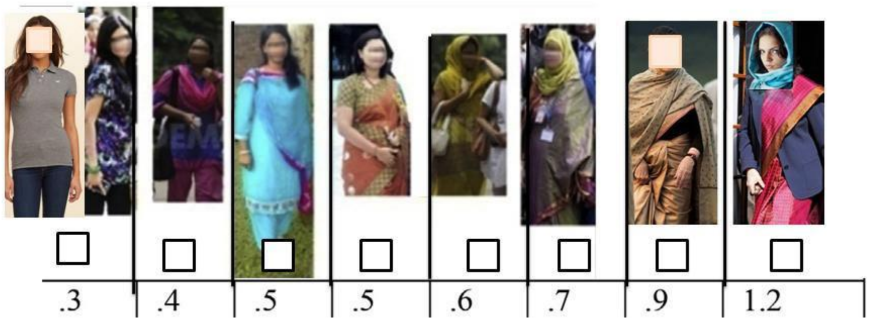
□ Yes □No

8 Clothing items

M



F



15. **Your feeling in outdoor conditionis** □ Uncomfortable □ Neutral □ Comfortable

16. **You prefer...** □ prefer warmer weather □ this is perfect weather □ prefer cooler weather

Survey conducted by Rohini Mazumder Chakraborty, Dept. of Architecture, Jadavpur University in 2019.

APPENDIX-II

Sr no.		SITE	height	weight	age	sex	cloth.
1		BALLYGUNGE_PHARI	1.8	75	35	m	0.62
2		BALLYGUNGE_STATION	1.8	70	32	m	0.55
3		BANTOLA	1.8	75	35	m	0.55
4		BARISHA	1.7	59	29	f	0.82
5		BEHALA_CHOWRASTA	1.7	80	48	f	0.82
6		BIRLA_PLANETORIUM	1.6	70	32	m	0.64
7		CALCUTTA_BLIND_SCHOOL	1.6	70	32	m	0.64
8		CHINGRIHATA	1.6	74	40	f	0.78
9		COLLEGE_STREET	1.8	75	34	m	0.64
10		DHAKURIA	1.8	75	34	m	0.64
11		DHAPA	1.6	55	32	f	0.67
12		DIAMOND_HARBOUR(MINT)	1.7	55	38	f	0.46
13		ESPLANADE	1.8	82	38	m	0.55
14		EXIDE	1.8	82	37	m	0.55
15		GARDEN_REACH	1.8	82	37	m	0.55
16		GARIA_BUS_STAND	1.6	65	27	f	0.78
17		GARIAHAT	1.6	65	27	f	0.78
18		GOLF_GREEN	1.8	78	45	m	0.55
19		HATIBAGAN	1.8	52	43	f	0.73
20		INDIAN_MUSEUM	1.8	78	45	m	0.55
21		JADAVPUR_THANA	1.8	52	43	f	0.73
22		KAKURGACHI	1.6	65	50	m	0.52
23		KALIKAPUR	1.6	65	50	m	0.52
24		KHIDIRPORE_MORE	1.6	65	50	m	0.52
25		LAKE_MARKET	1.6	65	50	m	0.52
26		LENIN_SARANI	1.8	85	50	m	0.55
27		MAIDAN	1.6	74	40	f	0.78
28		MANIKTALA	1.8	80	46	m	0.64
29		MG_ROAD	1.8	80	46	m	0.64
30		MUKUNDAPUR	1.8	85	39	m	0.64
31		NARKELDANGA	1.8	80	46	m	0.64
32		PARK_CIRCUS	1.8	80	46	m	0.64
33		PARK_STREET	1.8	80	46	m	0.64
34		PATULI	1.8	80	46	m	0.64
35		RABINDRA_SAROBAR	1.8	80	46	m	0.64
36		RAJABAZAAR	1.8	80	46	m	0.64
37		RASHBEHARI	1.6	71	38	m	0.78
38		RUBY	1.6	65	38	f	0.78
39		SAKHERBAZAR	1.6	71	38	m	0.78
40		SCIENCE_CITY	1.8	80	46	m	0.64
41		SEALDAH	1.7	81	41	m	0.64
42		SHYAMBAZAAR	1.7	81	41	m	0.64
43		SINTHEE	1.6	65	38	f	0.78
44		SOVABAZAAR_FERRY	1.7	81	41	m	0.64
45		SSKM	1.7	81	41	m	0.64
46		THAKURPUKUR	1.6	70	32	m	0.64
47		THEATRE_ROAD	1.8	76	28	m	0.64
48		TOLLYGUNGE_PHARI	1.8	76	28	m	0.64
49		TOLLYNALA	1.6	70	32	m	0.64
50		ULTADANGA	1.6	70	32	m	0.64

Table a showing station wise physiological data - age, sex, height, weight, clo for spring (2019).

Sr no.		SITE	height	weight	age	sex	cloth.
1		BALLYGUNGE_PHARI	1.8	75	35	m	0.45
2		BALLYGUNGE_STATION	1.8	70	32	m	0.31
3		BANTOLA	1.8	75	35	m	0.49
4		BARISHA	1.7	59	29	f	0.49
5		BEHALA_CHOWRASTA	1.7	80	48	f	0.49
6		BIRLA_PLANETORIUM	1.6	70	32	m	0.45
7		CALCUTTA_BLIND_SCHOOL	1.6	70	32	m	0.45
8		CHINGRIHATA	1.6	74	40	f	0.45
9		COLLEGE_STREET	1.8	75	34	m	0.49
10		DHAKURIA	1.8	75	34	m	0.49
11		DHAPA	1.6	55	32	f	0.45
12		DIAMOND_HARBOUR(MINT)	1.7	55	38	f	0.45
13		ESPLANADE	1.8	82	38	m	0.49
14		EXIDE	1.8	82	37	m	0.45
15		GARDEN_REACH	1.8	82	37	m	0.45
16		GARIA_BUS_STAND	1.6	65	27	f	0.49
17		GARIAHAT	1.6	65	27	f	0.49
18		GOLF_GREEN	1.8	78	45	m	0.45
19		HATIBAGAN	1.8	52	43	f	0.45
20		INDIAN_MUSEUM	1.8	78	45	m	0.45
21		JADAVPUR_THANA	1.8	52	43	f	0.45
22		KAKURGACHI	1.6	65	50	m	0.45
23		KALIKAPUR	1.6	65	50	m	0.45
24		KHIDIRPORE_MORE	1.6	65	50	m	0.45
25		LAKE_MARKET	1.6	65	50	m	0.49
26		LENIN_SARANI	1.8	85	50	m	0.45
27		MAIDAN	1.6	74	40	f	0.45
28		MANIKTALA	1.8	80	46	m	0.49
29		MG_ROAD	1.8	80	46	m	0.49
30		MUKUNDAPUR	1.8	85	39	m	0.45
31		NARKELDANGA	1.8	80	46	m	0.45
32		PARK_CIRCUS	1.8	80	46	m	0.45
33		PARK_STREET	1.8	80	46	m	0.45
34		PATULI	1.8	80	46	m	0.45
35		RABINDRA_SAROBAR	1.8	80	46	m	0.45
36		RAJABAZAAR	1.8	80	46	m	0.45
37		RASHBEHARI	1.6	71	38	m	0.49
38		RUBY	1.6	65	38	f	0.49
39		SAKHERBAZAR	1.6	71	38	m	0.31
40		SCIENCE_CITY	1.8	80	46	m	0.45
41		SEALDAH	1.7	81	41	m	0.49
42		SHYAMBAZAAR	1.7	81	41	m	0.49
43		SINTHEE	1.6	65	38	f	0.45
44		SOVABAZAAR_FERRY	1.7	81	41	m	0.45
45		SSKM	1.7	81	41	m	0.45
46		THAKURPUKUR	1.6	70	32	m	0.49
47		THEATRE_ROAD	1.8	76	28	m	0.31
48		TOLLYGUNGE_PHARI	1.8	76	28	m	0.31
49		TOLLYNALA	1.6	70	32	m	0.31
50		ULTADANGA	1.6	70	32	m	0.31

Table b showing station wise physiological data - age, sex, height, weight, clo for summer (2019).

SITE	height	weight	age	sex	cloth.
BALLYGUNGE_PHARI	1.8	75	35	m	1.06
BALLYGUNGE_STATION	1.8	70	32	m	1.18
BANTOLA	1.8	75	35	m	0.72
BARISHA	1.7	59	29	f	1.18
BEHALA_CHOWRASTA	1.7	80	48	f	1.18
BIRLA_PLANETORIUM	1.6	70	32	m	0.72
CALCUTTA_BLIND_SCHOOL	1.6	70	32	m	1.06
CHINGRIHATA	1.6	74	40	f	0.72
COLLEGE_STREET	1.8	75	34	m	1.18
DHAKURIA	1.8	75	34	m	1.18
DHAPA	1.6	55	32	f	0.72
DIAMOND_HARBOUR(MINT)	1.7	55	38	f	0.72
ESPLANADE	1.8	82	38	m	1.18
EXIDE	1.8	82	37	m	1.06
GARDEN_REACH	1.8	82	37	m	0.72
GARIA_BUS_STAND	1.6	65	27	f	1.18
GARIAHAT	1.6	65	27	f	1.18
GOLF_GREEN	1.8	78	45	m	0.72
HATIBAGAN	1.8	52	43	f	1.06
INDIAN_MUSEUM	1.8	78	45	m	0.72
JADAVPUR_THANA	1.8	52	43	f	1.06
KAKURGACHI	1.6	65	50	m	1.18
KALIKAPUR	1.6	65	50	m	1.18
KHIDIRPORE_MORE	1.6	65	50	m	0.72
LAKE_MARKET	1.6	65	50	m	1.18
LENIN_SARANI	1.8	85	50	m	1.18
MAIDAN	1.6	74	40	f	0.72
MANIKTALA	1.8	80	46	m	1.18
MG_ROAD	1.8	80	46	m	1.18
MUKUNDAPUR	1.8	85	39	m	1.18
NARKELDANGA	1.8	80	46	m	0.72
PARK_CIRCUS	1.8	80	46	m	1.18
PARK_STREET	1.8	80	46	m	1.18
PATULI	1.8	80	46	m	1.18
RABINDRA_SAROBAR	1.8	80	46	m	1.18
RAJABAZAAR	1.8	80	46	m	1.18
RASHBEHARI	1.6	71	38	m	1.18
RUBY	1.6	65	38	f	1.18
SAKHERBAZAR	1.6	71	38	m	1.18
SCIENCE_CITY	1.8	80	46	m	0.72
SEALDAH	1.7	81	41	m	1.18
SHYAMBAZAAR	1.7	81	41	m	1.18
SINTHEE	1.6	65	38	f	1.06
SOVABAZAAR_FERRY	1.7	81	41	m	1.06
SSKM	1.7	81	41	m	0.72
THAKURPUKUR	1.6	70	32	m	1.18
THEATRE_ROAD	1.8	76	28	m	1.18
TOLLYGUNGE_PHARI	1.8	76	28	m	1.18
TOLLYNALA	1.6	70	32	m	1.18
ULTADANGA	1.6	70	32	m	1.18

Table c showing station wise physiological data - age, sex, height, weight, clo for Winter (2019).

SITE	height	weight	age	sex	cloth.
BALLYGUNGE_PHARI	1.8	75	35	m	0.78
BALLYGUNGE_STATION	1.8	70	32	m	0.65
BANTOLA	1.8	75	35	m	0.54
BARISHA	1.7	59	29	f	0.49
BEHALA_CHOWRASTA	1.7	80	48	f	0.49
BIRLA_PLANETORIUM	1.6	70	32	m	0.7
CALCUTTA_BLIND_SCHOOL	1.6	70	32	m	0.7
CHINGRIHATA	1.6	74	40	f	0.7
COLLEGE_STREET	1.8	75	34	m	0.49
DHAKURIA	1.8	75	34	m	0.78
DHAPA	1.6	55	32	f	0.65
DIAMOND_HARBOUR(MINT)	1.7	55	38	f	0.54
ESPLANADE	1.8	82	38	m	0.49
EXIDE	1.8	82	37	m	0.7
GARDEN_REACH	1.8	82	37	m	0.7
GARIA_BUS_STAND	1.6	65	27	f	0.7
GARIAHAT	1.6	65	27	f	0.49
GOLF_GREEN	1.8	78	45	m	0.78
HATIBAGAN	1.8	52	43	f	0.65
INDIAN_MUSEUM	1.8	78	45	m	0.54
JADAVPUR_THANA	1.8	52	43	f	0.78
KAKURGACHI	1.6	65	50	m	0.65
KALIKAPUR	1.6	65	50	m	0.54
KHIDIRPORE_MORE	1.6	65	50	m	0.49
LAKE_MARKET	1.6	65	50	m	0.78
LENIN_SARANI	1.8	85	50	m	0.65
MAIDAN	1.6	74	40	f	0.54
MANIKTALA	1.8	80	46	m	0.49
MG_ROAD	1.8	80	46	m	0.49
MUKUNDAPUR	1.8	85	39	m	0.49
NARKELDANGA	1.8	80	46	m	0.78
PARK_CIRCUS	1.8	80	46	m	0.7
PARK_STREET	1.8	80	46	m	0.49
PATULI	1.8	80	46	m	0.78
RABINDRA_SAROBAR	1.8	80	46	m	0.49
RAJABAZAAR	1.8	80	46	m	0.49
RASHBEHARI	1.6	71	38	m	0.49
RUBY	1.6	65	38	f	0.78
SAKHERBAZAR	1.6	71	38	m	0.7
SCIENCE_CITY	1.8	80	46	m	0.49
SEALDAH	1.7	81	41	m	0.78
SHYAMBAZAAR	1.7	81	41	m	0.65
SINTHEE	1.6	65	38	f	0.77
SOVABAZAAR_FERRY	1.7	81	41	m	0.74
SSKM	1.7	81	41	m	0.49
THAKURPUKUR	1.6	70	32	m	0.49
THEATRE_ROAD	1.8	76	28	m	0.49
TOLLYGUNGE_PHARI	1.8	76	28	m	0.49
TOLLYNALA	1.6	70	32	m	0.49
ULTADANGA	1.6	70	32	m	0.49

Table d showing station wise physiological data - age, sex, height, weight, clo for Autumn (2019)

		height	weight	age	cloth.	PET	mPET
height	Pearson Correlation	1	.489**	.201	-.313*	-.002	-.030
	Sig. (2-tailed)		.000	.161	.027	.988	.836
	N	50	50	50	50	50	50
weight	Pearson Correlation	.489**	1	.247	-.201	-.152	-.147
	Sig. (2-tailed)	.000		.084	.161	.292	.310
	N	50	50	50	50	50	50
age	Pearson Correlation	.201	.247	1	-.303*	-.012	-.012
	Sig. (2-tailed)	.161	.084		.033	.934	.936
	N	50	50	50	50	50	50
cloth.	Pearson Correlation	-.313*	-.201	-.303*	1	.164	.155
	Sig. (2-tailed)	.027	.161	.033		.257	.283
	N	50	50	50	50	50	50
PET	Pearson Correlation	-.002	-.152	-.012	.164	1	.989**
	Sig. (2-tailed)	.988	.292	.934	.257		.000
	N	50	50	50	50	50	50
mPET	Pearson Correlation	-.030	-.147	-.012	.155	.989**	1
	Sig. (2-tailed)	.836	.310	.936	.283	.000	
	N	50	50	50	50	50	50

Table e showing correlation between physiological parameters and PET & mPET (SPRING, 2019)

		height	weight	age	cloth.	PET	mPET
height	Pearson Correlation	1	.489**	.201	.011	.010	.013
	Sig. (2-tailed)		.000	.161	.937	.945	.930
	N	50	50	50	50	50	50
weight	Pearson Correlation	.489**	1	.247	.033	.219	.277
	Sig. (2-tailed)	.000		.084	.822	.126	.052
	N	50	50	50	50	50	50
age	Pearson Correlation	.201	.247	1	.301*	.167	.148
	Sig. (2-tailed)	.161	.084		.034	.247	.304
	N	50	50	50	50	50	50
cloth.	Pearson Correlation	.011	.033	.301*	1	-.280*	-.185
	Sig. (2-tailed)	.937	.822	.034		.049	.197
	N	50	50	50	50	50	50
	Sig. (2-tailed)						
	N	50	50	50	50	50	50
PET	Pearson Correlation	.010	.219	.167	-.280*	1	.919**
	Sig. (2-tailed)	.945	.126	.247	.049		.000
	N	50	50	50	50	50	50
mPET	Pearson Correlation	.013	.277	.148	-.185	.919**	1
	Sig. (2-tailed)	.930	.052	.304	.197	.000	
	N	50	50	50	50	50	50

Table f Table 14 showing correlation between physiological parameters and PET & mPET (Spring, 2019)

		height	weight	Age	cloth.	activ.	PET	mPET
height	Pearson Correlation	1	.489**	.201	.028	.b	-.064	-.095
	Sig. (2-tailed)		.000	.161	.845		.660	.513
	N	50	50	50	50	50	50	50
weight	Pearson Correlation	.489**	1	.247	.061	.b	-.054	-.078
	Sig. (2-tailed)	.000		.084	.673		.711	.592
	N	50	50	50	50	50	50	50
age	Pearson Correlation	.201	.247	1	-.082	.b	.047	.040
	Sig. (2-tailed)	.161	.084		.572		.747	.783
	N	50	50	50	50	50	50	50
cloth.	Pearson Correlation	.028	.061	-.082	1	.b	.340*	.453**
	Sig. (2-tailed)	.845	.673	.572			.016	.001
	N	50	50	50	50	50	50	50
	Sig. (2-tailed)							
	N	50	50	50	50	50	50	50
PET	Pearson Correlation	-.064	-.054	.047	.340*	.b	1	.974**
	Sig. (2-tailed)	.660	.711	.747	.016			.000
	N	50	50	50	50	50	50	50
mPET	Pearson Correlation	-.095	-.078	.040	.453**	.b	.974**	1
	Sig. (2-tailed)	.513	.592	.783	.001		.000	
	N	50	50	50	50	50	50	50
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table g showing correlation between physiological parameters and PET & mPET (December, 2019)

THERMAL SENSATION		mPET (º C)		
		Mean	Maximum	Minimum
	SLIGHTLY COOL	20.0	24.4	15.6
	NEUTRAL	**24.1**	**28.8**	**20.2**
	SLIGHT;Y WARM	25.5	29.8	21.3
	WARM	26.5	29.8	21.9
SPRING	HOT	26.1	27.9	19.7
	VERY WARM	37.6	37.6	37.6
	HOT	39.1	41.9	37.3
SUMMER	VERY HOT	41.4	45.9	37.4
	COOL	26.6	28.3	24.7
	SLIGHTLY COOL	26.5	29.0	23.8
	NEUTRAL	**27.0**	**31.2**	**21.8**
	SLIGHTLY WARM	27.1	30.3	23.2
AUTUMN	WARM			
	VERY COLD	22.9	23.1	22.7
	COLD	23.3	26.4	19.6
	COOL	20.5	23.9	17.1
	SLIGHTLY COOL	25.0	27.2	20.9
	NEUTRAL	**22.0**	**26.4**	**16.3**
WINTER	SLIGHTLY WARM	22.5	26.9	14.2

Table h show thermal conditions reflected by mPET in which respondents feel neutral

THERMAL COMFORT		mPET (° C)		
		Mean	Maximum	Minimum
SPRING	COMFORTABLE	**24.3**	28.9	15.6
	SLIGHTLY UNCOMFORTABLE	25.6	29.8	21.3
	UNCOMFORTABLE	25.9	29.8	19.7
	VERY UNCOMFORTABLE	27.7	28.0	27.0
SUMMER	COMFORTABLE	**37.6**	37.6	37.6
	SLIGHTLY UNCOMFORTABLE			
	UNCOMFORTABLE	39.4	42.3	37.4
	VERY UNCOMFORTABLE	41.6	45.9	37.3
AUTUMN	COMFORTABLE	**26.8**	31.2	21.8
	SLIGHTLY UNCOMFORTABLE	27.2	30.3	22.5
WINTER	COMFORTABLE	**23.1**	26.9	14.2
	SLIGHTLY UNCOMFORTABLE	23.2	27.2	17.1
	UNCOMFORTABLE	23.3	23.4	23.1

Table i show thermal conditions reflected by mPET in which respondents feel comfortable

SITE	Mpet_SP	Mpet_SU	Mpet_AU	Mpet_WI	avg mpet	SITE	Mpet_SP	Mpet_SU	Mpet_AU	Mpet_WI	avg mpet
MAIDAN	23.9	41.1	26.1	21.5	28.15	RUBY	23	43.2	24.7	24.5	28.85
KAKURGA	25.2	39	25.1	24.3	28.4	BEHALA_C	24.9	39.5	25.1	26	28.88
DHAPA	28.9	37.3	26.6	20.6	28.35	DHAKURIA	25	39.4	28.3	23.1	28.95
NARKELDA	22.9	42.2	25.3	23.7	28.53	TOLLYNAL	25.1	45.9	26.1	25.4	30.63
BANTOLA	26	37.7	27.6	22.7	28.5	ESPLANAD	25.3	41.2	29.8	20.4	29.18
DIAMOND	25.6	39.4	24.1	25	28.53	SAKHERBA	27.8	42.3	29.3	26.8	31.55
ULTADAN	27	39.5	29.1	24.8	30.1	PARK_CIR	27	42.2	28.6	27.2	31.25
KHIDIRPOI	26.5	43.8	27.8	24.3	30.6	LENIN_SA	28.7	40.9	28.9	26.9	31.35
TOLLYGUN	27.8	43.9	28.2	16.6	29.13	PARK_STR	28	41.9	28.6	26.8	31.33
SOVABAZA	25.9	42.5	26.7	26.1	30.3	THEATRE_	27.6	43.1	28.8	26.4	31.48
RABINDRA	24.4	41.9	24.9	26.7	29.48	SEALDAH	29.8	44	30.2	27.2	32.8
SINTHEE	29.8	43.7	29.4	26.1	32.25	BARISHA	27.1	38.4	28.8	26.4	30.18
INDIAN_M	24.6	42.3	26.9	26	29.95	LAKE_MAI	27.9	41.5	29.2	20.9	29.88
HATIBAGA	28.8	38.8	31.2	26.9	31.43	THAKURPI	26.3	43.1	29	24.5	30.73
RAJABAZA	27.9	41.6	28.7	26.8	31.25	BALLYGUN	28.1	39.7	29	25.9	30.68
						GARIA_BL	29.4	41.2	29.6	23.9	31.03
						MANIKTAI	29.8	41.8	28.8	25.6	31.5
						RASHBEHA	25.8	42.8	27.6	24.8	30.25
						SHYAMBA	28.9	44	30.2	26.8	32.48
						COLLEGE_	28.6	40.3	27.4	22.9	29.8
						MG_ROAD	28.4	41.3	30.3	22	30.5

Table j showing stations that have thermal conditions closest to mPET 28.1 degree Celsius.

	Spring	Mean Difference	Summer	Mean Difference	Autumn	Mean Difference	Winter	Mean Difference
A2	33.0	-0.46	42.00	-3.58	25.00	-0.78	18.00	-1.93
B2	32.9	-0.56	42.00	-3.58	25.00	-0.78	17.90	-2.03
C2	32.9	-0.56	47.90	2.32	26.00	0.22	20.00	0.07
D3	32.0	-1.46	38.00	-7.58	22.00	-3.78	17.50	-2.43
E3	28.3	-5.16	45.00	-0.58	25.00	-0.78	19.00	-0.93
F3	32.0	-1.46	45.00	-0.58	24.00	-1.78	17.00	-2.93
G4	37.0	3.54	49.70	4.12	29.00	3.22	23.00	3.07
H4	35.0	1.54	48.60	3.02	27.00	1.22	22.00	2.07
I5	38.0	4.54	52.00	6.42	29.00	3.22	25.00	5.07
Mean	33.5		45.6		25.8		19.9	

Table k showing mean difference from mPET for four seasons in 2019. nine stations as case studies for effect of water fraction was taken.

STATIONS WITH HIGH NATURAL SURFACE COVER					
PAF CATEGORY	**Station**	**Mpet_SP**	**Mpet_SU**	**Mpet_AU**	**Mpet_WI**
4	MUKUNDAPUR	22.5	42	23.7	17.8
4	SAKHERBAZAR	27.8	42.3	29.3	26.8
4	PARK CIRCUS	27	42.2	28.6	27.2
4	EXIDE	19.7	38.1	21.8	25.7
4	BALLYGUNGE_PHARI	24.9	40.4	25.8	19.6
4	LENIN_SARANI	28.7	40.9	28.9	26.9
4	PARK STREET	28	41.9	28.6	26.8
4	THEATRE ROAD	27.6	43.1	28.8	26.4
4	TOLLYGUNGE PHARI	25.1	45.9	26.1	25.4
5	SEALDAH	29.8	44	30.2	27.2
5	RUBY	23	43.2	24.7	24.5
5	BEHALA CHOWRASTA	24.9	39.5	25.1	26
5	BARISHA	27.1	38.4	28.8	26.4
5	LAKE MARKET	27.9	41.5	29.2	20.9
5	THAKURPUKUR	26.3	43.1	29	24.5
5	ESPLANADE	25.3	41.2	29.8	20.4
5	BALLYGUNGE_STATION	28.1	39.7	29	25.9
5	GARIA BUS STAND	29.4	41.2	29.6	23.9
5	GARIAHAT	22.8	39.7	23.8	23.4
5	DHAKURIA	25	39.4	28.3	23.1
5	MANIKTALA	29.8	41.8	28.8	25.6
5	RASHBEHARI	25.8	42.8	27.6	24.8
5	SHYAMBAZAAR	28.9	44	30.2	26.8
5	COLLEGE STREET	28.6	40.3	27.4	22.9
5	MG ROAD	28.4	41.3	30.3	22
variance		6.61	3.44	5.44	6.75

Table l showing 25 stations with low natural landscape (low dynamic potential)

Redefining Urban Planning Process through Human Biometerological approach in sustainable urban development

By Rohini Chakraborty

Redefining Urban Planning Process through Human Biometerological approach in sustainable urban development

ORIGINALITY REPORT

6%
SIMILARITY INDEX

Professor
Department of Architecture
Jadavpur University
32

Debashish Das
9/4/2021

PRIMARY SOURCES

1	www.scribd.com Internet	355 words — 1%
2	www.cse.dmu.ac.uk Internet	287 words — < 1%
3	Erik Johansson, Sofia Thorsson, Rohinton Emmanuel, Eduardo Krüger. "Instruments and methods in outdoor thermal comfort studies – The need for standardization", Urban Climate, 2014 Crossref	246 words — < 1%
4	www.ilee.org.in Internet	204 words — < 1%
5	www.researchgate.net Internet	196 words — < 1%
6	thesis.binus.ac.id Internet	146 words — < 1%
7	www.urbanclimate.net Internet	121 words — < 1%
8	docplayer.net Internet	116 words — < 1%

9	mafiadoc.com	Internet	105 words — < 1%
10	link.springer.com	Internet	90 words — < 1%
11	files.eric.ed.gov	Internet	87 words — < 1%
12	Yuchun Zhang, Jianlin Liu, Zhimin Zheng, Zhaosong Fang, Xuelin Zhang, Yafeng Gao, Yongxin Xie. "Analysis of thermal comfort during movement in a semi-open transition space", Energy and Buildings, 2020	Crossref	84 words — < 1%
13	report.ipcc.ch	Internet	84 words — < 1%
14	Katerina Pantavou, Spyridon Lykoudis, Basil Psiloglou. "Air quality perception of pedestrians in an urban outdoor Mediterranean environment: A field survey approach", Science of The Total Environment, 2017	Crossref	70 words — < 1%
15	orca.cf.ac.uk	Internet	67 words — < 1%
16	engineering.purdue.edu	Internet	60 words — < 1%
17	cyberleninka.org	Internet	56 words — < 1%
18	epdf.pub	Internet	49 words — < 1%

19	Nadine Walikewitz, Britta Jänicke, Marcel Langner, Fred Meier, Wilfried Endlicher. "The difference between the mean radiant temperature and the air temperature within indoor environments: A case study during summer conditions", Building and Environment, 2015 Crossref	48 words — < 1%
20	freidok.uni-freiburg.de Internet	48 words — < 1%
21	1lib.education Internet	46 words — < 1%
22	repository.londonmet.ac.uk Internet	44 words — < 1%
23	repository.uinjkt.ac.id Internet	37 words — < 1%
24	Andreou, E.. "Thermal comfort in outdoor spaces and urban canyon microclimate", Renewable Energy, 2013. Crossref	35 words — < 1%
25	Chao Ren. "Urban climatic map studies: a review", International Journal of Climatology, 12/2011 Crossref	35 words — < 1%
26	www2.fau.usp.br Internet	33 words — < 1%
27	Balslev, Yaron Jørgen, Oded Potchter, and Andreas Matzarakis. "Climatic and thermal comfort analysis of the Tel-Aviv Geddes Plan: A historical perspective", Building and Environment, 2015. Crossref	32 words — < 1%

28 dx.doi.org
Internet
31 words — < 1%

29 doczz.net
Internet
30 words — < 1%

30 Hyunjung Lee, Helmut Mayer. "Validation of the mean radiant temperature simulated by the RayMan software in urban environments", International Journal of Biometeorology, 2016
Crossref
29 words — < 1%

31 www.tandfonline.com
Internet
29 words — < 1%

32 repository.radenfatah.ac.id
Internet
28 words — < 1%

33 "Fuzzy Computing in Data Science", Wiley, 2022
Crossref
26 words — < 1%

34 Sining Peng, Minjung Maing. "Influential factors of age-friendly neighborhood open space under high-density high-rise housing context in hot weather: A case study of public housing in Hong Kong", Cities, 2021
Crossref
26 words — < 1%

35 Darya Gachkar, Seyed Hassan Taghvaei, Saeid Norouzian-Maleki. "Outdoor thermal comfort enhancement using various vegetation species and materials (case study: Delgosha Garden, Iran)", Sustainable Cities and Society, 2021
Crossref
23 words — < 1%

36 K.R. Colter, A.C. Middel, C.A. Martin. "Effects of natural and artificial shade on human thermal
23 words — < 1%

comfort in residential neighborhood parks of Phoenix, Arizona, USA", Urban Forestry & Urban Greening, 2019
Crossref

37	Teri Knight, Sian Price, Diana Bowler, Sian King. "How effective is 'greening' of urban areas in reducing human exposure to ground-level ozone concentrations, UV exposure and the 'urban heat island effect'? A protocol to update a systematic review", Environmental Evidence, 2016 Crossref	23 words — < 1%
38	daneshyari.com Internet	23 words — < 1%
39	repository.up.ac.za Internet	23 words — < 1%
40	www.tech.dmu.ac.uk Internet	22 words — < 1%
41	Lin, T.P.. "Thermal perception, adaptation and attendance in a public square in hot and humid regions", Building and Environment, 200910 Crossref	21 words — < 1%
42	mdpi-res.com Internet	21 words — < 1%
43	scholarbank.nus.edu.sg Internet	21 words — < 1%
44	pubmed.ncbi.nlm.nih.gov Internet	20 words — < 1%
45	repositorio.unesp.br Internet	20 words — < 1%

46 Thainá Faria Oliveira, José Maria Franco de Carvalho, Júlia Castro Mendes, Gabriela Zuqui Souza et al. "Precast concrete sandwich panels (PCSP): An analytical review and evaluation of CO2 equivalent", Construction and Building Materials, 2022 — 19 words — < 1%
Crossref

47 Ioannis Charalampopoulos, Ioannis Tsiros, Aikaterini Chronopoulou-Sereli, Andreas Matzarakis. "Analysis of thermal bioclimate in various urban configurations in Athens, Greece", Urban Ecosystems, 2012 — 18 words — < 1%
Crossref

48 Matzarakis, Gulyás, Ali-Toudert, Höppe et al. "Assessing the accuracy of globe thermometer method in predicting outdoor mean radiant temperature under Malaysia tropical microclimate", 'EDP Sciences', 2017 — 18 words — < 1%
Internet

49 researchonline.gcu.ac.uk — 18 words — < 1%
Internet

50 www.scielo.br — 18 words — < 1%
Internet

51 Katabarwa Murenzi Gilbert, Yishao Shi. "Slums Evolution and Sustainable Urban Growth: A Comparative Study of Makoko and Badia-East Areas in Lagos City", Sustainability, 2023 — 17 words — < 1%
Crossref

52 Peng Yin, Ying Ji, Jingchao Xie, Jiaping Liu, Qixian Hou, Shanshan Zhao. "Research on residential thermal environment differences in relation to transition and heating periods in Beijing", Building and Environment, 2021 — 17 words — < 1%
Crossref

53	Sin Yi Chan, Chi Kwan Chau. "On the study of the effects of microclimate and park and surrounding building configuration on thermal comfort in urban parks", Sustainable Cities and Society, 2021 Crossref	16 words — < 1%
54	dl.lib.uom.lk Internet	16 words — < 1%
55	www.icis.unimaas.nl Internet	16 words — < 1%
56	Mukherjee, Subham. "An Integrated Socio-Eco-Hydrological Framework to Assess and Evaluate Urban Water Security", Freie Universitaet Berlin (Germany), 2021 ProQuest	15 words — < 1%
57	en.wikipedia.org Internet	15 words — < 1%
58	Giorgia Chinazzo, Jan Wienold, Marilyne Andersen. "Daylight affects human thermal perception", Scientific Reports, 2019 Crossref	14 words — < 1%
59	Lingjun Zhao, Xiaoqing Zhou, Li Li, Shiquan He, Raochao Chen. "Study on outdoor thermal comfort on a campus in a subtropical urban area in summer", Sustainable Cities and Society, 2016 Crossref	14 words — < 1%
60	Sofia Thorsson. "Different methods for estimating the mean radiant temperature in an outdoor urban setting", International Journal of Climatology, 11/30/2007 Crossref	14 words — < 1%

61	cors.archive.org Internet	14 words — < 1%
62	dl.icdst.org Internet	14 words — < 1%
63	edoc.pub Internet	14 words — < 1%

EXCLUDE QUOTES	OFF	EXCLUDE SOURCES	< 14 WORDS
EXCLUDE BIBLIOGRAPHY	ON	EXCLUDE MATCHES	< 14 WORDS