Framework for Urban Cooling Plan for Rajkot City, India



Supported by United Nations Environment

Prepared by ICLEI South Asia



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• List of Abbreviations

SE4ALL	Sustainable Energy For ALL
AAQMS	Ambient Air Quality Monitoring System
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AQI	Air Quality Index
BEA	Building Energy Efficiency
BEEP	Building Energy Efficiency Programme
BRTS	Bus Rapid Transit System
CREDAI	Confederation of Real Estate Developers' Association of India
DGPS	Differential Global Positioning System
ECBC	Energy Conservation Building Code
EIA	Environmental Impact Assessment
EWS	Economic Weaker Section
FAME II	Faster Adoption And Manufacturing Of Electric Vehicles In India Phase II
FSI	Floor Space Index
GCF	Green Climate Fund
GDCR	General Development Control Regulation
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIDC	Gujarat Industrial Development Corporation
GHG	Green House Gases
GJ	Giga Joules
GPCB	Gujarat Pollution Control Board
GRIHA	Green Rating for Integrated Habitat Assessment
GSRTC	Gujarat State Road Transport Corporation
IIA	Indian Institute of Architects
IGBC	Indian Green Building Council
LIG	Low Income Group

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NBC	National Building Code
NDVI	Normalized Difference Vegetation Index
NMGI	National Mission on Green India
NRSC	National Remote Sensing Center
PMAY	Pradhan Mantri Awas Yojana
RCC	Reinforced Cement Concrete
RCM	Regional Climate Model
RGB	Red Green Blue
RMC	Rajkot Municipal Corporation
RMTS	Rajkot Municipal Transport System
RRL	Rajkot Rajpath Limited
RSCDL	Rajkot Smart City Development Limited
RUDA	Rajkot Urban Development Authority
SAUNI	Saurashtra Narmada Avtaran Irrigation
SJMMSVY	Swarnim Jayanti Mukhya Mantri Shaheri Vikas Yojana
SPV	Special Purpose Vehicle
SBM	Swachh Bharat Mission
tCO2e	Tonnes (t) of Carbon Dioxide (CO2) Equivalent (e)
TOZ	Transit Oriented Zones
ТР	Town Planning
UHI	Urban Heat Island
ULB	Urban Local Body
UNEP	United Nations Environment Programme
UPVC	Un-Plasticized Polyvinyl Chloride
URDPFI	Urban And Regional Development Plans Formulation And Implementation

1 Introduction

The project focuses on supporting Rajkot city to identify and implement interventions to check the urban heat island effect under the framework of an Urban Cooling Plan. The project is supported by United Nations Environment Programme (UNEP) and implemented by ICLEI - Local Governments for Sustainability, South Asia (ICLEI SA) in close collaboration with the Rajkot Municipal Corporation. The project aims at carrying out technical assessments to study and analyze causes and factors leading to Urban Heat Island (UHI) in the city, followed by strategizing feasible interventions to create thermally comfortable environment for its citizens. This first of its kind study for Rajkot city provides a framework for a more comprehensive Urban Cooling Plan for Rajkot.

Surface urban heat profile and atmospheric urban heat profile were prepared at the city level for Rajkot based on satellite imagery and information from local network of environmental sensors. Surface and atmospheric heat islands were then correlated with Normalized Difference Vegetation Index (NDVI) and Air Quality Index Analysis (AQI) to identify probable reasons for increased UHI. Heat index was also developed based on correlation between air temperature and humidity to establish and understand levels of thermal comfort in the city based on ward level 'feel-like' temperature¹. Urban hotspots² and cool spots³ areas were identified and analysis undertaken to draw correlations between surface heat and urban features existing in and around such areas.

Based on the hotspot and cool spot areas identified, four locations or neighborhoods were selected for further thermal analysis through drone. This thermal analysis at the neighborhood scale helped to address and understand micro level information related to land use, built up form, surface area type, various material used and emissivity of various material, blue and green infrastructure and various anthropogenic activities.

This scientific approach was supplemented with stakeholder consultations to identify city-level recommendations and solutions for urban cooling that are locally suitable and well-aligned with existing plans, guidelines and available standards for urban cooling (building, neighborhood, urban design, surfaces and nature-based solutions). The project has drawn on the guidance provided in the **Beating the Heat: A Sustainable Cooling Handbook for Cities**, published by the United Nations Environment Programme in partnership with the Rocky Mountain Institute, across various steps and in the identification of sustainable urban cooling strategies and solutions in Rajkot's context.

¹ Feel-like temperature (also known as apparent temperature) is used to represent thermal comfort levels, and reflects how the temperature feels like to the human body when the effect of ambient relative humidity is combined with the air temperature (Source: Website of National Weather Service, USA. Accessed October 2021)

² Surfaces having high temperature as compared with surrounding areas. Areas having surface temperature more than median of temperature for particular season and duration are considered as hot spots.

³ Surfaces having lower temperature as compared with surrounding areas. Areas having surface temperature lower than median of temperature for particular season and duration are considered as cool spots.

1.1 Background

With rising population and rapid urbanization driving demand for infrastructure and built spaces, cities are now covered with high terrestrial radiation emitting, impermeable surfaces, most of which are not shaded. Surfaces in urban areas absorb heat (incoming short-wave solar radiation), increasing the temperature of the material and surroundings. Heat islands are an area specific phenomenon, where the temperature of one area is higher than that of the surrounding areas. Roads, pavement, buildings, natural cover (water bodies and vegetation) and open ground absorbs heat during the day time and releases the heat to the atmosphere during the evening and night time. However, this released heat is restricted from escaping into the higher atmosphere, resulting into the formation of heat islands (US Environment Protection Agency, 2021). The negative impact of the increase in temperature is very significant and affects almost all aspects of the environment and human health. Both climate change and urbanization have led to an increase in the surface temperature of cities, which has led to the formation of urban heat islands (UHI). Due to the heat island effect, cities are getting hotter every day, so it is necessary that cities analyze local sources and causes of heat generation, their associated impacts, and design and implement focused solutions to reduce urban temperatures and promote sustainable cooling.

One of the objectives of this study is to identify UHI hotspots (intra urban heat islands) in Rajkot, which have characteristically higher temperatures than the surrounding urban space. UHIs are characterized as surface UHI and atmospheric heat islands. UHIs depend on variety of factors, including but not limited to the location and size of the city, density, land use and built environment, time (day and night), season (winter, summer and monsoon), wind speed and direction, building practices (material used), and proximity to water bodies and green cover. The magnitude of UHI effect varies with seasons, time of day (due to changes in solar radiation intensity), as well as vegetation cover and prevalent weather conditions. While surface heat islands exist at ground/surface level, atmospheric heat islands. Canopy layer UHIs are observed in the layers of air contiguous with dwelling spaces (from the ground up to the tops of trees and roofs), while the boundary layer UHIs extend from the rooftops and treetops up to the point where urban landscapes no longer influence the atmosphere (typically extending no more than 1.5 km from the surface). Globally several studies have proven that the direct or indirect impacts of UHIs are very significant.

1.2 Project Rationale

Several variables influence how urban areas experience and accumulate excess heat. These include existing land cover, distribution of urban surfaces, green spaces, water bodies, building density, construction practices and commonly used building materials, among others. Rajkot's urban development trend and causes of urban heating show that the city is witnessing rapid development with rising population density and growing number of built spaces. Energy demand in buildings is growing owing to higher penetration of air conditioning and need for thermal comfort. It is observed that given traffic population and congestion, major transport nodes that connect key commercial and residential areas have higher ambient temperatures and air pollution levels as compared to other areas. Urban planning practices and development patterns, for both existing and new development areas, do not adequately address urban heat, at the building-level as well as the neighborhood scale.

Thereby, there is an urgent need for Rajkot to plan for adoption of broad-based UHI mitigation strategies and measures along with a shift to more sustainable cooling practices, in terms of policy measures and solutions that can be implemented on-ground. It is necessary to keep the city's areas cooler and reduce adverse effects on human health and economic development. As multiple factors contribute to increasing ambient and surface temperatures at various scales in an urban setting, Rajkot city's strategies should be multi sectorial, addressing effects of the UHI and neutralizing the impact of the current and future cooling requirements to enable access to cooling for all.

2 Methodology

The step wise methodology followed is shown in Figure 1, which includes;

- 1) Review of National/ State/ Local context on urban heat and cooling and setting the baseline
- 2) Preparation of city level surface temperature and atmospheric temperature profile to identify hotspot and coolspot areas
- 3) Micro level thermal analysis for four prioritized areas through drone survey at neighbourhood scale for typical urban features and material emissivity
- 4) Identification of interventions and recommendations for urban cooling aligned with existing plans, guidelines and available standards



Figure 1 Methodological Approach

The following section summarizes the methodological approach under each step with limitations of the study highlighted subsequently under this section 2.1

Step 1: National/ State/ Local context on urban heat and cooling (set the baseline)

As a first step of this study; a baseline assessment addressing the city's profile, local context and state of play on urban heat and cooling was undertaken. The baseline assessment involved a review of various laws, policies, standards and guidelines across different governance levels to identify existing policy and regulatory landscape for urban heat and cooling. While the policies reviewed were seen to mainly focus on sustainable planning and environmental protection, their clauses or sections that provided opportunities to mitigate the effects of rising urban temperatures and urban cooling initiatives were highlighted as part of the review. Stakeholders were mapped and consulted with to understand local drivers for urban heat island and barriers for sustainable urban cooling. Potential roles of the stakeholders in the development and deployment of urban cooling actions in Rajkot were also identified.

Activity 1: Review of various laws, policies, standards and guidelines across different governance levels

Various national and subnational frameworks directly or indirectly addressing UHIs and urban cooling initiatives have been reviewed in terms of objectives, targets, actions suggested, gap analysis, and recommendations (See section 3.4). Some of these frameworks include; National Environment Policy 2006; Urban and Regional Development Plan Formulation and Implementation (URDPFI), 2014; National Mission on Green India (NMGI), 2014; National Mission on Sustainable Habitat, 2014; Atal Mission for Rejuvenation and Urban Transformation (AMRUT), 2015; Smart Cities Mission, 2015; Energy Conservation Building Code (ECBC), 2017; Eco-Niwas Samhita 2018; National Cooling Action Plan, 2019; Green Rating for Integrated Habitat Assessment (GRIHA); Leadership in Energy and Environmental Design (LEED) developed by Indian Green Building Council (IGBC); General Development Control Regulations (GDCR) of Gujarat, 2017; and Gujarat State Action Plan on Climate Change, 2014 etc. Review of these frameworks helped to know various sustainable planning and environmental protection related clauses or sections, which may also provide the opportunities to mitigate the effects of rising urban temperatures and urban cooling initiatives in the city.

Activity 2: Review of city level sustainability initiatives

City level plans and initiatives supporting or addressing the mitigation of urban heat island effects have been reviewed, some of which includes Development Plan 2021 and related General Development Control Regulations (GDCR), Climate Resilient City Action Plan 2019, Draft Green Building Guidelines 'Prakruti', Green Field Development Plan under Smart Cities Mission, tree density analysis 2019, Prefeasibility for District Cooling 2017 etc., (See section 3.3). Various cause of UHIs in the city and opportunities to mitigate the effects of rising urban temperatures and promote urban cooling were highlighted as part of the review and preparation of baseline. Month-wise average daily relative humidity and temperature variation with respect to annual average temperature for Rajkot city from 1982 to 2006 has been analyzed to identify seasonal variations. Based on this analysis, a suitable month that appropriately represents the particular season has been selected in subsequent steps to correlate seasonal variation in temperature and humidity.

Activity 3: Stakeholder mapping and consultations

Key stakeholders from various institutions influencing the development and deployment of urban cooling actions in Rajkot were identified along with their role and responsibilities, which includes planning authority, real estate developers, confederation of real estate developers' association of India (CREDAI), The Indian Institute of Architects (IIA), DISCOM, Gujarat Pollution Control Board (GPCB), Gujarat Industrial Development Corporation (GIDC) etc., (See Section 3.2). Stakeholders have been consulted at various steps of the project to discuss urban cooling related challenges and opportunities in Rajkot. Stakeholder insights, inputs and recommendations have been appropriately reflected in the subsequent sections of this document outlining barriers and solutions for urban cooling. Potential roles of the stakeholders in the development and deployment of urban cooling actions in Rajkot were also identified.

Step 2: Surface Temperature and Atmospheric Temperature Profile (Pan City Level)

This step supported preparation of surface and atmospheric heat profile of the city and to undertake its correlation with NDVI analysis, Air Quality Index (AQI), and feel-like temperature (heat index). The heat profile and analysis helped to identify and prioritize hotspot areas for neighborhood scale (micro level) thermal analysis. Detailed approached used to prepare surface urban heat profile, atmospheric urban heat profile, identification of priority areas or hotspots or cool spots based on correlation with NDVI, heat index and AQI is shown in the Figure 2 below. Surface and atmospheric heat islands are identified at pan city level, while four hotspots were prioritized for micro level thermal assessment at neighborhood scale through drone.



Figure 2 Overview of urban heat profiling and mapping at the city and neighbourhood scale

Activity 1: Surface Urban Heat Profile

- Satellite thermal imagery of 30m x 30m resolution from Landsat 8 has been used to analyze variation in land surface temperature during the day time (at 17.30 hours) for three seasons (Winter month of January, Summer month of May and Monsoon month of September) and across three years (2010, 2015 and 2020)
- As thermal imagery for night time was not available in Landsat 8, satellite thermal imagery of 500m x 500m resolution from MODIS has been used to analyze the variation in surface temperature during the night time (at 23 hours) for three seasons (Winter January, Summer May and Monsoon September) and three years (2010, 2015 and 2020)
- Availability of thermal imagery from same satellite has been ensured. Also, ratification of errors, cloud cover corrections, and verification on ground have been undertaken to address anomalies and help derive better results.
- Based on past trends, Rajkot is observed to witness the highest atmospheric temperature during the summer month of May. Thereby, surface temperature for May 2020 has been analyzed to identify hotspots and cool spots (See Section 4.1). Analysis under this step has supported to identify prioritized locations in the city for neighborhood scale thermal assessment through drone in subsequent steps.

Activity 2: Atmospheric Urban Heat Profile

- While surface heat islands exist at ground/surface level, atmospheric heat islands are further divided into two layers 1) canopy layer heat islands⁴ and 2) boundary layer heat islands^{5.} Analysis of canopy layer urban heat islands has been considered for developing atmospheric urban heat profile.
- Air temperature related information from 18 environmental sensors⁶ installed by Rajkot Municipal Corporation (RMC) have been analyzed for year 2020 for 3 seasons (winter January, summer May, and monsoon September) for day time and night time.
- Considering hot and dry summer in Rajkot, atmospheric temperature for summer (May 2020) has been used to explore hot spot areas and urban features associated with this temperature (See Section 4.2).

Activity 3: Normalized Difference Vegetation Index (NDVI) analysis

- Satellite thermal imagery of 30m x 30m resolution from Landsat 8 has been used to analyze variation in NDVI for three seasons (Winter January, Summer May and Monsoon September) and for three years (2010, 2015 and 2020).
- Analysis of land surface temperature and atmospheric air temperature have been then correlated with NDVI to analyze the surface and atmospheric temperature differences with respect to vegetation cover.

Activity 4: Air Quality Index (AQI) mapping and wind direction

⁴ Canopy layer urban heat islands are observed in the layers of air contiguous with dwelling spaces (from the ground up to the tops of trees and roofs) (observed between 2m to 15m)

⁵ Boundary layer urban heat islands extend from the rooftops and treetops up to the point where urban landscapes no longer influence the atmosphere (typically extend no more than 1.5 km from the surface)

⁶ These environmental sensors are installed at around 10 meter height

- AQI related information from 18 local environmental sensors, installed by RMC, has been analyzed for year 2020 for 3 seasons (winter January, summer May, and monsoon September).
- Air Quality Index analysis along with wind direction has been then utilized to identify atmospheric air temperature hotspots.

Activity 5: Feel–Like temperature and cooling demand estimates

- Air temperature analysis carried out for May 2020 under Activity 2 of step 2 has been correlated with humidity values for the same month to derive feel-like temperature (apparent temperature) and heat index as per 'National Guidelines for Preparation of Action Plan Prevention and Management of Heat Wave', prepared by NDMA (See Section 4.2.3).
- To better understand implications of urban heat on Rajkot's space cooling demand and draw • correlations, electricity consumption data has also been analyzed at the city-level. Local data frameworks and practices do not record disaggregated information on cooling consumption for buildings. Thereby cooling estimates have been further determined for residential and commercial buildings based on available information on electricity consumption, which includes end-uses such as lighting and pumping along with cooling. To scale-down city-wide aggregated electricity consumption to the ward-level, proxy data on number of properties existing in a particular ward has been collected from the property tax department of Rajkot Municipal Corporation. Ward-wise electricity consumption has been estimated based on the corresponding number of residential and commercial properties in the ward and using the approximated average values of electricity consumption for every residential and commercial unit. Information available with the city's Property Tax department was limited to number of properties, with details on floor space, height, and density to better inform the cooling estimates not available. Electricity consumption for space cooling in residential and commercial buildings has subsequently been estimated using secondary information on proportion of space cooling load in their total electricity consumption. (See Section 4.3)

Step 3: Thermal analysis for prioritized areas through drone survey (Neighborhood Scale)

Activity 1: Identification of prioritized areas for thermal analysis through drone

- Surface temperature analysis (May 2020), atmospheric temperature analysis (May 2020), NDVI analysis (May 2020), land use analysis, air quality index (May 2020), heat index (feel like temperature for May 2020) have been correlated to identify prioritized locations for micro-scale thermal analysis through drone. The analysis covered micro level information related to land use, built up form, surface area type, various material used and emissivity of various materials, blue and green infrastructure, and prevalent anthropogenic activities.
- Based on the analysis of hot spots and cool spots for May 2020, four potential locations were selected based on diversity of land use (i.e., including residential, commercial, industrial, and green field development, slums, traffic junction, water bodies, barren land, and green cover), diversity in material used in various built spaces, and varied range of surface area temperatures for the same duration and season. (See Section 5)

- Some of the potential areas initially identified were not considered for thermal survey through drone, considering their close proximity to locations with prohibitions on flying drones such as Airport, Research and Analysis Wing (RAW) office, and Indian Oil Corporation (IOC) depot etc.
- The drone mapping undertaken for identified locations was limited to two-dimensional mapping, which could-map the surface temperature of roofs only and not the walls, given the resource constraints.

Activity 2: Thermal analysis of four prioritized locations through drone

- Quad copter drone mounted with Red, Green, Blue (RGB) and thermal camera has been used for conducting the thermal assessment of four prioritized locations. Prior to deployment of the drone at each selected site, specific flight missions were planned using flight planner.
- Each drone mission consisted of defining of flight path at an altitude of 80 meters. The flight missions defined were set to capture images to ensure that each consecutive images overlap 75% from each side to provide the image resolution of 2cm Ground Sampling Distance (GSD).
- Post the flight mission plan for each site, Ground Control Points (GCP) have been marked on the site by using white paint. Positional readings using Differential Global Positioning System (DGPS) instrument were taken to ensure the positional accuracy of the survey.
- The pre-planned flight missions of the drone survey were then executed on the sites using automated flight controller to capture required data. Two separate missions were executed for each site, one for RGB camera and one for Thermal camera. More than 2000 images were captured for each location depending on the area of the sites.
- Initial processing for alignment of the images captured during the flight missions and calibration were also ensured. Thermal profile, urban features of the area, use of different materials and corresponding surface temperature were then analyzed to draw inferences and provide recommendations. (See Section 5)

Step 4: Suggestions and Recommendations

Based on baseline assessment, thermal profiling and analysis of urban heat island at city scale, microlevel neighbourhood scale assessment involving analysis of surface temperatures, prevalent urban features and material analysis, and stakeholder consultations, various recommendations have been identified. The locally appropriate interventions and recommendations have been identified across the short, medium and long term, including roles and responsibility of various stakeholders involved. Some of these technical recommendations address various aspects related to building design, use and operation; urban design; surfaces and material; and nature (blue and green infrastructure). The proposed interventions have been given at pan city scale as well as local area scale. Various suggestions and recommendations have further been translated into site specific pilot interventions which the city can prioritise to start implementation of urban cooling strategies. Further, actions to guide city level scalability of these interventions have also been suggested (See section 6).

2.1 Limitations of the study

The limitations of the study given the time, information availability and resource constraints are captured below. Alternate approaches adopted to mitigate constraints for certain activities are noted.

- As procurement of high resolution imagery from National Remote Sensing Center (NRSC) was time and cost intensive, satellite imagery available freely on public domain has been used across three years i.e., 2010, 2015, 2020 to prepare surface urban heat profile and evaluate temporal change (day time and night time) and three seasons⁷ for each year (Winter – January, Summer – May, and Monsoon – September).
- 2. All images of Rajkot city between January 2010 and December 2020 were inspected from Landsat 8. Cloud and smoke free images across the city area were considered for further analysis. As satellite image for August month had cloud issues, September was considered as monsoon month for further analysis.
- 3. Though analysis of surface UHIs was envisaged for day time between 13.00 hour to 16.00 hour and night time between 23.00 hour to 01.00-hour, satellite imageries of 30X30m resolution from Landsat 8 (day time at 5.30pm) has been used for land surface temperature and Normalized Difference Vegetation Index (NDVI) analysis, considering orbit cycle of Landsat 8 for Rajkot. As satellite thermal imagery of 30X30m resolution from Landsat 8 for night time was not available, satellite image of 500X500m resolution from MODIS (night time at 23.00 hour) has been used for land surface temperature during the night time.
- 4. Though temporal analysis has been done to identify the change in land surface temperature periodically for three years (2010, 2015 and 2020), detailed analysis of May 2020 (summer month) is considered as a baseline to identify hot spots and cool spots in the city.
- 5. Drone mounted with RGB and thermal sensor could provide flexibility on timings to analyze land surface temperature at a city level, but it is cost intensive and time-consuming exercise. Considering time and resource constrain, thermal analysis through drone for land surface temperature, urban features and material emissivity etc. was proposed for four locations (limited to 4 sq. km of total area) for one season (monsoon), based on drone flying permission granted from police department. Few potential areas were not considered for thermal survey through drone considering its close proximity to 'drone flying prohibited areas' like; Airport, Research and Analysis Wing (RAW) office and IOC depot etc., which was the limitation for drone mapping. In the concurrent study, drone mapping has been carried out for specific areas only based on permission granted.
- 6. As temperature and humidity related data from 18 environment sensors is available only for the year 2020, analysis for atmospheric urban heat island (canopy layer heat islands) has been undertaken for year 2020. Boundary layer urban heat islands at city level have not been analyzed due to time and resource constrain.
- 7. Detailed watershed and green cover analysis to examine the status of blue and green infrastructure for regulation of microclimatic conditions in the city has not covered in the methodology.
- 8. Given the absence of information on electricity use for space cooling, electricity consumption figures for year 2020 have been estimated based on secondary studies and appropriate assumptions. Information on space cooling demand as well as for electricity consumption, specifically for cooling, is not available, both at the ward-level and city-wide. Such disaggregated information is not metered and thereby not recorded in electricity consumption figures available. Electricity consumption for

⁷ Best suitable month representing each season, based on past trends, was selected for seasonal variation analysis.

space cooling in residential and commercial buildings has subsequently been estimated using secondary information on proportion of space cooling load in their total electricity consumption

3 Rajkot City Baseline Assessment

3.1 City Overview

Rajkot is the fourth largest city in the state of Gujarat, housing a population of nearly 1.7 million as of year 2020 as compared with 1.3 million in year 2011. Rajkot is ranked 22nd in the list of fastest growing cities and urban areas from 2006 to 2020 around the globe. The area of Rajkot city expanded to 161.86 sq.km in year 2020 from its previous area of 129.21 sq.km and the city's population has increased to 1.79 million in year 2020 from 1.28 million in year 2011. To support the needs of the growing population and city area, infrastructure is being built at an increasing rate in the city. The on-going growth trajectory of the city will alter or re-define its land cover, distribution of urban surfaces, water bodies, building density, construction practices, commonly used building materials and green spaces; which in turn would influence how urban areas will experience and retain heat.

3.1.1 Location

Rajkot is in the Western part of India at a distance of 245 km from the state capital Gandhinagar, at the center of the peninsular Saurashtra region in Gujarat state. The city is situated at a height of 138 meters above mean sea level and is located on the banks of the Aji River and Nyari River. Rajkot lies at coordinates of 22° 18' 29.3580'' N and 70° 48' 2.5380'' E. The city is well connected to major Indian cities by rail, air and road.

3.1.2 Demography

Rajkot is the biggest city in terms of population in the Saurashtra-Kutch region, thriving with commercial and industrial activity, spurred by Gujarat's economic and industrial policy. Rajkot experiences heavy inmigration from surrounding districts due to numerous opportunities in the city for business and employment. In-migration has been observed not only from surrounding districts of Saurashtra, but also from various states of the country. As per the details received from Rajkot Municipal Corporation (RMC), the present area of the city is 161.86 sq.km, which has increased from 129.21 sq. km in 2015 and from 104.86 sq. km in 2011.

Area of the city (2020)	161.86 Sq.km
Zones in the city	3 (East, Central & West)
Wards in the city	18 (East – 6, Central – 6 & West – 6)
Population (2020) ⁸	1,797,530 (Based on data submitted for CSCAF 2.0 ⁹)
Population (2011)	1,28 million (Office of the Registrar General & Census Commissioner, India, 2021)

Table 1: Rajkot at a glance

⁸ Estimated and shared by RMC

⁹ CSCAF (Climate Smart Cities Assessment Framework) 2.0 is a city assessment framework on climate relevant parameters for Indian cities, launched in February 2019 by the Ministry of Housing and Urban Affairs (MoHUA).



Population Density (2020)	11,105 persons per sq.km
Total Household (2020)	384,138
Household size (2020)	4.68

3.1.3 Economy

Gujarat had the 4th largest contribution in the national GDP among India states in 2019. (Statistics Times, 2021). Being an industrial town, housing heavy and small-scale industries, Rajkot is one of the prominent contributors to the state GDP. The major industries in Rajkot are foundry, metal-based, and machine tools. There are many small-scale industries within and around the city. Due to its strategic location, Rajkot is also a major trade center in the Saurashtra region for agriculture products. Industries are located in 3 different directions of the city, namely, Shapar – Veraval in South, Khirasara – Metoda in west and Kuwadva – Gunda in north-east direction.

3.1.4 Climate

Rajkot falls under India's hot and dry climatic zone. Rajkot has a semi-arid climate, with hot and dry summers. Rajkot experiences three distinct seasons of summer, monsoon, and winter.

- The average summer temperature and the average winter temperature recorded over the last 40 years are 43.5°C and 24.2°C respectively.
- The summer season extends from the months of mid-March to mid-June, with temperatures ranging from 24°C to 42°C. It is observed that the temperature in the city rises from mid-February and peaks in mid-May. The average daily temperature from March to October is observed higher than the average annual temperature.
- In the winter, from the month of November to February, the temperature varies from 10°C to 22°C, resulting in pleasant winters.



Figure 3 Month wise average daily temperature variation with respect to annual average temperature for Rajkot city (1982-2006) (Source: District Energy in Cities Initiative, 2017)

- The average annual rainfall is 500 mm. However, the city has received lower than normal rainfall in 20 of the last 60 years.
- The city's annual average relative humidity stands at 60%. Relative humidity increases from mid-May in summer to August in monsoon, peaking in July. Average daily humidity is higher during the months of June to September.



Figure 4 Month wise average daily relative humidity variation with respect to annual average relative humidity for Rajkot city (Source: District Energy in Cities Initiative, 2017)

3.1.5 Land Use

While detailed land use information for the present situation is not available, Rajkot's draft Development Plan 2031 (Rajkot Urban Development Authority, 2021) provides information on proposed land-use in 2031 vis-à-vis the city's land use in 2011. The draft Development Plan 2031 has been prepared considering the demand of the projected population for the larger metropolitan region spanning 686 sq. km. under the jurisdiction of the Rajkot Urban Development Authority (RUDA), which includes Rajkot city. The proposed land use of the RMC and RUDA area is shown in below table 2.

Table 2: Existing and p	proposed Land	Use for Raikot	City from Draft	Comprehensive	Development Plan - 2031
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	2001		2011		2031	
Land Use for Rajkot City area	Area in hectare	Share of categor y (%)	Area in hectare	Share of category (%)	Area in hectare	Share of category (%)
Residential	4,247	40.05	5,502	52.4	6,228.2	59.4
Commercial	209	2	279	2.6	221.7	2.1

	2001		2011		2031	
Land Use for Rajkot City area	Area in hectare	Share of categor y (%)	Area in hectare	Share of category (%)	Area in hectare	Share of category (%)
Industrial	628	5.9	738	7.1	635.2	6.1
Traffic/ Transportation	1,400	13.3	1,650	15.7	Not Availabl e	Not Available
Public and semi public	149	1.4	249	2.3	305.3	2.9
Recreational Space	123	1.2	523	4.9	517.1	4.9
Agriculture	995	9.5	800	7.6	69.3	0.7
Water Bodies	236	2.3	236	2.3	236	2.3
Vacant Land	1.510	14.4	-	-	-	-
Other	988	9.4	508	4.8	2307.5	22.01

It can be observed that land use for residential, commercial, industrial, transportation and recreational spaces has increased from 2001 and 2011. Land use for residential, commercial, industrial and transportation is expected to have increased since 2011 and this trend is expected to continue in the future also.



The city's development is seen to have expanded in all directions along the major transit corridors (highways), with most of the residential and commercial development occurring in its western part. The upcoming project of AIIMS, outside the city limit in the northern side, has buffeted growth in the northern part. Further residential development is also expected to occur in the south due to industrial development in surrounding areas. The presence of natural geographical barriers such as the Aji River and water bodies has restricted the growth of the city on the eastern side and in some portions on the northern side.

A noticeable difference also exists in the form of typology of development on the eastern and northwestern side of Rajkot. The eastern and central part of the city is characterized by low-rise apartments, informal housing, and small-scale retail and commercial shops. North-west part of the city is characterized by a mix of large-scale retail and commercial development that typically includes shopping malls, complexes with cinema theatres, office complexes, educational institutes and business parks along with premium high-rise residential apartments.

The city's bus rapid transit system (BRTS) corridor has been developed in western zone area. In close proximity to the BRTS, Transit Oriented Zones (TOZ) covering an area of about 34.5 sq. km has been proposed around the transit corridor along the outer ring road in the city. The maximum permissible floor space index (FSI) in the TOZ shall be 3.75, with a base FSI of 1.8 and the remaining FSI can be availed by paying a charge by the developer. The western part of the city has mixed development and better planning in comparison to the central and north part of the city. As a result, real estate value has

appreciated significantly in areas located in Rajkot's western part and will continue to do so in the coming years as well.

The city is also undertaking green field development in its identified Smart City area - the Raiya area, situated in ward no. 1 and in conjunction with the growth direction (west) of the city. Rajkot has selected this pilot green field zone, spanning 2 sq. km, to create a sustainable development model through effective land use planning. This location is in close proximity to Rajkot's BRTS corridor as well. The Raiya Smart City area will also have roads with higher width and adopt TOZ principles, thereby promoting high density development. Rajkot's Smart cities proposal intends to have 9% of commercial buildings, 27% of residential buildings and 14% of mixed-use buildings in the Raiya area, all of which will be eligible for higher FSI and thereby lead to higher population density.

3.1.6 Green Cover

RMC is undertaking efforts to increase its green cover through plantation of trees at locations including along the sides of its city roads, on open public lands and by establishing gardens. At present, the city has 3.24 sq. km of green space which represents approximately 2% of the total city area. The Urban Green Guidelines¹⁰, 2014 prepared by the Ministry of Housing and Urban Development (MoUD) (presently known as MoHUA) recommend that a minimum of 20% of a city's geographical area should be under green cover. The per capita green cover in the city stands at 1.8 sq. m, which is significantly lower than the World Health Organization (WHO) recommended standard of a minimum of 9 sq. m. of urban green space for each person, and URDPFI Guidelines, 2014 recommended per capita open space¹¹ of at least 10 sq. m.

Detailed tree cover maps at the city-scale were developed for Rajkot as shown in figure 6 under the



Figure Tree density map of Rajkot

CapaCITIES phase I project. Through this mapping activity, critical wards with less tree cover density were identified (see figure 7). The assessment helped identify and prioritize wards with less tree cover. City has initiated tree plantation program in such critical wards. Such plantations and green cover enhancement is being carried out based on the availability of open space in the wards and not necessarily at locations that appropriately contribute to dissipation of heat and pollution. City intends

¹⁰ http://mohua.gov.in/upload/uploadfiles/files/G%20G%202014(2).pdf

¹¹ The open spaces include three categories, namely, (a) recreational space, (b) organised green, and (c) other common open spaces (such as vacant lands/ open spaces including flood plains, forest cover etc).

to develop an urban forest spanning an area of 153 acres in total. To this end, work towards developing urban forest over an area of 47 acre has already commenced.



Figure Ward wise tree cover in Rajkot

3.1.7 Transportation

Based on the data received from the Road Transport Office (RTO), the total vehicles registered in the city till 2015-16 were around 1.12 million. Nearly 430,000 new vehicles were added in the city from 2016 to 2020 (a notable increment of 38% in its vehicular population in 5 years), which has contributed to traffic congestion and increased air pollution.

Rajkot's public transit system comprises of a public bus fleet of 100 buses. From this bus fleet, 10 buses are being operated on the city's 10.7 km long dedicated Bus Rapid Transit System (BRTS) route on 150 feet road, which passes through six wards in west zone of the city. The remaining 90 buses are being operated as Rajkot Mass Transport Service (RMTS), plying across 44 different routes in the city. The public bus service is being managed and operated by Rajkot Rajpath Limited (RRL), a 'Special Purpose Vehicle (SPV)' established by RMC. By the next year, RMC has planned to replace existing 100 buses with 150 E-buses under the FAME II Scheme.

3.1.8 Air Quality

Total 18 environmental sensors are installed by Rajkot Municipal Corporation (RMC) through Smart Cities Mission, which monitors air quality data including AQI, PM2.5, PM10, NO2, SO2 and CO etc. Based on analysis of the AQI data recorded from July 2019 to June 2021, annual average Air Quality Index (AQI) of the city is observed to moderate according to the Central Pollution Control Board (CPCB) standards. Concentration of NO2 and SO2 is more than permissible limits due to vehicular and industrial activities are noted to be higher.

The analysis of air quality data from July 2019 to Sept 2020 shows that the Morbi Road area has the highest number of days in a year with AQI more than 100 (34.15% of total annual days), followed by Hospital chowk (22.95% of total annual days), Devpara (22.40% of total annual days), East zone office (22.40% of total annual days), Sorathiyawadi (19.67% of total annual days), Trikon Baug (10.66% of total

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annual days), and Mahila College Chowk (9.29% of total annual days). All these areas with higher levels of air pollution are major traffic junctions and intercity nodes.

3.1.9 Energy consumption

At the city-scale, Rajkot's total energy consumption has increased at an annual average growth of 7 %, up from 15.7 million Gigajoule (GJ)¹² in year 2015-16 to 20.5 million GJ¹³ in year 2019-20.

Road transport, dependent primarily on petrol and diesel fuels, is the largest energy consumer, accounting for 41% of overall energy consumption. Residential Buildings accounts for 29% of the city's energy, followed by Manufacturing Industry and Construction (26%) and Commercial and Institutional Buildings/Facilities (4%). In the Residential Buildings, the total energy consumption is predominantly driven by the use of electricity and to a lesser extent by the fuels used for cooking.



Figure Sector-wise energy consumption in Rajkot, 2019-20

Electricity is the predominant energy type in Rajkot city and makes up 32.5% of the energy mix, being used prominently in all sectors, followed by natural gas (28.2%), LPG (14%), petrol (13%), diesel (11%), and kerosene (1.3%).



Figure Source-wise supply-side energy consumption in Rajkot, 2019-20

¹² Climate Resilient City Action Plan, Rajkot - 2018

¹³ Draft GHG Emissions Inventory for Rajkot city, 2019-2020

3.1.10 GHG emission

Rajkot's total community level GHG emission amounted to 2.61 million tCO₂e in year 2019-20. The city's GHG emission has increased at an average annual growth rate of 7 %, from 2.01 million tCO2e in year 2015-16. The per capita GHG emission in year 2019-20 was 1.45 tCO₂e in year 2019-20, which is lower than India's per capita GHG emission of 1.6 tCO2e in year 2018.

While Manufacturing Industry and Construction is third largest contributor in energy consumption, it is highest contributor to GHG emissions (37%) given that the sector consumes the highest amount of electricity. Residential Buildings are a key contributor to GHG emissions with a share of 30%, followed by Transport (21%), waste (8%) and Commercial and Institutional Buildings/Facilities (4%).



Figure 10: Sector-wise GHG emission in Rajkot, 2019-20

It is interesting to note that although electricity accounts for 32.5% of the energy mix it contributes to 65.6% of the GHG emission in Rajkot, largely due to India's GHG intensive thermal power-based generation system. This is followed by natural gas (10.5%), petrol (8%), LPG (7.8%), diesel (7.2%), and kerosene (0.8%)



Figure 11: Source-wise supply-side GHG emission based on energy source in Rajkot, 2019-20

3.2 Stakeholder Mapping

Key stakeholders from various institutions impacting or influencing the development and deployment of urban cooling actions in Rajkot were identified along with their role and responsibilities, which includes decision making authorities, developers, architects, DISCOM etc. (See Table 3). Stakeholders have been consulted at a various stage of the project to discuss the urban cooling related challenges and opportunities in Rajkot. Stakeholder insights, inputs and recommendations have been appropriately reflected in the subsequent section on barriers and solutions for urban cooling.

Institution Type	Agency	Role and Responsibility
City planning and policy relevant interventions	 Rajkot Municipal Corporation (RMC) Rajkot Urban Development Authority (RUDA) Rajkot Smart City Development Ltd. (RSCDL) 	 RMC: The RMC is main planning authority for the city of Rajkot and responsible for all the micro level planning for the urban infrastructure and related services planning. RUDA: RUDA oversees the planning and development of larger Rajkot Urban Agglomeration area (including Rajkot city) including long term planning, promotion of new growth centres, implementation of strategic projects and financing infrastructure development for the Rajkot Urban Agglomeration area. RSCDL: The key responsibility of RSCDL is to oversee the planning and execution of smart city plan for Rajkot city in selected green field area and in the pan city area. UHI is the result of the changes in the land surface by urban development along with waste heat generated by energy use. As urbanization increases, the dense population centres will also grow. Such centres tend to change greater areas of land which then undergo a corresponding increase in average temperature. Identified stakeholders can use the existing local regulatory framework for urban development and buildings such as building permits, bye-laws and development control regulations, building efficiency standards to develop complementary policies to encourage urban cooling development and adoption.
Real Estate, Property Developers and related Institutions	 Real Estate Developers Confederation of real estate developers' 	 Rajkot Builders Association and real estate companies can identify upcoming projects, which can affect the local temperature of the neighbourhood, where it's getting developed and provide information to real estate firms on

Table 3: List of stakeholders including their roles and responsibilities

	association of India (CREDAI) Rajkot	enabling policies or standards which can help them to reduce its impact on urban heat. They can also share inputs on practical issues, risks and possible enabling policies and programmes with regards urban cooling with city planning authorities to support them to plan heat mitigation strategies.
Architects, Building Design and Civil Engineering related institutions	 The Indian Institute of Architects (IIA), Saurashtra Region Architects 	 These institutions can advocate interests and learnings of architects to promote best practices in urban planning and architecture. They can enable exchange of knowledge and present a platform to share new techniques, technologies and developments in the field of civil engineering through implementation in new developing projects in the city. They can provide technical inputs on integrating cooling techniques in the prevalent building design and other practical aspects in terms of market acceptance
Electricity Distribution Company	 Paschim Gujarat Vij Company Ltd. (PGVCL) 	 The PGVCL is responsible for distribution of electricity to end-consumers. It is also responsible for planning the electrical infrastructure to strengthen the electricity distribution network, to reduce the electricity losses, its downtime and enhance the reliability of power supply. They have energy consumption as per consumer type for all the users in the city. They can share information on baseline and future energy demand, which can be direct result of the increased cooling demand due to the UHI effect.
Regional Pollution Control Board	 Gujarat Pollution Control Board (GPCB) 	 The GPCB is responsible to plan and execute programs for the prevention, control or abatement of pollution. GPCB is also responsible for issuing consents to establish and operate a business/industry which is likely to discharge pollutants/ effluents/ hazardous waste into atmosphere during the process.

		• They can support to identify potential waste heat sources in the city to implement cooling strategies
Industry related Institutions	 Aji GIDC Industries Association (AGIA) Gujarat Chamber of Commerce and Industries 	 Industrial Associations are industry bodies concerned with representing and highlighting the issues concerning the industries in Rajkot and same for Gujarat Chamber of Commerce and Industries in state of Gujarat. They can identify existing and upcoming large scale industrial developments in and around the city with high potential to increase neighbourhood temperature and later can support to plan cooling strategies to mitigate its effects. They can share information on typical cooling demand for different industry building types in the city in consideration of the local climate, building use, envelope and size, and prevalent cooling technology in use to estimate possible waste heat sources.

3.3 Rajkot's Existing Sustainable Initiatives

Rajkot has demonstrated leadership by implementing action on a range of sustainability issues, particularly piloting and advocating for clean and innovative technologies and policy level interventions to address climate change at the local level.

1. The city has prepared detailed 'Climate Resilient City Action Plan (CRCAP)', which addresses both climate mitigation and adaptation. Rajkot City Council adopted the CRCAP in February, 2019 and committed to reduce 14% of its GHG emission by 2022-23 as compared to its 2015-16 baseline. The CRCAP includes various interventions on energy efficiency (including replacement of cooling and lighting appliances) and renewable energy, implementation of green building policy, green building design for social housing schemes among others. The city has implemented various energy efficiency and renewable energy projects to reduce GHG emissions.

RMC is including various climate resilient interventions and actions in its annual municipal budget in order to fund and enable their implementation. The city has allocated around 20% of its municipal budget for 2021-22 towards climate resilient actions.

2. Green Building Guidelines 'Prakruti' was prepared by Rajkot Municipal Corporation through the support of the Building Efficiency Accelerator (BEA) project under the global SE4ALL initiative. The said guideline includes indicators and building assessment criteria addressing building orientation, envelope, construction and operation of buildings towards enhancing energy efficiency and environmental performance. Assessment criteria are based on climate responsive planning and design (urban harmony, building massing and spatial configuration, sustainable architecture), building energy performance (energy efficiency and renewable energy), water conservation and management, resource stewardship (material efficiency, waste management), livability (indoor environment quality, spatial quality, building operations including energy demand and control systems) and innovative green efforts etc. The guideline which is in the draft stage also



Figure : Climate Resilient City Action Plan, Rajkot



Figure : Draft Green Building Guideline -Prakruti

includes various incentive options for private developers that adopt green building principles and solutions.

3. The Indo-Swiss Building Energy Efficiency Project (BEEP) provided technical assistance to RMC to incorporate green building measures in its 'Smart Ghar 3' social housing scheme. The Smart Ghar - 3 social housing scheme had a total floor area of 57,408 sq. m spread over 11 residential towers with 1176 houses. It was implemented by RMC under the Pradhan Mantri Awas Yojana (PMAY), a national affordable housing program. Recommendations identified through this initiative

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addressed building orientation, envelope design, and construction material to achieve energy efficiency and improve thermal comfort of the affordable houses. RMC implemented various interventions including reducing heat gains through building envelope i.e., windows, walls and roof; utilizing and improving potential of natural ventilation for better cooling; adopting energy efficient appliances (BEEP India, 2021). RMC replicated adoption of these green building measures in three other social housing schemes Smart GHAR 4 (floor space of 2,645 sq. m), Smart GHAR 5 (floor area of 23,774 sq. m) and Smart GHAR 6 (floor area of 68,406 sq. m). As of 2020, Rajkot has a total of 93 IGBC precertified green buildings in its affordable housing projects with total floor area of 355,193 sq. m. Rajkot has issued occupancy approvals to 11 such green affordable housing buildings in 2020.

- 4. For its Smart City area, based on the provisions made in the plan, the Raiya Smart City area has received the IGBC Green Cities 'Platinum' rating and has become the first smart city in India to receive this certification. The certification will enable the development authorities and developers to apply green and sustainable concepts, planning principles and policy initiatives, so as to reduce environmental impacts and improve the overall quality of life in the city. Some of the green city features of the Raiya Smart City area are:
 - Comprehensive Hazard and Risk Analysis based on Zonation maps (Earthquake, Cyclone, Drought & Flood) with prevention and mitigation measures integrated in master planning.
 - Green cover improved by 25% with tree preservation & plantation initiatives, as per Gujarat's Development Control Regulation (DCR).
 - Rejuvenation of 4 lakes covering 4 km of catchment area, to enable an improvement in the water table.



Figure : Green Building Design in Social Housing Scheme (Smart Ghar 3) –



Figure : Rajkot smart city area plan

 23,489 dwelling units developed under various schemes and action plan developed towards Slum-free city for 135 slums. 15% dwelling units for affordable category housing (EWS/LIG) proposed in ABD area.

- 100% of 23 km road network in ABD planned with footpaths on both sides, with cycle lane and parking stations proposed.
- 100% water supply coverage, 100% consumer metering, 24x7 supply through concept of District Metered Areas, 100% treatment & reuse planned in ABD.
- 100% LED lighting and 3.2 MWp of solar power generation proposed

3.4 Frameworks for Urban Cooling

India has formulated various laws, policies and guidelines at different levels of governance, focusing on sustainable planning and environmental protection. The said policies do not directly support the addressal of UHIs and their effects. However, focus areas of the policies do offer entry points and support strategies to mitigate the effects of rising urban temperatures and promote sustainable urban cooling initiatives. Relevant national and subnational level legislations and policies are mapped below in Table 4 and Table 5, with linkages to UHI effect noted.

At the city level, is main planning authority for the city of Rajkot and responsible for all the micro level planning for the urban infrastructure and related services planning. The RUDA is responsible for overseeing the planning and development of the larger urban agglomeration area of Rajkot (including the city of Rajkot). RMC and RUDA are implementing two types of planning approaches that address different scales, macro-planning and micro-planning. At the macro level, urban planning is carried out in the form of a development plan for the entire urban agglomeration area. The development plan which encompasses a larger area gets implemented through micro level planning which usually encompasses an area of less than 2 sq. km. These micro level plans are called Town Planning Schemes. Given their planning and regulatory authority, frameworks such as building permits, bye-laws and development control regulations, building efficiency standards offer entry points to develop complementary policies to encourage urban cooling development and adoption at the local level.

Frameworks with clauses / sections that directly address UHI	Frameworks with clauses / sections that indirectly address UHI
Urban and Regional Development Plan Formulation and Implementation (URDPFI), 2014	National Environment Policy, 2006
National Mission on Sustainable Habitat, 2014	National Mission on Green India (NMGI), 2014
Energy Conservation Building Code (ECBC), 2017	Atal Mission for Rejuvenation and Urban Transformation (AMRUT), 2015
Eco-Niwas Samhita 2018	Smart Cities Mission, 2015
National Cooling Action Plan, 2019	Rajkot Urban Development Plan as per GTPUDA 1976
Green Rating for Integrated Habitat Assessment (GRIHA)	Town Planning Scheme as per the GTPUDA 1976
Leadership in Energy and Environmental Design (LEED) developed by Indian Green Building Council (IGBC)	
General Development Control Regulations (GDCR), 2017	

Table 4: Frameworks addressing UHI, Directly and Indirectly



Frameworks with clauses / sections that directly address UHI	Frameworks with clauses / sections that indirectly address UHI
Gujarat State Action Plan on Climate Change, 2014	

Table 5: Brief on frameworks supporting UHI directly and indirectly

Frameworks	Description
National level	
National Environment	Objective:
	 Targets for conservation and efficient use of environmental resources, livelihood security of poor, environmental governance and integration of environmental concerns in economic and social development Aims to establish environment standards for pollution relating to water, air, land, and noise and co-ordination aspects between multiple agencies Identifies polluter as one whose action potentially results in adverse impacts on third parties and recommends that polluters must pay Encourages Environmental Impact Assessment (EIA) for appraising large development projects Acknowledgement of urban heat or strategy for urban cooling:
	 Some measures identified in the policy supports mitigation of heat island effect i.e., pollution control (including air pollution) and enhancing green cover based on plantation of native species
	Gaps for implementing cooling strategy:
	Increased focus for economic development without fulfilling environmental standards has aggravated the environment
	Recommendation:
	Being a long-term policy to prevent degradation of the

Being a long-term policy to prevent degradation of the environment, effects of heat island and its preventive measures can be introduced as additional measures

Objective:

Frameworks		Description
Urban and Development Formulation Implementation (URDPFI), 2014	Regional Plan and	 Provide a framework for resource mobilization, necessary techniques, specifications, standards, including land use planning and development regulations for regional and urban planning
		Acknowledgement of urban heat or strategy for urban cooling:

- Direct (Land use planning, Surface Characteristics)
 - It acknowledges that activities happening in urban centres have formed UHI effect.
 - Suggests UHI analysis as one of the parameters under environment section for regional plan
 - Highlights green city development approach for green field development of cities
 - Identifies open spaces and vegetation as heat and carbon sinks and suggests green cover and shading for cooling effect.
 - Recommends a city to provide at least 10m² of per capita open space¹⁴ to its citizens

Gap for implementing cooling strategy:

Lack of differentiation between green space and open spaces, wherein the latter includes the former along with recreational spaces, and other common open spaces such as vacant lands/open spaces including flood plains, forest cover etc). This lack of differentiation hinders the development of organized green space as the focus often shifts to other categories.

Recommendation:

Differentiation between open spaces and green spaces may be included, which can help promote development of urban forests and other green spaces in parts of the city

National Mission on **Objective:** Green India (NMGI), 2014

¹⁴ The open spaces include three categories, namely, (a) recreational space, (b) organised green, and (c) other common open spaces (such as vacant lands/ open spaces including flood plains, forest cover etc).

Frameworks	Description		
	 One of the eight missions under the National Action Plan on Climate change with cumulative target of increasing forest cover on 5 million hectares of land in 10 years. It has projected that nearly 77% to 68% of the forest grids are likely to be impacted by climate change leading to shifts in forest types, based on the scientific modelling done using RCM (Regional Climate Model) and BIOME model (BIOME 4) it talks about increasing urban forest cover, developing parks, and greening of institutional lands 		
	Acknowledgement of urban heat or strategy for urban cooling:		
	 In-Direct (Land use planning, Surface Characteristics) Improving green coverage (especially in urban areas) is an indirect mitigation strategy, which will help solve the heat island effect 		
	Gap for implementing cooling strategy:		
It was planned to be launched in 2012 but, got delayed and t was launched in 2015, with target for afforestation the increase tree count. But no detailed information has been on how to plan such activities in line with the cities need for cover. Recommendation:			
			As, its long-term policy to improve forest cover, it may be linked with identification of heat island and implementation of prevention measures through plantation of trees to reduce effects of heat as one of the co-measures. Allocation of funds can also be linked with need of improvement in green cover based on identification of heat effects.
National Mission on Sustainable Habitat, 2014	Objective:		
	• One of the eight missions under the National Action Plan on Climate change with target for promoting energy efficiency in the residential and commercial sector and promotion of urban public transport		
Frameworks	Description		
---------------------------------------	---	--	
	• Better urban planning to achieve better disaster management; promote urban planning models, reduce the use of private transportation, and increase the use of public transportation		
	Acknowledgement of urban heat or strategy for urban cooling:		
	 Direct (Building morphology, Surface Characteristics, urban lifestyle) Based on example of Delhi, it has quoted that space air conditioning accounted for nearly 52%, and refrigerators accounted for around 28% of energy consumption in the residential sector of Delhi and suggests energy saving measures which would help in achieving around 30% electricity savings in new residential buildings and 20% in existing buildings Suggests R&D in residential and commercial sector for energy-efficient building component, windows, low-cost insulation material, lights and ceiling fans, home appliances and to develop simulation software to predict the energy used in buildings Suggests to improve adequate barrier free pedestrian facilities along overall road network, NMT facilities and parking spaces which would lead to reduced GHG emissions Suggests to bridge the knowledge gap in all areas including technical recommendation for design and construction of green buildings 		
Can for implementing cooling stratogy			
	Knowledge gap in the adoption of various energy efficiency		

Knowledge gap in the adoption of various energy efficiency practices, lack of clarity on enforcement and implementation, and cost of green technologies and technology development.

Recommendation:

It's work and implementation may be linked with Energy Conservation Building Code (ECBC) and National Urban Transport Policy (NUTP) for better implementation, as the code and policy has suggested better implementation plan

Frameworks	Description
Atal Mission for Rejuvenation and Urban Transformation (AMRUT), 2015	 Objective: Aims to provide basic services (water supply, sewerage, storm water, urban transport & green spaces) to households and build amenities in cities which will improve the quality of life for all, especially for the poor and the disadvantaged. City develops road map for reform implementation and capacity building through preparation of Service Level Improvement Plan (SLIP) at city level, which gets aggregated in broader State Annual Action Plan (SAAP).
	Acknowledgement of urban heat or strategy for urban cooling:
	 Indirect (Land use planning, Building morphology) The component green spaces of AMRUT mandates cities to prepare action plan for progressively increasing green cover in cities to 15% within 5 years The guideline also suggests to provide incentives for green buildings (e.g., rebate in property tax or charges connected to building permission/development charges) for their actions Recommends Energy (Street lights) and Water Audit (including nonrevenue water or losses audit) for urban services improvement
	Gap for implementing cooling strategy:
	Development of parks is one of the thrust areas of the mission however the focus is to make it more of a recreational area rather than a dense green cover to mitigate waste heat of the city. Also, there is no guidance on selection of location for the parks.

Recommendation:

Location finalization of park should be based on its need, derived through waste heat generation hotspots or areas with high UHI effect.

Objective:

Framev	vorks		Description
Smart 2015	Cities	Mission,	 To address the governance and infrastructure concerns of the growing urban population of cities, and to promote quality of life. Aims to integrate smart technologies in different sectors to achieve sustainable urban development in an energy-efficient and cost-effective manner through two major aspects: (1) Pan City Project, which includes information and communication technology (ICT) solutions such as Integrated Traffic Management System (ITMS), automated city level waste collection, e-Governance, and rooftop solar panels in government buildings; and (2) Area Based Development (ABD) Project, wherein a small area within the city is identified and is developed with identified smart solutions for improving its infrastructure which becomes a prototype for other parts of the city.
			Acknowledgement of urban heat or strategy for urban cooling:
			 Indirect (Land use planning, Building morphology, surface characteristic, urban lifestyle) Aims to create urban spaces which are energy efficient to reduce the burden on existing resources. Guidelines outline that, 80% of the buildings in the smart cities need to be energy-efficient with a 'green building' design and 10% of the Smart City's energy requirement should come from solar energy.
			Gap for implementing cooling strategy:
			It requires modern technologies and huge infrastructure based on massive interconnected networks of sensors, cameras, smart devices, and smart grid communication etc. In spite of identifying energy efficient components in smart city proposal, most cities are facing issues related availability of funds, operation monitoring and maintenance of smart infrastructure.
			Recommendation:
			ULB generally lacks in skilled staff and depends on external agencies or consultants for handling technical works. Cities have constructed integrated command centre which are handled by private staff for O&M so, capacity building of municipal staff

should be planned for skill improvement. All energy efficient infrastructure should be regularly monitored for benefits analysis

Frameworks		Description
		and to undertake corrective actions in term of abnormalities to receiving better yields.
Energy Building 2017	Conservation Code (ECBC),	 Objective: Recommends building envelope, HVAC, lighting criteria for commercial buildings having connected load of more than 100 kW or contract demand of more than 120 kVA. Includes Energy performance standards for Building Envelope, Heating Ventilation and Air Conditioning, Service Water Heating, Lighting and Electric Power and Distribution State governments also have the flexibility to modify ECBC to suit local or regional needs
		 Acknowledgement of urban heat or strategy for urban cooling: Direct (Building morphology, urban lifestyle) Estimates that ECBC compliant buildings can use 40% to 60% less energy than conventional buildings. Energy use reductions from ECBC compliance can contribute significantly to UHI risk from increased energy consumption Directly stresses the use of cool roof to mitigate heat effects
		Gap for implementing cooling strategy:
		 Energy efficient interventions are cost sensitive and its overall breakeven point for investments made, is medium to high. At consumer side there is no awareness for considering the life cycle cost of building or appliances and in absence of that there is no demand from consumers for energy efficient buildings. That also results in low or no adaptation of such initiative by private developers. Such initiatives also get monetary incentives in various schemes like, in GDCR it states that incentives in the rate of chargeable FSI for Green Buildings of up to 5% discount in the total payable amount to any owner or developer shall be given but, process for

developers avoid it

availing such advantages are unknown or too lengthy so, many

Fromourovico	Description
Frameworks	Description
	Recommendation:
	 Energy efficient commercial buildings shall be provided monetary benefits and process for availing those benefits should be easily understandable to all developers or city should run awareness campaign to educate local developers on benefits available to them if green or energy efficient projects are planned. A dedicated team and helpline service shall be provided for resolving doubts of developers which will motivate them to undertake innovative strategies for energy efficiency.
Eco-Niwas Samhita 2018	Objective:
	• Sets minimum building envelope performance standards to limit heat gains (for cooling dominated climates) and to limit heat loss (for heating dominated climate) as well as for ensuring adequate natural ventilation and day lighting. The code is applicable to all residential use building projects built on plot area more than 500 m ² .
	Acknowledgement of urban heat or strategy for urban cooling:
	 Direct (Building morphology, urban lifestyle) Energy use reductions from Eco-Niwas Samhita compliance can contribute significantly to UHI risk from increased energy consumption
	Gap for implementing cooling strategy:
	• Energy efficient interventions are cost sensitive and its overall benefits are hard to explain to consumers and in absence of that there is no demand from consumers for energy efficient buildings, resulting in less supply of such buildings.
	Recommendation:

• Energy efficient residential buildings shall be provided monetary benefits and process for availing those benefits should be easily understandable to all developers or city should run awareness campaign to educate local developers on benefits available to them if green or energy efficient projects are planned.

Frameworks	Description
	 A dedicated team or helpline service shall be provided for resolving doubts of developers which will motivate them to undertake innovative strategies for energy efficiency.
National Cooling Action Plan, 2019	Objective:
	 Recommendations to achieve sustainable cooling for India in the next 20 years and discusses the cooling growth scenarios and the potential pathways under the following key areas: 1. Space Cooling (or comfort cooling) in Buildings 2. Cooling for Transportation 3. Cold Chain & Refrigeration 4. Air Conditioning & Refrigeration Technologies 5. R&D and Production Sector (alternative refrigerants and technologies) 6. Servicing Sector 7. Cross-cutting Policy and Regulations

Acknowledgement of urban heat or strategy for urban cooling:

- Direct (Building morphology, Surface Characteristics, urban lifestyle)
 - Focusses on space cooling technologies like, (i) Refrigerantbased (room AC, Chiller system, VRF system) (ii) nonrefrigerant-based (Fan, Air cooler) and (iii) not-in-kind, for providing thermal cooling in buildings. The not-in -kind technology suggests alternative cooling strategies like district cooling (DC) systems, which require about 15% less capacity than conventional distributed cooling systems for the same cooling loads due to load diversity and flexibility in capacity design and installation.
 - Analyses refrigerant demand in the transport sector and suggests to calculate fuel consumption while keeping the AC ON, which is presently done when AC is OFF. This will help to identify clear fuel efficiency of the vehicle while cooling is used

Gap for implementing cooling strategy:

• In needs high initial investment, technical expertise for design, policy level support, and favourable financial and business mechanisms e.g., district cooling system.

Frameworks	Description
	 Plan has not prescribed the institutional and governance framework for implementing the recommendations, at both national and state levels. The plan emphasis on technological fixes, which is unlikely to solve the cooling challenge that lies ahead for the cities due to urbanization. The plan proposes demand-side strategies like incorporating passive design principles in buildings and enforcement of National Building Code, Model Bye-Laws and Energy Conservation Building code to curb the growth of cooling demand. But these codes have negligible implementation on ground even after their introduction. The plan has focused and suggested pathways in different sectors but, it shall address the need of cooling at larger urban level planning and project execution
Recommendation:	
	 Cooling strategies for overall city cannot be planned or implemented in silos. There should be institutional set up within ULB to monitor all ongoing activities and projects including its impact on the urban heat. The institutional set up within ULB shall support with all green infrastructure and energy efficiency related guidelines, Acts and policies to the implementation teams for sustainable project planning and executions. City shall undertake study for UHI mapping and based on that cooling strategies shall be planned. Future project's locations and technology shall be in line with the findings of the heat mapping study.
	Objective:
Green Rating for Integrated Habitat Assessment (GRIHA)	 Aims to reduce the building energy demand, thus indirectly GRIHA rated green buildings will supply less detrimental form of energy into the environment. Building is classified as a green building if it's building design and construction aspects fulfil various GRIHA criteria. The rating system broadly comprises of nine different environmental categories - site planning, health & well-being, water, building planning & construction stage, energy - renewable, energy - end

use, recycle recharge and reuse of water and waste management

Frameworks	Description
	Acknowledgement of urban heat or strategy for urban cooling:
	 Direct (Building morphology, Surface Characteristics) It focuses on the reduction of heat island effect by reducing total paved areas, increasing green cover and also by application of high SRI coatings on exposed materials. The rating system also advises application of cool roof/green roofs to reduce building heat gain through roofs. The reduction of heat island effect in not among the mandatory criteria of the rating system, yet an attempt has been made to identify and reduce the heat island effect.
	Gap for implementing cooling strategy:
	 It is voluntary for developers, rather than being mandatory. It needs capital expenditure in terms of using sustainable material to achieve criteria of GRIHA certification. Consumers do not understand benefits of having green and energy efficient practices in building material though they do not demand such measures in projects. Developer has to spend one time cost for the registration of project for certification.
	Recommendation:
	 Consumer awareness campaign shall be run to inform overall life time benefits of following such certification measures so that consumers demand can be increased. Benefits in terms of increased FSI or some rebate in taxes shall be given to motivate developers to adopt certification guidelines
Leadership in Energy and Environmental Design (LEED) developed by Indian Green Building Council (IGBC)	 Objective: It is a voluntary scheme to promote sustainable design for buildings. Rating systems for Green Homes, New Construction and Township include criteria for UHI effect (roof and non-roof) under Site Selection and Planning sustainable sites, thereby directly addressing the issue.

Frameworks	Description
	 Intent is to cut down on heat island effect through use of high reflective, high albedo materials, vegetative cover and shaded spaces
	Acknowledgement of urban heat or strategy for urban cooling:
	 Direct (Building morphology, Surface Characteristic) The IGBC rating for townships under its SSP 6 provides maximum of 8 points for having 95% or more exposed/impervious surfaces under either tree cover/shade or with reflective materials. Townships has to work for footpaths, pathways, roads, surface parking and other non- impervious areas within the township, provide tree cover (within 5 years) or use light coloured/ high albedo materials (reflectance of at least 0.3) or open grid pavements Rating system for green homes has identified that increase in constructed areas leads to UHI effect where the local temperature increases due to heat retention. The UHI effect results in increased cooling energy requirement and affects the site flora and fauna. For non-roof area the rating allots 2 points for providing at least 50% of exposed non-roof impervious areas with a combination of the shade from tree cover within 5 years of project completion, Open grid pavers) with SRI of at least 29 (and not higher than 64) and allots 2 points for providing at least 75% of exposed roof areas with a combination of the High SRI materials, High albedo materials and Roof garden/ Vegetation to maintain SRI > 95%
	Gap for implementing cooling strategy:
	 It is voluntary for developers, rather than being mandatory. It needs capital expenditure in terms of using sustainable material to achieve criteria of LEEDs certification. Consumers do not understand benefits of having green and
	energy efficient practices in building material though they do not

demand such measures in projects.
Developer has to spend one time cost for the registration of project for certification.

Frameworks	Description
	Recommendation:
	 Consumer awareness campaign shall be run to inform overall life time benefits of following such certification measures so that consumers demand can be increased. Benefits in terms of increased FSI or some rebate in taxes shall be given to motivate developers to adopt certification guidelines.
State Level	
General Development Control Regulations (GDCR), 2017	Objective: • Controls FSI & Rules regarding the development of land, permissible building heights, road and other side margins, parking requirement, etc. and based on the road width, the use of land and permissible FSI are regulated. (In Rajkot residential areas have base FSI of 1.8 with chargeable FSI of 0.9, resulting as maximum permissible FSI of 2.7, commercial areas have base FSI of 1.5 with chargeable FSI of 0.7, resulting as maximum permissible FSI of 0.7, resulting as maximum permissible FSI of 2.2 and TOZ areas have base FSI of 1.8 with chargeable FSI of 2.2, resulting as maximum permissible FSI of 4.0)
	Acknowledgement of urban heat or strategy for urban cooling:
	 Direct (land use planning, building morphology, surface characteristics) It promotes Green buildings and has indicated that the Competent Authority shall offer incentives in the rate of chargeable FSI for Green Buildings of up to 5% discount in the total payable amount to any owner or developer, who constructs an Energy Efficient Buildings and produce a certificate from GRIHA or any other Government recognized Institute, showing the green rating received for the building. For hospitals, where 4.0 or more FSI is granted, centralized HVAC systems have to be compulsorily implemented for ICU, operation theatres & other critical facilities. States that Auditorium or cinema halls shall be airconditioned and shall keep Temperature Range at 22 to 26.5 degrees Celsius

Frameworks	Description
	 It also indicates for garden open space of 5% in the public purpose land for development, where town planning scheme has been not declared.
	Gap for implementing cooling strategy:
	 Disaggregated IEC activities hinder promotion of the benefits available for developers if energy efficient buildings are planned and constructed Process of getting incentives for energy efficient buildings is time consuming, which demotivates many developers while trying to get such incentives. Although, the GDCR provides incentives at the rate of chargeable FSI for Green Buildings of up to 5% discount in the total payable amount to any owner or developer however, process for availing such advantages are obscure or too lengthy therefore developers usually avoid it
	Recommendation:
	 The process of receiving incentives for energy efficient buildings shall be easy to understand and the institutional set up within ULB shall be established to support and clarify queries of the developers There must be post approval checking and monitoring on the approved plans of the projects to ensure that criteria for green spaces and open spaces are rightly meet.
Gujarat State	Objective:
on Climate Change, 2014	 Enabling a low carbon pathway for Gujarat's economic growth Providing a sustainable and climate resilient scenario Mainstreaming action on climate change in government departments Devising innovative and forward-looking policies and their means of implementation Generating comprehensive climate change consciousness among policy planners Building wide ranging strategic knowledge partnerships

Ensuring broad based people's participation

Institutionalizing capacity building at the State level

Frameworks	Description
	Acknowledgement of urban heat or strategy for urban cooling:
	 Direct (Building morphology, surface characteristic, urban lifestyle) The SAPCC identifies heat island effect to be an issue for urban areas and suggests plantation and greening initiatives to reduce the negative impacts of the same The SAPCC recognizes the apprehension among the builders regarding the incremental cost they bear to build green buildings whose benefits automatically get transferred to the consumers, without leaving any benefits for the builders. Consequently, it suggests market transformation and a strong education and public outreach programme to overcome this apprehension. The SAPCC suggests popularization of building certification systems like GPIHA
	Gaps for implementing cooling strategy:
	 Lack of specification of greening/plantation guidelines, concerned authority to carry out greening and linkage with parallel government initiatives. Lack of mandates to develop green buildings which focusses on reduction of heat island effect Lack of focus on identification of heat hotspots within an urban area
	Recommendation:
	 Guidelines with a focus on identification of heat hotspots and subsequent greening, and mandates to develop green buildings with incentives for the developer may be included
Local Level	
Rajkot Urban Development Plan as per GTPUDA 1976	• Defines the direction of growth and visualizes the citywide

- infrastructure for the entire development area and prepare macro level planning for the entire urban area including the city.
- Covers detailed analysis on availability of existing physical and social infrastructure facilities along with analysis of carrying

Frameworks	Description
	 capacity of city, and policies for densification/re-densification, renewal/redevelopment and congestion are also included. Includes issues such as disaster management, environment management, and heritage conservation in development plan. Development plan shows the broad areas under different land use zones, land reservations for roads and other different social and public purposes. Acknowledgement of urban heat effect or strategy for urban cooling:
	 Indirect (land use planning, surface characteristic) Rajkot's Second Revised Draft Development Plan, 2031 considers the demand of the projected population for the next two decades across the entire urban agglomeration area of 686 sq. km. under RUDA's jurisdiction, including the Rajkot city area. Based on the plan, it is estimated that area for vacant and

agricultural land will reduce from 67% (2011) to 55% (2031), which will get utilised for residential, commercial, industrial or transportation related purposes.

Gap for implementing cooling strategy:

- Lack of greening guidelines
- It is very difficult to achieve the sustainability, liveability and workability concept as there is huge gap in present condition and future demand
- It considers physical and social infrastructure facilities along policy analysis of disaster management and environment management, but Development Plans are ultimately macro level plan and it must be supported through micro level town planning for getting better results on the field.

Recommendation:

• Development Plan may offer greening guidelines with strict enforcement

Town Planning Scheme **Objective:** as per the GTPUDA 1976

Frameworks	Description
	 Prepared for smaller areas, to influence targeted development across the city by defining different land uses in different zones. TPS is a form of land readjustment used for expanding urban infrastructure without compulsory land acquisition but promoted as land pooling activity. (The area for TPS is first surveyed and then the road network is determined. Then, plots for a variety of public uses such as schools, parks, health facilities, and housing for economically weaker sections are drawn up. Increasingly, plots are also being set aside for the Development Authority's land bank, which to be sold to raise finances for infrastructure development. Then the total land area used up for roads and plots for public uses is calculated as a proportion (percentage) of the total land area of the TPS and that proportion.)
Linkages to urban heat or strategy for urban cooling:	
	 In-Direct (land use planning, Surface Characteristic) It suggests allocation of up to 5% of area for the green cover or open plot and overall, 40% of the land is reserved for social infrastructure.
	Gap for implementing cooling strategy:
	 The timeline proposed in the regulatory framework to preparation, finalization and implementation of the town planning schemes is too lengthy The significant land assets generated by the local authority are not managed in an appropriate manner Green areas are not finalised based on future densification and possible waste heat generation in the area.
	Recommendation:
	• The process of finalizing town scheme plan shall be optimized for faster decisions and finalization of plans.

Frameworks	Description
	• Plot allocation for social amenities shall be supported with base
	line survey and future projection of development so that effects of
	waste heat can be avoided.

3.5 Causes of Urban Heat Island Effect in the City

The direct or indirect effects of excess heat on urban systems are significant. Some of the causes of urban heat in Rajkot are identified based on stakeholder consultation as listed below:

• Rising ambient air temperature and hotspots

Ambient air temperature analysis for year 2018 was carried out by RMC, utilising the information from the 18 local environment sensors. The analysis showed that some areas such as Trikon Baugh and Hospital Chowk have daily maximum and minimum temperatures (24-hour average) up to 3 °C to 4 °C higher as compared to the surrounding areas. Analysis of air quality data from July 2019 to December 2020 indicates that these two areas have higher concentration of air pollution as well, with their Air Quality Index (AQI) exceeding 100 frequently, which is also higher than the city's average AQI 50 over the same period. Trikon Baugh and Hospital Chowk represent major traffic junctions, with their higher level of air pollution identified as one of the major drivers of higher ambient temperatures in these areas. At the same time, it was noted that temperature is rapidly reducing in some of the hotspot areas such as Race Course during the night time due to their higher existing green cover (see Figure 16). While the city does not have specific records of mortality due to extreme heat events, rising temperatures may lead to higher risks of heat mortality.

• Increase in commercial and industrial activities

Being a prominent commercial and industrial hub in the Saurashtra region, an increase in commercial and industrial activities in Rajkot will lead to an increase in migration population from surrounding areas. Share of manufacturing and forging industries in the city's economic activities is high, where working environment temperature is already higher than the workers' thermal comfort level. Some of these high commercial and industrial activity areas located in and around the city's peripheral may act as a source of heat and contribute in raising the canopy layer temperature within the city limit. The effect of increase in temperature may be significant on lower income group i.e., industrial workers, street vendors, construction labours etc., considering less access to mechanical cooling.

• Increasing penetration of mechanical space cooling in buildings

Industries located within the city and its surrounding areas are the main contributors to Rajkot's economy. With economic growth and corresponding rise in income levels, proliferation of air conditioners has increased in buildings. This is reflected in market trends noted by local real estate developers such as increased demand for provision of two air conditioners in residential properties, instead of a single air conditioner typically provided in the bedroom previously. With higher purchasing capacities, many lower and lower-middle income households in the city are increasingly

using air conditioners. Increased AC penetration drives higher peak electricity demand and related GHG emissions while also leading to increased waste heat generation from air conditioning units. Rajkot's energy profile for 2019-20 shows an increase in per capita energy consumption with electricity consumption growing at 9% annually on average from 2011-12 to 2019-20. Electricity consumption in residential sector has grown at an annual average rate of 7% over the same period. While there is no data available on electricity consumed specifically for space cooling, it is difficult to evaluate the full impact that proliferation of mechanical space cooling based on the city's energy consumption. With urban heat contributing to higher ambient air temperatures in certain hotspot areas in the city, such areas are likely to have lower levels of thermal comfort and thereby increased demand for space cooling in buildings.

• Traffic congestion given lower land area allocation for roads in the city

Roads have typically occupied a relatively lower share of Rajkot's total land area, resulting in traffic congestion in highly commercial areas and adding to the UHI effect. Cities boundary has been increased from 129.21 Sq.km in the year 2015 to 161.86 Sq.km in the year 2020 and most of the newly added areas has been in the west side of the city. While the extent of land area utilized by roads as well as the average width of roads has improved in the recent years, this trend is largely occurring in the west zone of the city that is witnessing new developments.

• Increase in use of private vehicles

Vehicular traffic is a major anthropogenic heat source in the city, with tailpipe emissions and traffic congestion contributing to the UHI effect. Rajkot's citizens are observed to undertake about 1.3 trips per day with an average trip length of around 4 km (CapaCITIES, 2018). While the city is undertaking efforts to improve the existing public transportation system¹⁵ and also plans to strengthen last-mile connectivity through non-motorized solutions, provision of such an integrated transportation system along with last mile connectivity at present, the number of private vehicles in Rajkot have been observed to be increasing. Information received from the Regional Transport Office (RTO) shows that there has been addition of 100,000 personal vehicles on average every year, starting from 2011. Increase in private vehicles is thereby a key driver for increasing ambient air temperature.

• Rising building stock constructed with conventional methods

Rapid urbanization and increase in population (including migration population), has increased the demand for housing, built spaces and other urban infrastructure development in Rajkot. Residential, commercial and industrial spaces accounted for 62.1% of the city's total built up area in 2011 as compared to 46.6% in 2001. Given the expansion of city boundaries and its development trajectory, the number of residential, commercial and industrial buildings is anticipated to increase significantly in the future. Thereby, Rajkot has significant opportunities to promote adoption of green buildings that are built to deliver sustainable cooling to occupants at the building scale as well as address urban heat at the neighbourhood scale. RMC is already incorporating various green

¹⁵ At present, 100 diesel-based public buses are operating in Rajkot. RMC has proposed to introduce 150 electric buses to replace all its existing fossil fuel-based bus fleet.

building measures in terms of building design, orientation, and use of green building material that address building sustainability and improve thermal comfort levels in its social housing projects. 93 social housing buildings constructed by RMC, spanning a total area of 355,193 sq. m, have received IGBC pre-certification. RMC has issued occupancy certificate and approvals to 11 such green buildings in 2020. While RMC is demonstrating leadership on adoption of green building concepts in its projects, the market demand for green buildings remains low at the community scale owing to reasons such as lack of awareness on long term benefits among buyers, high upfront construction costs for private developers, lack of robust and enabling policy and regulatory mechanisms on-ground. Therefore, a large portion of the city's upcoming building stock is being constructed through standard practices that do not adequately tap into opportunities to realize green and sustainably cooled buildings. Furthermore, such buildings are often constructed with materials having impervious surface and low albedo, which can consequently lead to increase in surface and ambient air temperature, thereby enhancing the UHI effect.

Use of air-conditioners for personal thermal comfort

Responses to increased heat in most Indian cities have been mainly focused at the individual level, through installation of air-conditioning for space cooling in residential or commercial spaces to improve personal thermal comfort. However conventional air-conditioning is very energy intensive and often dependent on fossil-powered electricity in Indian cities. As per the findings of a rapid assessment on district cooling for Rajkot in 2017, space cooling accounts for about 22.6% of the total electricity consumed in residential properties (16.27% accounted by air-conditioners and 6.33% accounted by devices such as ceiling fans, table/wall fans, exhaust fans, and evaporative air-coolers) and 45% of the total electricity consumed in commercial properties (37% from air-conditioners and 8% from ceiling fans, table/wall fans, exhaust fans, and evaporative air-coolers) respectively. Considering the above proportion, city-wide electricity consumption for space cooling and air conditioning by residential buildings is estimated to be about 159 million kWh and 114 million kWh respectively in 2020-21 as seen in the table below. Similarly for commercial end-users, electricity consumption for space cooling is estimated to be about 277 million kWh, with as much as 228 million kWh consumed by air-conditioning in 2020-21.

Year 2020-21	Share of the total electricity consumptio n of city	Total annual electricity consumptio n (Million kWh)	Estimated electricity consumption for space cooling (Million kWh)	Estimated electricity consumptio n for air- conditionin g (Million kWh)
Residential Sector	40.14%	702	159 (22.6%)	114 (16.27%)
Commercial and Services Sector	35.22%	616	277 (45.0%)	228 (37.0%)

Table 6: Electricity consumption from Residential and Commercial units of Rajkot in FY 2020-21

Consultations with local real-estate developers indicated that proliferation of air conditioners has increased in residential buildings due to rise in income levels. A significant proportion of new residential buildings in Rajkot are now being built so as to incorporate split room air conditioners, with in-built provisions to install indoor units and dedicated space to install outdoor units of such air-conditioning. Increasing use of air conditioners leads to increased energy demand from the local power grid that is primarily dependent on fossil fuels and thereby contributes to rising greenhouse gas emissions. Areas with significant commercial and industrial activity are located in and around the city's periphery and act as a source of heat due to increased use of air-conditioning in commercial areas and heat losses in the industrial processes, contributing to a rise in the canopy layer temperature within the city boundaries.

Air conditioning also releases waste heat to the environment, which further exacerbates the city's heat island effect and thereby mechanical cooling continually contributes to urban heat. Air conditioning also disproportionately affects people who do not have sufficient financial resources to procure mechanical cooling solutions (United Nations Environment Programme, 2021). Minimizing use of mechanical cooling and addressing its impacts on urban heat requires focusing on improving thermal comfort, for both indoors and outdoors, through the integration of appropriate cooling strategies to maintain temperature, humidity, and airflow in the urban environment.

1. Lack of green and blue infrastructure

Well-designed, appropriately located and adequately maintained green infrastructure can be effective in reducing the impacts of higher temperatures across urban neighbourhoods. At present, Rajkot has only 3.24 sq. km of green space, representing approximately 2% of the total city area. Rajkot's proportion of green spaces is much lower than the recommended minimum of 20% of urban geographical area as per the Urban Green Guidelines, 2014 prepared by the Ministry of Housing and Urban Development (MoUD) (presently known as MoHUA)¹⁶. The per capita green cover in the city stands at 1.8 sq. m. which is significantly lower than the World Health Organization (WHO) recommended standard of a minimum of 9 sq. m. of urban green space for each person, as well as the Urban and Regional Development Plan formulation and Implementation (URDPFI) Guidelines, 2014 recommended per capita open space of at least 10 sq. m¹⁷. Also, as per the guidelines of the local Town Planning (TP) scheme¹⁸, around 40% of the land parcel for a new developed area is to be reserved by RMC for construction of public services and amenities. Of this reserved public land parcel (18%-20%) is to be allocated for uses including

¹⁶ Detailed guideline can be found on MoHUA's website: www.mohua.gov.in/upload/uploadfiles/files/G%20G%202014(2).pdf

¹⁷ The open spaces include three categories, namely, (a) recreational space, (b) organised green, and (c) other common open spaces (such as vacant lands/ open spaces including flood plains, forest cover etc). The detailed guideline is available at https://mohua.gov.in/upload/uploadfiles/files/URDPFI%20Guidelines%20Vol%20I(2).pdf

¹⁸ TP scheme (Town Planning Schemes) is the micro level planning process for pooling together all the land under different ownerships and redistributing it in a properly reconstituted form after deducting the land required for open spaces, social infrastructures, services, housing for the economically weaker section, and road network. This process enables the local authority to develop land without fully acquiring it and gives it a positive control over the design and the timing of the urban growth.

construction of affordable/social housing, public schools, health centres, fire stations, open spaces and parks. Thereby, on an average only about 3% of the total land for a selected area can be utilized for establishing green cover in any TP scheme. At present, Rajkot does not have a local guideline to support conceptualization and planning of green infrastructure in a way that supports mitigation of urban heat island effect, from the surrounding urban spaces as well as that anticipated from the future development of built environment, land use, property density and traffic patterns.

The river Aji passes through the city, but it is nonperennial and dry throughout the year. Although some water bodies exist in the peripheral areas of Rajkot, no major perennial water bodies exist in its central areas. While three lakes are being developed as part of the new green field



Figure : Tree density map of Rajkot

development taking place at the Raiya Smart city area located in the city's western part, overall there is a lack of sufficient blue infrastructure within the city limits to support natural cooling through evaporation and condensation.

2. Building density and low adoption of green buildings

Residential, commercial and industrial spaces accounted for 62% of the city's total built up area in 2011 as compared to 46.6% in 2001. The urban development in the city's central and east zone, housing dense population and characterized by narrow roads and low-rise buildings located in closed proximity, is not effective for dissipation of urban heat, with the emitted longwave terrestrial radiation getting trapped between impervious building surfaces and street surfaces. On the other hand, the west zone of the city, wherein new development is taking place, is characterized by high-rise buildings given the densification resulting from adoption of Transitoriented zone (TOZ) policy in this new area. These high-rise buildings are typically constructed with conventional building materials and are not built considering wind-induced air flow patterns that assist cooling, thereby leading to high heat absorption during the day and equivalent dilution with air temperature.

Rajkot has significant opportunities to promote adoption of green buildings that are built to deliver sustainable cooling to occupants at the building scale as well as to address urban heat at the neighbourhood scale. RMC has prepared voluntary Green Building Guidelines 'Prakruti' to promote adoption of green building principles and enhance energy efficiency and environmental performance of its building stock, through the support of the Building Efficiency Accelerator (BEA) project under the global SE4ALL initiative. However, the 'Prakruti' Guidelines are yet to be adopted by the city. 93 social housing buildings constructed by RMC, spanning a total floor area

of 355,193 sq. m., have received IGBC green building pre-certification. Through such initiatives, RMC is demonstrating leadership on adoption of green building concepts in its projects. However, the market demand for green buildings remains low at the community scale owing to reasons such as lack of awareness on long term benefits among buyers, relatively higher upfront construction costs for green buildings and inadequate financial support for private developers in this regard, and the lack of robust and enabling policy and regulatory mechanisms on-ground.

Therefore, a large portion of the city's upcoming building stock is being constructed through conventional practices, having impervious surfaces and low albedo, which leads to increase in surface and ambient air temperature, thereby enhancing the urban heat island effect.

3. Absence of institutional set up and policy support

Addressing urban heat island effect effectively through appropriate mitigation interventions and adoption of more climate-friendly cooling techniques requires coordination between multiple institutions having varied roles and responsibilities for development of plans and their subsequent execution. At the same time, efficient governance is essential to create awareness among all the stakeholders to further aid the development of plans and their execution. Presently, there are very few information, tools and resources available in the public domain to help government authorities to understand or measure the impact and causes related to urban heat island effect and to prepare a baseline assessment for the city. The absence of baseline assessments that highlight evidence of urban heat and identify appropriate solutions at the local level, inhibits efforts and measures to initiate or scale holistic urban cooling related practices.

Building development that takes place in the city follows the General Development Control Regulation (GDCR), enforced by the town planning department of the RMC. This GDCR promotes adoption of voluntary guidelines and standards for green and energy efficient buildings. However, urban heat island effect is not directly addressed in the GDCR. The GDCR includes requirements for provision of green spaces and plantation of trees in new building developments. However, guidance to support the effective development of green cover and land zoning in order to address the effects of heat generation in the city is lacking.

As multiple factors contribute to increasing ambient and surface temperatures at various scales in an urban setting, therefore Rajkot city's strategies to address urban cooling should be multi sectoral, addressing effects of the urban heat island and neutralizing the impact of the current and future cooling requirements to enable access to cooling for all.

3.6 Barriers to Urban Cooling in Rajkot

Adoption of sustainable urban cooling requires coordination between multiple institutions with varied roles and responsibilities for development of plans and their subsequent execution. At the same time efficient governance to create awareness among all the stakeholders will further aid the development of plans and their execution. The selection of apt policies is paramount in the implementation of urban cooling strategies, which should ideally be supported through capacity building and shared learnings

from best practices. However, there exists barriers for developing and implementing urban cooling strategies. It is very important to identify these barriers and challenges in order to efficiently allocate resources and efforts to key obstacles hindering effective action. The barriers for urban cooling are listed below. These barriers were identified based on secondary research and through consultation with key stakeholders. Overcoming these challenges is necessary to facilitate and accelerate the successful accomplishment of cooling strategies in different projects, and validation of the barriers is the first step towards overcoming the same.

Following are the key barriers identified for urban cooling in Rajkot:

- Lack of technical studies and coordination mechanisms to address UHI effect
 - Rajkot's geographical boundary has increased by 60% in the last decade, with resulting infrastructure and real estate development and growing population density contributing to rising anthropogenic heat in the city. While there is a general acknowledgement of the issue of UHI effect and its linkages with anthropogenic activities, there is no study or assessment, both at the neighbourhood and city scale in Rajkot, which identifies and quantifies existing heat island effect and its mitigation strategies., there have been limited interventions to address the same.
 - At the city level, detailed understanding of the effects of heat island, information on available urban cooling solutions, its adaptability and performance in the local context, and the potential benefits of incorporating them within urban planning and building development processes and practices is lacking. In its absence, RMC has not placed sufficient emphasis on addressing UHI effect and thereby enabling support and ecosystem to initiate or scale up cooling practices is missing.
 - There are very few information tools and resources available in the public domain, applicable to the local context, to help public or government authorities to understand or measure the impact and causes related to UHI effect.
 - There is no responsible department/staff, at either the national, state or local level, to coordinate with other departments and stakeholders, prepare guidelines, implement urban cooling solutions and monitor the executed projects to track their impacts related to urban heat.
 - RMC has limited control on specific areas (e.g., industrial estates, forest land) in the city and its surroundings. Such areas are also governed by specific planning guidelines, which are not within RMC's purview.
 - In the absence of baseline assessments that highlight evidence of urban heat and identify appropriate solutions, and lack of awareness and cooperation mechanisms amongst key stakeholders, there is no ecosystem to initiate or scale holistic urban cooling related practices.

4. Lack of dedicated policy focus and enforcement mechanisms

 While recommendations and actions for reducing the effects of heat island can be found in guidelines, policies and voluntary certificates to certain extent, there is no dedicated policy and guidelines at national, state or city level which addresses UHI effect in a holistic manner. There are national policies and programmes which have direct and indirect linkages to UHI effect, however the main focus of these policies is mainly related to;

- improving urban infrastructure (e.g., AMRUT, Smart Cities Mission, URDPFI guidelines),
- city planning (e.g., GDCR, Development plan, Town planning scheme)
- addressing issues of environment (e.g., National Environment Policy),
- improving energy efficiency (e.g., ECBC Code) and
- Green building certification (e.g., GRIHA, LEED by IGBC) The National Cooling Plan, 2019 emphasizes upon technological solutions while the institutional and governance framework for implementing the recommendations, at both national and state levels are not clearly outlined which may hinder the implementation of the National Cooling Plan at the urban scale.
- Following the local development regulations (GDCR) is mandatory and it is enforced by the Town Planning department of the RMC. While the GDCR promotes adoption of voluntary guidelines and standards for green and energy efficient buildings, the UHI effect is not directly addressed in the GDCR.
- The GDCR includes requirements for provision of green public spaces and plantation of trees at new buildings. However, there is no guideline to support the effective development of green cover and land zoning in order to address the effects of heat generation in the city.
- As per GDCR, buildings with an area of more than 100 sq. m. have to plant a minimum of three trees for every 200 sq. m. area or part there-of. As an implementation mechanism to promote plantation in such large residential developments, RMC also collects security deposits of 550 INR per tree for such work from building developers at the time of building approval. However, often times this guideline is not followed by developers, with developers opting to give up the security deposit amount.
- As per the guidelines of TP scheme¹⁹, around 40% of the overall land for an area under development is reserved by RMC for construction of public services and amenities. Of this reserved public land parcel, about 20% to 22% land is utilized for construction of roads. The remaining land parcel (18%-20%) is allocated for uses including construction of affordable/social housing, public schools, health centres, fire stations, open spaces and parks. Thereby, on average only about 3% of the total land for a selected area can be utilized for establishing green cover in any TP scheme.
- Ideally Town Planning schemes have a time frame of about 2 years for their completion, once their preparation is announced. At times TP scheme finalization takes longer time which can go up-to 4 to 5 years due to issues such as providing responses and resolution to all the litigation queries, consultations with the citizens, among others. Given the pace of development taking place in and around such schemes or areas, such delays, at times,

¹⁹ TP scheme (Town Planning Schemes) is the micro level planning process for pooling together all the land under different ownerships and redistributing it in a properly reconstituted form after deducting the land required for open spaces, social infrastructures, services, housing for the economically weaker section, and road network. This process enables the local authority to develop land without fully acquiring it and gives it a positive control over the design and the timing of the urban growth.

can result in unavailability of continuous land parcels which can be effectively utilized for establishing green and blue infrastructure, with scattered and smaller land parcels available instead.

- Once land use plan is prepared and a Town Planning scheme gets finalized, RMC has limited control on type building to be constructed on land plots and on the building use. Thereby actual utilization of land parcels and built spaces may not reflect the utilization planned/envisaged and can also be of mixed-use type. This barrier makes it difficult to translate urban cooling actions identified at the planning stage (i.e., on documents) to actual development taking place on-ground.
- Town Planning schemes reserve land for development of green cover and parks. However, no specific guidelines exist for selecting a location of such green spaces in order to effectively address urban heat. Generally, such green spaces are placed in a scattered manner based on availability of reserved land, which may not be in line with potential heat island pockets, existing ones as well as ones resulting from the said development.
- Building level initiatives which would support cooling related activities are identified in voluntary certifications from IGBC, LEED and GRIHA. However, adoption of these voluntary actions will increase the capital cost of the projects which inhibits adoption of these green building standards in Rajkot.
- Adoption of sustainable practices is at times hindered by existing practices and frameworks to be followed by public institutions (including RMC) for creation of infrastructure and development. For example, procurement policies which emphasize selection based on lowest cost to minimize overall project costs instead of prioritizing best technology, inhibit integration of sustainable solutions.
- It is also difficult to monitor execution and compliance actions taken for reducing heat absorption. Such monitoring also needs to be supplemented by validation through surface temperature measurements during its operational phase.
- Rajkot is implementing actions that address and can reduce heat island effect, through various programmes and policies. However, such activities remain in silos, being implemented and monitored under different programmes or policies. Integration of such activities is necessary to cohesively adopt and implement urban cooling at scale.

• Lack of technical awareness and proven pilots on urban cooling

- Understanding of heat island effect and impacts associated with increasing ambient and near-surface temperatures is limited among all the stakeholders. Rising urban heat is being experienced by all but understanding of its linkages with anthropogenic activities is limited.
- The Town Planning department guides and regulates urban planning, development and building construction in the city. However, limited technical know-how and capacity in relation to UHI effect exists within decision-makers and key departments such as Town Planning and Smart City SPV to systematically promote and integrate urban cooling solutions. Effective monitoring and evaluation mechanisms to capture impacts and benefits of urban cooling actions are also lacking.

- Urban cooling solutions are commonly perceived as complicated and expensive due to low awareness amongst government authorities, potential users, and consumers.
- Targeted efforts are needed to address lack of awareness and technical capacity of the construction industry, architects, contractors, utility and service providers on adoption of sustainable cooling solutions in buildings and urban infrastructure.
- Urban cooling solutions such as high albedo materials, permeable surfaces, reflective surfaces are not considered in the planning and procurement of built and service infrastructure such as urban roofs, walls, roads and pavements. Similarly, opportunities to develop vertical surfaces of bridges, flyovers, façades of government and institutional buildings as green or cool walls are not tapped into. This results in lock-in of technologies and materials within urban infrastructure and areas that do not address urban heat effectively.
- Adoption of Transit Oriented Zone (TOZ) principles near the BRTS corridor has resulted in high-rise buildings and dense development (given the higher FSI) in the west zone of the city. It is observed that the buildings therein are typically constructed on small parcels of land, also owing to the high cost of land. The type of development prevalent in this rapidly developing area can potentially act as a barrier to wind-induced air flow and inhibit natural cooling.
- Penetration of mechanical cooling (i.e., air conditioners) to improve thermal comfort in buildings is increasing. Waste heat generated from accelerated penetration of air conditioning in buildings can pose a significant challenge and contribute to increased heat levels at the building and neighbourhood scale. However, limited recognition of this issue and its impacts exists amongst building occupiers and consumers in particular.
- The city lacks successful pilot project examples to showcase to the consumers and developers for promoting urban cooling solutions. RMC does not have projects, both at the neighbourhood and the building scale, which can demonstrate adoption of passive as well as active cooling solutions and increase stakeholder awareness.

• Low willingness of consumers and developers to adopt sustainably cooled green buildings and real estate projects

- Construction of green buildings that address thermal comfort has been largely limited to government backed affordable housing projects in the last two to three years. This indicates lack of willingness from private developers to implement certified green/energy efficient buildings in their real estate projects.
- There is no demand for green and energy efficient buildings from the consumer side, given that buyers generally consider initial costs in purchasing decisions. Awareness on cooling solutions and their monetary and non-monetary benefits is lacking and these are perceived to have higher initial capital cost, making it difficult to secure consumer confidence. Benefits and costs savings accruing from adoption of building-level cooling measures are realized at a later stage over the building's operational lifetime and not considered by buyers/occupiers, who are not willing to pay additional upfront costs for such benefits.



- Developers do not necessarily have a mandate to ensure long-term sustainability of a building and are not as concerned with thermal comfort and associated energy costs that are realized post-construction, resulting in less motivation to pursue cooling measures and achieve energy efficiency.
- Buildings and land plots, particularly in the core areas of Rajkot that are already developed are poorly maintained and structurally weak. Undertaking retrofits to integrate urban cooling strategies and solutions in such areas would require bringing all the associated stakeholders on board which can be challenging.
- Roof areas of most buildings are typically either used as living spaces or utilised for common amenities and utilities. Common open areas of residential and commercial projects are generally used as parking spaces. Such prevalent conditions and practices leave limited space that can be utilized for the development of green spaces and solutions that aid cooling.
- Poor operation and maintenance practices in buildings pose a challenge towards sustenance of urban cooling interventions and realizing long-term benefits thereof.

• Inadequate financial support for adoption of cooling solutions

- Building-level cooling strategies are included in voluntary green building certifications such as GRIHA and IGBC as well as in mandatory standards such as ECBC and Eco-Niwas Samhita. However, adoption of such strategies increases the investment and capital cost of real estate projects.
- To promote green and energy efficient buildings, RMC offers incentives in the form of 5% discount in the chargeable FSI²⁰ for certified green buildings. The chargeable FSI represents additional FSI (floor space allowance essentially) that can be purchased by developers by paying a certain charge. In Rajkot, this additional chargeable FSI can be availed by paying 40% of the jantri rate²¹, a government published minimum land rate which is applicable to the corresponding area of the city. It was noted that the existing level of incentives are insufficient to cover the additional capital expenditures incurred by developers to follow green building guidelines and standards and implement cooling solutions. There is a need to provide fiscal/monetary benefits that sufficiently incentivize developers and adequately reflect additional costs incurred by them at market rates.
- Limited information exists in the local context as well as at the state-level on urban cooling solutions and technologies and associated benefits. This poses challenges in monetizing the benefits possible from adoption of urban cooling solutions, e.g., increased green cover, cool roofs, permeable surfaces, which makes it hard to attract private capital and external financing for implementation of urban cooling projects at-scale.

²⁰ The GDCR guides and regulates development through land use zoning, density, floor space index (FSI). The Base FSI is FSI which is permissible for different zones and is defined by the GDCR. In certain zones, developers can avail additional FSI by pay a certain charge depending on the zone. Chargeable FSI is offered to encourage development in underutilized areas and redevelopment in brownfield areas. The maximum permissible FSI is a sum of permissible FSI and chargeable FSI.

²¹ Jantri rate (Jantri of Gujarat Land Value Certificate) is a legal document that specifies land costs (minimum) for different areas. The Gujarat government regularly sets unit rates for land to inform and guide various stakeholders. Many times these rates are not at par with the market prices and are significantly lower, representing the minimum land value.

• To address financial barriers, RMC will have to ensure sustained financial support and allocation towards urban cooling efforts is provided through its municipal budget, which is lacking at present.

3.6.1 Suggested actions to address the barriers

UHI is a local phenomenon, and its characteristic can differ across neighbourhoods based on land use, population density, built environment, micro-climate, air quality, blue and green cover, etc. This requires contextual solutions for reducing the UHI effect and promoting sustainable cooling.

An enabling environment starting from policy support, governance and enforcement structures, awareness, technical understanding and financial incentives are important to address the UHI effect. Key actions to address the barriers to urban cooling in Rajkot are noted below.

Identified barrier	Suggested Actions
Lack of technical studies and coordination mechanisms to address UHI effect	 RMC can undertake a heat mapping study to identify temperature trends and heat islands across its wards, and determine contributors and possible solutions. Such a study will enable identification of urban cooling strategies and solutions, and help guide actions and planning for brownfield and greenfield developments and built spaces in a targeted manner. RMC is undertaking a source apportionment study through utilization of 15th Finance Commission's grant for improving air quality. This study will help further identify information about pollution sources and their contribution to ambient air pollution. Outcomes of the study such as findings related to the location of pollution sources and hotspots can be analysed together with ambient temperature data recorded through RMC's network of temperature sensors to identify correlation and drivers for urban heating. RMC has mapped ward-wise density of trees at the city level. Temperature sensors are in place at 20 locations in the city. RMC can overlay the information on temperature and green cover and regularly update this analysis to help identify future locations and design of green cover and open spaces such as parks. City administration needs to play the role of an anchor to motivate and enable coordinated action amongst all the stakeholders. RMC should strengthen coordination with other public/semi-public institutions and departments that govern planning and operations of industrial areas and special zones in and around Rajkot city, which are not directly under RMC's purview but can significantly influence and contribute to the city's efforts on urban cooling.

Table 7: Suggested Actions to address barriers to urban cooling

Identified barrier	Suggested Actions
Lack of dedicated policy focus and enforcement mechanisms	 Several national and state level policies, programmes and schemes being implemented in the city directly or indirectly support actions that address urban heat. However, such actions are implemented in silos. To establish and leverage linkages amongst the implementation of such policies and programmes, a coordination/technical support team shall be established within the RMC. This technical team can analyse and suggest urban cooling actions to be considered in a coordinated manner in the implementation of different policies and programmes. Adopting urban cooling strategies through land use planning processes and practices is a key enabling action to tap into opportunities and mainstream such strategies at the city-scale. Preparation of Town Planning schemes is under the purview of the local government, wherein cities can plan land use at the micro level. With the expansion of Rajkot's city area and future development, additional town planning schemes will be finalized and implemented in the coming years. At the conceptualization and planning stage of such development. Green areas can be located based on the expected heat generation considering the UHI effect, from the surrounding urban spaces as well as that anticipated from the future development. Green areas can be located based on the expected heat generation considering the built environment, land use, density, surfaces and traffic patterns. Guidelines can be prepared for identifying and locating blue and green cover/infrastructure in Town Planning schemes, new developments and redevelopments, in a manner that addresses the UHI effect of the said area. The guidelines should also direct and support the RMC in fractoring in urban heating island effect when planning and establishing green cover and parks through its municipal budget, and infrastructure programmes and schemes. As per the development regulations (GDCR), residential and commercial developments of more than 2000 sq. m size must have a

²² Common plots can be utilised for electric/power infrastructure, water tank and pump room, parking spaces as per GDCR.

Identified barrier	Suggested Actions
	 reserved and developed as recreational open spaces (City And Industrial Development Corporation Of Maharashtra Limited, 2016). The GDCR can be similarly updated to include specific provisions to reserve and include recreational green spaces in common plots of residential and commercial developments. RMC shall ensure that all new buildings follow the requirements in the GDCR for establishment of green cover, at a minimum. RMC shall also ensure that plantations at such new developments are monitored regularly. There is a need to appropriately document and undertake continuous monitoring of the type of buildings being constructed and utilization of built spaces, post finalization of land use.
Lack of technical awareness and proven pilots on urban cooling	 Given that RMC plays the role of planner, controller and implementer of urban planning and building development within its jurisdiction, training and capacity building of technical staff from such departments is very crucial to integrate urban cooling strategies in its planning processes and frameworks and to disseminate awareness on the same. RMC can bring on-board various stakeholders such as builders association, architects and designers association, technical institutions, residential associations and establish one urban cooling working group which would work together to generate awareness on cooling solutions through trainings, campaigns and IEC activities. There is a need to promote passive cooling solutions and address impacts of rising waste heat from air conditioning units. Actions must be planned to spread awareness on cooling strategies such as reflective roofs, green cover, reflective materials, and permeable surfaces. RMC shall consider adoption of cooling solutions (e.g., reflective roofs and walls, green roofs, design for passive cooling) in upcoming municipal buildings to pilot and showcase interventions and to generate awareness. Subsequently, RMC can target large projects initially (for example projects with 500 or more residential units) to adopt and successfully implement cooling recommendations, which can then be widely enforced as a next step. Technical assessments on district cooling technology in Rajkot

have shown that district cooling is commercially viable for high

Identified barrier	Suggested Actions
	density commercial use centric development and can deliver significant benefits to consumers. The city has looking to adopt district cooling technology in its Smart city area. Information and findings from district cooling assessments can be disseminated with state government institutions, local developers and architects for consideration of the technology in future development projects.
Low willingness of consumers and developers to adopt sustainably cooled green buildings and real estate projects	 RMC can undertake awareness campaigns to educate citizens on the heat island effect and solutions to address the same at the building scale. Enhancing understanding of property buyers/occupiers on direct and in-direct benefits accrued in the long-term related to energy savings, air quality, improved thermal comfort, human health can foster increased willingness and market demand for sustainable buildings. Knowledge materials that quantify energy and cost savings realized from implementation of various solutions can be prepared for dissemination. Land cost is very high in Rajkot due to which the proportion of building construction cost in the overall project cost is low as compared to other cities. This scenario offers opportunities to adopt sustainable cooling solutions in buildings to a degree, without significant escalation in the overall cost of real estate projects and should be highlighted in outreach to developers and architects. Through the proposed urban cooling working group, RMC can prepare a guidebook on building and neighbourhood level solutions, steps involved for implementation, database of service/solution providers to support and enable adoption of cooling solutions.
Inadequate financial support for adoption of cooling solutions	• Existing incentives offered by RMC for green and energy efficient buildings through the GDCR are deemed by developers to be insufficient to enable financial feasibility for at-scale adoption of cooling solutions at the building scale. RMC should work collaboratively with stakeholders to identify mechanisms that appropriately incentivize adoption of sustainable cooling solutions in alignment with prevalent market conditions. The financial

incentives and mechanisms should be actively promoted by RMC

Identified barrier	Suggested Actions
	 to generate wider awareness and developers do not know about it. The existing incentives for green buildings (5% discount on chargeable FSI) can be availed once the building receives green building certification, which is typically after completion of construction. Thus, developers need to invest upfront capital and can avail incentives only after project completion which can take two to three years. Projects with green/energy efficient building precertification can be offered rebates and incentives such as
	relaxation in development charges, taxes or security deposit charges.
	• Instead of flat-rate incentives, discounts can be offered in an incremental manner in proportion to scale/extent to sustainable cooling actions implemented in projects.
	• Offering upfront incentives on pre-certification for green/energy efficient buildings will motivate developers to consider sustainable cooling solutions from the planning stage of projects.

4 Urban Heat Profile (Pan-city level)

Rajkot falls under India's hot and dry climatic zone. Rajkot has a semi-arid climate, with hot and dry summers. Rajkot experiences three distinct seasons of summer, monsoon and winter. The average maximum and minimum temperatures recorded over the last 40 years are 43.5°C and 24.2°C respectively. The average annual rainfall is 500 mm. However, the city has received lower than normal rainfall in 20 of the last 60 years. Summer season extends from the months of mid-March to mid-June, with temperature ranging between 24°C to 42°C and highest temperature in March. In the months of winter lasting from November to February, the temperature varies between 10°C and 22°C, resulting in pleasant winters.

In the summers, the temperature in the city rises from mid-February onwards and peaks in mid-May, with the average daily maximum temperature rising to 42°C. Based on data analysis from ASHRAE 2009, the average daily temperature of the city ranges from 20°C to 32°C. Rajkot city has hot and humid weather conditions for about 8 months in the year. Relative humidity is significantly high during the summer season, increasing from mid-May onwards, and continues to rise in the monsoon season during the months of July to October, peaking in mid-September. Average relative humidity in Rajkot is 60%. The humidity of 65% to 85% is noted in the months of June, July, August and September, which is above the annual average.

Analysis undertaken on the past trends of temperature and rainfall using the India Meteorological Department's (IMD) thirty-year gridded data as part of Gujarat State Action Plan on Climate Change, indicates an increase of 0.11°C in Gujarat state's mean maximum temperature over the period from 1969-2005 (Government of Gujarat, 2014). Based on analysis of data recorded by weather monitoring stations over the period from 1969-2008, the report further indicates that the increase in temperatures is higher over the Saurashtra region, wherein Rajkot is located, as compared to other regions of Gujarat.

Also, the soil of the entire Rajkot city area is broadly classified as medium black to shallow black. Thermal conductivity and magnitude of thermal diffusivity are considerably higher for black soil. Thermal characteristics of soil type may also be the reason for high surface temperature.

This study focuses on identifying Surface Urban Heat Islands by analysing satellite imagery and identify various causes of variation in surface temperature. Results of surface temperature analysis were correlated with land use, built up, vegetation cover, water bodies etc. Based on detailed analysis of temporal variation in land surface temperature and surface temperature profile of May 2020, various hot spots²³ and cool spots²⁴ are identified for further thermal analysis through drone. This study will provide further information on type of building materials used along with albedo and emissivity.

Atmospheric Urban Heat Islands are identified for three seasons (winter, summer and monsoon) for day and night time by analysing air temperature information received from environmental sensors installed by RMC at 18 locations. Results of atmospheric temperature analysis were correlated with surface temperature profile and air quality to identify probable reasons. Also, heat index is developed based on correlation between air temperature and humidity to know ward level 'feel like' temperature, which may support further to know the levels of thermal comfort in the city. (See Figure below)

²³ Surfaces having high temperature as compared with surrounding areas. Areas having surface temperature more than median of temperature for particular season and duration are considered as hot spots.

²⁴ Surfaces having lower temperature as compared with surrounding areas. Areas having surface temperature lower than median of temperature for particular season and duration are considered as cool spots.



4.1 Surface Urban Heat Profile

Satellite imageries of 30 x 30m resolution from Landsat 8 (day time at 5.30pm) and 500x500m resolution from MODIS²⁵ (night time at 11pm) have been used to analyse land surface temperature and Normalised Difference Vegetation Index (NDVI) for Rajkot. Temporal change (diurnal, seasonal and inter-annual) is also analysed during the study. Two durations of the day (i.e., day time and night time); three seasons (i.e. summer from March to June, monsoon from July to October and winter from November to February); and three years (i.e.2010, 2015, and 2020) are considered for this analysis.

All images of Rajkot city between January 2010 and December 2020 have been inspected from Landsat 8. Cloud and smoke free images across the city area have been considered for further surface temperature analysis. Based on analysis from 2010 onwards, January was considered to represent best scenario of winter while May and September²⁶ have been considered as representative summer and monsoon months respectively. Though temporal analysis has been done to identify the change in land surface temperature periodically, detailed analysis of year 2020 was considered as a baseline to identify hot spots and cool spots in the city.

4.1.1 Temporal change in land surface temperature

Surface temperature is a result of emissivity of surface area of various land use, various material used, blue and green infrastructure, and various anthropogenic activities. Temporal change in land surface temperature due to various planning and development activities was analysed from 2010 to 2020 by using satellite imagery and correlated with development pattern. Maximum temperature for day time

²⁵ Satellite image of 30X30m resolution from Landsat 8 for night time is not available. Satellite image of 500X500m resolution from MODIS was used for land surface temperature during night time.

²⁶ As satellite image for August month had cloud issues, September has been considered as monsoon month for further analysis.

(Figure 19) and night time (Figure 20) was analysed for 2010, 2015 and 2020 and compared with development of the city (Figure 17) and Normalised Difference Vegetation Index (Figure 18) for respective years. Based on analysis, it can be seen that the maximum land surface temperature during the day has decreased from 50°C in 2010 to 46°C in 2020, while minimum temperature has increased from 27°C in 2010 to 29°C in 2020. It is also noticed that the land surface temperature of barren land is highest as compared to other built-up areas (Figure 19). Higher surface temperature of barren land is due to shallow and medium black soil type in Rajkot, which has high thermal conductivity and diffusivity. Due to this thermal characteristic of black soil, barren land in Rajkot absorbs heat faster than other surfaces during day time and releases heat faster and gets cooler during night time.

As city is developing in western and southern side, land surface temperature is decreasing in those areas, as barren land is converted to various built-up forms (Figure 17). Also, very less changes in vegetation cover is noticed between 2010 and 2020 (Figure 18). Surface temperature of various built-up form depends on land use, density, material used, type of roofs, paved/ unpaved surface, change in NDVI, anthropogenic heat sources etc. Different types of building and surface material used in the city can store more heat during the day time and emit or radiate heat during the night time, depending on specific heat values. This can be observed from maximum land surface temperature during the night time, where built up areas are hotter than barren land, considering heat emission values (Figure 20). Clear relationship between built up areas, NDVI and land surface temperature can be noticed in Figure 17, 18 and 19.

Based on analysis, it can be seen that the maximum land surface temperature during night time has increased from 31°C in 2010 to 32°C in 2020, while minimum temperature has increased from 27°C in 2010 to 29°C in 2020. Year 2020 is considered as a base year for further analysis under this study.



Figure Development in Rajkot for 2010 (left), 2015 (middle) and 2020 (right)

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Figure Normalised Difference Vegetation Index for 2010 (left), 2015 (middle) and 2020 (right)



Figure Day time Maximum Land Surface Temperature for 2010 (left), 2015 (middle) and 2020 (right)



Figure Night time Maximum Land Surface Temperature for 2010 (left), 2015 (middle) and 2020 (right)

4.1.2 Seasonal vegetation cover and land surface temperature

There is strong correlation between vegetation cover and land surface temperature. Seasonal change in vegetation cover is important factor that influences land surface temperature. Under the same weather conditions, barren land will have higher surface temperature as compared to sparse or dense vegetation cover. As year 2020 is considered as a baseline year, seasonal variation in NDVI and land surface temperature for year 2020 (winter, summer and monsoon) is considered for further analysis. Variation in NDVI for Rajkot is shown in Figure 21, which shows the highest NDVI in monsoon followed by winter and summer.

There is a clear relationship between vegetation cover and corresponding land surface temperatures as shown in the maps (Figure 22). As per comparative analysis of the cities NDVI maps for 3 seasons in year 2020, it comes out as the green cover is reduced during summer, resulting as more barren land is being exposed. Considering the high thermal conductivity and magnitude of thermal diffusivity of black soil in Rajkot, surface temperature is observed to comparatively higher in barren land during the day time (in Rajkot's peripheral area) as compared to the land having tree cover or different types of building roofing material like concrete, UPVC sheet and ceramic stone (in the central part of Rajkot city) (Figure 22). At the other side, considering high emissivity of developed surfaces of different types of building roofing material (i.e., central part of the city), surface temperature is higher during the night time as compared to barren land (i.e. peripheral area) (Figure 23). Analysis shows that the maximum surface temperature in summer for year 2020 is 45°C, as compared to 31.17°C in winter and 32.44°C in monsoon. Surface temperature of barren land is varying from 42°C to 46°C as compared to surface temperature of sparse vegetation cover (33°C to 39°C) and surface temperature of water body (~29°C) (lowest).

Considering hot and dry summer in Rajkot, land surface temperature for summer (May month) is used to explore hot spots (consistently higher land surface temperature as compared with median), cool spots (consistently lower land surface temperature as compared with median) and urban features associated with this temperature.


Figure Day time Land Surface Temperature for winter 2020 (left), summer 2020 (middle) and monsoon 2020 (right)

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Figure Night time Land Surface Temperature for winter 2020 (left), summer 2020 (middle) and monsoon 2020 (right)

4.1.3 Surface level hot spots (Pan City)

Identification of urban features associated with thermal 'hot spots'²⁷ and 'cool spots'²⁸ can support to frame appropriate urban cooling strategies. As May is the hottest month for Rajkot, surface temperature of May 2020 (day time) has been considered for further analysis and identification of hot spots. Considering maximum (45.75°C) and minimum (28.62°C) land surface temperature in May (See Figure 22), median has been calculated based on satellite imagery by using pixel-based statistics. 39.5°C is the median for land surface temperature in May 2020.

Areas with land surface temperature above the median are considered as hot spots (See Figure 24) and areas with land surface temperature below the median of 39.5°C were considered as cool spots (See Figure 25). In Rajkot, hot surface temperatures can be found in extensive bare ground (peripheral area), which cools down quickly at night.

Areas with hotter surface temperatures include (other than barren land parcels):

- Small scale industrial plots i.e., Lati plot
- Major industrial areas i.e., Aji industrial estate, Shri Hari industrial estate, Parshuram industrial area, Mavdi plot industrial area etc.

²⁷ Locations with land surface temperature that is consistently higher as compared to the median surface temperature of 39.5°C

²⁸ Locations with land surface temperature that is consistently lower as compared with median surface temperature of 39.5°C

- Developing areas around major traffic junctions i.e., Kothariya and Vavdi areas around Gondal road and Ganteshwar area near Jamnagar highway
- Rajkot Airport with barrel ground and runway
- Marketing yard in east zone old buildings, temporary structures, storage and handling hub with little shade, large paving areas
- Ishwariya park, a large land parcel with some barren land



Figure Land surface temperature (LST) 'hot spots' and examples of areas and characteristic

4.1.4 Surface level cool spots (Pan City)

'Cool spots' are the areas having lower land surface temperature as compared with other areas of the city in same weather condition. Areas with land surface temperature below the median of 39.5°C were considered as cool spots in the city for May 2020 (Figure 25). Areas with cooler land surface temperature are usually water bodies, sparse vegetation cover and dense green areas. Areas with shade cast by buildings or trees are also cooler.

Areas with cooler surface temperature include:

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- Areas covered with sparse vegetation
- Water bodies like natural water drain, Lalpari and Randarda lakes, Aji dam and three lakes in smart city area
- Urban forest area i.e. Ram van urban forest
- Green areas like race course (having large parcel of lawn grass)
- Developed areas with increased tree density per sq.km (mostly in ward 7,8,9,10,13, 14, 16, 17) as identified in Tree Density report of Rajkot
- Developed areas with tree density varying from 200 to 400 trees per sq.km (mostly in ward 14, 16, 17)



Figure Land surface temperature (LST) 'cool spots' and examples of areas and characteristic

4.1.5 Potential areas for thermal mapping through drone for material emissivity analysis

Based on analysis of hot spots and cool spots for May 2020, some potential areas are prioritised for further thermal analysis through drone. Thermal analysis through drone has supported to understand the micro level information related to land use, built up form, surface area type, various material used and emissivity of various material, blue and green infrastructure and various anthropogenic activities. Total four potential areas have been identified depending on time and resources allocated as shown in Figure 26 & 27. Few potential areas were not considered for thermal survey through drone considering its close proximity to 'drone flying prohibited areas' like; Airport, Research and Analysis Wing (RAW) office and IOC depot etc. Identified four potential areas includes diverse land use (i.e. residential, commercial, industrial, slums, traffic junction, green field development, water bodies, barren land,

green cover etc.), diversity of material used for various built up, higher and lower surface area temperature for same duration and season. Location of identified potential areas, type of built up form, and surface temperature are shown in Figure 26 & 27.



Figure 27 Location and type of potential areas for drone mapping (part A)



Figure Location and type of potential areas for drone mapping (part B)

4.2 Atmospheric Urban Heat Profile (Pan City)

While surface heat islands exist at ground/surface level, atmospheric heat islands are further divided into two layers 1) canopy layer heat islands and 2) boundary layer heat islands. Canopy layer UHIs are observed in the layers of air contiguous with dwelling spaces (from the ground up to the tops of trees and roofs), while the boundary layer UHIs extend from the rooftops and treetops up to the point where urban landscapes no longer influence the atmosphere (typically extend no more than 1.5 km from the surface). Only canopy layer urban heat profile is analysed under this study.

Hourly air temperature related information from 18 environmental sensors installed by RMC, at around 10 meter height above the ground, has been analysed for day time and night time and across the three seasons of summer, monsoon and winter for year 2020. Results of this atmospheric temperature analysis were correlated with average air quality index and surface temperature to identify hotspots. Atmospheric temperature for summer was further correlated with average humidity to develop heat index and estimate ward level 'feel like' temperature and level of thermal comfort.

4.2.1 Seasonal change in atmospheric air temperature

Seasonal change in atmospheric air temperature is shown in the Figure 27 (day time) and Figure 28 (night time). Maximum air temperature during the day time in the city is 42°C during the summer month of May) while the maximum temperature is observed to be 35°C in September during the monsoon season and 31°C in the winter month of January. The maximum air temperature during the night time stands at 26°C during summer in the month of May and 25°C in September during monsoon, falling to 16°C in January during the winter season. During mapping of hotspots, it emerged that while majority of surface temperature hotspots are located in the periphery of the city, mostly in the west, south-west and north-west side (Figure 24), atmospheric temperature hotspots are situated in the central and eastern side of Rajkot (Figure 27). Considering that the direction of wind flow locally is from west or south-west towards east or north-east (Figure 30), there is a possibility that heat transfer from surface temperature hotspots (west, south-west and north-west side) to the central and eastern side of the information of the stands at the direction of the central and eastern side contributes to their higher atmospheric temperature.

Areas with high density, heavy vehicular traffic, and industrial activities are also seen to have a higher atmospheric air temperature. Based on the air quality data from RMC's sensors across 18 locations, city level Air Quality Index (AQI) was also analysed (Figure 29). Results of air quality analysis shows a direct correlation between AQI and atmospheric air temperature. Some of the areas including Nana mauva circle, Madhapar chowk, Greenland chowk, Rajkot-Bhavnagar highway, Sorathiyawadi circle, Trikon bag, and Jilla panchayat chowk were observed to have high air quality index, owing to higher pollution levels, as well as high atmospheric air temperature compared to other areas.

Considering hot and dry summers prevalent in Rajkot, atmospheric temperature for summer (May month) has been used to explore hot spots and urban features associated with this temperature. Atmospheric temperature hotspots along with urban features associated with that area are further shown in section 4.2.2.

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Figure 27 Day time air temperature for winter 2020 (left), summer 2020 (middle) and monsoon 2020 (right)



Figure Air Quality Index (AQI) analysis for winter 2020 (left), summer 2020 (middle) and monsoon 2020 (right)



Figure Wind rose plot for Rajkot

4.2.2 Atmospheric temperature hotspots

In Rajkot, the correlation of areas with the atmospheric temperature hotspots highlighted those areas having major traffic junctions, new development with significant construction activities, high air pollution levels, high density, and prominence of commercial and industrial activity have Higher atmospheric temperatures and the areas are:

- Major traffic junctions i.e., Madhapar, Trikon Baug, Mahila college chowk, Nana mava, Sorathiyawadi, Aji dam chowkdi, Deluxe chowk, Greenland chowk, Hospital chowk
- Developing areas with significant construction activities i.e., Nana mava, Madhapar, Morbi road
- Areas with high recreational activities i.e. Race course
- Areas with high density i.e., Jangleshwar area in ward 16
- Commercial and industrial areas i.e., Jilla panchayat chowk, Mahila college chowk,
- Small scale industrial plots i.e., Atika industrial area, Aji industrial area, Bhakti nagar
- Major roads and highways passing through the city i.e., Bhavnagar highway, Morbi highway, Kothariya ring road

From the analysis of hotspots and correlation with air quality and green cover, it can be seen that areas with tree canopy and water bodies in their vicinity have relatively lower night time air temperatures, potentially due to the cooling effect of such green and blue spaces as compared to areas with other urban features. For example, areas such as Race course, Jilla panchayat chowk, and Trikon baug are

surrounded by green cover and experience lower traffic, and thereby night time air temperatures in these locations are cooler as compared to major traffic junctions in Rajkot (See Figure 31 & 32).



Figure Atmospheric air temperature hotspots, May 2020 (Day time)

4.2.3 Heat index and 'feel-like' temperature

Heat index chart has been prepared for Rajkot city by using air temperature and humidity data received from local environmental sensors installed by RMC at 18 locations (Figure 33). The chart shows that 33°C temperature in summer will feel like 41°C with a relative humidity of 62%, while 30°C will feel like 35°C with a relative humidity of 71%. Feel-like temperature (also known as apparent temperature) is used to represent thermal comfort levels, and reflects how the temperature feels like to the human body when the effect of ambient relative humidity is combined with the air temperature (Website of National Weather Service, USA. Accessed October 2021).

Rajkot's heat index chart indicates that the city experiences heat conditions classified as 'extreme caution' and 'danger' during summer, posing increased risks of heat cramps, heat exhaustion or even heat strokes to the community. Correlation between air temperature, relative humidity and feel-like temperature is shown in Figure 34, with wards 4, 6, 7, 8, 11, 12, 13, 15, 17, 18 identified as critical wards in terms of thermal comfort.



Source: Prepared based on data received from environmental sensors & calculation by using Heat Index Chart from National Guidelines for Preparation of Action Plan – Prevention and Management of Heat Wave, prepared by NDMA in October 2019

Figure Heat index chart, Rajkot



Figure Average air temperature (left), average relative humidity (center), Feel like temperature (right) for May 2020

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4.3 Electricity Consumption for Cooling

As noted in the sections above, urban heat has been profiled at the city-level through surface temperatures, air temperature and feel-like temperature. To better understand implications of urban heat on Rajkot's space cooling demand and draw correlations, electricity consumption data has also been analyzed at the city-level. Information on annual and monthly electricity consumption has been gathered from the DISCOM. In 2020, city-wide electricity consumption was observed to be 81% higher during the summer season (78.3 million kWh) as compared to the winter season (43.21 million kWh), with space cooling expected to a significant driver of increased consumption.

Based on the information available on annual electricity consumption, cooling estimates have been further determined at the ward-level for residential and commercial buildings. The aggregated electricity consumption has been scaled down to the ward level, using proxy data on number of commercial and residential properties existing in a particular ward (received from the Property Tax department, Rajkot Municipal Corporation) and the approximated unit basis values of electricity consumption for every residential and commercial property/unit. Information with the city's Property Tax department was limited to number of properties and details on floor space, height, and density are not available.

To further estimate electricity consumption specific to cooling (i.e., proportion of space cooling consumption from the total electricity consumption), secondary data from a USAID and IIM-A study undertaken for Gujarat has been used. Surveys in this load research study found that space cooling accounted for 22.6% of the total electricity consumption for residential units, while the share of space cooling consumption goes up to 45% for commercial units. Thereby, ward-level approximations of electricity consumption (kWh basis) for space cooling of residential and commercial properties have been worked out. Considering the above proportion, city-wide electricity consumption for space cooling and air conditioning by residential buildings is estimated to be about 159 million kWh and 114 million kWh respectively in 2020-21. Similarly for commercial end-users, electricity consumption for space cooling is estimated to be about 277 million kWh, with as much as 228 million kWh consumed by airconditioning in 2020-21.

The cooling consumption analysis indicates that high density wards (wards 3, 7, 11, 18) with high/ moderate surface temperature and high feel-like temperature also have high electricity consumption for space cooling. Ward 7 is estimated to have the highest electricity consumption for space cooling. This ward is a very dense commercial area, with 64% commercial properties and less residential buildings, and also has the highest feel-like temperature in the city.

4.4 Correlation Analysis for Space Cooling

This section captures key information on city and ward level cooling consumption as well as urban heat for Rajkot city. Given the absence of information on electricity use for space cooling, consumption figures have been estimated based on secondary studies and appropriate assumptions. Given the limited information available for space cooling and spatially accurate information on urban heat island, projections of cooling consumption and urban heat island are not possible for Rajkot. Information on city-wide electricity consumption from residential and commercial consumers was collected from the local DISCOM. Total electricity consumption in the residential sector amounted to 735.93 million kWh for year 2020, while the commercial sector used 616.21 million kWh of electricity in 2020. Information on space cooling demand as well as for electricity consumption specifically for cooling is not available, both at the ward-level and city-wide. Such disaggregated information is not metered and thereby not recorded in electricity consumption figures available.

Electricity consumption data is also not recorded for each administrative ward in the city. To scale-down city-wide aggregated electricity consumption to the ward-level, proxy data on number of properties existing in a particular ward has been used. Ward-wise electricity consumption has been estimated based on the corresponding number of residential and commercial properties in the ward and using the approximated average values of electricity consumption for every residential and commercial unit. Electricity consumption for space cooling in residential and commercial buildings has subsequently been estimated using secondary information on proportion of space cooling load in their total electricity consumption.

To identify ward level electricity consumption, information on residential and commercial properties across the city's wards was collected from the property tax department of Rajkot Municipal Corporation. There are 410,374 residential properties and 129,948 commercial properties in total in the city. Total electricity consumption from residential and commercial properties in each ward was approximately estimated²⁹. While electricity consumption will vary across homes due to factors such as income-levels, household size, type and scale of built structure, the high level estimated undertaken assumed that average electricity consumption from one residential property remains constant across wards. Information that captured number of households disaggregated by income group/levels was not available at the ward level. Similar rationale was used to estimate electricity consumption at the ward-scale for commercial buildings.

Given the lack of localized and specific data to identify electricity consumption for space cooling, secondary data from space cooling studies carried out for Gujarat has been used. Average space cooling load out of the total electricity consumption for residential buildings is 22.6%, while it is 45% for commercial buildings as per the load research survey conducted by USAID and IIM-A for Gujarat state (IIM Ahmedabad, 2010). These numbers are used for further analysis and calculating ward level space cooling consumption from residential and commercial properties. Relationship between surface temperature profile, feel-like temperature and estimates of electricity consumption for space cooling is shown in the table below. Analysis shows the average of property density (residential and commercial) in the city is 4,985. Also, average of estimated total electricity consumption for space cooling in residential and commercial properties per ward is 25 million kWh.

²⁹ For example, total electricity consumption from residential properties in particular ward is estimated by multiplying the total number of residential properties in the ward with average electricity consumption of a single residential property (unit basis). Similar calculation was done to estimate ward level electricity consumption from commercial properties

Table 8: Estimates o	f electricity co	onsumption	from s	bace cooling and	comparison with su	rface tem	perature p	profile and	feel-like tem	perature
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Ward Numbe r	Area of ward (sq. km)	Total no. of residential properties	Total no. of commercial properties	Property density ³⁰ (properties/ sq. km)	Estimated total electricity consumption for space cooling in residential and commercial properties (Million kWh/ year)	Development characteristic of the ward	Surface and Feel Like Temperature
1	19.0	36,227	5,846	2,214	27.16	Developing area with low density, 86% residential properties (MIG and HIG) and 14% commercial properties. Significantly high electricity demand for space cooling as compared to average, with low property density.	Highest surface temperature (44°C) with high feel like temperature (39°C) and less vegetation cover
2	5.41	18,558	4,037	4,177	16.14	Developed area with medium property density and dense tree cover, airport, 82% residential (MIG and HIG) and 18% commercial properties. Significantly low electricity demand for space cooling as compared to average.	Moderate surface temperature (39°C) With low feel like temp. (37.5°C) due to dense tree cover
3	21.8	32,450	7,036	1,811	28.17	Very low property density, developing area, residential (EWS, LIG and MIG), commercial along the roads. Relatively high electricity demand for	Highest surface temperature (44°C) due to barren land, moderate

³⁰ Includes both, residential and commercial properties

Ward Numbe r	Area of ward (sq. km)	Total no. of residential properties	Total no. of commercial properties	Property density ³⁰ (properties/ sq. km)	Estimated total electricity consumption for space cooling in residential and commercial properties (Million kWh/ year)	Development characteristic of the ward	Surface and Feel Like Temperature
						space cooling as compared to average, with low property density.	feel like temp. (38.5°C) and less vegetation cover
4	11.1	28,351	5,130	3,016	22.44	Rapidly developing area with low density, Rajkot- Morbi highway, Bhagwatipara area with EWS, LIG and MIG households, commercial along the roads.	Medium-High surface temperature (39 to 41°C), high feel like temperature (40°C), moderate green cover
5	5.73	13,957	4,081	3,148	14.37	Low density area with EWS and LIG housing, small scale industries, dense green area i.e. Pradyuman park and lakes, marketing yard, RTO. Significantly low electricity demand for space cooling as compared to average.	Comparatively low surface temperature (33 to 36°C), lowest feel like temperature (37°C) due to dense green cover and water body
6	6.15	15,429	5,008	3,323	16.94	Low density area with LIG and lower MIG housings, commercial areas and small-scale industries (industrial area). Significantly low electricity demand for space cooling as compared to average.	Moderate surface temperature with moderate feel like temperature (38°C)

Ward Numbe r	Area of ward (sq. km)	Total no. of residential properties	Total no. of commercial properties	Property density ³⁰ (properties/ sq. km)	Estimated total electricity consumption for space cooling in residential and commercial properties (Million kWh/ year)	Development characteristic of the ward	Surface and Feel Like Temperature
7	4.24	18,993	33,141	12,296	78.42	Very dense commercial area with 64% commercial properties - highest in the city (around trikon bagh). Significantly high electricity demand for space cooling as compared to average (highest in the city).	Moderate surface temperature (38 to 41°C) with highest feel like temperature (42°C)
8	3.96	20,451	6,668	6,848	22.52	Moderately dense area with mixed land use, residential (higher MIG and HIG), high commercial activity around KKV chowk. Relatively low electricity demand for space cooling as compared to average, with high property density.	Comparatively low surface temperature (35 to 38°C) with moderate feel like temperature (39°C)
9	12.7	30,665	7,118	2,975	27.62	Low density area with institutions, residential (MIG and HIG) and commercial around university road and sadhu vasvani road. Relatively high electricity demand for space cooling as compared to average, with low property density.	High surface temperature (40 to 42°C) with moderate feel like temperature (38.5°C)

Ward Numbe r	Area of ward (sq. km)	Total no. of residential properties	Total no. of commercial properties	Property density ³⁰ (properties/ sq. km)	Estimated total electricity consumption for space cooling in residential and commercial properties (Million kWh/ year)	Development characteristic of the ward	Surface and Feel Like Temperature
10	4.75	25,181	6,488	6,667	24.05	Moderately dense area with mixed land use, premium residential (higher MIG and HIG), high commercial activity around Nana mava chowk. Relatively low electricity demand for space cooling as compared to average, with high property density.	Low surface temperature (35 to 38°C) with moderate feel like temperature (38.5°C)
11	18	36,470	7,362	2,435	30.49	Developing area with large scale township projects (i.e. Ambika MIG and HIG township) and commercial complexes. Relatively high electricity demand for space cooling as compared to average, with low property density.	High surface temperature (40 to 43°C) with high feel like temperature (39.5°C)
12	11.3	29,256	6,927	3,202	26.64	Newly developing area with LIG and MIG households, commercial, small- scale industries at Vavdi and Mavdi. Relatively high electricity demand for space cooling as compared to average, with low property density.	High surface temperature (40 to 43°C) with high feel like temperature (40°C)

Ward Numbe r	Area of ward (sq. km)	Total no. of residential properties	Total no. of commercial properties	Property density ³⁰ (properties/ sq. km)	Estimated total electricity consumption for space cooling in residential and commercial properties (Million kWh/ year)	Development characteristic of the ward	Surface and Feel Like Temperature
13	3.69	17,393	8,335	6,972	24.84	Moderately dense area, LIG and MIG residential housing, commercial, small-scale industries i.e. Mavdi plot industrial area, Atika industrial area.	High surface temperature (40 to 43°C) with very high feel like temperature (41°C)
14	2.64	15,031	5,362	7,725	17.53	Moderately dense area, LIG and MIG housing, commercial along the road (around Sorathiyawadi circle). Very low electricity demand for space cooling as compared to average, with high property density.	Moderate surface temperature (39 to 41°C) with low feel like temperature and moderate tree cover
15	8.07	13,250	3,437	2,068	12.70	LIG and MIG housing with moderate commercial area, Aji industrial estate	High surface temperature (39 to 41°C) with high feel like temperature (40.5°C)

Ward Numbe r	Area of ward (sq. km)	Total no. of residential properties	Total no. of commercial properties	Property density ³⁰ (properties/ sq. km)	Estimated total electricity consumption for space cooling in residential and commercial properties (Million kWh/ year)	Development characteristic of the ward	Surface and Feel Like Temperature
16	1.79	13,798	2,738	9,238	11.43	Highly dense area, majorly LIG and MIG housing around Jangleshwar area. Significantly low electricity demand for space cooling as compared to average, with high property density.	Moderate surface temperature (39 to 40°C) with moderate feel like temperature (38.5°C)
17	2.06	15,373	4,597	9,694	16.04	Dense area with MIG housing and commercial activities around Kothariya main road; small scale industries in Bhakti Nagar. Significantly low electricity demand for space cooling as compared to average, with high property density.	Moderate surface temperature (39 to 40°C) with high feel like temperature (39°C)`
18	18.9	29,541	6,637	1,914	26.14	Low density area with LIG, MIG and HIG apartments, commercial complexes, and industries. Comparatively high electricity demand for space cooling as compared to average, with low property density.	High surface temperature (40 to 43°C) with high feel like temperature (40.5°C)

5 Neighborhood Scale Assessment of Identified Hotspots

5.1 Site Selection for Drone Mapping

Based on the analysis of hot spots and cool spots for May 2020, some potential areas in Rajkot city have been identified to undertake thermal analysis through drone, in order to understand micro level information related to land use, built up form, surface area type, various material used and emissivity of various materials, blue and green infrastructure, and various anthropogenic activities. From the list of potential areas, four areas in total were prioritized for this micro-level thermal mapping and analysis as shown in Figure 35. Some of the potential areas initially identified were not considered for thermal survey through drone, considering their close proximity to locations with prohibitions on flying drones such as Airport, Research and Analysis Wing (RAW) office, and Indian Oil Corporation (IOC) depot. The four areas selected for drone surveys included diverse land use (i.e., including residential, commercial, industrial, and green field development, slums, traffic junction, water bodies, barren land, and green cover), had diversity in materials used for various built spaces, and varied range of surface area temperatures for the same duration and season. Two-dimensional mapping of identified locations through drone mapping. Location of identified priority areas, type of built-up form, and surface temperatures recorded are shown in Figure 35³¹. Reflectivity index maps for roofs of buildings have also been prepared for the neighborhood areas, with roofs that use high reflective surfaces and that are thereby comparatively cooler depicted in blue color while roofs with low reflectivity and that are relatively hotter marked in red color (Annexure 1). Reflectivity maps have not been prepared for the Smart City area wherein no built footprint exists currently. High-level estimates of existing space cooling demand have been prepared for three of the neighborhoods based on total building footprint captured through drone mapping as shown in Figure 35, with the exception of the greenfield Smart City area that does not have any buildings currently and determination of cooling estimates is not possible with available information.

³¹ Existing cooling demand is estimated by using 290 sq. ft / TR factor as suggested in General Specifications For Heating, Ventilation & Air-Conditioning (HVAC) Works (2017), CPWD and National District Cooling Potential Study for India, March 2021



Figure Locations selected for thermal analysis through drone

1.1 Site 1: Smart City (Green Field)



About the area:

Total Area: 1.15 sq. km (Land use: Built up – 0%, Green area – 37%, Open area and water body – 63%)

Built up forms: Green field area with water body and open plots

Surface Thermal Profile:

Figure 37: Smart city (green field area) - Built up vs. surface temperature

1.1.1 Smart city area - Correlation between surface temperature and materials found in the area Thermal profile of the area was assessed in relation to various materials found in the area. Surface temperature of the water body³² is observed around 26°C to 27°C. As this green field area is still being developed, existence of materials used for built spaces is limited and thereby corresponding thermal analysis is limited. Due to ongoing construction activities at this site, various construction materials including metal sheets (recorded surface temp. of 39°C), cement piles (recorded surface temp. of 38°C) and clay piles (recorded surface temp. 35°C) were found during the survey. The area has a lake with

³² Surface temperature of water body is measured separately as thermal sensor mounted on drone was showing false temperature results due to reflection of sunlight in water body.

stone pitched surface around its periphery³³. Surface temperatures of the stone pitching around the lake and stone paving on the roads was observed to vary from 38°C to 39°C (See figure 37).



Figure Types of material used and surface temperature for Smart city (green field area)

³³ A stone pitched surface is hard-wearing stone surface using large stones, set into to provide a reasonable surface. Stone pitching consists of medium sized rocks set into the ground like rough cobble stones and is used around drains and artificial water bodies to prevent erosion and overflow.

1.2 Site 2: East Zone (Patel Vadi)

About the area:

Total Area: 0.37 sq. km with 11.6 km road length (Land use: Built up – 49%, Green area – 12.4%, and Others (includes roads, open land, and railway) – 38.6%)

Built up forms: Residential development (mainly mid-income and high-income group households located in the central part of the area and low-income groups present on the western part), Commercial development (along the roads), dense green cover existing in isolated/small patches and a public park, very few trees located along the road side and in different parts of the site.

Thermal Profile:

Surface temperature range: 29°C to 40°C with a median of 37°C (highest median surface temperature as compared to other three identified areas for drone mapping). This area was identified as a cold spot area based on the high-level land surface temperature mapping (see Figure 35).

Micro-level thermal mapping revealed that the area is a hotspot, having the highest median temperature of the four neighbourhoods surveyed.

Around 10% of this area is found to be relatively cooler, with a temperature ranging from 29°C to 32°C, which is mainly due to existence of green spaces (including trees and public gardens). This area has the lowest extent of green spaces of the four areas surveyed. 77% of this area was identified as a hotspot having surface temperature above the median. Thereby, the East Zone is observed to have the highest proportion of hotspots amongst the four areas surveyed (See Figure 38). Area of building roofs having high reflectivity (relatively cooler roofs):



Figure East zone (Patel vadi) - Built up vs. surface temperature

1.2.1 East zone (Patel vadi) - Correlation between surface temperature and materials found in the area

In terms of land use, 80% of the built-up land parcels has been found to be residential (mostly midincome and high-income independent houses and duplexes) and the remaining 20% comprises of commercial use along the roads. Around 61% of the total area was observed to have a temperature ranging from 36°C to 39°C (which is highest proportion as compared to the other three areas surveyed), possibly given the lower tree cover and undeveloped open plots as compared to the other neighborhoods. Around 16% of the total area has surface temperature of more than 39°C, possibly due to the existence of rooftop solar PV (with surface temperature of ~40°C) on 10 to 12% of the households and commercial complexes. It should be noted that while surface temperature of solar panels recorded through the mapping exercise is high (around 40°C), drone analysis shows that panel installation offers benefits in terms of direct heat insulation and hence reduces the roof temperature by around 2°C. Red clay roof and reflective roofs (china mosaic, white tiles etc.) are observed to be predominant roof materials, with surface temperature of these materials varying from 36°C to 37°C (2°C to 3°C as compared to concrete roof). A number of households and commercial units located in this area use UPVC sheets (with average surface temp. of 36.5°C) and green matt (with surface temp. of 35.5°C) as roof materials for shading purposes. An animal hostel situated in the area uses galvanized iron sheet and metal sheets as roofs (average temp. 39.4°C). Analysis of various material used in hotspot or cold spot areas along with surface temperature is shown in Figure 39.



Figure 40: Types of material used and surface temperature for East Zone (Patel Vadi)

1.3 Site 3: Malaviya and Atika

About the area:

Total Area: 1.49 sq. km with 38 km road length (Land use: Built up – 43%, Green area – 20%, and Others – 37%)

Built up forms: Residential (comparatively old buildings located in the eastern part of the area and new buildings in the western part), Commercial (along the major roads), Small Scale Industries



Figure 41: Malaviya and Atika - built up area vs. thermal profile

1.3.1 Malaviya and Atika - Correlation between surface temperature and materials found in the area Of the total built up land parcel, residential land use accounts for 40% (including new/recently constructed independent houses and apartments in western part of the area). 40% of the built-up area consists of small-scale industries (Atika and Bhakti Nagar in eastern side of the area), followed by 10% towards commercial use (along the road) and 5% for institutional use (including educational institutes and hospitals). Around 62% of the total area is identified as a hotspot having surface temperature above the median (lowest proportion of hotspots among the four neighbourhoods). 29% of the area is observed to have surface temperature of more than 39°C (highest share of land parcel exceeding 39°C among the four areas surveyed), possibly owing to presence of rooftop solar PV (with surface temperature of ~40°C) on 20% of households and institutes in this neighborhood and predominant use of metal sheets as roofs in industries. Around 18% of this area is observed to be relatively cooler, having surface temperature in the range of 32°C to 36°C and lower than the area-wide median, which is due to availability of open plots, where temperature varies from 32°C to 35°C.

The analysis shows that blue/green/silver coated metal sheets (surface temp. ranging from 38°C to 41°C) and bitumen coated roofs (average surface temp. 39°C) are prominent materials used as roofs in small scale industries. Majority of the commercial, residential and institutional buildings are observed to have either white or reflective roofs (36°C to 37°C surface temperature), particularly in new buildings. While recorded surface temperature of solar panels is high (around 40°C), drone analysis shows that panel installation supports direct heat insulation and hence reduces the roof temperature by around 2°C. Analysis of various materials used in hotspot or cold spot locations along with corresponding surface temperature is shown in Figure 41.

Figure 42: Types of material used and surface temperature for Malaviya and Atika area



1.4 Site 4: Gondal Chowk and Mavdi

About the area:

Total Area: 1.04 sq. km with 30 km road length (Land use: Built up – 37%, Green area – 20%, and Others – 43%)

Built up forms: Residential (mostly new independent houses i.e. bungalows and duplex houses along with a few apartments), Commercial (along the roads), Small Scale Industries (eastern side of



Figure 43: Gondal Chowk and Mavdi - built up area vs. thermal profile

1.4.1 Gondal Chowk and Mavdi - Correlation between surface temperature and materials found in the area

60% of the built-up area comprises of residential land use (bungalows, duplexes and few apartments in the western part). Commercial development (along the highway) accounts for 20% of the built-up land parcel, with 8% to10% consisting of industrial use. Around 66% of the total area is observed to be a hotspot (surface temperature above the median) (second lowest extent of hotspots among the four neighbourhoods), with surface temperature in 24% of the area exceeding (highest proportion with surface temperature of more than 39°C of the four neighbourhoods). This is primarily owing to existence of rooftop solar PV in more than 20% of households and high use of metal sheets as roofs in small scale industries and as shading for parking spaces. Around 19% of this area is observed to be relatively cooler, with temperature ranging between 32°C to 36°C, which can be correlated to the existence of undeveloped open plots in the area.

As the area is developing, new residential houses (bungalows and duplexes) were observed in its western part, with use of reflective roofs (average surface temp. of 38°C), rooftop solar panels (average surface temp. 40°C), and UPVC sheet for parking area (average surface temp. 38°C) prominent. Also, construction activity in the area showed surface temperature ranging from 40°C to 41°C. Small scale industries are located in the eastern side of the area, with blue/green/silver coated metal sheets used as roof materials (surface temp. ranging from 40°C to 42°C) and galvanized iron sheets (average surface temp. 38.5°C). With regard to transport infrastructure, asphalt roads were observed to be hotter than reinforced cement concrete (RCC) roads, with the surface temperature of asphalt-based roads higher by 1°C. Average surface temperature at traffic junction is noted to be 38°C, which is 6°C to 7°C hotter as compared to dense tree cover area.

Low-income houses located in slums are unable to afford permanent roofs and were observed to use plastic banners/ sheets as roof material instead, having temperatures between 37°C to 38°C. While surface temperature recorded for such materials is 1°C to 2°C cooler than concrete roof, such non-permanent roof materials increase direct exposure to sunlight and thereby has health risks. Analysis of various materials used across identified hotspot or cold spot areas along with surface temperature is shown in Figure 43.



Figure 44: Types of material used and surface temperature for Gondal Chowk and Mavdi

5.2 Summary of materials used and corresponding surface temperatures

As part of this study, a neighborhood scale thermal assessment was conducted, based on recorded temperature data for May 2020. Based on analysis of hot spots and cool spots as part of this thermal assessment, select areas were identified and prioritized to undertake further detailed thermal analysis through drone. The drone-based thermal analysis aimed to capture and analyze micro level information related to land use, built up form, surface area type, various materials used and their emissivity, blue and green infrastructure and various anthropogenic activities. Four areas from diverse land use (i.e., including residential, commercial, industrial, and green field development, slums, traffic junction, water bodies, barren land, and green cover) were selected for the thermal survey through drone, with materials used for different built spaces, infrastructure and purposes captured. The drone mapping

helped to understand surface thermal profile of the surveyed areas and to analyze and compare surface temperatures for various materials across different uses in the four areas surveyed as listed in the Table below.

East zone (Patel wadi) has the lowest extent of green spaces of the four areas surveyed. 77% of this area was identified as a hotspot having surface temperature above the median of 37°C. Thereby, the East Zone is observed to have the highest proportion of hotspots amongst the four areas surveyed. A number of households and commercial units located in east zone, use UPVC sheets (with average surface temp. of 36.5°C) and green mat (with surface temp. of 35.5°C). The green mat acts as roof materials for shading purposes, which helps them to reduce effects of direct sunlight and has potential to reduce temperature by 2°C as highlighted in the Table. Smart city area is still being developed and due to that the existence of materials used for built spaces is limited and thereby corresponding thermal analysis is limited. As barren land parcels have direct exposure to sunlight, 70.5% of the area is assessed to be a hotspot area having surface temperature exceeding the median of 35°C, mainly due to direct exposure to sunlight. Going ahead 40% of the smart city area has been identified to develop green cover which would help to reduce hotspots of the area. Small scale industries in Malviya and Atika uses blue/green/silver coated metal sheets (surface temperature ranging from 38°C to 41°C) and bitumen coated roofs (average surface temperature 39°C), with higher temperature than the median temperature so, the use of either white or reflective roofs (36°C to 37°C surface temperature) should be promoted in all existing and upcoming new buildings. Transportation infrastructure in Gondal chowk and Mavdi area, highlighted that asphalt roads were observed to be hotter than reinforced cement concrete (RCC) roads, and with the surface temperature of asphalt-based roads higher by 1°C. Reflective paints, permeable pavements, plantation of trees along the roads would help to reduce overall temperature of the area. Vehicle congestion at the traffic junction increases overall AQI of that area. Average surface temperature at traffic junction is noted to be 38°C, which is 6°C to 7°C hotter as compared to dense tree cover area. Installation of mechanical sprinklers and dense plantation of trees in road dividers near to the junction, can help lower resulting heat stress.³⁴

Based on the micro-level drone surveys conducted at the four selected sites, a comparison of average surface temperatures recorded for various types of materials across different land uses and purposes is listed in the table below. Use of reflective roofs (i.e., china mosaic, white ceramic tiles/ stone roof etc.) is observed in new residential and commercial developments/properties. The reflective roofs have average surface temperature of 36°C to 37°C, which is ~2°C cooler as compared to concrete roofs (average surface temp. of 39°C) and older concrete roofs observed in some areas (surface temp. of 40°C to 41°C). Considering the cost to replace the existing concrete roof with reflective surface roofs, application of reflective white paint can be a good option to achieve cooler roof surfaces. Reflective white paint can reduce the roof temperature by 3°C to 4°C as compared to concrete roof. Similarly, it was found that many properties are using green mat on the roof for shading purpose. Shading from the green mat is observed to bring down temperature of the roof to around 34°C to 34.5°C. During the analysis, it is also observed that many of the buildings (particularly bungalows and duplex houses and few commercial buildings) have installed solar panels on the roof, with surface temperature of solar

³⁴It should be noted that while surface temperature of solar panels recorded through the mapping exercise is high (around 40°C), drone analysis shows that panel installation offers benefits in terms of direct heat insulation and hence reduces the roof temperature by around 2°C.

panel recorded at around 40°C. While the surface temperature of the panels is higher, given that solar panels are installed over a certain height above the roof surface, these provide shading to the roof and supports a reduction of about 2°C in the roof temperature.

Blue/Green/Silver coated metal sheets and Galvanized Iron sheets were prominent materials used in roofs of small-scale industries and some of the commercial establishments, followed by bitumen coated roofs, with average surface temperatures of these materials ranging from 39°C to 40°C. These industrial areas and surfaces are comparatively hotter than other areas, and thereby require attention to adopt appropriate cooling solutions.

The road network in the surveyed areas consists of asphalt roads followed by RCC roads. Unpaved roads (kuccha roads) are also observed in some areas that are now included within the city's extended boundaries. Surface temperature of RCC road is observed to be 35.5°C as compared to 36.5°C for asphalt road and 36°C for unpaved roads. While the city can opt for use of RCC as road material over asphalt given that it is observed to relatively cooler, asphalt surfaces fare better than RCC on aspects such as offering adequate friction and thereby higher skid resistance during monsoons, reflection of light during the night time etc. Thereby, these aspects should be duly considered during the design phase when opting for RCC based road surfaces. It is also observed during the study that the surface temperature of asphalt roads having adjoining tree cover and shading thereof was approximately 33.7°C, which is almost 3°C cooler than asphalt roads without tree cover. Thereby, including appropriate plantation and tree cover alongside roads during their design can help to reduce the surface temperature by 2°C to 3°C.

Land use	Type various material used	Observed Surface Temperature Range (°C)	Average Surface Temperature (°C)	
	Concrete roof	39	39	
	Reflective roof (china mosaic, white ceramic tiles etc.)	36 to 37	36.5	
	Roof with white paint	35 to 36	35.5	
Residential	Solar panels on roof (While temp. of solar panels is higher, temp. of roofs covered with solar panels is varies from 37 to 38°C)	40	40	
	UPVC sheet for parking area	37	37	
	Green matt for shadow	35.5	35.5	
	Red clay roof	36	36	
	Cement roof duct	37	37	
	Very old concrete roof (with lime construction)	37	37	

Table 9 Material wise surface temperature for different land uses

		Observed Surface	Average Surface
Land use	Type various material used	Temperature	Temperature
		Range (°C)	(°C)
	Ceramic stone roof	36 to 37	36.5
	Galvanized iron sheet	39 to 40	39.5
	Old RCC roof	41	41
Commercial	Blue/ Green/ Silver coated metal sheet	39 to 40	39.5
	Paver blocks	36	36
	Concrete roof	39	39
	Reflective roof	36 to 37	36.5
	Galvanized iron sheet	39 to 40	39.5
Induction	Blue/ Green/ Silver coated metal sheet	39 to 40	39.5
industrial	Bitumen coated roofs	39	39
	Old corrosive metal sheets	37 to 40	38.5
	Very old concrete roof	38	38
Open and Green	Park and garden with grass	31 to 33	32
open and dreen	Dense tree cover	30 to 31	30.5
areas	Bare ground	34	34
	Asphalt roads	36.5	36.5
Transport	RCC roads	35.5	35.5
network/	Kuccha roads	36	36
infrastructure	Rail network	37	37
	Footpath (paver blocks)	35 to 36	35.5
Slum	Plastic banners/ sheets	37 to 38	37.5
Sidili	UPVC sheet	37	37
	Water body	26 to 27	26.5
	Tree Shadow	33.7	33.7
	Green matt shadow	34.2	34.2
Others	Scrap material storage	36 to 39	37.5
others	BRTS station	36.5	36.5
	Police station (reflective surface)	37 to 38	37.5
	Construction activities	40 to 41	40.5
	Stone paving	36 to 37	36.5

Key Findings:

Predominantly used materials:

Residential buildings – Reflective roof i.e., china mosaic, ceramic tiles etc. (2°C to 2.5°C cooler than concrete roof), concrete roof (39°C surface temperature). roof with solar panels installed (40°C surface temperature)

Based on the surface temperatures recorded for material through the drone survey, interventions have been identified for roofing techniques and materials. Concrete roofs were observed to have the highest surface temperature and are prevalent in existing and new buildings. The table below lists recommended roofing solutions and their impact on temperature reduction, considering concrete roofs as the reference base material. The analysis highlights that roofing interventions as mentioned in Table 10 has potential to reduce the surface temperature. From all the interventions green vegetation and vegetation shadow are interventions with the highest potential temperature reduction as compared to concrete roofs of the base roofing structure.

Sr. No	Base material of roofing	Roofing intervention	Colour of roofing interventio n	Base material temperature ³⁵ (°C)	Post roofing intervention temperatur e (°C)	Potential temperatur e reduction range (°C)
1		Heat resistant tiles	White	36.3 °C	34.9 °C	1-2.5 °C
2		White roof paint	White	36.4 °C	34 °C	1.5-3 °C
3		Shadow from nearby tree/vegetation ³⁶	Shadow	36.3 °C	33.7 °C	2-3 °C
4	Concrete roof	Shading from green garden matt ³⁷	Green	36.3 °C	34.2 °C	2-3 °C
5		China mosaic	Multi-color	36.7 °C	35.3 °C	1-3 °C
6		Green roof (having garden / vegetation on roof)	Green	36.4 °C	32.8 °C	2-4 °C

Table 10: Roofing intervention technique for concrete roofing

³⁵ Temperature of the concrete roof, located near to the intervention roof material in the same locality as per the drone survey

³⁶ It covers roof, where there is a tree adjacent to the building and the building roof is getting benefit from the shadow of the tree.

³⁷ It covers roofs, which has cover through HDPE green garden shade cloth

6 Recommendations: Implementation Strategies and Interventions for Urban Cooling

As cities grow, they are shaped by the way they are planned and built. Built infrastructure such as commercial, residential, industrial and public buildings have significant impact on urban environment and heat (Urban Cooling Strategy, City of Kingston, 2020). Urban form has the potential to increase local temperatures and the hours of thermal discomfort. Therefore, specific analyses are required to examine impacts of heat island effect and associated causes locally.

Thermally higher temperatures lead to decreased thermal comfort within the city and impact health and well-being of citizens. Cooler cities have positive impacts on human health, air quality, economic productivity, energy use, and quality of life. Improved thermal comfort can boost social cohesion of a space by encouraging more people to spend time outdoors.

To address higher urban surface temperatures and to combat resulting impacts, there is a need of identify, plan and implement appropriate urban cooling strategies and solutions. Heat island effects can vary across neighbourhoods or areas within a city, depending on factors such as building types and design, development density, traffic patterns, economic activities, prevalence of green cover and water bodies. To begin with an assessment to map vulnerable areas or hotspots with higher temperatures, gather information, and evaluate and analyse activities and causes of excess heat should be carried out. Appropriate cooling policies and actions can then be designed and prioritized for vulnerable hotspots.

A mix of urban cooling strategies and solutions, as noted in the following sections, can be implemented to address excess heat at the building, neighbourhood and urban scales. Broad-based strategies and technical options are noted in this section and a plan of action for urban cooling has been captured in section 6.1. Site specific projects that can be prioritized for implementation by RMC have been further identified in section 6.3.

- I. Installation of reflective surfaces at urban roofs, walls, and pavements that reflect more solar radiation, rather than absorption
 - Cities typically have numerous impervious surfaces located closely together, which increases local temperatures by trapping heat and reducing ventilation. The old core city areas of Rajkot are more prone to such conditions.
 - New developments in west zone of Rajkot are characterized by high rise buildings which also increases the overall surface area, resulting in increased storage of heat in building envelope.
 - At the city level black top road surface and asphalt paver blocks on pedestrian paths absorbs and stores more heat than the natural surfaces. Thus, heat is emitted in the atmosphere and subsequently leads to the increased surface temperature.
 - Roof and pavements cover about 60% of urban surface (roof 20% to 25% and pavement 40%) and absorbs more than 80% of the sunlight which restores heat. (C40 Cities, 2016) It is also important to assess the age of buildings, materials used, and typical design features of the built environment in order to understand the opportunities for advancing thermal efficiency in the building stock and planning any of the mitigation actions as below.


- Reflective roofs Through use of coating (e.g., Acrylic, Elastomeric, Polyurethane, silicone) an increase in solar reflectance of an existing functional roof or planned roof in ongoing projects could be done. It is commonly created by lightening roof colour to reflect more solar energy and improved indoor thermal comfort.
- Reflective walls Similar to cool roofs, it is applied to vertical building surfaces.
 There are many light colour wall cooling products (e.g., paints) available worldwide which are commercially viable and tend to stay clean and reflective over time.
- Reflective pavements It is commonly made up of Asphalt or concrete which are dark in colour. Such paving materials can reach the peak temperature of the city in summer time; therefore, it is good to choose some lighter colour options which has reflective paints on it or to opt for reinforced grass pavements.

II. Expanding green cover and tree canopy as green roofs/walls

- Vegetated or green rooftops help to achieve lower temperatures in comparison to other conventional rooftops. Use of open grid pavers and grass pavers could be used in non-roof impervious areas to reduce heat absorption.
- Increasing the green cover by installation of green roofs/walls requires regular watering of plants, based on the vegetation selection, climate, and maturity of the plants (Yenneti, Santamouris, Prasad, & Lan, 2017).

III. Increasing shading and permeable surface

- Permeable surfaces allow water infiltration and facilitate cooling by evapotranspiration, which cools the air by increasing the latent heat storage capacity of air. The process uses heat from the air to evaporate the water present in a tree, vegetated area, or permeable pavement. (Global Platform for Sustainable Cities, 2020)
- Shading refers to the ability of a structure or a tree to block sunlight from striking and heating surfaces such as pavements or buildings. In summertime, 10–30 percent of the sun's energy reaches the area below a tree and the rest of the sunlight is either absorbed by leaves and used for photosynthesis, or reflected back into the atmosphere. (Global Platform for Sustainable Cities, 2020) This mechanism can further be used for increase in intended shading areas of the city.

IV. Increasing blue spaces or water bodies

- The application of water creates cooling effect through evaporation and improved evapotranspiration of green spaces.
- Water bodies cool their surroundings through evaporative cooling. The cooling effect increases as the area of water surface increases which is complemented well with dense vegetation.
- Evaporation of water in some cases increases humidity but if mechanical sprinklers are installed in planned manner, then it allows urban temperatures to rapidly drop and provide a period of lower heat stress.

V. Improve urban design to promote wind-induced air flow

- Wind-induced air flow helps to remove heat from the area. The present pattern of built spaces constructed in the city may hinder the wind flow, which reduces the speed of flow and results in slow removal of heat from the area.
- To mitigate the above problem, construction of buildings shall be aligned with the wind direction so that it allows wind to flow with natural speed and support heat passage.
- Roof and pavements cover about 60% of urban surface (roof 20% to 25% and pavement 40%) and absorbs more than 80% of the sunlight and converts it into heat (C40 Cities, 2016). It is also important to assess the age of building, materials used, and typical design features of the built environment in order to understand the opportunities for advancing thermal efficiency in the building stock and planning any of the mitigation actions as below.
 - Reflective roofs Through use of coating (e.g., Acrylic, Elastomeric, Polyurethane, silicone) increase the solar reflectance of an existing functional roof or planned roof in ongoing projects. It is commonly created by lightening roof colour so that to reflect more solar energy and improved indoor thermal comfort.
 - Reflective walls It is same as cool roofs but applied to vertical building surfaces. There are many light colour wall cooling products (e.g., paints) available worldwide, which are commercially viable and tend to stay clean and reflective over time.
 - Reflective pavements It is commonly made up of Asphalt or concrete which is tend to be dark colour. Such paving materials can reach the peak temperature of the city in summer time; therefore, it is good to choose some lighter colour options which has reflective paints on it or to choose reinforced grass pavements.

VI. Reduce waste heat generation

- Transportation is one of the major contributors in anthropogenic heat emissions with rising private vehicle ownership and traffic congestion. Planting trees and vertical gardens along major roads and junctions can help in efforts to reduce excess heat and air pollution.
- Commercial and industrial areas housing waste heat sources can have higher temperatures. Solutions including promotion of higher space cooling efficiency, energy and process efficiency, waste heat recovery, enhancing green cover can be suitably identified for such areas.
- One of the major contributors to waste heat generation is mechanical cooling through airconditioners. Inadequate adoption of passive cooling strategies (such as building orientation, insulation, natural ventilation, and shading) leads to increased need for active cooling in buildings. While air conditioners are effective at delivering indoor thermal comfort, but exhaust heat generated by air conditioning units in external areas is a growing concern. Solutions include promoting passive cooling measures in buildings, adoption of energy efficient air conditioners, and adopting guidelines on locating air conditioning units in buildings to minimize exhaust heat impacts.

• Cities can encourage adoption of green building and energy efficiency standards to enhance the sustainability of buildings. District cooling solutions that deliver chilled water to buildings from a central plant or a set of distributed sources, offer a more efficient and climate-friendly cooling solution by substituting individual air-conditioning units. Rajkot's district cooling rapid assessments have shown that the technology is financially sustainable in the local context, when integrated appropriately with commercial and high-density residential buildings with significant cooling loads.

VII. Distribution of land use and urban design

 While zones and neighbourhoods are ideally meant to have planned development, the city and its areas have their own characteristics leading to organic growth. Urban planning aspects (e.g., population density, land use, green cover) and landscape features (e.g., spacing, orientation, and positioning of buildings) are important factors resulting in increased urban heat generation, storage of heat, movement of wind and penetration of sun light in the urban space. Given its planning and regulatory authority, RMC has the authority to steer and control urban design, planning, building design and construction in order to integrate mitigation strategies and solutions to reduce urban heat at the neighbourhood and city scale. Public land and facilities can be utilized to adopt and showcase cooling strategies to reduce the UHI effect.

VIII. Establish Cooling Cell and prepare long term strategy

- There is a strong need to develop a city-wide cooling strategy using passive cooling measures (that reduce the need for cooling) and active cooling measures (such as energy efficiency interventions) (Cool Coalition, 2019). While there are several national and state level policies, programmes and schemes being implemented in the city, that directly or indirectly, support actions that address urban heat, such actions are implemented in silos.
- To establish and leverage linkages amongst the implementation of such policies and programmes, a Cooling Cell should be established within the RMC to undertake the activities related to coordination with other key stakeholders. The Cooling Cell can be housed within the Smart City SPV RSCDL and it can be expanded over time as to involve dedicated technical experts/resources and external consultants as it advances on urban cooling activities.
- There should be stakeholder committee also; which comprise of multiple sectoral experts from Rajkot Urban Development Authority (RUDA), Rajkot Smart City Development Limited (RSCDL), Paschim Gujarat Vij Company Ltd. (PGVCL) and Gujarat Pollution Control Board (GPCB), Aji GIDC Industries Association (AGIA), Gujarat Chamber of Commerce and Industries, The Indian Institute of Architects (IIA), Saurashtra Region and Confederation of real estate developers' association of India (CREDAI) Rajkot. The stakeholder committee shall regularly meet to review cities progress and share feedback and way forward.
- There is a general acknowledgement of the issue of urban heat island effect and its linkages with anthropogenic activities but, there is no study or assessment, both at the neighbourhood and city scale in Rajkot, which identifies and quantifies existing heat island effect and its mitigation strategies. The Cooling Cell through its dedicated staff should

undertake a heat island mapping exercise as a first step that analyses factors such as energy demand at neighbourhood level, sources and locations of hot and cool spots, adequacy and location of blue and green spaces, common materials and surfaces used for various purposes and their surface temperatures. Remote sensing, which helps to capture land surface temperature across a large spatial area, can be used to appropriately identify areas with excess heat or 'hotspots'. The findings should be discussed with all the stakeholders to prepare detailed cooling strategies and action plan for the city. The strategies must be specific with clear indication of roles and responsibilities for different stakeholders.

- Achieving overall goals of the Cooling Plan at the city scale is a process that is expected to happen over a long period of time. Hence, appropriate prioritization and phasing of strategies is necessary. Areas with high exposure to excess heat that has direct impacts on the vulnerable groups should be prioritised. Cooling strategies and activities therein can be planned in a phased manner, accounting for anticipated population densities, development trends and future land use change across various areas and potential implications on urban heat. Preparation of Town Planning schemes³⁸ is under the purview of RMC, which can leverage to influence and plan land use at the micro level and incorporate necessary actions to support cooling in new developments and major redevelopments.
- RMC can play the role of an anchor to develop, motivate and enable coordinated action amongst all the stakeholders. RMC should strengthen coordination with other public/semipublic institutions and departments that govern planning and operations in and around Rajkot city, which are not directly under RMC's purview but can significantly influence and contribute to the city's efforts on urban cooling. The Cooling Cell can arrange quarterly meetings with all stakeholders to gather information and feedback, steer implementation of urban cooling and heat mitigation strategies and actions, and monitor impacts and benefits.

IX. Policy implementation and financial incentives

- The local development regulations (GDCR) guide and regulate utilization of land, its zoning, density, and building development and are enforced by the Town Planning department, RMC. The GDCR includes requirements for provision of green public spaces and plantation of trees in new buildings and developments. However, there is no guideline to support the effective development of green cover and land zoning in order to address the effects of urban heat generation. Local real estate developers deem existing incentives, offered by RMC through the GDCR, for adoption of green and energy efficient buildings to be insufficient to enable financial feasibility for at-scale adoption of cooling solutions at the building scale. RMC should work collaboratively with stakeholders to identify mechanisms that appropriately incentivize adoption of sustainable cooling solutions in alignment with prevalent market conditions.
- At present, existing incentives for green buildings (5% discount on chargeable FSI) can be availed once the building receives green building certification, which is typically after completion of construction. Thus, developers need to invest upfront capital and can avail

³⁸ Town Planning Scheme is a micro level implementation of the larger development plan which is prepared for smaller areas, to influence targeted development across the city by defining different land uses in different zones.

incentives only after project completion which can take two to three years. For green buildings, developers generally opt for certifications of the IGBC or GRIHA rating systems. While the IGBC and GRIHA certification has different levels/grades of certification (i.e. silver, gold and platinum), the incentive offered by RMC is the same regardless of the level of certification received for green buildings. Offering monetary incentives in an incremental manner, corresponding to the certification level/grade, would motivate developers to construct greener and thermally efficient buildings that are able to achieve higher building certification standards.

The Town Planning schemes include conditions to set aside around 40% of the overall land area under new development for construction of public services and amenities. Of this reserved public land parcel, about 20% to 22% land is typically utilized for construction of roads. The remaining land parcel (18%-20%) is allocated for uses including construction of affordable/social housing, public schools, health centres, fire stations, open spaces and parks. Thereby, in business-as-usual practice, on an average only about 3% of the total land for a selected area in a TP Scheme is available for establishing green cover. Also, once the land use plan is prepared and a Town Planning scheme gets finalized, RMC has limited control on the specific type of buildings to be constructed on land plots and on the building use. Thereby actual utilization of land parcels and built spaces may not reflect the utilization planned/envisaged and can also be of mixed-use type. This barrier makes it difficult to translate urban cooling actions identified at the planning stage (i.e. on documents) to actual development taking place on-ground. To overcome such challenges, TP scheme should be prepared and finalized when the land parcel has minimum or no development works started, which would give freedom to the city to allocate land parcels for various uses as per the need at most appropriate locations.

X. Heat resilient urban design and infrastructure

Urban design, surfaces and materials that absorb, reflect, and emit a wide range of wavelengths of radiation have significant impacts on urban heat. Management of public spaces is crucial for reducing the city-wide hotspots. There is a need to promote active and passive cooling solutions as listed below:

• Include and improve green spaces in Rajkot's western part through Town Planning Scheme and Urban Forest Program – Based on the hotspot mapping, it is found that the surface temperature hotspots are located primarily in the peripheral areas of the city, mostly in the west, south-west and north-west side, while atmospheric temperature hotspots can be seen in the central and eastern side of the city. With the city's prevalent wind direction observed to be from west or south-west to east or north-east, it is possible that heat transfer from surface hotspots in western part contributes to higher atmospheric temperatures in the central and eastern parts.

Providing appropriate green spaces in Rajkot's western part can not only reduce the land surface temperature by 3°C to 4°C locally in this zone but also contribute to lower heat

transfer and atmospheric temperatures in the city's central and eastern zones. Through Rajkot's ongoing Urban Forest program and corresponding funding, additional areas in its western part can be developed as urban forests. Also, new areas of nearby villages has been recently added in the city overall area, which would be developed in future through implementation of town planning scheme. During preparation of new town planning scheme, location of parks and gardens can be selected in a manner so that it would help to reduce temperature rise in the area.

- Promote urban design interventions (i.e. wind-induced air flow in neighbourhoods by regulating building height and street orientation), especially in new developments The shape, size, density and use of buildings influence the intensity of the heat island effect in a particular area. High-rise buildings block ventilation and trap heat and pollutants. Improving ventilation and natural airflow is important for dissipating heat and contaminants and increasing thermal comfort. Midrise buildings with sufficient space between them allow for better ventilation and thereby such an urban design promotes a greater diurnal range (i.e., such areas cool down more at night) than areas with mid-rise buildings located close to each other. Such passive cooling interventions also play an important role in reducing the energy consumption during the operational phase of a building. In green field and new developments such as Rajkot's Smart City area, interventions on building heights and street orientation can help pedestrian-level ventilation. Recommended measures include
 - Most of the new town planning schemes in Rajkot are getting developed in the north-west side of the city's periphery and as this area is surrounded by barren/vacant land with direct exposure to sunlight; it becomes necessary to appropriately plan for establishing blue and green infrastructure in this area to deliver cooling effect considering the wind direction, which needs to be included, during the conceptualization and planning stage of new town planning schemes.
 - Include passive techniques such as improved building orientation and positioning, porosity, vegetation and coatings to reduce urban heat accumulation in the new neighbourhood planning through TP scheme or in the green field developments such as the *Raiya Smart City* area
 - Longer axis and openings/windows can also be aligned perpendicular to the prevailing wind direction with maximum openable area (net openable area for casement window is 90%, whereas for sliding windows it is 50%) to facilitate maximum airflow and cross ventilation through the building.
 - Promoting a step-up configuration for buildings, in which downwind buildings become progressively taller and implementing a grid-like layout in which the main streets are arranged parallel to the direction of the prevailing wind flow.
 - Outdoor units of air-conditioners should be placed to leverage their position and should aim at using the natural wind flow to carry the exhaust heat released, to help reduce impacts on thermal environment around the building
 - Use open grid grass pavement, permeable pavers, using materials of high emissivity, lighter colour paint on pavers or other cool materials with Solar Reflective Index (SRI) of at least 29 as recommended in IGBC's green building

guideline (and not higher than 64)³⁹, in the pavements to reduce the heat storage. Inclusion of vegetation and tree cover can be undertaken for existing infrastructure such as bridges, highways and traffic junctions.

- Plant trees of different heights along transport corridors i.e. BRTS lane, and at other strategic locations as mitigation measure for heat accumulation in road surfaces.
- RMC can incorporate such improved urban design measures in the building byelaws and regulations to promote wind-induced air flow and improved heat dissipation at the city scale.
- Adopt Nature-based solutions in new developments Increase blue spaces such as water bodies that cool their surroundings through evaporative cooling. The cooling effect increases proportionately with area of the water surface, with dense vegetation further complementing cooling impact of water bodies. Specifically in the Greenfield developments (i.e. smart city area and western part of the city) plan to retain and leverage existing green and blue spaces with increased new large green spaces.
- Consideration of tree canopies for shading on asphalt road and green cover increment to reduce air pollution It is observed during the thermal mapping that the average surface temperature of asphalt road is 1°C higher than RCC road and 0.5°C hotter than unpaved (kuccha) road. While the city can opt for use of RCC as road material (average surface temperature of 35.5 °C) over asphalt given that it is observed to relatively cooler, asphalt surfaces fare better than RCC on aspects such as offering adequate friction and thereby higher skid resistance during monsoons, reflection of light during the night time etc.

Tree canopies can provide shading and help reduce temperature of asphalt roads by as much as 3°C as compared to asphalt roads without tree cover based on city wide material temperature identified and mentioned in Table 9. Thereby, RMC can plan for provision of tree cover during the early design stage of new roads as well as increase tree coverage along existing streets with high traffic densities to help in cooling around such street infrastructure.

Increased green cover around roads can also support in reduction of the air pollution in the city and facilitate cooling, as busy traffic junctions are observed to have higher levels of air pollution and correspondingly high atmospheric air temperatures.

• **Open/undeveloped areas and public gardens to be developed with sufficient green cover** - It is observed during the thermal mapping that the surface temperature of green cover (including dense tree cover and vegetation cover) varies from 29 °C to 32°C, while vacant undeveloped areas have higher surface temperature, varying from 33°C to 36°C. Such open spaces without green cover are observed in several parts of the city, mostly in

³⁹ SSP credit 6 (Heat island reduction, non-roof) of the project checklist for Green New Buildings guideline of IGBC. Available at: https://igbc.in/igbc/html_pdfs/abridged/IGBC%20Green%20New%20Buildings%20Rating%20System%20(Version%203.0).pdf

smart city area and western part of the city along Kalawad road. Thereby, it is recommended that RMC develops such land parcels as green areas by establishing sufficiently dense tree plantation through the 'Mission Million Trees' program being implemented by RMC. RMC shall also consult with private land owner to motivate them to undertake green cover development related activities on their vacant land through support of RMC.

- Promote cool roof program in industrial areas in collaboration with Gujarat Industrial Development Corporation (GIDC) - Galvanized iron sheets/ metal sheets are predominantly observed to be used as roof materials in industrial areas, with surface temperatures of 39.5°C. Other roof materials used in industrial structures such as bitumen coated roof (surface temperature of 39°C) and corrosive metal sheets (surface temperature of 38.5°C) also have relatively higher surface temperatures. Applying cool roof strategies i.e., cool roof coating (cementitious coatings and elastomeric coatings) can reduce the roof temperature by 1°C. RMC in conjunction with GIDC can undertake a wider cool roof program for industries to promote application of such strategies and solutions.
- Increase solar reflectance in urban surfaces- Roofs and pavements cover about 60% of urban surfaces (roofs: 20% to 25%; and pavements: 40%) and absorb more than 80% of the incident sunlight (C40 Cities, 2016). Thus, it is vital to promote installation of reflective surfaces on urban roofs, walls, and pavements to mitigate absorption of solar radiation. Use of coating solutions (e.g., Acrylic, Elastomeric, Polyurethane, silicone) and white paint, can increase solar reflectance of built surfaces and lead to reduced urban heat in highly dense areas of central and east parts of Rajkot.
- Achieve lower surface temperature through vegetation Promote vegetation and expand green cover through green roofs and walls that helps to achieve lower surface temperatures in comparison to conventional rooftops. Increase adoption of permeable surfaces in new developing public places, which allows for water infiltration and facilitates cooling by increased evapotranspiration. Shading provided through trees and green cover blocks and at times reflects incident sunlight, thereby limiting heating of surfaces such as pavements and buildings. (Global Platform for Sustainable Cities, 2020). RMC should undertake tree plantation along major footpaths to provide shaded walk ways to pedestrians.

XI. Thermally efficient buildings

- Regulatory frameworks, voluntary guidelines and standards established by national and state governments are particularly important for facilitating and accelerating the transformation of urban buildings. Through such frameworks, city governments can play an important role in facilitating the transformation of the building sector.
- Incentivise adoption of green building standards and energy conservation and efficiency Green building certifications and standards such as IGBC, GRIHA, LEED, and

Energy Conservation Building Code (ECBC) include both passive and active measures to support improved cooling and reduced energy demand in newly developing buildings. A combination of appropriate building materials (such as refractive materials, low emissivity window glass) orientation and design features (positioning windows to enable cooling and ventilation, use of green surfaces, shading measures) can be adopted to minimize heat gain due to thermal transmittance, which results in reduced energy demand for cooling. While passive design measures with no cost or low cost can be implemented, implementation of the wider range of cooling measures results in increased capital costs for design and construction to be borne by developers, which inhibits adoption of green building standards in Rajkot. Energy efficient interventions are cost sensitive and its overall breakeven point for investments made, is medium to high. At consumer side there is no awareness for considering the life cycle cost of building or appliances and in absence of that there is no demand from consumers for energy efficient buildings, which results in low or no adaptation of such initiative by private developers.

- Such energy efficient initiatives also get monetary incentives in various schemes like, in GDCR it states that incentives in the rate of chargeable FSI for Green Buildings of up to 5% discount in the total payable amount to any owner or developer shall be given but, process for availing such advantages are unknown or too lengthy so, many developers avoid it. To increase the adoption of the energy efficient commercial and residential buildings; provide monetary benefits and process for availing those benefits should be easily understandable to all developers or city should run awareness campaign to educate local developers on benefits available to them if green or energy efficient projects are planned. To achieve higher standards; instead of a flat-rate incentive, offer benefits in an incremental manner in proportion to scale/extent to green building and energy efficient actions implemented in the project. Offering upfront incentives on pre-certification for green/energy efficient buildings will motivate developers to consider it from the planning stage of the projects. A dedicated team and helpline service shall be provided for resolving doubts of developers which will motivate them to undertake innovative strategies for energy efficiency.
- Enforce mandatory energy disclosure or energy audits Evaluating or monitoring energy performance is a strategy that can be applied to improve cooling efficiency of existing buildings. Rajkot can lead by example through public disclosure of energy performance of all government owned and managed buildings and services. RMC has undertaken energy audits in its water pumping and distribution and waste water collection facilities. Based on the audit findings, non-efficient equipment has been replaced and energy efficiency improvement has been achieved. Such type of audits can be conducted on a voluntary basis in other buildings. However, to maximize their uptake and effectiveness periodic energy audits should be made a mandatory requirement for priority building types, owned by government as well as by private developers. (Buildings that are older or large and energy intensive buildings of the city). Audits may apply to the whole building, or only to specific building components only.

XII. District Cooling

• In addition to increasing adoption of strategies to mitigate the urban heat island effect and passive cooling approaches for buildings that can reduce the cooling demand, mechanical

space cooling solutions in the form of air-conditioners are usually still needed to provide indoor thermal comfort. The waste heat released to the environment by the air conditioning systems further exacerbates the urban heat island effect, resulting in a vicious cycle of further mechanical cooling and continuing to warm the city. Implementation of the district cooling systems in dense urban environments provides an opportunity to deliver space cooling with much lower energy and emissions impact. New developments, high cooling load density, diversity of consumers, and a focus on commercial, institutional and industrial developments are vital components of typical project types that can lead to feasible district cooling implementation.

- As part of the District Energy in Cities Initiative, rapid assessments for deploying a district cooling system were undertaken in Rajkot. The greenfield site at Raiya, proposed to be developed as pilot Smart City area as part of Rajkot's Smart City Plan was specifically assessed for high-level feasibility of district cooling. The Raiya area has a good mix of diverse buildings proposed including commercial and corporate office spaces, educational facility, multi-speciality hospitals and a sports arena. The proposed business park at this site, spread over an area of 30 acres (0.12 sq. km) and housing banking and financial services, IT/ITeS, and retail spaces and a convention and exhibition centre spread over 36 acres (0.14 sq. km), can serve as anchor loads for the district cooling network.
- The high-level analysis concluded that district cooling is commercially viable in Rajkot for well-designed projects and can deliver significant benefits to the environment, consumers and the local economy. RMC can direct the Smart city SPV to incorporate district cooling into the design and planning of the smart city area and shall undertake preparation of Detailed Project Report (DPR) to accelerate district cooling implementation and mandate that specific building types are developed as 'district cooling ready' beyond existing mandate on hospitals to have centralised cooling. Such initiatives would make Rajkot the first India urban local body to demonstrate this technology.

XIII. Community centric initiatives

- Early involvement of the community as a key stakeholder may result in cooling policies and programs that are more acceptable and likely to be sustainable over the long term. Significant engagement with the most marginalized and vulnerable communities is essential to ensure that they benefit from cooling, which would provide long-term benefits of the improved quality of life to the community.
- Rajkot has prepared a heat wave action plan in 2017 but, it mainly talks about early warning
 indicators for heat wave, identification of the heat wave illness and recording of casualties,
 Do's and Don'ts during heat waves, prevention of heat wave related illness, roles and
 responsibilities of the RMC departments and communication plan within RMC nodal officers.
 But it does not identify preventive measures related to urban design or planning, which
 would reduce the instances of heat wave. It also lacks integration and use of the cities

command and control system to identify threats in advance. There is no clear SOP to communicate with the citizens.

• City should establish a heat alert system as a basic measure to alert the public for anticipated periods of heat. This can be supplemented with communication strategy to spread information on how to reduce vulnerability to and symptoms of heat-related illness during extreme heat conditions. Also, Identify and make available cooled spaces that are accessible to heat-vulnerable communities in the event of heat waves.

XIV. Implement pilots to demonstrate cooling solutions and their benefits

- Successful pilot projects can create confidence amongst the citizens to adopt cooling strategies and improve awareness on their benefits. RMC can utilize opportunities to adopt and demonstrate cooling solutions in its upcoming infrastructure and projects. For instance, solutions such as reflective roofs and walls, green roofs, building design for passive cooling can be incorporated in new municipal buildings to pilot and showcase interventions and to generate awareness. RMC can ensure that new public buildings employ surface cooling solutions which are often cost-effective and simple. RMC can also set requirements or conditions for use of climate friendly cooling through procurement guidelines.
- Emerging technologies and approaches can be piloted by RMC, supported by technical • feasibility studies and monitoring mechanisms to leverage private sector finance. For instance, technical assessments on district cooling technology in Rajkot have shown that district cooling is commercially viable for high density commercial use centric development and can deliver significant benefits to consumers. The city is looking to adopt district cooling technology in its green field project of Raiya smart city area. Apart from smart city area, city should also Incorporate district cooling concepts or evaluate district cooling viability in large mix-used greenfield or brownfield development, major redevelopment projects. Such assessment should be done at an early stage during conceptualization and design. RMC can leverage its authority to design Town Planning Schemes to promote district cooling by ensuring new developments are mixed-use and of high density. This delivers a diversity of building types in the said area which improves significantly the commercial viability of district cooling. Information and findings from district cooling assessments can be disseminated within state government institutions, local developers and architects for consideration of the technology in future development projects.

XV. Advocate and Promote

• At the city level, detailed understanding of the effects of heat island, information on available urban cooling solutions, its adaptability and performance in the local context, and the potential benefits of incorporating these solutions within urban planning and building development processes and practices is lacking. In its absence, RMC has not placed sufficient emphasis on addressing urban heat island effect and thereby enabling support and ecosystem to initiate or scale up cooling practices is missing. RMC needs to play the role of an anchor to motivate and enable coordinated action amongst all the stakeholders.

 RMC should utilize demonstration or pilot projects and support their adoption to disseminate knowledge and raise public awareness. Awareness and promotional campaigns can be rolled out for public outreach of cooling solutions, technologies, and successful projects; highlighting specific interventions and its associated cooling/heating impact achieved to influence citizens and private developers. The promotional activities can target enhancing understanding of property buyers and occupiers on direct and in-direct benefits accrued in the long-term related to energy savings, air quality, improved thermal comfort, human health, which will foster increased willingness and market demand for sustainable and thermally efficient buildings. Apart from these activities, RMC should also focus on training and providing access to knowledge resources for engineers, urban planners, architects, developers, financiers and the citizens.

6.1 Focus areas and activities under identified strategies

Priority strategic interventions with focus areas and key steps therein across the short, medium and long term are outlined below, reflecting a plan of action for Rajkot city that can be implemented through identified departments and stakeholders.

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
Establish cooling cell and prepare long term strategy	Short	A Cooling Cell within the Smart City SPV, RSCDL. can coordinate with multiple stakeholders and it can be expanded over time as to involve dedicated technical experts/resources and external consultants as it advances on urban cooling activities. It supports team to establish and leverage linkages amongst the implementation of various national, state and local policies and programmes being implemented in the city; directly or indirectly support actions that address urban heat.	Cooling Cell (RMC) (proposed within RMC through this study)
Establish stakeholders and it can be expanded over time as to involve dedicated technical (k cooling cell and experts/resources and external consultants as it advances on urban cooling the implementation of various national, state and local policies and programmes being implemented in the city; directly or indirectly support actions that address urban heat. Medium Undertake a heat island mapping exercise; analysing factors such as energy P demand at neighbourhood level, locations and sources of hot and cool spots, (for address urban determal mapping, to capture land surface temperature across a large spatial area, and to appropriately identify 'hotspots' Undertake city wide tree density analysis, identifying no. of trees per ward and coverlay the information on temperature; to identify locations with high (for temperature but, less green spaces, which can act as one of the indicators to help to identify future locations for developing the green cover and open spaces. List native trees, which can be promoted for plantation in the city.	Proposed Cooling Cell (RMC)		
		Undertake city wide tree density analysis, identifying no. of trees per ward and overlay the information on temperature; to identify locations with high temperature but, less green spaces, which can act as one of the indicators to help to identify future locations for developing the green cover and open spaces. List native trees, which can be promoted for plantation in the city.	Garden department (RMC)

Table 11 Focus areas and activities under identified urban cooling strategies for Rajkot city

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers			
		List city wide building material and its related temperature and propose interventions to reduce its heat impacts. Through consultation with housing and TP department, propose interventions in on-going housing projects.	Affordablehousingdepartment (RMC),Townplanningdepartment (RMC)			
	Based on the identified hotspots and building materials, prepare action plan for urban cooling. Include urban cooling actions as part of the climate actions and prioritize intervention locations and phase wise implementation of cooling strategies					
	Long	Incorporate appropriate cooling measures and solutions in upcoming Town Planning schemes in new developments. During conceptualization and planning stage of development schemes/projects, blue and green infrastructure should be planned by considering the wind direction i.e. south-west in Rajkot and urban heat island effect, from the surrounding urban spaces as well as that anticipated from the future development. Green areas can be located based on the expected heat generation considering the built environment, land use, population density, surfaces and traffic patterns.	Town planning department (RMC)			
		Promote voluntary green building certifications such as GRIHA and IGBC as well as mandatory standards such as ECBC and Eco-Niwas Samhita in building developments, as these include building-level cooling strategies. As, Intervention related to cooling are cost sensitive and its overall breakeven point for investments made, is medium to high. Awareness should be made at consumer side for considering the life cycle cost of building because in absence of that there may not be demand from consumers for measures related to cooling from developers.	Town planning department (RMC), The Indian Institute of Architects (IIA), Saurashtra Region, Confederation of real estate developers' association of India (CREDAI) Raikot			

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
		Monitor implementation of cooling intervention through coordination/technical support team. RMC shall start to document and undertake continuous monitoring of the type of buildings being constructed and utilization of built spaces, post finalization of land use.	Proposed Cooling cell (RMC), Town planning department (RMC),
		Quarterly arrange consultation with the all stakeholders of the cooling cell, to take their feedback on activities completed and to get guidance for the way forward. Based on minutes of the meetings and learnings from the on-site implementation, periodically update the cooling strategy and measure the impact of the interventions undertaken	ProposedCoolingcell(RMC),Gardendepartment (RMC),Affordablehousingdepartment (RMC),Townplanningdepartment (RMC)
Policy implementatio n and financial incentive	Medium	GDCR has provision of green public spaces and plantation of trees at new buildings. So, develop guideline to support the effective development of green cover and land zoning in order to address the effects of heat generation in the city, while preparing land use plan. Considering wind flow direction from the south-west, RMC shall implement its maximum green spaces in the south-west side of any TP schemes, which would support to reduce temperature of the flowing wind. Dense urban forest should be proposed in south-west side of the city.	Town planning department (RMC), Garden department (RMC)
	Long	Offer incremental benefits in a manner corresponding to the certification level/grade achieved in green building certification. i.e., discount on chargeable FSI shall be highest for platinum certified building (e.g., 15%), medium for gold certified building (e.g., 10%) and lowest for silver certified building (e.g., 5%), to motivate the developers to achieve highest standard of certification	Town planning department (RMC)

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
		Offer tax incentives such as relaxation in development charges, taxes or security deposit charges in advance of project completion, to projects with green/energy efficient building pre-certification, which will motivate developers to consider sustainable cooling solutions from the design and planning stage of projects	Town planning department (RMC)
Implement planning interventions	Short / Medium	 Reflective surfaces and lighter colour at urban roofs, walls, and pavements Different types of building and surface material stores more heat during the day time and emit or radiate heat during the night time, depending on specific heat values, which is observed from maximum land surface temperature during the night time, where built up areas are hotter than barren land. So, through use of coating, increase reflective surfaces and walls at the old core city areas having numerous impervious surfaces located closely together and at the recently developed high rise buildings in west zone having high exposed surface area, to reduce storage of heat in building envelope. Adoption and Implementation in existing buildings should be promoted to reduce heat absorption in the day time. Choose lighter colours for painting of pavements or use refractive surfaces while selecting material for paver blocks for the city-wide installation. Promote Open grid pavers or Grass pavers and Hardscape materials (including pavers) with SRI of at least 29 (and not higher than 64) 	Proposed Cooling cell (RMC), Affordable housing department (RMC), Town planning department (RMC), Zonal city engineers (RMC), Garden Department (RMC)
		 Expand green cover and tree canopy Increase plantation and improve dense vegetation cover at barren land parcels in the western and southern parts of Rajkot city. From the Land surface temperature analysis conducted under this study, it is observed that surface temperature of barren land is higher than built up areas. This is due to the presence of shallow and medium black soil type in Rajkot, which has high thermal conductivity and diffusivity. Due to this thermal 	Proposed Cooling cell (RMC), Garden Department (RMC), Town planning department (RMC),

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
		 characteristic of black soil, barren land in Rajkot absorbs heat faster than other surfaces during day time and releases heat faster and gets cooler during night time. Prioritize plantation in wards with lesser tree coverage as highlighted in the tree density report i.e., ward 1, 3, 5, 11, 12 & 18 As per GDCR, buildings with an area of more than 100 sq. m. have to plant a minimum of three trees for every 200 sq. m. area or part there-of. As an implementation mechanism to promote plantation in such large residential developments, RMC also collects security deposits of 550 INR per tree for such work from building developers at the time of building approval. However, often times this guideline is not followed by developers, with developers opting to give up the security deposit amount. Mandate and ensure establishment of minimum plantation/green cover for different types of buildings as per the GDCR rules As per GDCR, commercial developments of more than 2000 sq. m size must have at-least 10% of the area to be allocated for common plots/amenities⁴⁰. However, there is no separate provision on integrating green spaces in such developments. Thereby, it is seen that such common plots/spaces are primarily utilized as parking areas, with minimal allocation towards green spaces. The GDCR can be updated to include specific provisions to reserve and include recreational green spaces in common plots/areas Conceptualize and plan green spaces at the initial stage of new town planning schemes, by considering factors such as the urban heat island 	Town planning & Valuation department (GoG), Industrial Associations

⁴⁰ Common plots can be utilised for electric/power infrastructure, water tank and pump room, parking spaces as per GDCR.

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
		 effect from the surrounding urban spaces, wind-flow direction that impacts heat dissipation, as well as urban heat anticipated from the future development. Promote vegetated or green rooftops in residential buildings and installation of green walls at bridges, flyovers and similar infrastructure. Engage industrial association (e.g. industrial associations) to improve vegetation in their corresponding areas or neighbourhoods such as Aji industrial estate, Shri Hari industrial estate, lati plot, Parshuram industrial area, Mavdi plot industrial area etc. 	
		 Increase shading and permeable surfaces Increase shading through plantation of trees or green cover mat and install permeable surfaces across pedestrian pavements to facilitate cooling by evapotranspiration, which cools the air by increasing the latent heat storage capacity of air. i.e., adoption of aggregate of large stone particles and concrete with interwoven pore spaces, grid of pavers and void space filled with sand 	Zonal city engineers (RMC), Garden Department (RMC)
		Involve community as a key stakeholder for cooling policies and programs that are more acceptable and likely to be sustainable over the long term. Significant engagement with the most marginalized and vulnerable communities is essential to ensure that they benefit from cooling, which would provide long-term benefits of the improved quality of life to the community.	Proposed Cooling cell (RMC)
	Long	 Improve blue spaces Rajkot smart city area is having 3 lakes conceptualize and being implemented in green field project, so similar way while concept or planning is initiated for new areas development at that time only blue 	Town planning department (RMC), Zonal city engineers (RMC),

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
		 spaces should be included from the initial stage of town planning schemes. It can be planned by considering the urban heat island effect from the surrounding urban spaces as well as that anticipated from the future development Install mechanical sprinklers in planned manner at traffic junctions to rapidly drop urban heat from its surrounding. It would also provide a period of lower heat stress in summer period 	Garden Department (RMC), Traffic and Transport department (RMC), Rajkot Urban Development Authority (RUDA)
		 Promote wind-induced air flow City has wind direction from west or south-west to east or north-east. As majority of surface temperature hotspots are on the periphery of the city, mostly in west, south-west and north-west side; atmospheric temperature hotspots can be seen in central or eastern side of the city because heat is transferred in the atmosphere from surface temperature hotspots with natural flow of wind. Hence RMC can target improvement in green cover on barren land parcels located in the west or south-west parts of the city. Educate private developers to construct buildings in the alignment which supports the natural flow direction of the wind so that it allows wind to flow with natural speed and support heat passage. 	Town planning department (RMC), Garden Department (RMC), The Indian Institute of Architects (IIA), Saurashtra Region, Confederation of real estate developers' association of India (CREDAI) Rajkot
		 Promote energy efficiency, energy audit to reduce waste heat Promote adoption of passive cooling strategies (such as building orientation, insulation, natural ventilation, and shading) to decrease the need for active cooling (such as air-conditioner) in buildings Adopt public disclosure of energy performance of all government owned and managed buildings and services 	The Indian Institute of Architects (IIA), Saurashtra Region, Paschim Gujarat Vij Company Ltd. (PGVCL)

Intervention	Time period for implementation Focus Areas / Activities • Promote adoption of energy officient air conditioners					
		 Promote adoption of energy efficient air-conditioners. Reduce air pollution As per the assessment of the air quality information and temperature data from environment sensors installed by RMC at 18 locations for the year 2020, it has come out as there is a direct correlation between air quality index (AQI) and atmospheric air temperature, so RMC can focus on improving AQI of areas having high density, heavy vehicular traffic, and presence industrial activities. Areas including. Nana mauva circle, Madhapar chowk, Greenland chowk, Rajkot-Bhavnagar highway, Sorathiyawadi circle, Trikon bag, Jilla panchayat chowk can be targeted. Measures to be taken to improve air quality in areas located in the vicinity of major traffic junctions such as. Kothariya and Vavdi near Gondal Road and Ganteshwar near Jamnagar highway As part of the utilization of 15th Finance Commission's grant for improving air quality, RMC is undertaking a source apportionment study to identify pollution sources. Findings of the study should be analysed together with ambient temperature data to identify correlation and drivers for urban cooling and reduction in air pollution, including identification of priority locations. 	Proposed Cooling cell (RMC), Air Quality Monitoring Cell			
Demonstrate pilots to demonstrate cooling	Medium	Adopt cooling solutions (e.g., reflective roofs and walls, green roofs, design for passive cooling) in upcoming municipal buildings e.g., affordable housing projects, public buildings such as library, new ward or zonal offices	Affordable housing department (RMC), The Indian Institute of Architects (IIA), Saurashtra Region			

Intervention	Time period for implementation	Focus Areas / Activities	Responsible Department/Stakehold ers
solution and their benefits		Create knowledge material of use cases which highlight and quantify the energy and cost savings realized from implementation of various cooling solutions/ interventions	Proposed Cooling cell (RMC)
	Long	Adopt emerging technologies/approaches by tapping into private sector finance e.g., adopting district cooling infrastructure in the greenfield Raiya Smart city area offers a more efficient and climate-friendly cooling solution instead of individual air-conditioning units.	Proposed Cooling cell (RMC), Rajkot Smart City Development Ltd. (RSCDL)
		Prepare a guidebook on building and neighbourhood level cooling solutions to support and enable their adoption in the local context. The guidebook can include information on cooling solutions and technologies, steps involved in their implementation, impacts and learnings from pilot-scale deployment, and database of service/solution providers.	Proposed Cooling cell (RMC)
Advocate &	Short	City administration needs to play the role of an anchor to motivate and enable coordinated action amongst all the stakeholders.	Proposed Cooling cell (RMC)
Promote		On-board various stakeholders such as builders' association, architects and designers association, technical institutions, residential associations and establish one urban cooling working group which would work together to generate awareness on cooling solutions through trainings, campaigns and IEC activities.	Proposed Cooling cell (RMC)
	Long	Undertake awareness campaigns to educate citizens on the heat island effect and solutions to address the same at the building scale. Enhancing understanding of property buyers/occupiers on direct and in-direct benefits accrued in the long- term related to energy savings, air quality, improved thermal comfort, human health	Proposed Cooling cell (RMC), Town planning department (RMC), Confederation of real estate developers association of India (CREDAI) Rajkot

6.2 Interventions and associated prominent benefits

Urban cooling interventions can deliver multiple benefits and co-benefits to cities. Prominent benefits expected from key interventions identified for Rajkot including economic savings, enhanced liveability, urban heat island effect mitigation potential and climate impact in terms of GHG emission reduction potential have been mapped on a qualitative basis against the corresponding interventions in the Table below.

Intervention	Attributable economic savings	Public good/ enhancing liveability	UHIE mitigation potential	GHG reduction potential
Include and improve green spaces in Rajkot's western part through Town Planning Scheme and Urban Forest Program	\checkmark	\checkmark	\checkmark	\checkmark
Promote urban design interventions (i.e. wind-induced air flow in neighbourhoods by regulating building height and street orientation), especially in new developments	\checkmark	\checkmark	\checkmark	
Adopt Nature-based solutions in new developments		\checkmark	\checkmark	\checkmark
Consideration of tree canopies for shading on asphalt road and green cover increment to reduce air pollution		\checkmark	\checkmark	
Open/undeveloped areas and public gardens to be developed with sufficient green cover		\checkmark	\checkmark	\checkmark
Promote cool roof program in industrial areas in collaboration with Gujarat Industrial Development Corporation (GIDC)	\checkmark	\checkmark	\checkmark	\checkmark
Increase solar reflectance in urban surfaces	\checkmark		\checkmark	\checkmark
Incentivize adoption of green building				
standards and energy conservation and efficiency	\checkmark	\checkmark	\checkmark	\checkmark
Enforce mandatory energy disclosure or energy audits	\checkmark	\checkmark	\checkmark	\checkmark
District Cooling	\checkmark	\checkmark	\checkmark	\checkmark
Community centric initiatives		\checkmark	\checkmark	

Table	12 Urban	Cooling	Interventions	and	prominent	expected	benefits
TUDIC	12 010011	coomig		unu	prominent	chpected	Seriejies

6.3 Priority Urban Cooling Projects Identified for Specific Sites in Rajkot

Based on the thermal analyses and mapping across the city scale and at the neighbourhood scale, site specific projects that can be prioritized for implementation in Rajkot city have been further identified in this section. For these priority urban cooling projects, the specific target location where the intervention should be sited (where relevant), mode of implementation, entities that are primarily responsible for the implementation, proposed monitoring strategy, and benefits are also indicated. Determination of cost estimates will need to be carried out further depending on specific projects of interest and corresponding scale of implementation. Suggested actions to guide appropriately scale these actions have been indicated as well in the Table below.

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
Cool	Roofs						
1	 Proposed Strategy: Installation of reflective roofs for structures with non- reflective roofs Context: Neighbourhood scale thermal mapping at four identified hotspots has helped in identification of galvanised/concrete roofs that are relatively hotter in these areas, out of a total roof area of 11,11,836 sq. m. Site: Residential building roofs at East Zone (Patel Vadi), Malaviya and Atika, and Gondal Chowk and Mavdi (as shown in Annexure 1) for roofs have non- reflective/hotter surfaces (reflective index 	Mediu m Term	Detailed mapping of non-reflective roofs across the city can be carried out and implementation of reflective roofs in all buildings targeted appropriately through Cool Roof programme. Potential beneficiaries can be provided with a catalogue of possible cool roof options. Deployment of cool roofs in all new	Town Planning Department, Property Tax Department (RMC)	Private implementation by building developers, owners and residents; supported by RMC incentives/rebate s on property tax	Periodic monitoring of buildings by Town Planning and Property Tax departments.	Reduction in UHIE. Lower indoor temperatures, reduction in building energy consumption and lower associated GHG emissions.

Table 13 Priority Urban Cooling Projects Identified for Specific Sites in Rajkot

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
	less than 0.8) constituting a total roof area of 1,22,646 sq. m. The Malviya and Atika area can be particularly prioritized as it has higher non-reflective roof surfaces (99,531 sq. m in total & 16.5% of roof area is non- reflective).		buildings can be mandated through the GDCR.				
	Intervention: Replace non-reflective roofs with cool roofs using china mosaic, insulation membrane cladding and reflective paint for the identified structures.						
2	Proposed Strategy: Deployment of Cool roofs at Hawker Zones and Vegetable Markets	Short Term	Mandate or notification for adoption of cool roofs	Zonal city engineers,	Through Municipal budget; supplemented by	Periodic monitoring and repairing	Reduction in overall UHIE in city. Shall also
	Context: Rajkot has 21 Hawkers Zones, constituting a total roof area of 41,660 sq. m., and six Vegetable Markets, constituting a total area of 6,570 sq. m. The vegetable markets are located in closed establishments with roofs. However, the hawker zones are located on open plots/parcel, with some zones being open to sky and others having corrugated roofs.		at all new public markets and hawker zones.	Garden Department, Estate Department (RMC)	CSR funds	of respective sites by Estate Department (RMC).	create thermally comfortable public spaces and enhance the overall aesthetic appeal of the city.
	Site: 21 Hawker Zones and 6 Vegetable Markets mapped in Figure 44 and Annexure 2.						

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
	Intervention: Adopt appropriate cool roofs to improve comfort and user experience for vendors as well as customers. Sites with existing conventional roofs are proposed to use inverted earthen pots with white paint on these to enhance the heat reflectivity. Sites where no roof is present are proposed to establish green roofs through use of creepers over temporary bamboo structures to provide shaded spaces.						
3	 Proposed Strategy: Solar Rooftop in Public Community Halls, Auditoriums and Urban Health Centres Context: 16 Community Halls, 4 Auditoriums and 21 Urban Health Centres currently exist in the city. (Annexure 3 and Annexure 7) Site: 8 Community Halls, 1 Auditorium and 4 Urban Health Centres with non-reflective surfaces as mapped in Figure 44. Intervention: Install rooftop Solar PV for establishments with non-reflective surfaces to promote renewable energy use and reduction in heat absorption by the buildings. 	Mediu m Term	All government buildings to be targeted for deployment of rooftop solar systems through mandates or notification.	Lighting Department (RMC)	Through Municipal budget	Periodic monitoring and maintenance of respective sites by Lighting Department (RMC)	Increased consumption of renewable energy and reduction in heat reflection from roofs of the respective buildings resulting in decreased UHIE.

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
4	 Proposed Strategy: Reflective roofs in Social Housing Context: Rajkot has 83 Social Housing Apartments, of which 51 apartments have reflective surfaces. Site: Social Housing Apartments at 32 locations with non-reflective surfaces shown in Figure 44 and Annexure 4. Intervention: Replace non-reflective roofs in old social housing schemes with cool roofs using china mosaic, insulation membrane cladding and reflective paints. 	Mediu m Term	RMC has voluntarily deployed reflective surfaces in all newly constructed social housing schemes. Appropriate mandates and notifications can be issued to mandate use of reflective roofs in all new social housing schemes.	Housing Department (RMC)	Through Municipal budget and supported with CSR funds. Communities living in social housing scheme may be encouraged to contribute through appropriate incentives and reward programs	Periodic monitoring of buildings by Affordable Housing Department (RMC).	Reduction in UHIE. Lower indoor temperatures, reduction in building energy consumption and lower associated GHG emissions.
Gree	en Roofs and Walls						
5	 Proposed Strategy: Development of green walls at Underbridges Context: Rajkot has six underbridges in total. These bridges have concrete structures and do not have plantation at present. Site: Six underbridges mapped in Figure 44. Intervention: Establish vertical plantation on the walls of the underbridges to enhance the green cover 	Short Term	All future proposed underbridges shall incorporate green walls in the project design.	Zonal city engineers (RMC), Garden Department (RMC)	Through Municipal budget; supported with CSR funds.	Regular watering of plantations and periodic monitoring of respective sites by Garden Department to ensure survival of the green walls.	Reduction in UHIE and overall increase in aesthetic appeal of the urban infrastructure.

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
	in the city's transport infrastructure. Treated wastewater shall be used for watering the plantation. Annexure 8 lists the recommended species of plants to be planted to minimise the maintenance required for survival of the plantation.					Sustenance and survival of plantation shall require high maintenance and regular monitoring.	
6	 Proposed Strategy: Green Roofs at East Zone Patel Vadi Context: East Zone Patel Vadi area has relatively less green cover compared to other three sites analysed through drone mapping. The East zone also has limited open space for establishing additional plantation and green spaces. Site: Residential buildings in East Zone Patel Vadi Intervention: Promote development of green roofs to enhance the green cover in the neighbourhood. This intervention shall be complemented with awareness programs and capacity building of beneficiaries and officials. Recommended species are mentioned in Appendix 	Long Term	Ward wise study of tree density at city scale shall be updated to prioritise replication of proposed intervention. As per tree density class critical wards in the city are 1, 4, 5, 11, 12, 14, 16, 17 and 18. City level incentives can be set within property tax along with media recognition to encourage citizens to develop green roof in their respective residential buildings.	Garden Department (RMC), Town planning department (RMC), Town planning & Valuation department (Govt. of Gujarat),	Private implementation by building developers, owners and residents with RMC incentives/rebate s on property tax.	Periodic monitoring by Town Planning Department (RMC)	Reduction in UHIE and increase in city green cover. Additionally, lower indoor temperatures, reduction in building energy consumption and lower associated GHG emissions.

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
7	 Proposed Strategy: Rooftop Gardens/play areas in municipal schools Context: Two schools present in two neighbourhood areas out of four areas analysed through drone i.e. East Zone (Patel Vadi), and Gondal Chowk and Mavdi. Site: Two schools; one in East Zone (Patel Vadi) (Shri Lal Bahadur Shashtri School), and another in Gondal Chowk and Mavdi (Shri Sant Punit Maharaj Prathmik School) mapped in Figure 45. Intervention: Develop rooftop gardens/play area for children in these schools to create additional recreational spaces along with reduction in heat absorption. Based on feasibility at each site, the garden area can be partially or completely established on the available rooftop/ terrace space. Recommended species are mentioned in Annexure 7. 	Mediu m Term	Intervention can be replicated in all 73 existing schools owned by RMC (as listed in Annexure 5) and in new public schools through mandates/notification. Further, the uptake of rooftop gardens/play areas can be promoted and incentivized in private schools.	Nagar Prathmik Sikshan Samiti (RMC) Garden Department (RMC), Town planning department (RMC),	Through RMC budget for Municipal Schools, CSR funding, School owners for private schools	Regular watering of terrace gardens by school staff. Periodic monitoring and maintenance of respective school terraces by Nagar Prathmik Sikshan Samiti (RMC) and Garden Department (RMC).	Additional recreational spaces for school children, awareness among children, increase in city's green cover and overall reduction in UHIE.
Urba	an Greening						
8	Proposed Strategy: Creating a connected blue-green infrastructure corridor in East Zone Patel Vadi	Mediu m Term	Creating a city level green corridor to connect all the major gardens to develop	Town planning department (RMC),	The city budget may incorporate implementation of the proposed	Regular watering of trees and periodic	Increase in per capita green cover and reduction in

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
	 Context: Currently the city lacks a contiguous network of blue-green spaces. A network is proposed in the greenfield development of Smart City Area. Potentially, a corridor of connected open spaces can be developed in the existing city fabric. Site: The corridor is proposed from Aji River to Lalpari Lake passing across various green spaces in East Zone (patel vadi) area. Intervention: Develop a green network spanning over a length of 7,440 metres with plantation of trees on both sides at a spacing of 5 metres between two trees (about 3,000 trees in total to be planted). This will also support NMT by creating shaded cool spaces for comfortable mobility. The network will further be complemented by the proposed revival and development of waterfront at Aji River, which could also be proposed/replicated for Lalpari Lake. Recommended species are mentioned in Annexure 7. 		connected open spaces within the city could be further proposed.	Zonal city engineers (RMC), Garden Department (RMC), Traffic Department (RMC), Rajkot Urban Development Authority (RUDA),	intervention. Tree plantations could be taken up under CSR funding and Mission Million Trees.	monitoring and maintenance by Garden Department (RMC). It could be further monitored by geotagging application developed by RMC.	UHIE by creating thermally comfortable urban environment to enhance social cohesion. Additionally, shall increase the overall aesthetic appeal of the city.

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
9	 Proposed Strategy: Developing landscaped gardens in Gondal Chowkdi & Mavdi Context: The area has various vacant open land parcels that can be developed into landscaped gardens, which serve as a neighbourhood level as well as a city level amenity. Site: Vacant public plots in Gondal Chowkdi & Mavdi Intervention: Landscaped botanical gardens at public plots in the area. The developed gardens can be complemented by creating a connected green corridor that also supports comfortable non- motorized mobility. 	Mediu m Term	Potential sites allocated as public gardens but with sparse green cover in TP schemes can be identified and developed into landscaped gardens.	Garden Department (RMC)	Through municipal budget, CSR funding and PPP	Regular watering of trees and periodic monitoring and maintenance by Garden Department (RMC).	Increase in per capita green cover and reduction in UHIE by creating thermally comfortable urban environment to enhance social cohesion by additional public spaces for people.
10	 Proposed Strategy: Plantation of trees along road medians Context: Currently a majority of the medians at East Zone (Patel Vadi), Malaviya and Atika, and Gondal Chowk and Mavdi do not have plantation. Site: Medians at identified hotspots, East Zone (Patel Vadi), Malaviya and Atika, and Gondal Chowk and Mavdi showed in Figure 45. 	Short Term	Plantation of trees can be ensured at all the medians present in the city. (Total length of roads with medians in the city: 93,580 metres, potential number of trees to be planted: 18,720) (as shown in Annexure 6)	Garden Department, RMC	The city budget may incorporate implementation of the proposed intervention along with CSR funding and Mission Million Trees.	Regular watering of trees and periodic monitoring and maintenance by Garden Department (RMC). It could be	Increase in per capita green cover and reduction in UHIE by creating thermally comfortable urban environments. This may also

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
	Intervention: Establish tree plantations along the medians, located at a spacing of 5 metres. Total cumulative length of median at the proposed locations is 10,000 m and at an interval of 5 m would constitute plantation of about 2,000 new trees. Recommended species are mentioned in Annexure 7.					further monitored by geotagging application developed by RMC.	increase the overall aesthetic appeal of the city.
Refle	ective and Permeable Pavements						
11	 Proposed Strategy: Developing permeable footpaths and green corridor along the Cycle Sharing Route Context: A 21 km long cycle track exists on both sides of the BRTS corridor along the 150 feet ring road. The site has a limited number of trees along the footpath and cycle track at present. Site: Cycle sharing route (150 feet ring road) showed in Figure 45. Intervention: Enhance green cover along the cycle sharing stretch through tree plantation on both sides of the road along with development of permeable footpaths (linked with stormwater drainage) to encourage pedestrian movement and also complement 	Mediu m Term	The proposed strategy can be further implemented on all the new footpaths which are planned to be developed in the city.	Zonal city engineers (RMC), Garden Department (RMC) Rajkot Rajpath Limited, Traffic Department (RMC)	Through RMC budget, CSR funding and Mission Million Trees.	Regular watering of trees and periodic monitoring and maintenance by Garden Department (RMC). It could be further monitored by geotagging application developed by RMC. Local NGOs may support in	Increase in per capita green cover and reduction in UHIE due to presence of permeable footpaths to create thermally comfortable urban environments. This may also increase the overall aesthetic appeal of the city.

Sr. No	Intervention	Time Period	Action for Pan-city Scalability	Implementation Entity	Implementation Mode	Monitoring and Maintenance Strategy	Value Addition
						regular monitoring.	
12	 Proposed Strategy: Cool Pavements at parking and footpath surfaces Context: There are 3 parking spaces and 4,300 meters of pedestrian footpaths in the hotspots of East Zone (Patel Vadi), Malaviya and Atika, and Gondal Chowk and Mavdi. Site: Footpaths and parking spaces in Malaviya and Atika, and Gondal Chowk and Mavdi mapped in Figure 45. Intervention: Use reflective paint coats in existing pedestrian and parking infrastructure to reduce the heat absorption of these surfaces. 	Mediu m Term	The proposed strategy can be further implemented in all the existing footpaths and parking spaces in the city (as shown in Annexure 6).	Zonal city engineers (RMC), Estate Department (RMC), Traffic Department (RMC)	The city budget may incorporate implementation of the proposed intervention.	Periodic monitoring by ward and zonal officers of RMC and Traffic and Transport Department (RMC) for the implemented locations as well as for replication.	Reduction in UHIE of the city. Additionally, may also help in visually demarcating spaces for specific use.



Figure Site Specific Urban Cooling Proposals for Rajkot (Part 1)



Figure Site Specific Urban Cooling Proposals for Rajkot (Part 2)



Gondal Chowkdi and Mavdi

Figure Urban Cooling Proposals for Gondal Chowkdi and Mavdi

Malaviya and Atika





Framework for Urban Cooling Plan for Rajkot City

East Zone Patel Vadi



Figure Urban Cooling Proposals for East Zone Patel Vadi

6.4 Guiding Recommendations for Smart City Area and Upcoming Town Planning Schemes

6.4.1 Smart City Area

As noted in previously, Rajkot is undertaking green field development in its designated Smart city area at Raiya. The city is adopting a sustainable development model that is enabled through effective land use planning for this pilot green field zone. Based on the provisions made in its planning documents, the Raiya Smart City area has notably received an IGBC Green Cities 'Platinum' rating at the planning stage. The development proposal for this green field area incorporates various urban planning interventions that comprehensively address urban heat and support urban cooling. These interventions include alignment and orientation of building with the prevailing wind direction for better cooling, appropriate distribution and placement of blue and green spaces, avenue plantation and water channel along the road etc.

Given the extent of interventions proposed in the plan, it is important that RMC and Rajkot Smart City Development Limited (RSCDL) build adequate capacities, frame enabling policies and enforce regulatory tools, leverage finance, and establish monitoring mechanisms to ensure that the plan translates into effective and at scale implementation on-ground.
The following recommendations have been identified for Rajkot's Smart City area

1. Reduce heat at urban scale: Incorporating blue-green infrastructure to leverage cooling benefits of green open spaces and water bodies will enable increased movement of cool air within the community. Proposed interventions such as establishing tree cover with naturalized tree species, water channels and shading on roads through trees will reduce the heat island effect and provide thermal comfort to citizens. Similarly, the concept of cool transit stops at 12 upcoming BRTS bus stations and cycle sharing stations can be explored in line with the suggestions provided in Table 13.

A 19 km long stretch of road along with NMT network (pedestrian and footpaths) on both sides is proposed within smart city area. Use of reflective and permeable pavements for footpaths and cycle tracks will help complement the proposed blue-green infrastructure and improve the level of thermal comfort for NMT users. Permeable pavements will not only reduce heat absorption by pavement material but also support water percolation.

2. Green roofs and facades for Cool and Green buildings: It is proposed that 80% of the buildings in the Smart City area are constructed as green buildings, enabled by maximizing use of energy efficient appliances and renewable energy. It is recommended to mandate that private developer has to go for highest rating of any building rating scheme. It is recommended to implement green facade walls and vertical gardens for public buildings to be built such as convention centre, sports complex, and integrated command and control centre, and to promote the same for private buildings through specific development and building regulations being prepared by RSCDL for the Raiya Smart City area. Also, green roofs and rooftop gardens may be promoted and mandated for private developments. Annexure 7 lists the recommended species of plants suitable for vertical garden and green roofs. The suggested plant species need minimum maintenance for their survival.

3. Serve cooling requirements in buildings efficiently: Though the use of energy efficient appliances is emphasized for buildings that will come up in the Raiya area, there is a strong opportunity to integrate district cooling system at the early planning stage to offset the effects of increase in cooling demand in a sustainable and resource efficient manner. Given the proposed mixed land use, higher allowable densities, and presence of anchor loads, prefeasibility study and technical assessments undertaken specifically for the Raiya area have found district cooling to be feasible and can be implemented in a PPP model.

6.4.2 Upcoming Town Planning Schemes

The proposed green field development under the Smart Cities Mission is a good example of a sustainable, efficient and heat resilient urban model. Opportunities exist to incorporate interventions at micro planning scale in Rajkot through the proposed Town Planning schemes to realize improved urban cooling.

Reduce heat at urban scale

- 1. Leveraging cooling benefits of green open spaces and water bodies
 - **Increase green open spaces** Currently the allocation of green spaces is not prioritized in many Town Planning schemes, which reduces the availability of green spaces in upcoming neighborhoods post allocation of other amenities. RMC can ensure a minimum of 5% or

more green cover in upcoming Town Planning schemes in order to increase per capita share of green space from 1.8 sq. m at present to 9 sq. m as recommended by WHO. Wards 1, 4, 11, 12 and 18 are not fully developed as yet and have relatively lower tree density. This intervention can be prioritized for adoption in the proposed Town Planning Scheme (TPS) nos. 34, 35, and 36 planned within wards 11 and 12 and can be replicated and promoted through appropriate provisions in the GDCR.

- **Connecting integrated blue-green infrastructure** With existing water bodies and considerable open areas located in and around wards 3, 4, 9, 11, 12, and 18, these wards offer significant opportunities to develop integrated corridors of blue-green infrastructure with appropriate distribution and placement of blue and green spaces, avenue plantation and water channels along the road. Integrated blue-green corridors can be piloted in TPS no. 11 proposed in ward 3 and TPS nos. 34, 35, and 36 proposed in wards 11 and 12, with TPS no. 11 particularly offering high potential as it is still at an early stage of development. This intervention can subsequently be replicated as appropriate in other TP schemes.
- **Develop dense urban forest** Considering Rajkot's prevalent wind direction is from southwest to north- east, development of urban forest can be prioritized in wards 9, 11, and 12 to help in cooling. It is also found that these wards have a comparatively higher land surface temperature and lower tree density (see Figure 6 and 18). Developing urban forests in these wards will not only increase the green cover but will also facilitate cooling of the air flowing into the city.

2. Promoting wind-induced air flow for better urban cooling

• The conceptualization and planning stage of TPS nos. 34, 35, 36 in wards 11 and 12 should be undertaken in consideration with the wind direction to promote better cooling. With Rajkot's wind direction prevalent from south-west to north-east, alignment and orientation of the proposed buildings in these TPS must complement the wind direction to create ventilation corridors for effective heat dissipation and cooling.

3. Cool Surfaces

- Undertake tree plantation along the medians/road dividers (each spaced 5 meters apart) Shading from tree cover can help to bring down the surface temperature of asphalt roads by about 3°C as compared to surface temperature of asphalt road without shading.
- Promote the use of reflective surfaces and permeable pavements at NMT routes, public transport stations, and parking plots Use of open grid grass pavement, permeable pavers, materials of high emissivity, application of light coloured paint on pavers or using other cool materials with Solar Reflective Index (SRI) of at least 29 (and not higher than 64)⁴¹ as recommended in IGBC's Green Building Guideline in pavements can help reduce heat absorption.

⁴¹ SSP credit 6 (Heat island reduction, non-roof) of the project checklist for Green New Buildings guideline of IGBC. Available at:

https://igbc.in/igbc/html_pdfs/abridged/IGBC%20Green%20New%20Buildings%20Rating%20System%20(Version%2 03.0).pdf



Reduce cooling requirement in buildings

- Eco Niwas Samhita 2018⁴² (Table 7 of Part I: Building Envelope guideline) can be used while selecting sustainable materials for walls, glass, and roofs. Adopt alternative construction technology and materials to reduce heat transfer such as cavity walls and rat trap bonds.
- Add coating of white paint or green cover as insulation to the walls of multi-storied buildings, wherein heat gain from walls exposed to direct sunlight can be significant.
- Use coating of white paint on UPVC sheets (average surface temp. of 36.5°C observed in Rajkot) and bitumen coated roofs (average surface temp. 39°C observed)
- Offer incremental incentives to real estate developers for green building projects, corresponding to the certification level/grade achieved instead of the existing flat-rate incentive of 5% discount in chargeable Floor Space Index (FSI) accorded through the GDCR.
- Appropriate enforcement and monitoring for tree plantation requirements for new buildings as per GDCR. The provisions currently require that buildings with an area more than 100 sq. m. shall plant three trees at a minimum for every 200 sq. m. area or part thereof. In new buildings, plantation of trees can be promoted in the south west direction of the building premises having unobstructed natural wind flow.
- Inclusion of specific provisions in GDCR to reserve and include recreational green spaces, such as plantation of trees or development of gardens, in the shared/common plots of residential and commercial developments. At present, the GDCR mandates that 10% of the area in commercial developments of more than 2000 sq. m should be allocated towards shared/common amenities⁴³. In the absence of a specific provision to integrate green spaces, the common spaces are mainly observed to be used for parking in the current practice, limiting space utilized for green cover.

6.5 Leverage finance through International, National and State programmes

There are various national as well as state supported programmes and missions which provide funds to the city to undertake specific projects which directly or passively helps in reduction of UHI and promotes sustainable cooling. Rajkot would need to devise a strategy that targets specific funding sources or a blend among the multiple options that are available to bridge the funding gap and meet the investment needs for implementation of projects.

Current flagship programmes such as Smart Cities Mission, AMRUT (Atal Mission for Rejuvenation and Urban Transformation), Jal Jeevan Mission, CAMPA (Compensatory Afforestation Fund Management and Planning Authority) grant have provided funds to the city to develop green and blue infrastructure which gets supported through state governments programmes like Swarnim Jayanti Mukhya Mantri Shaheri Vikas Yojana (SJMMSVY) and Saurashtra Narmada Avtaran Irrigation (SAUNI) Yojana, etc. Building and urban infrastructure projects may also be prioritized by RMC based on short term, medium term and long-term interventions suggested in Table 11, to include pro-cooling materials and design to

⁴² Available at https://www.beeindia.gov.in/sites/default/files/ECBC_BOOK_Web.pdf

⁴³ Common plots can be utilised for electric/power infrastructure, water tank and pump room, parking spaces as per GDCR



support cooling efforts. Such initiatives can be included in affordable housing projects being implemented through PMAY (Pradhan Mantri Awas Yojana).

For priority projects identified, project funding or concessional loans could be applied from international agencies such as the World Bank, Swiss Development Agency, Asian Development Bank, , among others that have funds targeted towards implementation of technologies, The Climate Investment Fund of World Bank allocates funding through Clean Technology Fund. Rajkot can work with the Gujarat State Government to tap into Global Environment Facility (GEF) and Green Climate Fund (GCF) through a proposal aimed at implementing medium to larger scale cooling projects, identified across multiple cities in the state.

Private sector investments will be a crucial avenue to mobilize the scale of resources required to undertake implementation of cooling actions at the city scale. Emerging market mechanisms such as green bonds, issued to finance green solutions can be explored to tap into private financing. Strengthening the capacity or readiness to receive and utilize private and climate and green finance will be a key enabler.

RMC is embedding climate-oriented budgeting in annual municipal budgets, enabled its, RMC is adopting climate-oriented budgeting in its annual municipal budgets, enabled through its continual climate action planning process. Priority and strategic cooling projects can form a part of the climate relevant interventions that are embedded in RMC's budget as part of this process.

• Annexure 1: Reflective Index of Neighbourhood Sites



Figure Reflective Index Mapping for Buildings in Gondal Chowkdi and Mavdi

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Figure Reflective Index Mapping for Buildings in Malaviya and Atika

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Figure Reflective Index Mapping for Buildings in East Zone Patel Vadi

• Annexure 2: Hawkers Zone and Vegetable Markets



Figure Mapping of Hawkers Zones and Vegetable Markets in Rajkot

• Annexure 3: Community Halls, Auditoriums and Urban Health Centres



Figure Mapping of Public Community Halls and Auditoriums in Rajkot

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Figure Mapping of Public Urban Health Centres at Rajkot

• Annexure 4: Social Housing



Figure Mapping of Social Housing Sites with Non-Reflective Surfaces

• Annexure 5: RMC Schools



Figure Mapping of RMC Schools





Figure Mapping of Footpaths, Medians and Parking Spaces

• Annexure 7: Suggested Tree Species

Table 14 Suggested Tree Species for Greening

Tree Corridor	Rooftop Gardens	Vertical Gardens	Herbs and Shrubs
 Mangifera indica Polyalthia longifolia Alstonia scholaris Terminalia bellirica Terminalia catappa Cassia fistula Cassia javanica Dalbergia sissoo Peltophorum pterocarpum Magnolia champaca Azadirachta indica Ficus amplissima Ficus benghalensis Ficus benjamina Ficus racemosa Ficus religiosa Ficus virens Morus alba Moringa oleifera 	 1. Tomato 2. Spinach 3. Radish 4. Cucumber 5. Sweet Potato 6. Curry Leaves 7. Brinjal 8. Coriander 9. Mint 10. Cabbage 11. Hibiscus 12. Jasmine 13. Rose 14. Bonsai of several species like Ficus, Terminalia etc 15. Aster 16. Daisies 17. Marigolds 18. Cactus 	 Plumbago zeylanica Pennisetum setaceum Dianella tasmanica Pandanus sp. Pittosporum tobira Asparagus densiflorus Ipomoea sp. Rhoeo spathacea Alternanthera sp. Portulaca sp. Asystasia gangetica Wedelia trilobata Tradescantia zebrina 	 Combretum latifolium Cymbopogon sp. Eragrotis sp. Pennisetum sp. Strobilanthes sp. Musa paradisiaca. Ricinus communis Bambusa sp. Costus speciosus Curcuma sp. Achyranthes aspera Stachyphrynium spicatum Zingiber officinalis Dioscorea alata; Dioscorea wallichii Ziziphus rugosa Ixora sp. Derris scandens
21. Syzygium cumini 22. Phoenix sylvestris	19. Aloe vera		19. Crotalaria sp. 20. Antidesma acidum



Tree Corridor	Rooftop Gardens	Vertical Gardens	Herbs and Shrubs
23. Citrus aurantifolia24. Ailanthus excels1. Mimusops elengi2. Holoptelea integrifolia3. Gmelina arborea4. Wrightia tinctoria5. Lagerstroemia speciose6. Butea monosperma7. Pongamia pinnat	Rooftop Gardens	Vertical Gardens	 Herbs and Shrubs 21. Clerodendrum inerme 22. Bryophyllum sp. 23. Tragia involucrata 24. Cryptolepis buchananii; 20. Hemidesmus indicus; 21. Phyla nodiflora; 22. Mimosa pudica; 23. Justicia procumbens; 24. Sida rhombifolia; 25. Hibiscus sp., 26. Tylophora indica; 27. Cynodon dactylon; 28. Abutilon sp.; 29. Murraya koenigii; 30. Capparis zeylanica;
			31. Capparis sepiaria

• Annexure 8: Summary of Stakeholder Consultations

Highlights of consultations with local stakeholders in Rajkot have been summarized below.

Name of the stakeholder	Organization
Mr. Dhruvik Talaviya	Founding Partner, Space Infraventures CREDAI member
Mr. Ankoor Sanghvi	AMAS Architects LEED-AP, IGBC-AP
Mr. Himanshu Shah	Executive Officer, Confederation of Indian Industry
Mr. Punit Agrawal	Senior Counsellor, Confederation of Indian Industry
Mr. Naresh Seth	President, Aji GIDC Industries Association
Mr. Rajesh Tanti	Vice President, Aji GIDC Industries Association
Mr. Ashish Vara	Deputy Engineer, Paschim Gujarat Vij Co. Ltd
Mr. Nilesh Parmar	Environment Engineer Nodal person – SBM, Rajkot Municipal Corporation
Mr. Ajay Vegad	Assistant Town Planner, Rajkot Municipal Corporation
Ms. Alpana Mitra	General Manager, RSCDL City Engineer, Rajkot Municipal Corporation
Mr. Y K Goswami	City Engineer (EZ), Rajkot Municipal Corporation

Table 7: Participants of Stakeholder consultation

1. Policy & Enforcement

- There is no study or assessment, both at the neighbourhood and city scale in Rajkot, which identifies and quantifies existing heat island effect and its mitigation strategies.
- No dedicated policy exists at national, state or city level that holistically addresses the issue of urban heat island effect. However, recommendations and actions that support reduction of the urban heat, either directly or indirectly and to differing extents, can be found in various guidelines, policies or voluntary certificates (as indicated in table 3).
- Adopting urban cooling strategies through land use planning processes and practices is a key enabling action to tap into opportunities and mainstream such strategies at the city-scale.
- In the absence of good cooperation mechanisms amongst key stakeholders, there is no ecosystem to initiate or scale urban cooling related practices. City administration can play the role of an anchor to enable coordinated action.
- Common development regulations (GDCR), issued to guide urban planning and development at the state-level, are followed by all cities of Gujarat. The GDCR includes requirements for provision of green public spaces and plantation of trees at new buildings. However, there is no guideline to support the effective development of green cover and land zoning in order to address the effects of heat generation in the city.
- TP schemes reserve certain proportion of land parcels to be utilized for green and blue infrastructure at the planning stage. However, the process of finalization of TP schemes can stretch over long timelines (upto 4 to 5 years due to issues of coordination, purchase and litigation of land parcels). Given the pace of development taking place in and around such

schemes or areas, such delays at times can result in unavailability of continuous land parcels which can be effectively utilized for green and blue infrastructure, with scattered and smaller land parcels available instead.

- While the city reserves land parcels for the development of parks in its land use planning process and is also improving its green cover through plantation of trees, a strategy to locate the parks from an urban cooling perspective is lacking. Parks are primarily constructed on open spaces available to the RMC, with the possible contribution from spatial location of such green spaces to address urban heat not considered
- RMC's land use planning processes details land utilization and regulates development of infrastructure and built spaces, both at the macro city-scale and at the micro-level through town planning schemes prepared for smaller areas of the city. Actual utilization of land and built spaces developed thereon can vary from utilization planned/envisaged. Thereby land reservations and building use from land use and area-level plans may not accurately reflect contributions and implications related to urban heat. There is a need to undertake continuous monitoring and appropriately document the type of buildings being constructed and utilization of built spaces even after the land use is finalised.

2. Limited awareness

- Understanding of heat island effect and impacts associated with increasing ambient and nearsurface temperatures is limited among all the stakeholders. Rising temperature is being experienced by all but understanding of its inter-relation with anthropogenic activities is limited within the city administration and citizens.
- Penetration of mechanical cooling (i.e., air conditioners) to improve thermal comfort in buildings is increasing. Waste heat generated from accelerated penetration of air conditioning in buildings can pose a significant challenge and contribute to increased heat levels at the building and neighbourhood scale. However, limited recognition of this issue and its impacts exists among building occupiers and consumers in particular. Actions to promote passive cooling solutions and address impacts of rising waste heat from air conditioning units are needed.
- There is a need to spread awareness on cooling strategies like, reflective roofs, green cover, and permeable surface, etc.

3. Willingness of consumers and developers

- There is no demand for green and energy efficient buildings from the consumer side, given that as buyers generally consider initial costs in purchasing decisions. Benefits and costs savings accruing from adoption of building-level cooling measures are realized at a later stage over the building's operational lifetime and not considered by buyers/occupiers, who are not willing to pay additional upfront costs for such benefits.
- Roof areas of most buildings are typically either used as living spaces or utilised for common amenities and utilities. Common open areas of residential and commercial projects are generally used as parking spaces. Such prevalent conditions and practices leaves limited space that can be utilized for the development of green spaces.

4. Limited financial incentives to cover additional expenditures incurred for green buildings

- Building-level cooling strategies are included in voluntary green building certifications such as GRIHA and IGBC as well as in mandatory standards such as ECBC and Eco-Niwas Samhita. However, adoption of such strategies increases the investment and capital cost of real estate projects.
- To promote green and energy efficient buildings, RMC offers incentives in the form of 5% discount in the chargeable FSI for certified green buildings. The chargeable FSI represents additional FSI (floor space allowance essentially) that can be purchased by developers by paying a certain charge. In Rajkot, this additional chargeable FSI can be availed by paying 40% of the jantri rate, a government published minimum land rate which is applicable to the corresponding area of the city. It was noted that the existing level of incentives are insufficient to cover the additional capital expenditures incurred by developers to follow green building guidelines and standards and implement cooling solutions. There is a need to provide fiscal/monetary benefits that sufficiently incentivize developers and adequately reflect additional costs incurred by them at market rates. Additionally, instead of a flat-rate incentive, these discounts can be offered in an incremental manner in proportion to scale/extent to green building and energy efficient actions implemented in the project.
- Offering upfront incentives on pre-certification for green/energy efficient buildings will motivate developers to consider it from the planning stage of the projects.

5. Lack of proven pilot projects and technical knowledge

- Officers from departments such as Town Planning department, Smart City SPV and decisionmakers have limited technical understanding and know-how on addressing urban heat. Given that RMC plays the role of planner, controller and implementer of urban planning and building development within its jurisdiction, training and capacity building of technical staff from such departments is very crucial to integrate urban cooling strategies in its planning processes and frameworks and to disseminate awareness on the same.
- The city lacks demonstration projects or pilots that holistically showcase adoption of urban cooling strategies and technological solutions at the building and neighbourhood scale. Such demonstration projects can serve as examples to show benefits and implementation of cooling solutions, thereby improving awareness and confidence among stakeholders.
- In absence of baseline study, implemented pilots and limited knowledge within the RMC officials, an enabling environment to promote cooling solutions at the wider scale is lacking

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