2025

GURUGRAM CITY COOLING ACTION PLAN

DEVELOPING COOLING ACTION PLAN AT SUBNATIONAL LEVEL

PREPARED BY

THE CELESTIAL EARTH

The Celestial Earth

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Abbreviations

AC	Air Conditioner
BAU	Business-As-Usual
BEE	Bureau of Energy Efficiency
CaaS	Cooling as a Service
CAGR	Compound Annual Growth Rate
CAPEX	capital expenditure
CEA	City Energy Analyst
CFORALL	Cooling for All
CO2	Carbon dioxide
CSP	concentrated solar power
CSV	Comma-Separated Values
DCS	District Cooling System
DDC	Data Distribution Centre
EC&SBC	Energy Conservation and Sustainable Building Code
ENS	Eco Niwas Samhita
EPW	EnergyPlus Weather
FAR	Floor Area Ratio
GFA	Gross Floor Area
GHG	Greenhouse Gas
GJ	Gigajoule
GOI	Government of India
HadCM3	Hadley Centre Coupled Model, version 3
hpa	hectopascal
HVAC	Heating, ventilation and air conditioning
ICAP	Indian Cooling Action Plan
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISHRAE	Indian Society of Heating, Refrigerating, and Air Conditioning Engineers
J	Joule
KPIs	Key performance indicators
kt	kiloton
M&E	Monitoring and evaluation
ML	Machine Learning
MWh	megawatt-hour
NCR	National Capital Region
NCT	National Capital Territory
OPEX	operating expenditure
OSM	Open Street Map
PHC	Primary Health Centre
PPHa	persons per hectare
PV	Photovoltaic
QGIS	Quantum Geographic Information System
RCP	Representative Concentration Pathway
RES_HIG	residential - high income group
RH	Relative humidity
SDG	Sustainable Development Goal

QGIS	**Quantum Geographic Information System**
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RH	Relative humidity
SDG	Sustainable Development Goal
SPIBEAT	Spatially Integrated Building Energy Assessment Tool
sqm	square meter
SRES	Special Report on Emissions Scenarios
t	tons
TAR	Third Assessment Report
W	Watts

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Foreword

Over the years, The Celestial Earth (TCE) has remained committed to its core mission of driving sustainability through innovative solutions in climate resilience, urban sustainability, and energy efficiency. As climate challenges intensify, our focus on sub-national interventions has strengthened, recognizing that meaningful change starts at the grassroots level.

With this vision, we are proud to present the "Gurugram Cooling Action Plan", a strategic framework developed to address the city's rising cooling demand while ensuring energy efficiency and environmental sustainability. This initiative has been made possible through the valuable support and funding from the International Sustainable Energy Foundation, to whom we extend our sincere gratitude.

We are especially thankful to the guidance and collaboration of various ministries, departments, and experts from Environment, Climate Change, and GIS whose insights have enriched this study. This comprehensive report is a culmination of rigorous research, data-driven methodologies, and strategic planning undertaken by the dedicated team at TCE. A special appreciation goes to Dr. Anindya Bhattacharya (ED, TCE) for his unwavering leadership and to all contributors who played an instrumental role in shaping this vision into action.

This report provides an actionable roadmap to optimize passive and active cooling strategies, promote energy-efficient technologies, and implement district cooling solutions to help Gurugram transition towards a climate-resilient future. As we work towards achieving sustainable urban cooling, we believe this effort will not only benefit Gurugram but also serve as a model for cities across India and beyond.

We deeply appreciate the collective efforts of all stakeholders and look forward to continued collaborations in making Gurugram a benchmark for sustainable cooling solutions.

Dr. Tania Ray Bhattacharya,
Founder CEO
The Celestial Earth

Acknowledgement

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We are also thankful for the contributions of interns Janhavi Parkhe and Kiran Kadam from Symbiosis Center for Information Technology (Symbiosis International University), whose efforts and contribution have enriched the report.

Preface

The Celestial Earth (TCE) has developed this report, titled: "Gurugram Cooling Action Plan," which aims to provide a comprehensive strategy for managing and mitigating the growing cooling demand in Gurugram city. This action plan consists of an in-depth assessment of cooling demand trends, projections for future scenarios, and strategic recommendations for reducing energy consumption, enhancing efficiency, and lowering greenhouse gas (GHG) emissions. The plan serves as a roadmap toward sustainable cooling solutions in alignment with Gurugram's Climate Action Plan and India's commitment to carbon neutrality by 2070.

The team has worked extensively with multiple stakeholders, including government officials and various departmental experts, who have provided valuable support and guidance throughout this endeavour. Initial results and findings were presented and discussed in stakeholder meetings and workshops, ensuring a collaborative and inclusive approach to cooling sector planning.

The Gurugram Cooling Action Plan is an essential step in addressing the city's increasing cooling needs while mitigating the urban heat island effect and reducing dependency on energy-intensive cooling systems. The study employs The Celestial Earth's (TCE) Spatially Integrated Building Energy Assessment Tool (SPIBEAT)—a machine learning-integrated geospatial analysis tool—to estimate cooling demand, energy consumption, and emissions. It explores multiple cooling scenarios, including passive and active cooling strategies, district cooling systems, and policy interventions to support sustainable urban development.

Achieving sustainable urban cooling requires policy-driven solutions, technological innovations, and community engagement. This report serves as a guiding document for city planners, policymakers, researchers, and stakeholders, outlining key strategies to improve urban resilience, enhance thermal comfort, and reduce overall cooling loads. It emphasizes the significance of passive cooling measures, energy-efficient cooling technologies, district cooling systems, and policy frameworks that encourage sustainable urban infrastructure development.

In essence, the Gurugram Cooling Action Plan underscores the critical role of localized action within the framework of national and global climate commitments. It serves as an exemplary case of how targeted city-level initiatives can align with broader environmental objectives, reaffirming a commitment to sustainability and reinforcing India's pathway to achieving carbon neutrality by 2070.

Executive Summary

The Gurugram City Cooling Action Plan is a strategic initiative designed to combat the rising cooling demand in response to rapid urbanization, increasing temperatures, and growing energy consumption. With a strong alignment to the India Cooling Action Plan (ICAP) and global sustainable cooling frameworks, the plan offers a detailed assessment of current and projected cooling needs, while presenting an array of strategic interventions to optimize energy efficiency and curb greenhouse gas (GHG) emissions. Gurugram, as a rapidly urbanizing city, is characterized by high-density commercial and residential developments that drive a substantial rise in cooling requirements. Given its location in the Composite Climate Zone, the city experiences intense summer heat, necessitating the adoption of efficient and sustainable cooling solutions to prevent excessive energy consumption and environmental degradation. The study utilizes the Spatially Integrated Building Energy Assessment Tool (SPIBEAT) to conduct a robust analysis of cooling demand, energy use, and emissions across the city. The research examines three distinct building typologies—residential, mixed-use, and commercial—to provide a comprehensive evaluation of a diverse city.

Projections indicate that under a business-as-usual (BAU) scenario, cooling demand could rise by 2050, leading to increased strain on energy resources and escalating carbon emissions. However, the adoption of sustainable cooling strategies, including enhanced building envelope modifications, installation of green roofs, district cooling systems, and high-efficiency HVAC technologies, has the potential to reduce energy consumption by up to 49% and mitigate GHG emissions by approximately 35%. The proposed action plan integrates a multi-faceted approach encompassing passive cooling techniques, advanced active cooling technologies, the establishment of district cooling infrastructure, and policy-driven incentives such as financial subsidies, public awareness initiatives, and capacity-building programs. The implementation roadmap is structured into phased milestones, with key performance indicators (KPIs) designed to track progress and ensure adaptability to evolving urban and climatic conditions. By offering a scalable and replicable model, the Gurugram City Cooling Action Plan aims to serve as a benchmark for other cities striving to balance urban expansion with climate resilience, ultimately fostering a sustainable, low-carbon cooling ecosystem that aligns with national and international climate goals.

① Introduction

Cooling is crucial for achieving several Sustainable Development Goals (SDGs), including Good Health and Wellbeing (SDG 3), Decent Work and Economic Growth (SDG 8), Sustainable Cities and Communities (SDG 11), and Climate Action (SDG 13) (India Cooling Action Plan 2019). As climate change intensifies, global heat stress and the frequency and severity of heatwaves are growing. In India, between 1981 and 2010, the number of days with temperatures ranging from 34.2 to 40.2°C (93.6-104.4°F) increased by 17 per cent, and the population exposed to high heat surged by 76 per cent (Sustainable Cooling for Urban India, 2023). The building sector, a significant energy consumer, is central to the country's economic development, particularly in urban areas with rising cooling demand. This demand is vital for protecting public health, especially for vulnerable groups like the urban poor, women, and the elderly, who are disproportionately affected by heat due to their economic, biological, and physical circumstances. Without adequate cooling and healthcare, these populations face higher mortality rates during extreme heat events (Energy Sector Management Assistance Program, 2020). However, while air conditioning offers some relief, its widespread use aggravates the problem by increasing greenhouse gas emissions,

highlighting the need for sustainable cooling solutions. By 2050, air conditioning in India could generate up to a quarter of global cooling-related emissions (Sustainable Cooling for Urban India 2023). However, the extensive energy consumption associated with traditional cooling methods poses environmental concerns, emphasizing the importance of implementing sustainable solutions such as energy-efficient ACs, cool roofs and district cooling to minimize carbon emissions and reduce strain on the energy grid. Implementing district cooling as a service, a Cooling as a Service (CaaS) model, can potentially reduce upfront equipment costs and align incentives for the most efficient operations and maintenance. Cooling as a Service (CaaS) is a pay-per-service model for clean cooling systems. It eliminates upfront investment in clean cooling technology for customers who instead pay per unit of cooling they consume, strengthening incentives for efficient consumption (Global Innovation Lab for Climate Finance)

1.1. Importance of sub-national / city level cooling plan compared to national cooling plan

Sub-national entities, such as regions, cities, or municipalities, have significant influence in addressing

cooling challenges due to their more action-oriented activities. These entities are well-positioned to tackle the climate variability, including localized temperature fluctuations and the urban heat island effect prevalent in cities. With jurisdiction over land use planning and building regulations, sub-national governments can integrate cooling considerations into urban development policies, ensuring that infrastructure is designed to mitigate heat and enhance cooling efficiency (Kotharkar, R., & Ghosh, A. 2022). Sub-national cooling actions contribute significantly to global efforts to mitigate climate change and adapt to rising temperatures, making them indispensable players in the broader landscape of climate action (Setzer, J., de Murieta, E. S., Galarraga, I., Rei, F., & Pinho, M. M. L. 2020). Sub-national cooling action plans and national cooling plans each offer unique advantages depending on the scale and scope of implementation. Table 1 below shows the comparison of the two.

Table 1: *Comparison of national and sub-national cooling action plan*

Aspect	Sub-national Cooling Action Plans	National Cooling Plans
Scope	Focuses on specific regions or cities	Covers entire nation
Customization	Tailored to local needs and characteristics	Applies uniform strategies nationwide
Decision-Making Authority	Decisions made at sub-national government level	Decisions made at national government level
Flexibility	More quick and adaptable to local conditions	May be slower to adapt due to larger scale
Community Engagement	Often involves greater community participation	Engagement may be more challenging due to scale
Resource Allocation	Resources allocated based on local priorities	Allocation may be standardized or based on national priorities
Implementation Speed	Can lead to quicker implementation due to localized decision-making	May face bureaucratic hurdles leading to slower implementation
Scale of Impact	Impact limited to specific regions or cities	Potential for broader national impact

2 Background

2.1.Cooling Zones of India

India's diverse climatic conditions necessitate the classification of the country into distinct cooling zones to address the varying cooling needs across regions. These zones include the Hot-Dry, Warm-Humid, Composite, Temperate, Cold, and Mountain zones, each characterized by unique temperature ranges, humidity levels, and seasonal patterns (India Cooling Action Plan 2019). For example, the Hot-Dry zone, found in Rajasthan and Gujarat, experiences extremely high temperatures and low humidity, requiring strategies like evaporative cooling and natural ventilation. On the other hand, the Warm-Humid zone, prevalent in coastal regions like Kerala and Tamil Nadu demands cooling approaches that focus on dehumidification and cross ventilation. The Composite zone, which includes areas like Delhi, parts of Uttar Pradesh, and Haryana, experiences significant seasonal variation, necessitating a mix of cooling strategies for different times of the year. Gurugram, located in Haryana, falls within the Composite zone. This zone's cooling needs vary across seasons, with hot summers, cold winters, and moderate monsoons, requiring a blend of shading, insulation, and ventilation techniques to maintain thermal comfort throughout the year. These region-specific cooling strategies are essential for energy efficiency, sustainable building design and climate resilience in India.
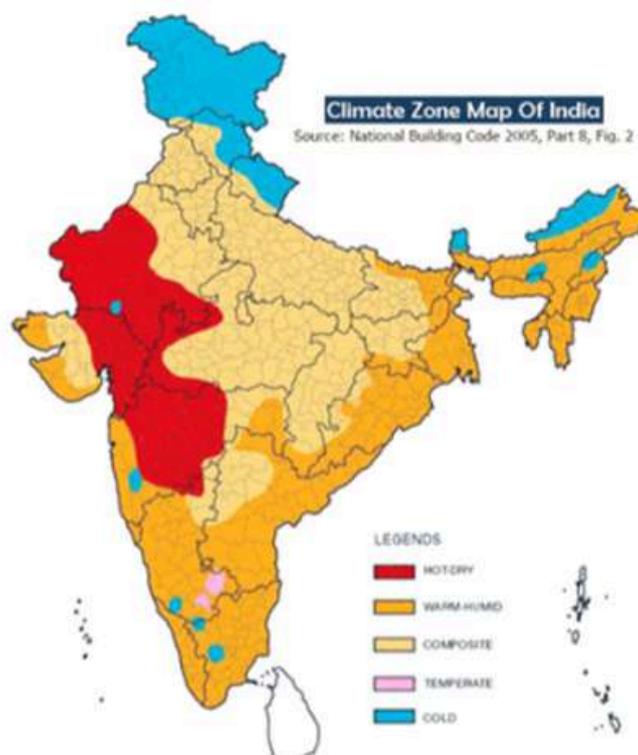
Figure 1: Climate Zone Map of India

2.2. An Overview of Gurugram City

The total geographical area of Gurugram city is approximately 673 km². As of 2021, the city's population stands at 1.87 million, according to the mobility report for Gurugram (Projected 2021). Haryana has a 35% urbanization rate, resulting in twenty Class-I cities, while the NCT of Delhi boasts three Class-I cities. Gurugram, classified as a Class-I city, also serves as the financial hub of the National Capital Region (NCR), hosting numerous major companies. It has recently become the city with India's third-highest per capita income. It has also earned the distinction of being the city with the country's highest carbon footprint (over 2 tons of CO2 per capita) (RIHN, 2021). The city had a population of 10.08 lakhs as per the 2011 India census. According to the Comprehensive Mobility Management Plan of Gurugram, the projected population of Gurugram city is estimated to reach 18.82 lakhs in the year 2021, and this figure is expected to grow to 42.5 lakhs by 2031. The study area encompasses 673 sq. km. The proposed overall gross population density for Gurugram city is 126 persons per hectare (PPHa).

2.2. An Overview of Gurugram City

Gurugram has been selected for the current study to estimate cooling demand and continue creating action plans. Gurugram, one of the fastest-growing cities in India, has seen a dramatic change from a little village to a thriving metropolis complete with skyscrapers, shopping centres, and contemporary facilities. Gurgaon's real estate market has flourished due to developers erecting gated communities, high-rise structures, and opulent flats to meet the city's expanding housing demand. Gurgaon is also home to numerous multinational corporations, financial institutions, and business parks, leading to the need for many such higher-rise buildings. However, issues including heating, environmental deterioration, and inadequate construction infrastructure arise with increased urbanization. Therefore, it has become necessary to address such issues in order to improve occupant comfort and simultaneously achieve sustainable targets. Gurugram can serve as a model for other cities looking to develop different cooling systems.

Additionally, the city's Climate Action Plan for Net Zero Gurugram by 2050 includes emission reduction strategies that can be studied further to understand their impact on cooling needs. Different technologies can also be adopted and implemented accordingly. Cooling technologies enhance indoor comfort, energy efficiency, and drive demand for space cooling in Gurgaon. They shape investment willingness and support sustainable urban goals. Effective stakeholder collaboration and proactive policy are key to resilient, livable cities.

③ Methodology and Study Area

3.1.Methodology for framing Cooling Action Plan of Gurugram

Identifying the scale of cooling needs, optimizing energy efficiency, and mitigating environmental impacts are crucial to framing Gurugram City's cooling action plan. For these purposes, we have conducted assessments of space cooling demand, energy consumption of cooling systems, and GHG emissions. The methodology integrates advanced data-driven tools and innovative modelling techniques to estimate current and future cooling demands. This approach ensures a comprehensive understanding of the city's cooling dynamics, leveraging geospatial analysis, machine learning, and energy simulation tools.

For cooling demand assessment, knowing the total volume of space that requires cooling is essential. However, no single data source provides this information for an entire city or region. Currently, most cooling-related studies in India use per capita floor space requirement for living, which ranges between 17~40m2/ person. The total floor space areas are generally calculated based on the population estimate of the study area. However, this

approach has certain limitations, especially in the context of FAR (Floor Area Ratio), which varies widely across the regions. Therefore, the estimate of per capita floor space area-based cooling space requirement is uncertain. It is estimated that in some instances, the margin of error could reach up to 30~50%. The total floor space area is the fundamental input for space cooling demand assessment, and the uncertainty of the floor space area gets carried forward to the cooling demand estimate.

To overcome this problem, especially to reduce the margin of error while calculating the cooling space volume, Celestial Earth has developed a unique tool called the Spatially Integrated Building Energy Assessment Tool (SPIBEAT), which largely overcomes the uncertainty of occupied building floor space areas in a particular area.

What is SPIBEAT?

SPIBEAT is a state-of-the-art machine learning integrated geospatial analysis tool that assesses the cooling demand of a region by assessing the building footprint and total living space volume. It is an open-source, user-friendly tool developed by The Celestial Earth to overcome long-standing technical

difficulties in assessing a region's occupational building space and volume without manual measurement. It was developed by integrating three different open source tools – Blender, QGIS, and City Energy Analyst (CEA) Model- through ML code, thus integrating spatial analysis and Building Energy Estimator.
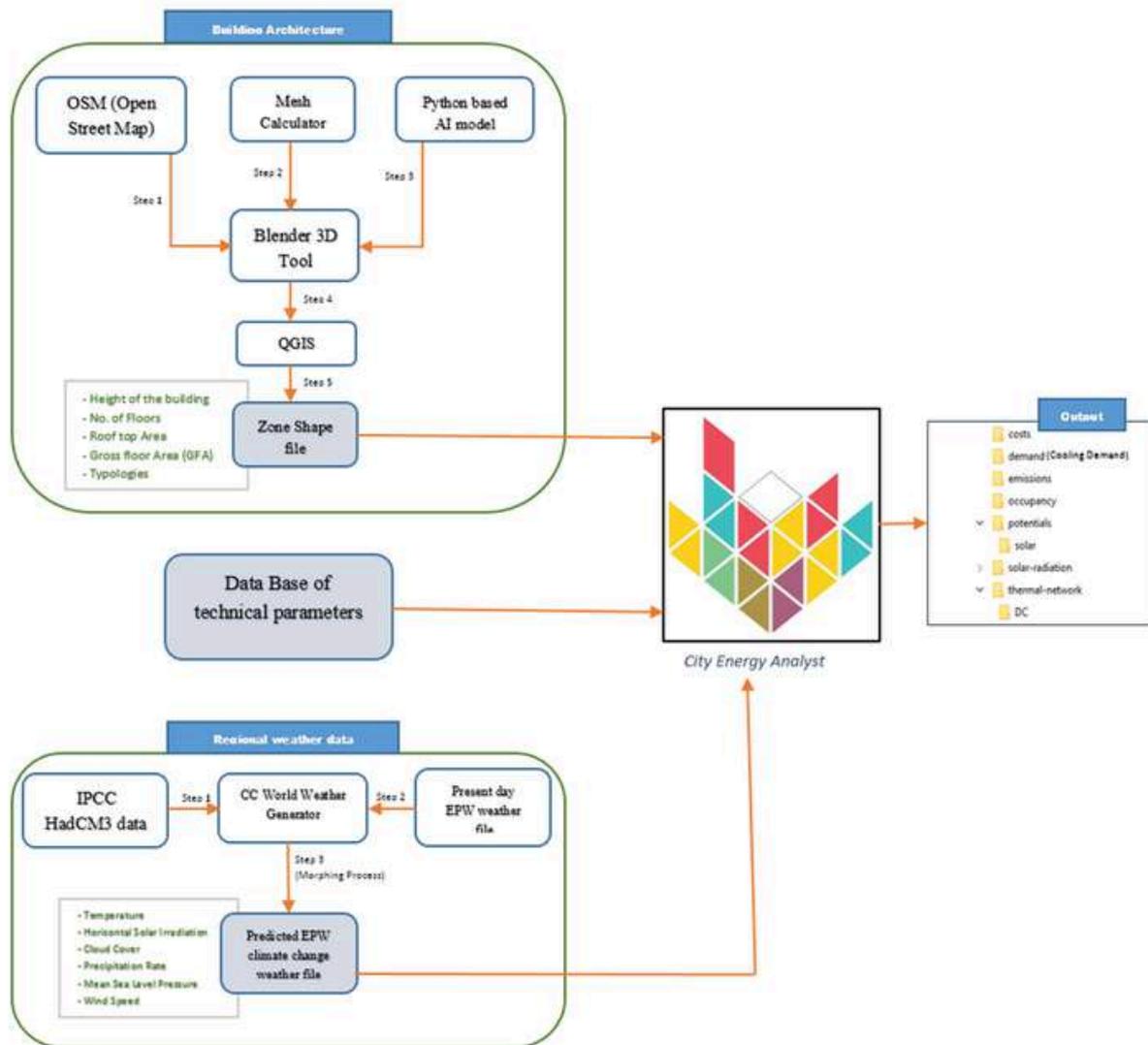
Figure 2: Cooling demand, energy consumption and GHG emissions estimation methodology using SPIBEAT open access tool

With the use of SPIBEAT, the following tasks under this project have been accomplished:

i. Estimation of residential building space areas

This assessment was done considering the existing building stock. The space area and the height of the existing buildings was calculated using Open Street Map (OSM) data and Blender (the free and open-source 3D creation tool). While OSM provided the comprehensive mapping information and detailed building footprints, Blender was used to extract building geometry

information including building heights and roof areas. This data has been crucial for assessing the total space area of residential buildings.

Steps followed for estimating residential building space area are explained in detail below:

Step 1: The **initial dataset on building footprints** had been extracted from **OSM**. It included building names and edge lengths but lacked unique identifiers for buildings.

Step 2: In **Blender**, there is a **Mesh add-on**. A mesh is a type of 3D model consisting of vertices, edges, and faces, and it is thus used to define the shape and surface of buildings.

Step 3: A **Python script** utilizing the 'bpy' add-on in Blender was used to extract the edge lengths of buildings from the mesh and export them as a CSV file. This file contains unique building IDs, heights, roof area, volume, and other properties.

Step 4: The shapefile containing

Gurugram City's sectorial boundaries is imported into QGIS, and the required sector is selected and clipped.

Step 5: The shapefile containing the building footprints of all the sectors is imported in QGIS, and then the sector-specific building footprint shapefile is isolated and mapped.

Step 6: The CSV file produced in the previous step was imported into QGIS, and the sector-specific building shapefile was merged using the QGIS joining function. The above steps generate the building geometry shapefile (zone shapefile), which contains data on above-ground and below-ground building height, above-ground and below-ground floors, and building coordinates. The final output generated by QGIS serves as the primary input for CEA.

Figure 3 below shows the flow activities to create the building geometry shape file which is the basic input for the next steps.
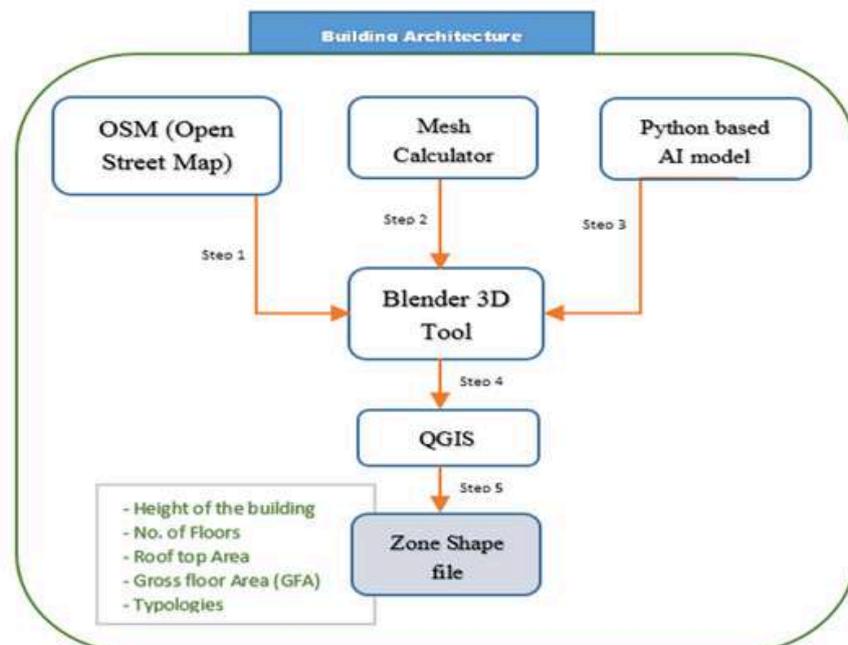
Figure 3: Flow-chart for creating zone shapefile using SPIBEAT tool

Pre-processing phase: It involved identifying and removing null values to maintain data integrity and avoid biases. A significant bias concerning building heights was identified, i.e., buildings exceeding 50 meters were significantly underrepresented.

To address this imbalance, the number of buildings with heights below 10 meters was reduced, while the representation of taller buildings was proportionally increased.

Model testing was conducted in two stages: using the OpenStreetMap dataset, divided into an 80% training set and a 20% testing set, and using updated building data from Google Maps. The entire OpenStreetMap dataset was used to comprehensively train the model, which was then applied to predict building heights across the updated dataset. This final step demonstrated the model's ability to perform in a real-world scenario, leveraging comprehensive training data to make accurate predictions.

ii. Assessment of Energy Consumption by Cooling System, Space Cooling Demand and GHG Emissions for base year 2023

To assess space cooling demand for 2023, the SPIBEAT tool, an advanced urban building energy modelling platform, was used. SPIBEAT integrates urban design principles with energy systems engineering, offering a comprehensive analysis of building space cooling demands across the subnational region.

SPIBEAT consists of default and input databases, which are divided into primary and secondary databases. The primary input was derived from OpenStreetMap (OSM), Blender, and QGIS tools and generated as a zone shapefile. This database is useful for calculating the geometry and position of buildings and serves as key elements in CEA, SPIBEAT's building simulator.

The databases required for the SPIBEAT are shown below in Figure 4:
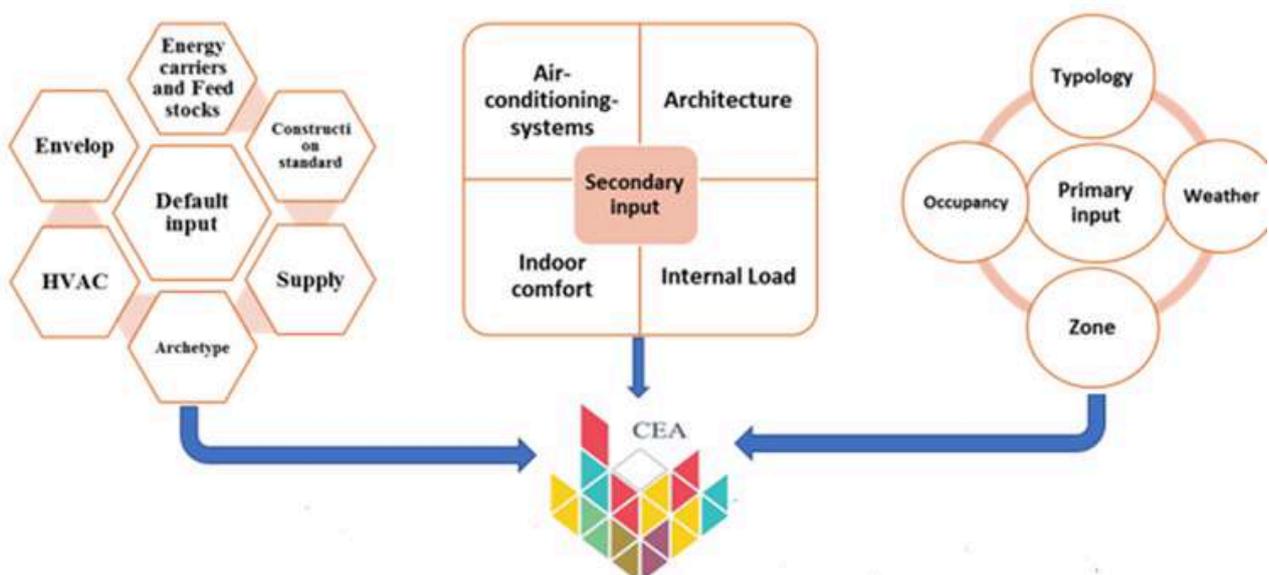
Figure 4: Inputs required for CEA model

SPIBEAT incorporated the primary data, which was a building geometry shape file, into its simulation models, allowing precise estimations of building space cooling demand. It considers factors influencing cooling demand, such as building orientation, insulation levels, and external weather conditions, occupancy schedules, and internal heat gains from appliances and occupants. By processing these inputs, CEA (the building simulator) simulates the energy consumption needed for space cooling at both individual building and citywide scales, thus giving a detailed idea of the spatial distribution of cooling demand of the area. Further, it also provides the corresponding GHG emissions. This analysis was critical in identifying areas with increased cooling needs and susceptibility to heat stress. There are some default secondary input databases in the SPIBEAT, especially in the CEA module, which are generated as per the primary inputs given. However, a key feature of CEA module is its ability to edit the secondary-level input datasets exogenously, providing flexibility to adjust fundamental cooling demand parameters such as HVAC system efficiencies, window-to-wall ratios, etc, by the users. The following are the parameters which can be customised by the user on the basis of the city's profile.

i. Building Properties

a) Typology: This encompasses various categories of buildings such as multi-residential, single residential, commercial, public utilities, and occupancy classifications.

b) Architecture: This includes factors like weather conditions, construction type, construction year (assumed year: 2020), shading techniques, and building orientation.

c) Indoor Comfort: This involves parameters like the set point temperature for cooling, setback temperature for cooling, relative humidity levels, and ventilation rates to ensure occupants' comfort.

d) Internal load: This refers to factors affecting the building's internal load, including occupancy density, heat generated by occupants, as well as electrical and water consumption patterns.

ii. Assemblies

a) Envelope: The envelope serves as the physical barrier separating the conditioned interior from the unconditioned exterior environment. It comprises elements such as windows, walls, roofs, floors, shading devices, and their orientations.

b) HVAC (Heating, ventilation and air conditioning): HVAC systems are interconnected systems that provide heating, ventilation, and cooling services to various areas within the building. This may include ceiling cooling, mini-split systems, central air conditioning, among others.

c) Supply: This pertains to the provision of various utilities to the building, including cooling, hot water, electricity, and heating supplies.

The outputs generated by the SPIBEAT include detailed maps and charts depicting cooling demand distribution, energy usage patterns, and potential areas for intervention. Thus, they enable data-driven decision-making for sustainable cooling action planning.

iii. Space cooling demand and energy consumption under different scenarios by 2050

The SPIBETA tool allows for scenario analysis, making it a powerful tool for urban planners and energy managers to evaluate different cooling strategies and their impacts on energy consumption and thermal comfort. In other words, not only the current cooling conditions, but SPIBEAT has also facilitated the development of Gurugram's future cooling demand and GHG emissions under different scenarios. The process began with importing the necessary datasets into SPIBEAT, including building characteristics, and spatial information sourced from the OpenStreetMap (OSM) and Blender, same as the baseline assessment. These datasets formed the foundation for the scenario analysis.

The next step involved identifying key factors that influence space cooling demand, such as population growth, temperature and precipitation trends until 2050, urban development patterns, building architectural designs, HVAC systems, etc. These factors form a part of the input database of the CEA module of the SPIBEAT tool, which were then changed as per scenario needs and used in the model.

Using SPIBEAT's advanced simulation capabilities, the impacts of these changes on building energy use and cooling demand have been assessed, thus aiding in the projections of future space cooling demands and GHG emissions till 2050 under different development pathways.

3.2. Selection of Sectors for city cooling demand assessment

Gurugram is a rapidly developing city with a mix of residential and commercial spaces, ranging from high-income housing to corporate offices, retail outlets, and educational institutions. When assessing these parameters, hence, it is crucial to consider both residential and commercial buildings, as each type has different energy consumption patterns and cooling requirements. Evaluating both ensures a comprehensive understanding of the city's total as well as per capita, per square metre and per building cooling demand, energy consumption and GHG emissions. Hence, three distinct sectors of the city have been selected for analysis: Sector 52A, Sector 112, and Sector 16. Each of these sectors has been selected from 3 different clusters of Gurugram, clusters that have been formed based on demographic, infrastructural and economic characteristics. The clusterization of the city has been referred fto rom the report titled 'Climate Action Plan for Net Zero Gurugram by 2050'.

Being part of different clusters, each sector represents a unique

composition of building types (residential and commercial) as well as having unique demographic, economic, administrative and infrastructural features, offering a comprehensive view of the entire city's cooling demand pattern under different conditions. Despite this diversity in building typologies, the same construction standard, "Standard 2 – Concrete and Masonry – Increased Conditioned Areas," has been applied uniformly in the CEA model for assessment of the baseline cooling conditions of the three sectors. This approach has been taken as concrete and masonry are the predominant construction materials across all building types in these sectors, reflecting common urban construction practices in a city like Gurugram. These materials, known for their durability and structural properties, form the foundation of the city's built environment. By standardizing the construction input across sectors, the analysis ensures consistency in evaluating energy performance while accounting for the thermal and material characteristics that are inherent to Gurugram's building stock. Key characteristics of this construction standard are summarized in the following table 2:

Table 2: *Building envelope and air-conditioning characteristics of buildings in selected sectors considered for baseline assessment*

Parameters	Characteristics
I. Construction type	Medium construction tightness
II. Roof type	Concrete roofs with rock pebbles finishing
III. Wall type	Clay brick walls with white paint
IV. Floor type	Concrete floors
V. Window type	Single glazing windows
VI. Window wall ratio	0.29
VII. Set point temperature	26-28 degrees Celsius
VIII. Setback temperature	27 degrees Celsius
IX. Relative Humidity	30-70%
X. Air-conditioning system	Mini split AC
XI. Cooling system	PI controller
XII. Cooling supply system	Vapour compression chiller and dry cooling tower
XIII. Ventilation system	Window ventilation

The annexure 1 provides detailed characteristics of each of these parameters. Further, for the scenario-based assessments, adjustments were made to parameters such as building tightness, insulation levels, window glazing, shading devices, roof materials, air-conditioning systems, etc., to reflect the impacts of active and passive cooling interventions. The details of all these scenario-based assumptions can also be referred to in the annexe. These changes enable a more accurate assessment of cooling demand and energy efficiency under different future scenarios.

The following section outlines the key characteristics of each of the selected sectors:

I. Sector 52A is predominantly a **residential area**, and for this sector, the building use type has been classified as residential or **'RES_HIG'** (residential - high income group). The entire gross floor areas of the buildings have been allocated for residential use. These buildings feature **higher proportions of climate-controlled spaces**, such as living areas, compared to non-conditioned spaces like storage or garages. This results in **higher energy demand** for heating, cooling, and ventilation.

II. Sector 112 comprises a mix of both residential and commercial buildings. Consequently, **75%** of the gross floor areas of buildings have been allocated to **RES_HIG** (residential-high income group), while **25%** have been designated for **'COMMERCIAL_FORMAL'.** This proportion reflects India's electricity consumption trends, where **commercial buildings account for 9%** of total electricity consumption, while **residential buildings contribute 24%**, highlighting the growing dominance of the residential sector (IESS 2047, Ver 3.0, NITI Aayog, GOI)

III. Sector 16 is primarily a **commercial hub** with a few residential spaces; hence, the building use type has been assumed as commercial or **'COMMERCIAL_FORMAL'** for this sector. The entire gross floor area is assumed to be used for commercial purposes.

Table 3: Building use type for each selected sector of Gurugram

Sectors	Building use type	Construction Standard
Sector 52A	Residential_High Income Group (RES_HIG)	Standard 2 – Concrete and Masonry – increased conditioned areas
Sector 112	Residential_High Income Group (RES_HIG) and COMMERCIAL_FORMAL	Standard 2 – Concrete and Masonry – increased conditioned areas
Sector 16	COMMERCIAL_FORMAL	Standard 2 – Concrete and Masonry – increased conditioned areas

In short, the above two tasks (estimation of building space area and assessment of current space cooling demand) have been undertaken for these three sectors using our SPIBEAT tool. Later, an average of these sectors' space cooling demand gives us an idea of Gurugram's overall average space cooling demand, the city's per capita, per building, and per square meter space cooling demand, as well as the separate cooling demand of residential and commercial buildings.

4 Cooling Demand of Gurugram City as of 2023

4.1. Building Height Estimation and Footprint Extraction for Selected Sectors

Firstly, the heights of buildings in the three selected sectors have been estimated following the above methodology involving the use of Blender and QGIS modules of SPIBEAT. Below, the calculation of building heights for the majorly residential sector 52A has been shown. For the other two sectors, same steps have been undertaken.

Figure 4: Python based script for extracting building height

The Blender module of SPIBEAT gives the following results on building heights for the 3 sectors. Additionally, the building wise number of floors above and below ground have been calculated manually, as shown in table 4, assuming that each floor in a building has a height of 3 metres.

Table 4: Average height and no. of floors of buildings in selected sectors

Sectors	No. of Buildings	Average Height Above Ground (metres)	Average Height Below Ground (metres)	Average No. of Floors Above Ground	Average No. of Floors Below Ground
52A	312	8	3	3	1
16	217	14	3	4	1
112	274	9	1	3	0

Then using the steps described in the previous chapter, the QGIS module of SPIBEAT has been used to generate the building footprint shapefile of the three sectors. As an illustration, the steps involved in the extraction of Sector 52A's building footprint shapefile has been shown in figure 6:

Sector selection from sectorial .shp ⟶ Selection of Building Footprint ⟶ Building Footprint Data (.shp)
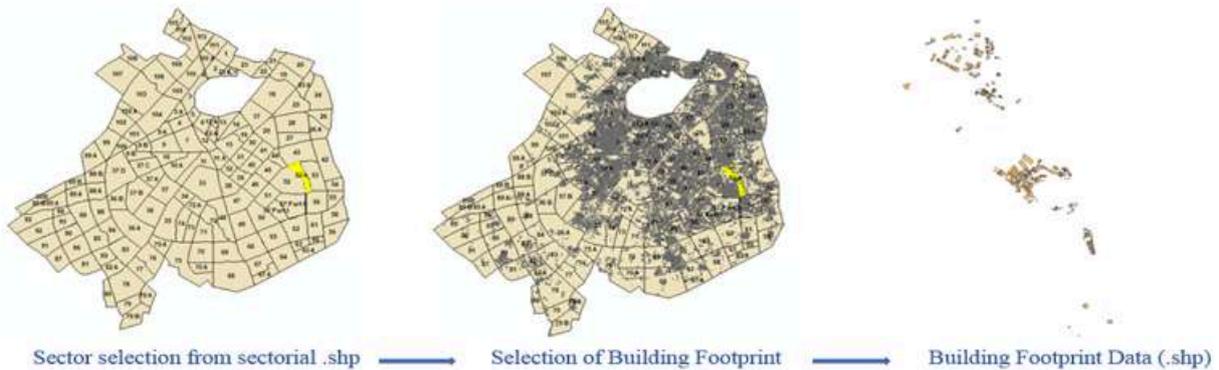
Figure 6: Extracted building footprint data of Sector 52A

The building footprint shapefile obtained for the three sectors, which includes both the visual representation of each sector as well as attribute data on building heights and the number of floors, serves as a crucial input for the CEA module of the SPIBEAT tool. These primary inputs, combined with the default inputs of CEA, give the secondary inputs.
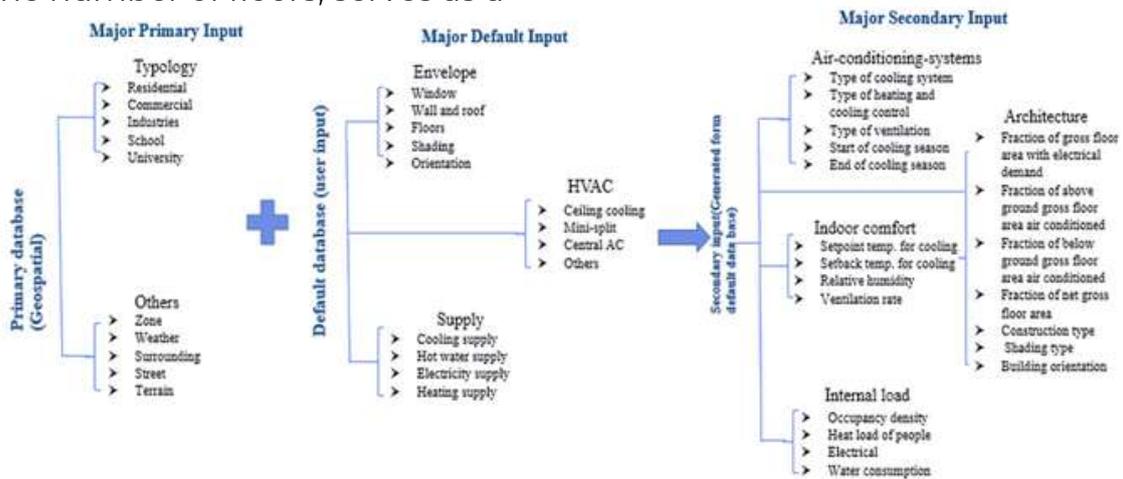
Figure 7: Inputs required for CEA module of SPIBEAT

These databases give the total gross floor areas of buildings in each sector as given provided in table 5:

Table 4: Sector wise total gross floor areas of buildings

Sectors	Gross Floor Areas (square metres)
Sector 52A	266310
Sector16	677529
Sector 112	205353

The CEA module of SPIBEAT further calculates building wise electricity consumption by cooling system, cooling demand and GHG emissions as given in the next sections.

4.2. Sector-wise cooling demand assessments for 2023

With the help of the SPIBEAT space cooling demand, the energy consumption of cooling systems and emissions for each building within these three sectors have been estimated for the base year of 2023. Apart from the primary, default and secondary inputs, the model also considered the regional weather file of the Hissar District of Haryana to make the cooling demand assessment more specific to the local areas.

This analysis used the Hissar weather file, sourced from the Indian Society of Heating, Refrigerating, and Air Conditioning Engineers (ISHRAE) section on the EnergyPlus website (detailed weather file generation in given in annexure 2). By integrating this climate data with the other datasets, the SPIBEAT model generated the following results for the concerned sectors, which are shown in Table 6.

Table 6: *Gurugram's sector wise energy consumption by cooling system, end use space cooling demand and GHG emissions for base year (2023)*

Parameters	Sector 52A	Sector 112	Sector 16
Energy consumption of cooling system (MWh)	19159	10517	57066
End use space cooling demand (GJ)	189389	103960	564098
GHG emissions (ktCO2)	34.7	13	65.17

Further, the sector-wise per capita, per square meter, and per building space cooling demand and GHG emissions have been assessed for the baseline year. A key input for calculating per capita space cooling demand and emissions is the sector-wise population distribution. We have estimated the per person space requirement as 40 m², based on the GMDA's report on the Water Supply & Sewerage Master Infrastructure Plan for Gurugram Manesar Urban Complex – 2031 A.D. and the Gual Pahari Development Plan – 2031 A.D. Using this standard, we estimated the residential sector population by dividing the gross floor area (provided by the CEA module) by 40 m² per person.[1]

[1] IIT Roorkee Report 21.03.24.pdf (gmda.gov.in): According to the report, the targeted population for 2025 is 40 lakh people, with a density of 250 PPH. Each person requires 40 m² of space, calculated as 10,000 m² (1 hectare) divided by 250 people.

The SPIBEAT also supplied each sector's total building space area, facilitating calculations for per square meter cooling demand and emissions. Further, the building footprint shapefile provided each sector's total number of buildings, enabling baseline per-building cooling demand and GHG emissions estimations. Table 7 shows the sector-wise per capita, per square metre and per building space cooling demand and GHG emissions for 2023:

Table 7: *Gurugram's sector wise per capita, per square metre and per building space cooling demand and GHG emissions for baseline year (2023)*

Indicators	Sector 52A	Sector 112	Sector 16
Per capita cooling demand (GJ/person)	11.5	9.4	5.00
Per square metre cooling demand (GJ/sq.m)	0.7	0.5	0.8
Per building cooling demand (GJ/building)	605	378	2599
Per capita GHG emissions (tCO2/person)	7.5	4.2	2.08
Per square metre GHG emissions (tCO2/sq.m)	0.47	0.23	0.35
Per building GHG emissions (tCO2/building)	399	170	1081

4.3. Cooling assessments of Gurugram City for baseline year (2023)

To estimate the total cooling demand and GHG emissions of the entire Gurugram City for 2023, these parameters' sector-wise per capita, per square meter, and per building values have been used. Then, using the total population of Gurugram for the year 2023 (calculated using a CAGR-Compound Annual Growth Rate of 4%), total building space area (provided by CEA model) and total number of buildings (accessed from building footprint data), the total cooling demand and GHG emissions of Gurugram's total population as well as per individual have been estimated, the details of which have been provided in table 8.

Table 8: *Total and per capita, per square metre and per building space cooling demand and GHG emissions for Gurugram City in baseline year (2023)*

Parameters	
Total cooling demand of population (GJ)	**48517243**
Per capita cooling demand (GJ/person)	23.7
Per m2 cooling demand (GJ/m2)	0.68
Per building cooling demand (GJ/building)	1196
Total GHG emissions of population (ktCO2)	**7035**
Per capita GHG emissions (tCO2/person)	3.4
Per m2 GHG emissions (tCO2/m2)	0.35
Per building GHG emissions (tCO2/building)	550
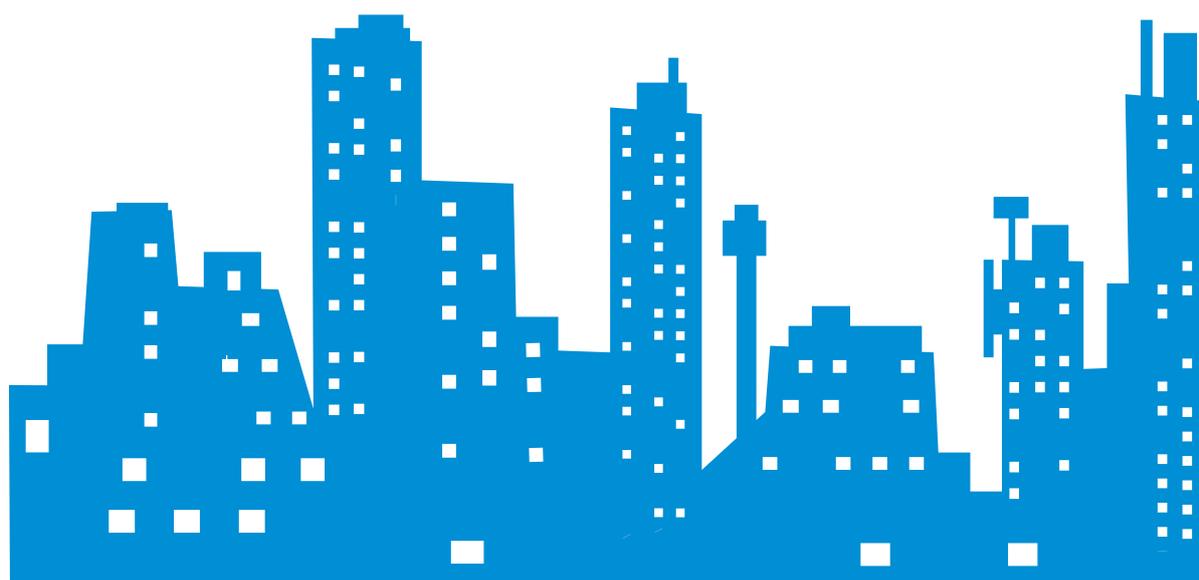
5 Cooling Scenarios of Gurugram City (2050)

After assessing the cooling conditions of Gurugram for the base year, the next step is to estimate the city's future cooling demand and emissions under different scenarios until 2050. Rising temperatures and increased urban heat will increase future cooling demand, leading to higher GHG emissions. However, as scenario-based assessments can help Gurugram's policymakers plan the necessary sustainable infrastructure development, explore equitable solutions and energy-efficient technologies, and anticipate energy demand, several architectural and technological options have been explored under these scenarios. The primary goal of developing these scenarios is to reduce overall cooling demand compared to current levels, providing access to thermal comfort to all, thereby protecting its vulnerable populations and fostering economic and environmental resilience for the city.

5.1. Description of cooling demand scenarios for year 2050

The following section describes in detail the scenarios that have been built for the Gurugram City Cooling Action plan considering various technological, behavioural and natural cooling aspects. Besides, active and passive cooling scenarios, the study have also conducted a climate scenario following the IPCC climate scenario guideline of B1 to assess the impacts of climate change on urban cooling demand in the city. Figure 8 provides the different scenarios which we have considered for this study.
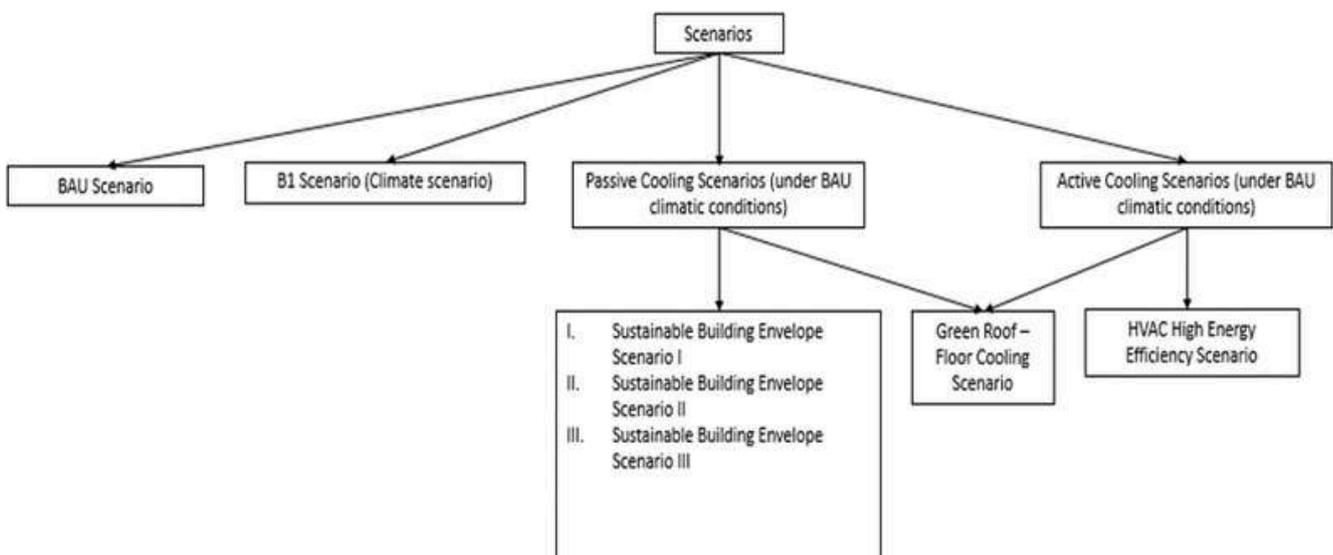
Figure 8: Gurugram City's cooling demand scenarios for year 2050

5.1.1. Business-As-Usual (BAU) Scenario

The BAU scenario represents the case where current policies, technological trends, and socio-economic patterns continue without significant changes or additional interventions. It assumes no new actions are taken to promote sustainable urban cooling, reduce greenhouse gas emissions, improve energy efficiency, or address climate change beyond what is already planned or expected under existing policies. Consequently, this scenario witnesses extreme climate change conditions in high-temperature rise, intense heat waves, Urban Heat Island intensification, and more significant variability in monsoon patterns. The population increases steadily in this scenario due to slowly converging fertility patterns across regions. Economic development is primarily driven by regional priorities, leading to fragmented and slower growth in per capita income and technological advancements compared to other scenarios.

5.1.2. Climate change scenario under B1 condition

The B1 scenario describes a convergent world where the global population peaks mid-century and declines thereafter. However, in the B1 scenario, there is a rapid shift in economic structures toward a service and information-based economy. This shift is accompanied by a reduction in material intensity and adopting clean, resource-efficient technologies. The focus is on global solutions for economic, social, and environmental sustainability, emphasizing improved equity, though without additional climate initiatives. As a result, climatic conditions in this scenario are less extreme than those in the BAU scenario.

5.1.3. Active and passive cooling scenarios

As part of developing the Cooling Action Plan for Gurugram, the study considers three pivotal scenarios outlined in the Indian Cooling Action Plan (ICAP): Comfortable Cooling, Sustainable Cooling, and Smart Cooling. These scenarios aim to achieve critical objectives, including reducing overall cooling demand, lowering energy consumption for cooling systems, and minimizing the use of refrigerants. A series of active and passive cooling sub-scenarios has been developed and implemented within each primary scenario framework to achieve these goals.

Passive design is a method that leverages natural elements to minimize reliance on artificial climate control by optimizing a building's layout, materials, openings, and orientation. On the other hand, active cooling techniques rely on mechanical systems to transfer heat out of a space or circulate cool air, ensuring comfort in hot conditions. In other words, these sub-scenarios involve introducing specific technological, architectural, and behavioural changes to evaluate how cooling

demand might reduce under different future conditions till 2050. The sustainable cooling techniques incorporated in these scenarios are based on government-approved building codes such as the Bureau of Energy Efficiency's Energy Conservation and Sustainable Building Code (EC&SBC), Eco Niwas Samhita (ENS), and the Council of Architecture's Green Building Code. In these scenarios, the climatic conditions were considered the same as BAU weather conditions (2050) as they are the baseline against which the impacts of proposed interventions, policies, or alternative scenarios can be compared. Table 9 outlines the detailed descriptions of each scenario for the year 2050 implemented in this study. It offers a comprehensive framework for estimating and managing future cooling demand in Gurugram. This approach ensures the development of sustainable and resilient cooling strategies tailored to the city's unique needs and challenges.

Table 9: *Gurugram's sector wise per capita, per square metre and per building space cooling demand and GHG emissions for baseline year (2023)*

S. No.	Description and basic assumptions
Scenario: BAU **Active/ Passive Cooling:** **ICAP Cooling Category:**	• The population continues to increase steadily in the city. • No new or additional actions are taken to address sustainability, and urban cooling, and current policies continue. • Fragmented and slower economic growth, with a lack of technological advancements. • Extreme weather conditions, such as intense heat waves and high variability in monsoon patterns.
Scenario: B1 **Active/ Passive Cooling:** Both Active and Passive **ICAP Cooling Category:** Sustainable Cooling	• The population peaks in mid-century and declines thereafter. • Rapid shift in economic structures toward a service and information-based economy. • Adoption of clean, resource-efficient technologies. • Focus on economic, social, and environmental sustainability. • Less extreme weather conditions as compared to the BAU scenario.

Scenario: Sustainable Building Envelope Scenario I **Active/ Passive Cooling:** Passive **ICAP Cooling Category:** Sustainable Cooling	• Reduction of reliance on mechanical cooling systems. • Focus on natural processes and architectural design strategies: a) Changes in building tightness, construction type, shading, roofs, windows and walls. b) Construction of buildings with heavy materials to enhance thermal mass. c) Increase in tightness of buildings to a highly tight level, minimizing air leakage. d) Upgradation of windows to triple glazing with two selective low-emissivity coatings to limit heat transfer. e) Coating of roof with white paint over plaster to reflect sunlight and reduce heat absorption. f) Applying dark blue paint over clay bricks on walls for improved insulation. g) For shading, use of venetian blinds to block direct sunlight and reduce indoor temperatures. These changes collectively create a more energy-efficient environment by optimizing passive cooling methods.
Scenario: Sustainable Sustainable Building Envelope Scenario II **Active/ Passive Cooling:** Passive **ICAP Cooling Category:** Sustainable Cooling	• Improvement of building insulation to minimize heat gain, leading to reduced cooling demand. • Following adjustments are made in the architecture section of the model: a) Setting of building's tightness to medium to control air leakage. b) Reduction in window-to-wall ratio is reduced to 0.1, minimizing window surface area to reduce heat gain. c) Upgradation of windows to double glazing with low-emissivity coating to limit heat transfer. d) Change in roof material to aluminium tiles for better heat reflection. e) Coating of roof with white paint over plaster to reflect sunlight and reduce heat absorption. f) Applying dark blue paint over clay bricks on walls for improved insulation.
Scenario: Sustainable Sustainable Building Envelope Scenario III **Active/ Passive Cooling:** Passive	• Involves minimizing air infiltration and exfiltration by effectively reducing the building's air leakage rate. • Changes made under this scenario: a) Improvement in building tightness to a highly tight level, ensuring that the building is well-sealed with minimal air leakage. b) Installation of triple glazing window with low emissivity coating.

ICAP Cooling Category: Sustainable Cooling	c) Applying dark paint over roof and wall. d) Use of roller blinds as a shading device. • These improvements significantly reduce the building's cooling demand by preventing the loss of cooled air and the entry of warm outside air.
Scenario: Sustainable Green Roof - Floor Cooling Scenario **Active/ Passive Cooling:** Active and Passive both **ICAP Cooling Category:** Sustainable Cooling	• Reduction in cooling demand by a combination of active and passive cooling techniques. • The following changes are made under this scenario: a) Modification in the roof architecture of buildings by implementing green roof construction, where roofs are covered with vegetation and soil; this design provides natural insulation and shading, significantly reducing heat absorption and lowering the overall cooling demand of the building. b) Additionally, changing cooling system to floor cooling, which helps maintain comfortable indoor temperatures by circulating cool water.
Scenario: Sustainable HVAC High Energy Efficiency Scenario **Active/ Passive Cooling:** Active **ICAP Cooling Category:** Comfortable & Sustainable Cooling	• Reduction in cooling demands my changing mechanical cooling demand. • The following changes are made in the HVAC systems: a) Changing to ceiling cooling (AC) combined with mechanical ventilation equipped with demand control and an economizer for optimizing energy use. b) Setting the cooling set point temperature has been adjusted to 26°C, ensuring comfortable cooling, while the setback temperature is set to 24°C. c) Regulation of relative humidity (RH) levels with a minimum of 30% and a maximum of 50%, preventing excessive dryness or humidity.

Following the same methodology, involving the use of the SPIBEAT tool, the BAU, B1 and the above active and passive cooling scenarios have been run for the three selected sectors of Gurugram, including Sector 52A, Sector 112 and Sector 16. This analysis highlights how implementing architectural, behavioural, and technological interventions can reduce building-wise space cooling demand and GHG emissions in Gurugram and guides policymakers for future urban resilience planning in the city.

6 Assessment of cooling demand and energy consumption under different scenarios by 2050

6.1. Sector Wise Cooling Demand and energy consumption Scenarios

6.1. Sector Wise Cooling Demand and energy consumption Scenarios

6.1. Pure residential areas

It is estimated that under the BAU condition, there will be a substantial increase in cooling demand, cooling energy demand and greenhouse gas (GHG) emissions, compared to 2023, driven by high population growth and a lack of sustainability interventions. Conversely, under the B1 climate scenario, there will be a lesser increase in cooling demand and emissions relative to the current year. However, implementing active and passive cooling techniques reduces the total energy consumption of buildings, their space cooling demand, and GHG emissions by 2050 compared to the 2050 BAU scenario.

The highest decrease in these indicators (cooling demand, cooling energy demand and GHG emissions) is observed when modifications are done to improve the buildings' air infiltration rate under the buildings' air leakage rate scenario, followed by the green roof combined with floor cooling scenario, the HVAC high energy efficiency scenario, the passive cooling scenario and the improved building insulation condition. This demonstrates that, even with the same climatic conditions in 2050 as in the BAU scenario, energy-efficient interventions and architectural upgrades can substantially lower space cooling demand and corresponding energy requirement and GHG emissions.

The tables and figures below present the cooling demand and GHG emissions across scenarios for sector 52A (a representative sector of pure residential area) and the percentage reduction of these indicator values for different scenarios relative to the BAU scenario.

Table 10: Gurugram's sector wise per capita, per square metre and per building space cooling demand and GHG emissions for baseline year (2023)

	BAU- (Baseline 2050)	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	HVAC high energy efficiency scenario	Green roof -floor cooling scenario	Sustainable Building Envelope Scenario III
Energy consumption of cooling system (Mwhyr)	21173	20813	16769	18264	16369	9946	6736
End use space cooling demand (GJ)	209300	205736	165766	18054	161809	98316	66582
GHG emissions (KtCO2)	35.837	35.636	32.427	33.737	18.463	13.413	12.506

Figure 9: Energy consumption of cooling system and space cooling demand of Sector 52A under different scenarios for year 2050

Table 11: *Percentage change in in cooling parameters from BAU scenario to other scenarios for year 2050 in Sector 52A*

	BAU - B1 Scenario	BAU Scenario - Sustainable Building Envelope Scenario I	BAU Scenario - Sustainable Building Envelope Scenario II	BAU Scenario - HVAC High Energy Efficiency Scenario	BAU Scenario - Green Roof - Floor Cooling Scenario	BAU Scenario — Sustainable Building Envelope Scenario III
% reduction in energy consumption of cooling systems	-2%	-21%	-14%	-23%	-53%	-68%
% reduction in space cooling demand	-2%	-21%	-14%	-23%	-53%	-68%
% reduction in GHG emissions	-1%	-10%	-06%	-48%	-63%	-65%
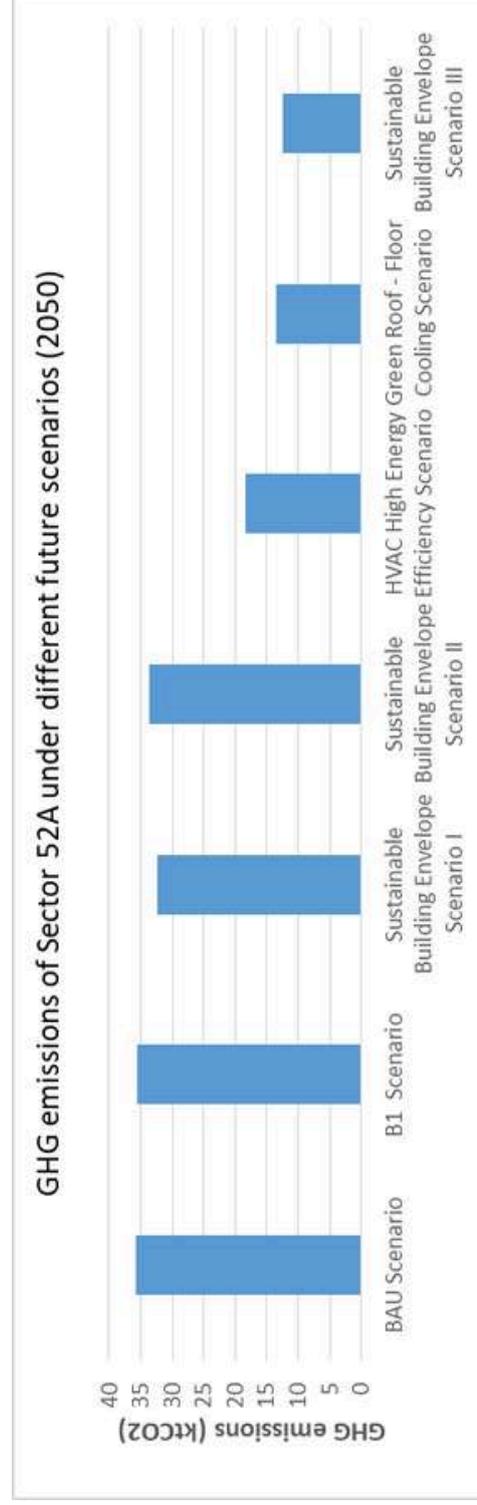
Figure 10: GHG emissions of Sector 52A under different scenarios for year 2050

Table 12: *Energy consumption by cooling system, space cooling demand and GHG emissions of Sector 112 under different scenarios for year 2050*

	BAU (Baseline 2050)	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	HVAC high energy efficiency scenario	Green roof-floor cooling scenario	Sustainable Building Envelope Scenario III
Energy consumption of cooling system (Mwh/yr)	11993	11783	7297	6930	9867	10116	3882
End use space cooling demand (GJ)	118548	116478	72133.2	68500.8	97534.8	99997.2	38372.4
GHG emissions (KtCO2)	13.867	13.743	10.467	10.409	12.8	11.445	8.591

6.1.2. Mixed use areas

In case of sector 112, which comprises both residential and commercial buildings, the space cooling demand, cooling energy demand and GHG emissions till 2050 under BAU and B1 scenarios follow the same pattern as Sector 52A. In the BAU scenario, these parameters go on increasing as compared to 2023 levels, while in the B1 scenario, they witness slight reductions, but still higher than current levels, due to the introduction of measures such as the use of clean or renewable technologies.

This sector encounters high to very high reductions in space cooling demand and GHG emissions as compared to BAU conditions, passive cooling strategies are implemented under the buildings' lower air leakage rate scenario, improved building insulation scenario and passive cooling scenario. Significant but comparatively lower reductions are also observed when green roofs are installed along with changes made in HVAC systems by switching to efficient cooling technologies like central AC and floor cooling.

Tables and figure below present the cooling demand and GHG emissions across scenarios for sector 52A and the percentage reductions in these parameters for different 2050 scenarios relative to the BAU scenario.

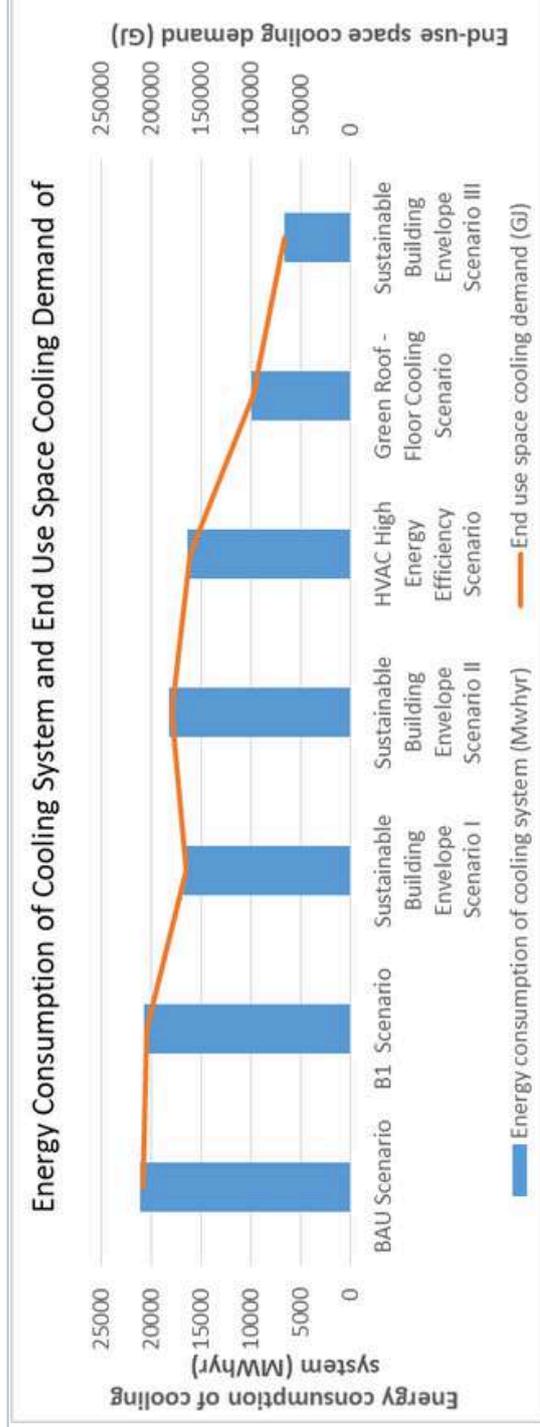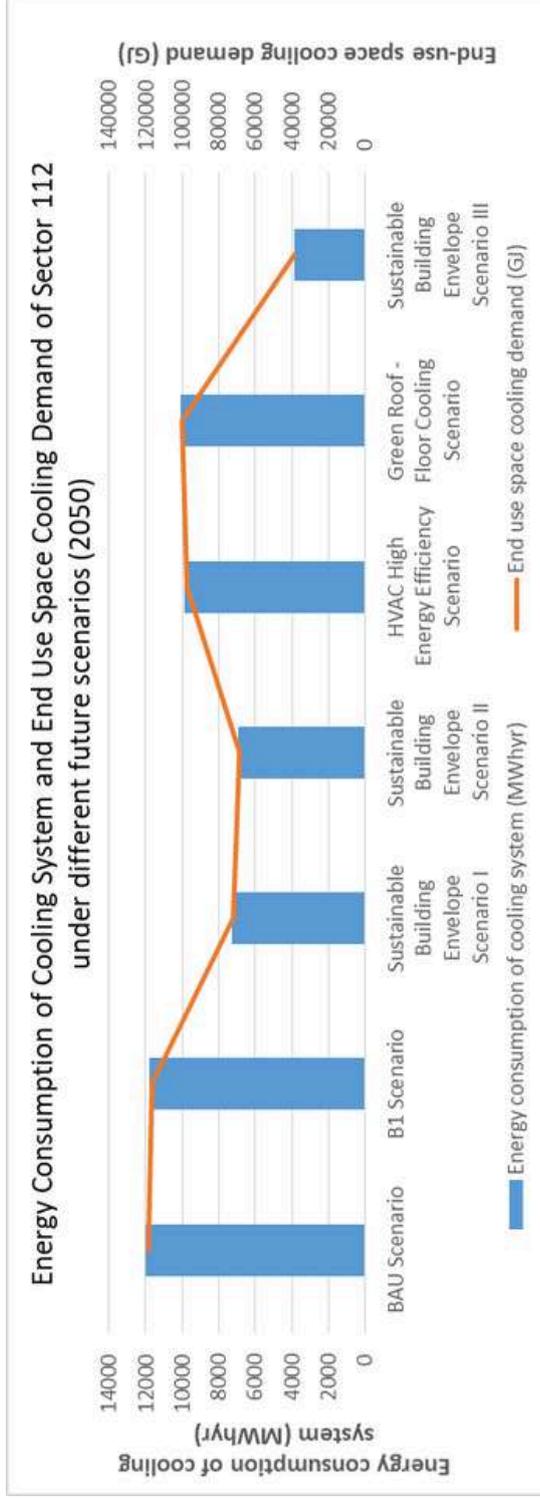**Figure 11:** Energy consumption by cooling system and space cooling demand of Sector 112 under different scenarios for year 2050.
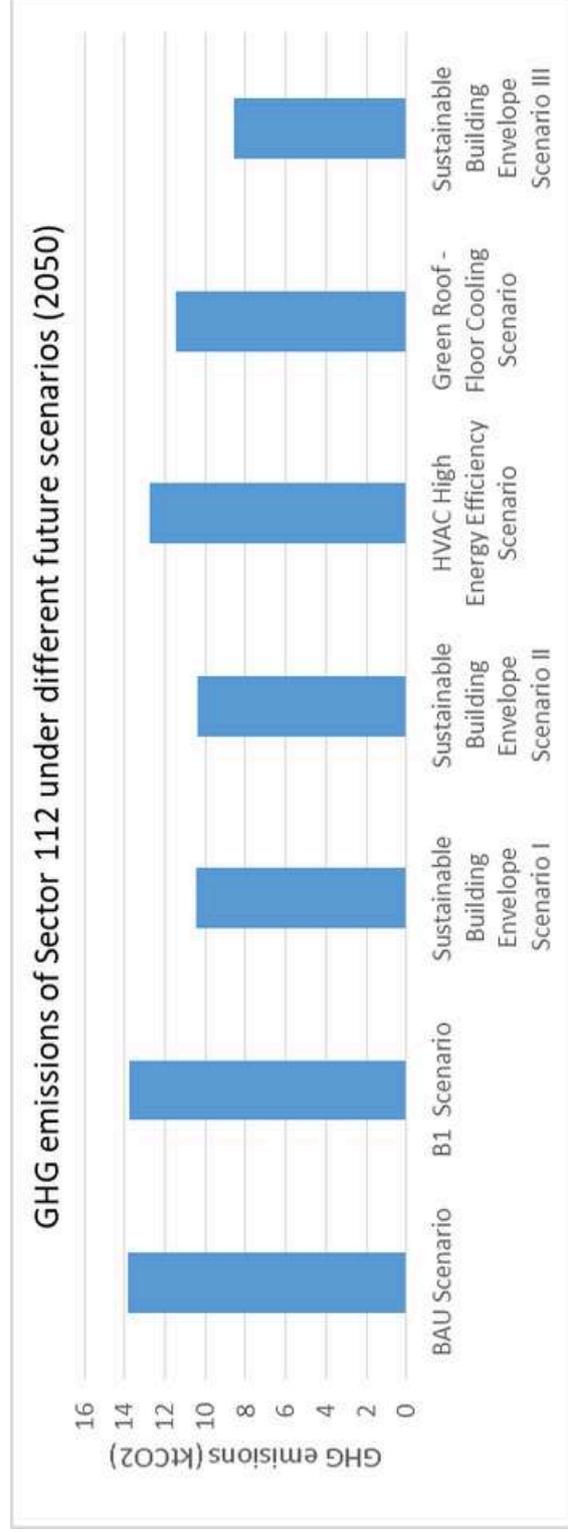
Figure 12: GHG emissions of Sector 112 under different scenarios for year 2050.

Table 13: *Percentage change in cooling parameters from BAU scenario to other scenarios for year 2050 in Sector 112*

	BAU - B1 Scenario	BAU Scenario – Sustainable Building Envelope Scenario I	BAU Scenario - Sustainable Building Envelope Scenario II	BAU Scenario - HVAC High Energy Efficiency Scenario	BAU scenario - Green Roof - Floor Cooling Scenario	BAU Scenario - Sustainable Building Envelope Scenario III
% reduction in energy consumption of cooling systems	-2%	-39%	-42%	-18%	-16%	-68%
% reduction in space cooling demand	-2%	-39%	-42%	-18%	-16%	-68%
% reduction in GHG emissions	-1%	-25%	-25%	-8%	-17%	-38%

6.1.3. Pure Commercial Areas

Sector 16 is primarily a commercial area, with current space cooling demand and greenhouse gas (GHG) emissions surpassing those of Sectors 52A and 112 due to its high concentration of commercial buildings. If conditions remain unchanged until 2050, as projected in the BAU scenario, space cooling demand and GHG emissions are expected to increase significantly. However, with the adoption of sustainability measures, as outlined in the B1 scenario, these metrics are projected to show a moderate reduction.

The introduction of both active and passive cooling techniques further help reduce space cooling demand and GHG emissions till 2050. The most substantial decrease occurs with the combined implementation of green roofs and floor cooling systems. Additional reductions can be achieved through the use of efficient HVAC systems, such as centralized air conditioning, and various architectural improvements. These include enhancing building tightness, installing double or triple-glazed windows with low-emissivity coatings, applying reflective or dark paint on roofs and walls, adding shading devices and so on. The details of these scenarios are reflected in the following tables and figure.

Table 14: *Energy consumption by cooling system, space cooling demand and GHG emissions of Sector 16 under different scenarios*

	BAU (Baseline 2050)	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	HVAC high energy efficiency scenario	Green roof -floor cooling scenario	Sustainable Building Envelope Scenario III
Energy consumption of cooling system (Mwhyr)	62158	61740	50358	51919	55419	43772	51082
End use space cooling demand (GJ)	614423	610297	497789	513220	490367	432688	504943
GHG emissions (KtCO2)	68.533	68.285	59.74224	60.529	59.734	50.611	60.294
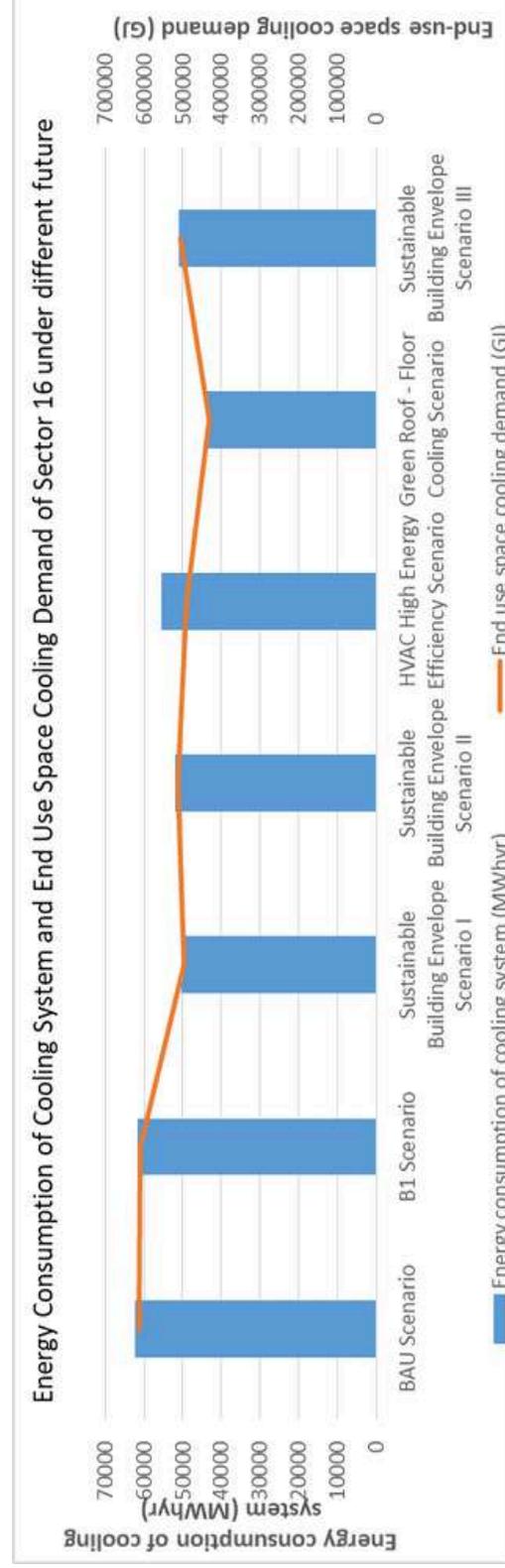
Figure 13: Energy consumption of cooling system and space cooling demand of Sector 16 under different scenarios for 2050.

Table 15: Percentage change in cooling parameters from BAU scenario to other scenarios in Sector 16

	BAU - B1 Scenario	BAU Scenario – Sustainable Building Envelope Scenario I	BAU Scenario - Sustainable Building Envelope Scenario II	BAU Scenario - HVAC high Energy Efficiency Scenario	BAU scenario - Green Roof - Floor Cooling Scenario	BAU scenario – Sustainable Building Envelope Scenario III
% reduction in energy consumption of cooling systems	-1%	-19%	-16%	-11%	-30%	-18%
% reduction in space cooling demand	-1%	-19%	-16%	-20%	-30%	-18%
% reduction in GHG emissions	-0.4%	-13%	-12%	-13%	-26%	-12%
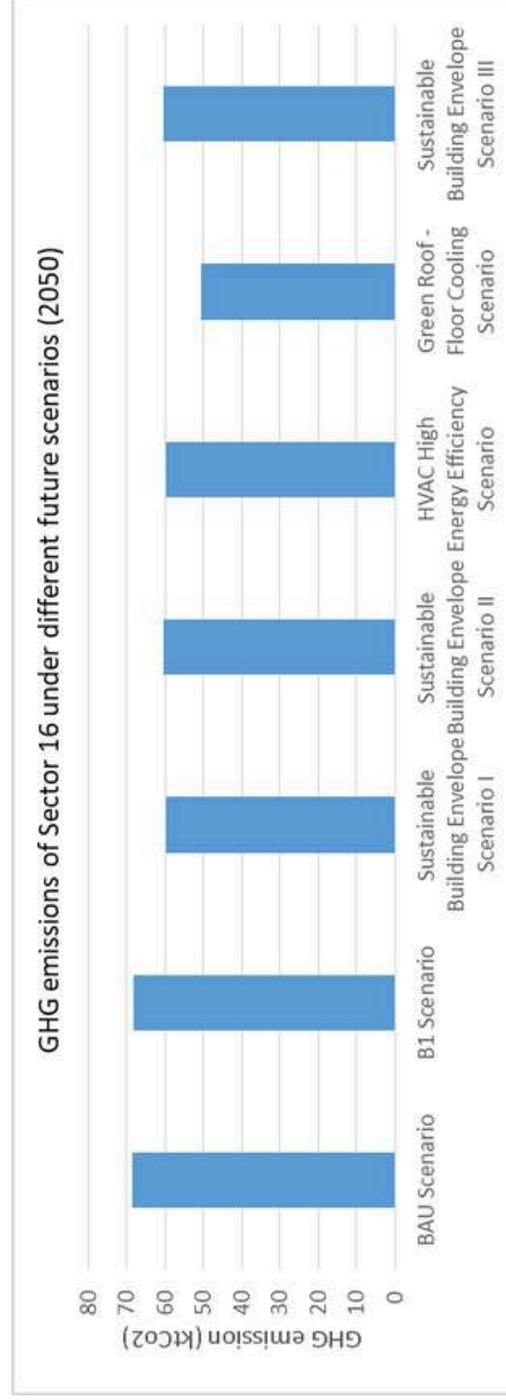
Figure 14: GHG emissions of Sector 16 under different scenarios for 2050.

6.2. Citywide Cooling Demand and GHG Emissions under different Scenarios (2050)

The total cooling demand for Gurugram under various future scenarios has been analyzed by estimating future per capita cooling demands and emissions across the three selected sectors. These calculations aim to project future cooling demands under different conditions for the entire city. The data required to estimate per capita cooling demand and GHG emissions, i.e. the population of each sector was provided by CEA. The table below presents the per capita space cooling demand and greenhouse gas (GHG) emissions for the three concerned sectors under different scenarios for year 2050. It is observed that implementing various active and passive cooling measures reduces cooling demand and emissions of each individual.

Table 16: Per capita space cooling demand and GHG emissions of selected sectors of Gurugram under different scenarios for year 2050

Sectors	Parameters	BAU	BI Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	HVAC High Energy Efficiency Scenario	Green Roof - Floor Cooling Scenario	Sustainable Building Envelope Scenario III
Sector 52A	Per capita cooling demand (GJ/person)	9.31	9.15	7.37	8.03	7.20	4.37	2.96
	Per capita GHC emissions (tCO2/person)	1.59	1.58	1.44	1.50	0.82	0.60	0.56
	Per capita energy consumption of cooling system (MWh/person)	0.94	0.93	0.75	0.81	0.73	0.44	0.30
Sector 112	Per capita cooling demand (GJ/person)	5.98	5.88	3.64	3.46	4.92	5.05	1.94
	Per capita GHC emissions (tCO2/person)	0.70	0.69	0.528	0.525	0.65	0.58	0.43

Parameters							
Per capita energy consumption of cooling system(MWh/person)	0.20	0.51	0.50	0.35	0.37	0.59	0.61
Sector 16 — Per capita cooling demand (GJ/person)	6.62	5.67	6.43	6.73	6.53	8.00	8.06
Per capita GHG emissions (tCO2/person)	0.79	0.66	0.78	0.79	0.78	0.895	0.899
Per capita energy consumption of cooling system (MWh/person)	0.67	0.57	0.73	0.68	0.66	0.81	0.82

The sector wise averages of per capita space cooling demand and GHG emissions under each scenario provide insights into this parameter for the entire city of Gurugram City for various future conditions. Subsequently, by combining the projected population of the city up to 2050 (estimated using a Compound Growth Annual Rate of 4%), the total cooling demand and GHG emissions of its population in 2050 has been determined. The table below provides the details of Gurugram's total 2050 cooling demand and GHG emissions.

Table 17: Per capita and total space cooling demand and GHG emissions of Gurugram under different scenarios for year 2050

Parameters	Baseline 2023	BAU 2050	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	HVAC High Energy Efficiency Scenario	Green Roof - Floor Cooling Scenario	Sustainable Building Envelope Scenario III
Per capita cooling demand (GJ/person)	23.7	7.8	7.7	5.8	6.1	6.2	5.0	3.8

Parameter							
Total cooling demand of population (GJ)	48517243	537771940	53041699	40395877	41953085	42718748	34759310	26528443
Per capita energy consumption of cooling system (MWh/person)	5.51	1.82	1.79	1.33	1.39	1.47	1.14	0.72
Total energy consumption of cooling system (MWh)	11277821	12565130	12368658	9218089	9596675	10144083	7905397	4966102
Per capita GHG emissions (tCO2/person)	3.44	1.064	1.058	0.92	0.94	0.75	0.61	0.59
Total GHG emissions of population (ktCO2)	7035	7352	7310	6342	6493	5183	4232	4100

Due to continuous rise in population, the per capita and total cooling demand and corresponding energy consumption for cooling and GHG emissions for the city of Gurugram till 2050 are expected to rise significantly. Under the BAU condition the cooling demand and energy consumption of cooling system are expected to grow by 10% & 11% between 2023 and 2050 respectively. However, under the same population growth and climatic conditions, when active and passive cooling technologies are implemented, both per capita and total space cooling demand as well as GHG emissions for the city also reduce significantly. Please see the table below to refer the corresponding reduction in cooling demand, energy demand and emissions under different cooling scenarios at the city level. Hence, policymakers must focus on airtight building designs, green roofs, efficient HVAC systems or a combination of both active and passive cooling techniques to curb the city's rising cooling demand and emissions.

Table 18: *Percentage change in cooling parameters from BAU scenario to other scenarios for Gurugram City*

	BAU - B1 Scenario	BAU Scenario – Sustainable Building Envelope Scenario I	BAU Scenario - Sustainable Building Envelope Scenario II	BAU Scenario - HVAC high Energy Efficiency Scenario	BAU scenario - Green Roof - Floor Cooling Scenario	BAU scenario – Sustainable Building Envelope Scenario III
% reduction in energy consumption of cooling systems	-1%	-24%	-21%	-17%	-36%	-49%
% reduction in space cooling demand	-1%	-22%	-19%	-20%	-33%	-35%
% reduction in GHG emissions	-0.5%	-13%	-11%	-23%	-36%	-31%

However, if there is a choice between implementing active and passive cooling strategies, it is wise to prioritize passive options because by 2040 only 40% of Indians are expected to have access to air conditioning systems (Climate Investment Opportunities in India's Cooling Sector, World Bank Group). The rest of the population has to rely on natural cooling systems or architectural and behavioural changes to reduce the space cooling demand. This limitation underscores the importance of passive cooling technologies which have been explored in all of Gurugram's future cooling demand scenarios except one.

7 Strategic Cooling Recommendations for Gurugram City

7.1. Passive Cooling Measures:

Passive cooling measures leverage natural processes and thoughtful design to reduce reliance on mechanical cooling. These approaches are cost-effective, sustainable, and adaptable to various urban environments, significantly enhancing the quality of life while minimizing environmental impact. Following are the measures which can be implemented:

7.1.1. Urban Greenery

Urban greenery is a cornerstone of passive cooling strategies, playing a vital role in mitigating the urban heat island effect through shade and evapotranspiration.

1) Tree Plantation Initiatives:

- **Large-scale Tree-planting Programs:** It is essential to develop large-scale initiatives focusing on planting native and drought-resistant species. Native species are well-suited to the local environment, requiring minimal resources while maximizing ecological benefits. Tree-lined streets, residential areas, and commercial zones create shaded corridors that reduce ambient temperatures.
- **Creation of Green Belts and**

Micro-forests: Establishing urban green belts and dense micro-forests provides significant cooling benefits. These areas act as carbon sinks, reduce air pollutants, and create cool zones through evapotranspiration, benefiting both residents and ecosystems.

2) Green Roofs and Vertical Gardens:

- **Green Roofs:** Installing vegetation on rooftops reduces heat absorption and improves thermal insulation for buildings. These roofs also enhance urban biodiversity and reduce stormwater runoff.
- **Vertical Gardens:** Promoting the installation of vegetation on building walls offers similar cooling benefits while utilizing vertical spaces effectively. Financial incentives, such as subsidies and tax rebates, can be provided to property owners and developers to encourage adoption.

7.1.2. Cool Roofs and Cool Pavements

Cool roofs and pavements directly address urban heat by reducing surface temperatures and minimizing heat absorption.

1) Reflective Roofing Materials:

- High-albedo materials like light-

coloured coatings or heat-resistant tiles reflect sunlight, decreasing roof surface temperatures and indoor cooling loads.
- Urban planning and building codes can mandate the use of such materials, ensuring widespread implementation of "cool roofs" in new and retrofitted structures.

2) Cool Pavements:
- Developing materials for sidewalks and streets that absorb less heat, such as permeable pavers or reflective concrete, is critical. Permeable pavements also assist in managing stormwater by improving drainage, adding to their sustainability.
- Implementing such materials in high-traffic areas and public spaces can significantly lower surface temperatures, improving urban comfort levels.

7.1.3 Building Design and Orientation

Designing buildings to harmonize with their environment can greatly reduce indoor cooling demands.

1) Optimized Orientation:
- Building orientation should minimize direct exposure to sunlight, especially on west-facing facades, which receive the most heat in the afternoon.
- Thoughtful positioning of buildings within plots can further ensure reduced solar gains and enhanced natural shading.

2) Natural Ventilation:
- Incorporating cross-ventilation principles by strategically placing windows, vents, and ducts enables natural airflow, cooling interior spaces without mechanical aids.
- Designs should consider local wind patterns to maximize ventilation effectiveness.

3) Shading Elements:
- Architectural features like overhangs, louvers, and window awnings prevent direct solar heat gain on windows and walls.
- Window films and shading screens, particularly those with reflective properties, are highly effective in reducing interior heat while maintaining visibility and daylight access.

4) Thermal Insulation:
- Modern thermal barriers in walls, roofs, and windows help maintain stable indoor temperatures. These include materials like insulated panels, reflective foils, and advanced glazing technologies.

Improved insulation reduces the need for artificial cooling, cutting energy consumption and costs

7.1.4. Water Features

Water features introduce a natural cooling element to urban spaces by leveraging evaporative cooling effects.

1) Urban Water Bodies:
- Revitalizing existing ponds and fountains provides multiple benefits, such as temperature

regulation and increased recreational opportunities. These features act as natural heat absorbers and promote local biodiversity.

- Incorporating water-sensitive urban design (WSUD) principles ensures sustainable maintenance of these bodies.

2) Rainwater Harvesting:

- Rainwater harvesting systems integrated into urban planning can support landscaping efforts, maintain greenery, and provide water for evaporative cooling.
- Harvested rainwater reduces dependency on external water supplies, making these systems cost-efficient and sustainable.

7.1.5 Revitalizing Traditional Techniques

Traditional architectural solutions offer timeless passive cooling benefits and are well-adapted to local climates.

- **Jaalis (Perforated Screens):** Jaalis diffuse harsh sunlight, reducing interior temperatures while allowing ventilation. Their aesthetic appeal also makes them a preferred choice in modern adaptations.
- **Courtyards:** Central open spaces in buildings provide natural ventilation and promote air circulation. Courtyards act as thermal buffers, regulating temperatures in surrounding rooms.
- **Earthen and Lime Plaster:** Utilizing locally available materials with high thermal mass properties ensures natural-

insulation, reducing heat gain in homes.

By revisiting these traditional methods, urban designs can embrace solutions that are both culturally significant and ecologically sound.

7.2. Active Cooling Technologies:

7.2.1. Energy-Efficient Air Conditioning Systems

1. Inverter Technology Air Conditioners: Inverter-based air conditioners are designed to offer superior energy efficiency by adjusting compressor speed to maintain a consistent indoor temperature. Unlike traditional systems that operate on a start-stop mechanism, inverter ACs continuously regulate cooling output, resulting in significant electricity savings and reduced greenhouse gas emissions. Promoting their adoption through awareness campaigns and highlighting long-term savings can accelerate their integration into urban households and offices.

2. Higher Energy Ratings: Air conditioning systems with higher energy efficiency ratings, such as the Bureau of Energy Efficiency (BEE) 5-star rated appliances, consume considerably less energy. To encourage widespread adoption, subsidies, financial incentives, and easy financing schemes can be introduced. This not only reduces electricity bills for consumers but also contributes to national energy conservation goals.

7.2.2 District Cooling System (DCS)

District Cooling Systems (DCS) offer an innovative approach to cooling large, high-density urban areas such as business hubs, commercial centres, and residential complexes. These systems operate by centralizing chilling plants and distributing cooled water or air through a network of insulated pipelines to individual buildings. This shared infrastructure significantly reduces energy consumption per user by optimizing efficiency at scale. Furthermore, DCS is ideal for integrating renewable energy sources or waste heat recovery, making it a sustainable alternative to conventional building-specific air conditioning.

7.2.3 Radiant Cooling Technology

1. Radiant Panels: Radiant cooling panels are installed in the ceilings or floors of buildings to cool indoor spaces through thermal radiation and conduction. These systems use water, a more efficient heat carrier than air, to absorb heat and reduce indoor temperatures. Radiant panels are particularly effective in large commercial and residential buildings, providing even cooling with reduced energy consumption compared to conventional systems.

2. Thermal Storage Systems: Thermal storage systems use phase change materials (PCMs) to store excess heat during peak hours and release it during cooler periods. This technology is ideal for regions with significant diurnal temperature variations, as it balances energy demand, reduces peak load on electrical grids, and ensures consistent indoor temperatures throughout the day and night.

7.2.4. Evaporative Cooling

Evaporative cooling systems use the natural process of water evaporation to lower surrounding air temperatures. This technology is especially suitable for semi-arid zones like Gurugram, where the dry climate enhances evaporation efficiency. Implementing evaporative coolers in residential, commercial, and industrial spaces can provide a low-cost, eco-friendly cooling solution while reducing dependence on conventional air conditioning systems.

7.2.5. Waste Heat Recovery Systems

Waste heat recovery systems capture unused heat from industrial processes and repurpose it for cooling nearby commercial or residential areas. For example, absorption chillers can utilize waste heat to drive cooling processes. Establishing partnerships with industrial units to implement these systems can create a sustainable symbiosis, reducing energy wastage and fostering environmentally conscious urban development.

7.2.6. Solar Cooling Systems

1) Solar-Assisted Air Conditioning: Photovoltaic (PV) solar panels can power air conditioning units, reducing dependence on grid electricity and lowering operational

costs. Solar-assisted air conditioning is ideal for sunny regions and can be integrated into urban planning policies to encourage renewable energy adoption.

2) Concentrated Solar Power (CSP): Large-scale solar thermal cooling systems leverage concentrated solar power (CSP) technology to generate thermal energy for cooling. This method is highly efficient for industrial and institutional applications, reducing carbon footprints while providing sustainable temperature control.

7.2.7 Smart Cooling Systems

Smart cooling systems use advanced technologies like IoT-enabled sensors and smart thermostats to optimize energy use. These systems can monitor temperature variations, occupancy levels, and user preferences in real time to adjust cooling outputs efficiently. By minimizing wastage and ensuring precise temperature control, smart cooling systems contribute significantly to energy conservation in urban infrastructure.

7.3. Policy and Community Engagement:

7.3.1 Capacity Building

Capacity building plays an important role in ensuring the success of modern cooling initiatives by equipping key stakeholders with the requisite knowledge and skills. Training programs should be developed to target local architects, engineers, urban planners, and municipal authorities, emphasizing

modern cooling techniques such as passive cooling solutions and active cooling technologies. These training modules will cover methods like implementing green roofs, applying reflective coatings, and utilizing energy-efficient HVAC systems. Furthermore, regular workshops and seminars can introduce stakeholders to emerging cooling technologies and disseminate successful case studies from other regions. Collaborating with academic institutions is another essential component; partnerships with universities and technical colleges can integrate cooling strategies and climate-resilient urban planning into their curricula, thereby ensuring long-term knowledge dissemination.

7.3.2. Regulatory Framework

A robust regulatory framework is critical for embedding cooling strategies into urban and building design. In terms of urban planning codes, mandatory adoption of cool roofing techniques, involving the use of reflective materials, should be enforced for all new residential and commercial buildings. Policies should also mandate energy-efficient building designs, ensuring proper ventilation and the integration of vegetation in public and private spaces. Sustainable urban landscaping should be promoted through the inclusion of trees, vertical gardens, and water features, effectively mitigating urban heat island effects.

Building efficiency standards must align with energy efficiency goals specific to cooling. These standards

should emphasize proper insulation, high-efficiency windows, and regular inspections for building energy performance. Additionally, introducing a tiered energy efficiency rating system would incentivize developers to surpass basic energy requirements and adopt more advanced solutions.

7.3.3 Financial Incentives

Financial incentives are a powerful tool for catalyzing the adoption of sustainable cooling measures, reducing initial costs and other barriers. Governments should provide tax rebates or exemptions to property owners and developers who integrate eco-friendly cooling measures such as cool roofs, solar shading, and energy-efficient appliances. Subsidized loans could facilitate retrofitting of existing buildings and incorporation of advanced cooling systems in new constructions. Furthermore, direct subsidies can support the adoption of passive cooling measures, such as solar chimneys and energy-efficient ventilation systems. Public-private partnerships should also be encouraged to attract private sector investments in cooling infrastructure, backed by government co-funding or guarantee schemes.

7.3.4 Awareness Campaigns

Public awareness is crucial for driving behavioural change and ensuring the widespread adoption of sustainable cooling measures. Community outreach programs should emphasize the multiple benefits of these measures, including cost savings, enhanced health outcomes, and environmental improvements. Case studies of successful cooling interventions in diverse settings can build public trust and generate interest. Comprehensive multimedia campaigns should be developed, leveraging print, television, and social media to disseminate information about cooling technologies and available incentives. Additionally, schools and community groups should be engaged through projects and initiatives such as tree-planting drives or the installation of cool roofs, fostering grassroots-level participation.

7.3.5. Monitoring and Evaluation

Effective cooling strategies require robust monitoring and evaluation frameworks for implementation and improvement.. These frameworks should incorporate performance metrics to assess outcomes such as temperature reduction, energy savings, and improved air quality. Digital platforms should be utilized to collect and analyse data on the uptake and efficiency of cooling technologies. Stakeholder feedback mechanisms will enable input from the community, industry, and regulators to identify gaps and refine policies. Regular audits and evaluations will ensure alignment with emerging technologies and needs. Transparency is key, with annual reports keeping stakeholders informed on progress and future plans.

8 District Cooling – Benefits and Implementation

As Gurugram rapidly expands, driven by population growth, urbanization, rising incomes, and increasing urban heat, the city's demand for space cooling will increase. According to the India Cooling Action Plan (ICAP), urbanization and economic growth are projected to increase commercial floor area by 2.5 to 3 times, while the number of urban households will nearly double between 2018 and 2038. In this context, promoting building energy efficiency, passive cooling, nature-based solutions, and the efficient use of fans and coolers becomes vital from an environmental perspective.

Apart from the implementation of various passive and active cooling measures, District Cooling Systems (DCS) present a viable answer to this challenge of escalating cooling demand in a densely populated area like Gurugram. Figure 15 illustrates a typical district cooling system where the chilled water from a central plant is distributed to multiple buildings through an underground network of insulated pipes. The chilled water circulates through the buildings to cool their spaces and then returns to the central plant for re-cooling. This centralized system enables multiple buildings to be cooled simultaneously, eliminating the need for each building to have its own independent cooling system.

8.1. Benefits of District Cooling System:

DCS offers significant energy savings, enhanced resilience, and reduced greenhouse gas emissions. This system can cater to a diverse range of facilities, including commercial offices, hotels, residential buildings, industries, data centres, and hospitals, delivering high efficiency and environmental benefits compared to stand-alone cooling systems.
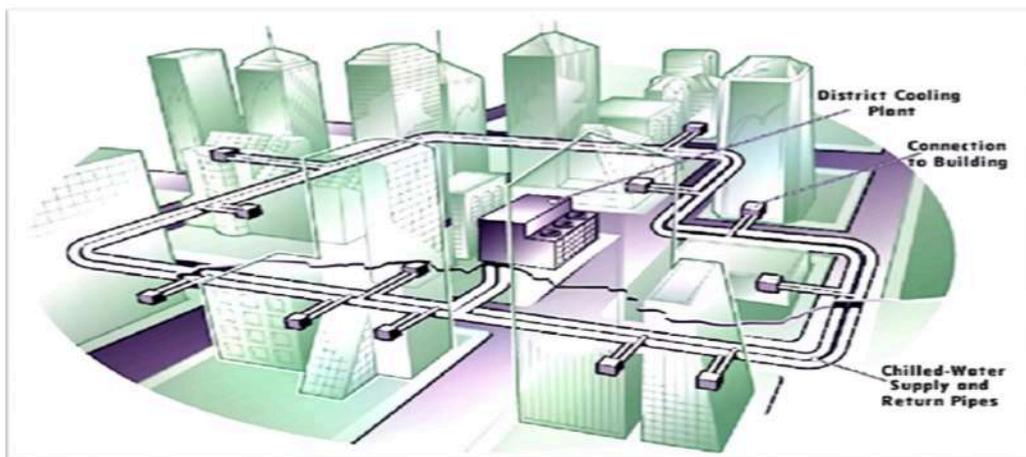
Figure 15: Gurugram City's cooling demand scenarios for year 2050

Globally, district cooling systems (DCS) are effective in shifting peak power demand through thermal storage and enabling large-scale renewable cooling solutions beyond the reach of individual buildings. Leveraging natural cooling sources like rivers and lakes, as well as integrating waste heat, DCSs enhance efficiency and environmental benefits. Governments can maximize these advantages by promoting DCS through policy incentives, urban greening, and public awareness campaigns. A comprehensive Cooling Action Plan incorporating these strategies will help Gurugram meet current cooling demands and strengthen resilience against future climate challenges.

8.2 Implementation of District Cooling System in Gurugram

Implementing a district cooling system (DCS) involves careful planning, design, and execution to ensure efficiency, sustainability, and economic viability. Below are the key steps to implement a district cooling system:

1) Feasibility study:
A feasibility study is the cornerstone of planning a district cooling system (DCS). It ensures the proposed system is technically viable, economically sound, and environmentally sustainable while meeting the cooling needs of the target area. Below is an in-depth explanation of the critical components of the feasibility study:

- **Assessment of cooling demand:** First, a detailed assessment of the cooling requirements in the target area must be conducted. This involves calculating peak and average cooling energy consumption and cooling demand for various building types, including residential, commercial, and industrial structures. Our SPIBEAT tool can be utilized for this.

- **Selection of buildings:** Next, the buildings for connection to the DCS shall be selected. Areas with high cooling demand density should be prioritized to maximize efficiency. Further, it is recommended to choose buildings close to the proposed plant to minimize pipeline lengths, network costs and heat losses. Lastly, the buildings selected should have existing centralized cooling systems or the ability to integrate with district cooling substations.

- **Energy source availability:** The potential sources of energy for cooling, such as renewable energy (solar thermal systems, geo thermal systems, etc.), waste heat, or conventional electricity have to be identified. It is, however, recommended to opt for sustainable energy sources.

- **Technical viability:** Further, potential for deploying the centralized cooling infrastructure, including plant location, distribution network, and compatibility with existing systems shall be evaluated.

- **Economic Analysis:** The next step is to assess a cost-benefit analysis

of the district cooling system considering capital expenditure (CAPEX), operating expenditure (OPEX), and projected revenues.

- **Environmental Impact:** The environmental benefits, including reductions in greenhouse gas emissions and energy consumption compared to decentralized systems shall be assessed.

The feasibility study can be effectively conducted using a combination of SPIBEAT and field surveys. SPIBEAT can provide valuable insights into current and future energy consumption and cooling demand projections, assist in building selection, propose distribution network layouts, and suggest potential plant locations. It can also estimate detailed system expenditures and assess environmental impacts. Field surveys, on the other hand, play a crucial role in validating these findings with on-ground insights. Additionally, technical expertise is essential for identifying suitable energy sources and evaluating system compatibility to ensure the project's success.

2) Stakeholder Engagement: After the feasibility assessment, key stakeholders, such as municipal authorities, property developers, building owners, utility providers, and financial institutions should be identified to conduct consultations in order to address concerns, gather input, and ensure alignment with local policies and community goals. Partnerships may also be developed for funding, implementation, and operation.

3) System Design and Planning: From our findings and from the insights gathered from stakeholders, a master plan shall be developed for the district cooling network, including plant location, pipe routing, and connection points. The size of the cooling plant and distribution network should be optimized to meet peak and average demand while allowing for future expansion.

4) Financial Structuring: A financial model that outlines CAPEX, OPEX, revenue streams, and payback periods shall be developed while evaluating pricing strategies, such as subscription-based or metered cooling charges, to recover costs and generate revenue. In this stage, funding must also be secured from private investors, government grants, or international financial institutions.

5) Construction and Installation: Finally, based on the master plan, the central cooling plant with components such as chillers, pumps, and thermal storage units shall be set up and insulated pipelines to transport chilled water from the plant to buildings and again to the plant shall be laid down as well. Substations can also be installed in connected buildings to transfer cooling energy efficiently.

6) Commissioning and Testing:
After installation, the entire system has to be checked for performance, efficiency, and safety, ensuring all components operate as intended.

7) Operation and Maintenance: An operations team shall be established to monitor and manage the system, ensuring optimal performance and reliability. Further, a maintenance schedule can be implemented for all equipment, pipelines, and connections to minimize downtime.

8) User Engagement and expansion: The last stage is to involve the users by educating and spreading awareness among them on the benefits of district cooling and how to optimize their systems for energy efficiency. They should be provided with transparent billing and support to address user queries and concerns.

8.3 A case study of district cooling network in Gurugram city

This case study outlines the impacts of a District Cooling System (DCS) in a commercial zone of Gurugram City, with a particular focus on its planning, execution, and performance. The goal is to explore energy-efficient alternatives and address the escalating demand for cooling in high-density commercial and residential areas, reduce energy consumption, lower greenhouse gas emissions, and ensure the sustainability of cooling infrastructure.

- **Study Area and Methodology**

A set of **24 commercial buildings** in Gurugram, from Sector 16, has been selected for the analysis. Using our SPIBEAT tool and following the methodology discussed above, the total cooling demand, energy consumption, and GHG emissions were estimated. It has been assumed that these buildings have been air conditioned with decentralized AC. The potential reductions in these parameters due to the implementation of a DCS were then calculated using benchmark data derived from some national and international studies.

For estimating the reduction in electricity consumption due to district cooling, a recent study by PwC (Strategy&, PwC, 2019) has been referred to, according to which this parameter will be reduced by 20-30% by implementing DCS compared to conventional cooling methods (Strategy&, PwC, 2019). Further, research shows that district cooling can decrease space cooling demand by approximately up to 50% (UNEP 2019), and this value has been considered as the benchmark for our estimation. This study indicates that this reduction directly impacts the GHG emissions, resulting in a reduction of 25-50%.

- **Results**
The following table 18 shows the

total annual energy consumption, cooling demand and GHG emissions in 2050 under business-as-usual conditions. In such a scenario, the selected buildings are still air-conditioned by traditional cooling systems (decentralized ACs).

However, if DCS is implemented in these buildings by 2050 under the same BAU conditions, the following will be the annually reduced energy consumption, cooling demand, and GHG emissions.

Table 17: Reductions in cooling parameters by 2050 by due to implementation of DCS

Parameters	2050 values with no DCS implementation	Estimated reductions as per studies die to DCS implementation	New values after reductions
Total energy consumption (Mwhyr)	19125	20%-30% reduction	15300 - 13387
End use space cooling demand (GJ)	153407	30%-50% reduction	107384 - 76702
GHG emissions (KtCO2)	18	25%-50% reduction	13 - 9

The figure 16 on the next page provides a layout of district cooling network of the selected buildings generated using the CEA model:

Building footprint of Sector 16

District cooling network layout for selected buildings

CEA generated District Cooling network for the selected buildings in Sector 16
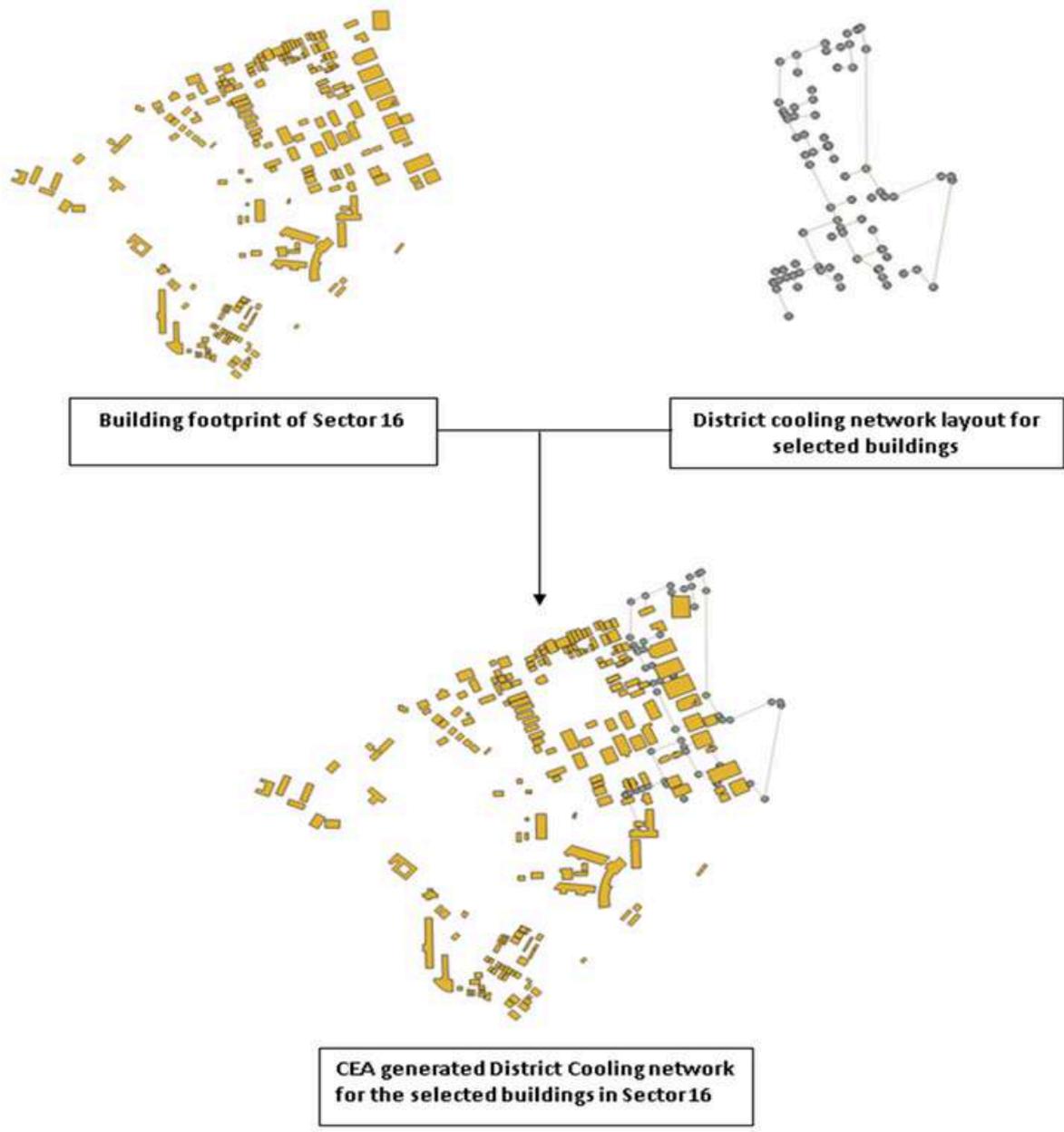
Figure 16: District cooling network for selected buildings in Sector 16

9 Implementating Road-map based on scenario analysis

Table 18: Roadmap Based on Scenario Analysis (Key Strategies and Targeted Reductions)

Scenarios	Activities to be performed	Expected Cooling Energy Consumption reduction			Expected Cooling Demand reduction			Expected GHG Emission reduction		
		2030	2040	2050	2030	2040	2050	2030	2040	2050
Passive Cooling	• Implement passive solutions: natural ventilation, shading, insulation. • Green roofs & reflective materials. • Design urban spaces for optimal airflow. • Enhance airtight construction to reduce air leakage.	15%	25%	34%	20%	30%	45%	10%	15%	23%
Active Cooling: HVAC High Energy Efficiency	• Encourage retrofitting of existing HVAC systems with high-efficiency models. • Enhance insulation and sealing of ducts.	5%	10%	17%	10%	15%	23%	10%	15%	23%
Active +Passive Cooling: Green Roof-Floor Cooling	• Install green roofs and integrate eco-friendly landscaping for temperature control. • Promote installation of green roof systems in high-rise buildings.	15%	25%	33%	10%	20%	28%	15%	25%	35%

With rising urban temperatures and increasing cooling demand, Gurugram aims to implement a Cooling Action Plan that integrates energy-efficient cooling technologies, urban design strategies, and sustainable cooling systems.

Table 18 outlines key activities, targets, and strategies for reducing electricity consumption, space cooling demand, and greenhouse gas (GHG) emissions from 2020 to 2050.

Table 19: Key Activities, targets, and strategies for reducing electricity consumption, cooling demand, and GHG emissions (2020–2050)

Goal	Targets	Activities	Targeted Timeline		
			Short-term (2030)	**Medium-term (2040)**	**Long-term (2050)**
Comfortable Cooling	Cooling for All (CFORALL): Providing space cooling for decent and comfortable living for all with a total of 45% cooling demand reduction by 2050.	• Mandate climate-responsive building designs with natural ventilation, shaded facades, and thermal insulation. • Expand cool roofs, reflective surfaces, and permeable pavements to reduce heat absorption. • Integrate urban greening solutions like tree-lined streets, vertical gardens, and green roofs. • Promote passive cooling materials such as high-albedo paints, earthen walls, and phase-change materials.	30% residential buildings should come under cool roof, urban greening programmes and passive cooling material usage etc. 30% commercial buildings should come under cool roof, vertical gardening and passive cooling material usage etc.	60% residential buildings should come under cool roof, urban greening programmes and passive cooling material usage etc. 60% commercial buildings should come under cool roof, vertical gardening and passive cooling material usage etc.	100% residential buildings should come under cool roof, urban greening programmes and passive cooling material usage etc. 100% commercial buildings should come under cool roof, vertical gardening and passive cooling material usage etc.
Affordable Cooling	Minimizing the cost of space cooling by adopting affordable alternative cooling technologies	• Encourage reflective coatings, white roofs, and thermally insulated walls to lower indoor temperatures. • Provide subsidies for high-efficiency fans, evaporative coolers, and solar-assisted cooling systems. • Promote district cooling to reduce reliance on energy-intensive HVAC systems.	20% adoption of affordable cooling technologies	40% adoption of affordable cooling technologies	60% adoption of affordable cooling technologies

Goal	Targets	Activities	Targeted Timeline		
			Short-term (2030)	Medium-term (2040)	Long-term (2050)
Sustainable Cooling	Green Cooling: Reduction in GHG emissions by 35% till 2050 and promotion of renewable based cooling systems.	• ·Promote district cooling to reduce reliance on energy-intensive HVAC systems. • ·Adopt high-performance building materials like triple-glazed windows, reflective roof coatings, and insulated walls to enhance energy efficiency. • ·Promote highly energy efficient HVAC systems like celling cooling and floor cooling technologies. • Promote solar energy based cooling system for residential and commercial purposes.	15% reduction in GHG emissions. 15-20% of building categories such as PHCs, gaushalas and cold storage facilities can come under the Green cooling programmes.	25% reduction in GHG emissions. 50-60% of building categories such as PHCs, gaushalas and cold storage facilities can come under the Green cooling programmes.	35% reduction in GHG emissions. 100% of building categories such as PHCs, gaushalas and cold storage facilities can come under the Green cooling programmes.

The Cooling Action Plan for Gurugram is a broad approach, incorporating energy-efficient HVAC solutions, passive cooling strategies, district cooling systems, and urban greening initiatives. The city aims to significantly enhance cooling efficiency, reduce greenhouse gas emissions, and minimise overall energy demand. To achieve these targets, strong policy enforcement, active stakeholder participation, and well-structured financial incentives will be required. This roadmap serves as a guiding framework for policymakers, urban planners, and developers to transform Gurugram into a leading example of sustainable and efficient cooling practices.

10 Monitoring and Evaluation Framework

Monitoring and evaluation (M&E) form the backbone of an effective Cooling Action Plan, ensuring that interventions suggested deliver measurable results while adapting to the dynamic urban and climatic conditions of Gurugram. Given the city's rapid population growth, urban expansion, and increasing vulnerability to heat stress, it is critical to establish a robust framework to track the progress of implemented cooling strategies. This chapter outlines key performance indicators (KPIs) to assess the impact of interventions, methodologies to measure reductions in cooling demand and GHG emissions, and a structured approach for recalibrating strategies annually based on evolving trends.

10.1. Key Performance Indicators (KPIs)

KPIs are essential for evaluating the effectiveness of Gurugram's Cooling Action Plan. By providing measurable benchmarks, these indicators help track progress in reducing cooling demand, improving energy efficiency, and lowering greenhouse gas (GHG) emissions. They capture both quantitative and qualitative outcomes, ensuring alignment with sustainability goals and enabling data-driven decision-making.

Focused on Cooling Demand, GHG Emissions, Energy Efficiency, and Passive Technology Adoption, these KPIs offer insights into the impact of interventions while highlighting areas for further optimization.

10.1.1 Primary Key Performance Indicators

1. **Per capita cooling demand reduction (%):** It measures the percentage change in individual cooling demand of Gurugram City over the years and can provide insights into the efficiency of passive and active cooling interventions. It also indicates behavioural changes or shifts toward energy-conscious consumption patterns.

2. **Total Cooling Demand (GJ):** This indicator is meant to track overall cooling energy consumption at the citywide scale and the changes in the parameter over time. It will reflect the overall cooling energy footprint of the city and can track the cumulative impact of architectural interventions and HVAC upgrades. This indicator is helpful for large-scale urban energy planning and grid management.

3. **GHG Emission Reduction (%):** This indicator evaluates the percentage reductions in GHG emissions resulting from the adoption of improved efficiency, building retrofits, clean energy use, and emission control technologies. Thus, it also indicates progress towards national and international climate commitments to achieve net-zero targets.

4. **Passive and Active Cooling Technology Adoption (% of Buildings):** The purpose of this indicator is to track the percentage of buildings implementing passive cooling measures such as green roofs, shading devices, high-performance glazing, architectural upgrades or active cooling techniques such as highly efficient HVAC systems like ceiling cooling, floor cooling, hybrid AC, etc. or both.

5. **Cooling Demand Intensity (J/m2):** This indicator is for measuring the cooling energy demand and energy consumption of cooling system by per metre square of building floor area. This indicator is helpful in assessing the improvement in building efficiency as well as for comparing energy performance across different building types.

10.2 Methodology for Monitoring

To effectively monitor and analyse key performance indicators (KPIs) related to urban cooling and energy efficiency, the **SPIBEAT tool** offers a robust, integrated approach. This innovative platform combines *geospatial data, simulation capabilities, and field insights*, making it a comprehensive solution for tracking urban sustainability efforts. A brief of the KPIs monitoring methodology using SPIBEAT has been summarized below:

1. **Data Collection:** Satellite imagery can capture temporal changes in building footprints, retrofits, and infrastructure development. Field visits and stakeholder consultation can provide detailed data on energy-efficient upgrades and cooling systems.

2. **Data Analysis and Simulation:** The recorded changes in building attributes and energy-related practices which might include retrofitting, implementing cool or green roofs, or installing energy-efficient windows and shading devices, among others are then inputted into SPIBEAT, enabling the tool to simulate and estimate their impact on cooling demand, energy consumption, and emissions.

3. **Comparative Analysis:** The simulated results of the

current year will be compared with baseline data to track progress over the years. This comparative analysis highlights trends in cooling demand reductions, energy savings, and emissions mitigation. Such insights are crucial for assessing the effectiveness of the cooling action plan and identifying areas needing further improvement.

4. **Generation of Outputs:** Detailed reports and visualizations of cooling demand, emissions, and energy use patterns will be developed to guide policy refinement.

SPIBEAT is a decision-support tool for policymakers and urban planners. It offers actionable insights to guide resource allocation and prioritize climate resilience initiatives. Its ability to seamlessly integrate data from diverse sources ensures accurate, real-time tracking of key indicators, fostering accountability and enabling data-driven decision-making.

10.3. Evaluation Mechanism

Evaluation is a systematic process of assessing the outcomes and impacts of the Cooling Action Plan. It ensures that the implemented strategies align with intended goals and informs necessary adjustments. The evaluation mechanism incorporates both quantitative and qualitative approaches:

1. **Baseline and Target Setting:** This involves defining clear baselines for KPIs using data from SPIBEAT and initial assessments. Further, the evaluation process should oversee whether the short-term, mid-term, and long-term targets for cooling demand reduction, GHG emissions, and technology adoption are met.

2. Regular Reporting: An annual reporting framework shall be developed to provide updates on progress toward targets. Include sector-wise performance summaries and highlight significant deviations from expected trends.

3. Stakeholder Engagement: Stakeholder consultations are to be conducted annually to gather data or feedback on the plan's implementation. Policymakers, urban planners, and local communities shall be involved to validate results and ensure inclusivity.

4. **Impact Assessment:** The broader impacts of the interventions, such as reduced urban heat island effects, improved air quality, and enhanced public health outcomes, as well as economic co-benefits, such as reduced energy bills and job creation in green construction, can also be evaluated.

5. Feedback Loop: Findings from evaluations shall be incorporated into the decision-making process. Meanwhile, the lessons learned to recalibrate strategies, refine interventions, and address identified challenges.

10.4. Frequency of Monitoring

Effective monitoring of the Cooling Action Plan requires a structured approach to track progress at various intervals. Establishing a defined frequency of assessments ensures that data collection, analysis, and evaluation remain consistent and actionable.

a) Annual Assessments:

Purpose:
Annual reviews will provide a snapshot of short-term progress, capturing incremental changes in cooling demand, energy efficiency, and GHG emissions. They allow for real-time identification of successes and bottlenecks in implementation.

Key Activities:
- Evaluate yearly cooling energy consumption, cooling demand and GHG emissions trends at the city and sectoral levels.
- Track annual adoption rates of passive and active cooling technologies and energy-efficient systems by yearly surveys or by geospatial techniques.
- Update geospatial datasets to reflect changes in urban morphology, building typologies, and demographic shifts.
- Assess compliance with cooling-related policies and building codes if introduced or revised during the year.

b) Mid-Term Reviews (Every 5 Years):

Purpose:
Mid-term reviews take a longer-term view of the Cooling Action Plan's progress, evaluating the cumulative impact of interventions over multiple years. These reviews are useful for assessing whether strategies are on track to meet medium- and long-term goals, such as those for 2030 or 2050.

Key Activities:
- Conduct comprehensive sectoral and citywide evaluations to measure progress against baseline values and projected scenarios.
- Review the adoption and effectiveness of both passive and active cooling technologies at a broader scale.
- Analyze energy consumption, cooling demand and emissions reductions across different building types and usage patterns.
- Evaluate policy compliance, stakeholder engagement, and the integration of cooling measures in urban development plans.

10.5 Adaptive Benefits of the Framework

- Real-Time Responsiveness: Based on the monitoring outcomes and stakeholder insights, the M&E framework enables immediate course corrections.
- Enhanced Flexibility: The framework accommodates evolving technologies, climatic scenarios, and urban growth trends.
- Sustainability and Resilience: Further, this framework ensures long-term effectiveness of cooling strategies while meeting socio-economic and environmental objectives.

By integrating adaptability into every phase of monitoring and evaluation, this framework ensures that Gurugram's Cooling Action Plan remains robust, inclusive, and aligned with its climate resilience goals.

The proposed M&E framework, with its robust evaluation mechanisms and adaptive strategies, ensures that Gurugram's Cooling Action Plan remains dynamic, transparent, and results-driven. By systematically tracking KPIs, leveraging innovative tools like SPIBEAT, and integrating stakeholder feedback, this framework supports the city's transition toward sustainable cooling and climate resilience. As the plan progresses, its adaptive nature will enable Gurugram to respond effectively to challenges, align with emerging global best practices, and build a more sustainable urban future.

11 Conclusions

The Gurugram City Cooling Action Plan presents a comprehensive, data-driven framework aimed at addressing the escalating cooling demand while ensuring energy efficiency and environmental sustainability. With urbanization, rising temperatures, and economic growth driving an unprecedented surge in cooling requirements, this plan provides a structured approach to mitigating energy consumption and greenhouse gas emissions through a combination of active and passive cooling measures. The scenario-based analyses, leveraging cutting-edge tools like SPIBEAT and CEA, demonstrate the effectiveness of sustainable building envelope designs, green roofs, district cooling, and high-efficiency HVAC systems in reducing cooling loads and emissions.

Findings indicate that a business-as-usual trajectory will significantly increase energy consumption, cooling demand, and emissions, further exacerbating the urban heat island effect. However, strategic interventions such as passive cooling techniques, efficient air conditioning systems, district cooling, and waste heat recovery present viable solutions to curb this trajectory. The study highlights that passive measures—such as improved building orientation, shading devices, reflective roofing materials, and urban greenery—can substantially lower cooling loads and reliance on energy-intensive air conditioning. Concurrently, the adoption of smart cooling technologies and district cooling systems can enhance system efficiencies, reduce peak demand, and support the transition to low-carbon cooling infrastructure.

Policy recommendations, including regulatory frameworks, financial incentives, and awareness campaigns, are essential for ensuring the widespread adoption of sustainable cooling solutions. The implementation of a robust monitoring and evaluation framework will further enable adaptive policy interventions, ensuring alignment with evolving climate challenges and technological advancements. Additionally, integrating community engagement and capacity-building programs will foster a culture of energy-efficient cooling practices across residential, commercial, and industrial sectors.

Moving forward, Gurugram has the opportunity to serve as a model city for sustainable urban cooling, setting an example for other rapidly growing urban centres in India and beyond.

This holistic cooling strategy will enhance thermal comfort, reduce energy dependence, and support climate goals. Success requires collaboration among policymakers, industry, and communities. Sustainable cooling is essential for a livable, resilient, and energy-efficient Gurugram.

Annexure

- **Annexure-1**

Weather Files

Firstly, using the CCWorldWeatherGen tool which utilized climate model summary data from the IPCC Third Assessment Report (TAR), specifically from the HadCM3 A2 (~RCP 8.5) and B1 (~RCP 4.5) experiment, two distinct weather files for the year 2050 were generated. The tool allowed us to modify 'present-day' EPW (EnergyPlus Weather) files to generate the two climate change weather files suitable for building performance simulation programs.

The EPW parameters considered in this analysis include:

- Daily mean temperature (°C)
- Maximum temperature (°C)
- Minimum temperature (°C)
- Horizontal solar irradiation (W/m²)
- Total cloud cover (% points)
- Total precipitation rate (%)
- Relative humidity (% points)
- Mean sea level pressure (hpa)
- Wind speed (%)

These two future weather files - HadCM3 A2 and B1 correspond to BAU and B1 scenarios respectively for year 2050. The key differences between these scenarios, based on the Special Report on Emissions Scenarios (SRES) by the IPCC DDC,

Table: Sector Details

Sectors	No. of buildings considered	Building typology	Construction standard	Occupancy density (m2/person)	Fraction of gross floor area with electrical demands (m2/m2)	Fraction of above ground gross floor area air-conditioned (m2/m2)	Fraction of below ground gross floor area air-conditioned (m2/m2)	Peak sensible heat load of people (W/p)	Moisture released by occupancy at peak conditions (ghp)	Peak specific electrical load due to computers and devices (W/m2)	Peak specific electrical load due to artificial lighting (W/m2)	Peak specific fresh water consumption including hot and cold water (ldp)	Cooling Schedule
Sector 52A (Residential)	312	100% residential	Standard 2 - Concrete and Masonry - increased conditioned areas	47	0.9	0.84	0	70	80	4	12.5	80	Set point temperature from 7AM to 6 PM / Set back temperature from 7 PM to 6 AM
Sector 112 (Mixed)	274	75% residential, 25% commercial	Standard 2 - Concrete and Masonry - increased conditioned areas	24	0.9	0.84	0	70	86.25	2.375	7.275	32.5	Set point temperature from 7AM to 6 PM / Set back temperature from 7 PM to 6 AM
Sector 16 (Commercial)	217	100% commercial	Standard 2 - Concrete and Masonry - increased conditioned areas	6	0.9	0.84	0	70	90	2	14.1	4	Set point temperature from 7AM to 12 AM / Off from 1 AM-6 AM

	Baseline scenario (2023)	BAU Scenario	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	Sustainable Building Envelope Scenario III	Green Roof-Floor Cooling Scenario	HVAC High Energy Efficiency Scenario
Weather file	2020 weather file of Haryana generated from ISHRAE	2050 HadCM3 A2 weather file of Haryana	2050 HadCM3 B1 weather file of Haryana	2050 HadCM3 A2 weather file of Haryana	2050 HadCM3 A2 weather file of Haryana	2050 HadCM3 A2 weather file of Haryana	2050 HadCM3 A2 weather file of Haryana	2050 HadCM3 A2 weather file of Haryana

Building envelope parameters

Construction								
i. Type	Medium	Medium	Medium	Heavy	Medium	Medium	Medium	Medium
ii. Internal heat capacity per unit of air conditioned area (J/km2)	165000	165000	165000	300000	165000	165000	165000	165000

Leakness								
i. Type	Medium	Medium	Medium	Highly tight	Medium	Highly tight	Medium	Medium
ii. Air exchanges per hour at a pressure of 50 Pa. (1/h)	3	3	3	1	3	1	3	3

Window								
i. Type	Single glazing	Single glazing	Single glazing	Triple glazing	Double glazing with low emissivity coating	Triple glazing with two selective low-emissivity coatings	Single glazing	Single glazing
ii. Thermal transmittance including linear losses (+10%).	5.4	5.4	5.4	0.99	1.1	0.6	5.4	5.4
iii. Solar heat gain / absorption coefficient.	0.85	0.85	0.85	0.7	0.67	0.5	0.85	0.85
iv. Emissivity of external surface. Defined according to ISO 13790. / UNIT: [-]	0.89	0.89	0.89	0.89	0.02	0.02	0.89	0.89
v. Window frame fraction coefficient. UNIT: [m2-frame/m2-window]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
vi. Window to wall ratio	0.29	0.29	0.29	0.29	0.1	0.29	0.29	0.29
vii. Embodied emissions per m2 of window. (entire building lifecycle) / UNIT: [kgCO2m2]	47	47	47	123	123	123	47	47

Roof								
i. Type	Concrete or peebles finishing	Concrete or peebles finishing	Concrete or peebles finishing	White paint over plaster over concrete	Aluminium tiles	Dark paint over plaster over concrete	Green roof	Concrete or peebles finishing
ii. Thermal transmittance including linear losses (+10%). UNIT: [-]	0.2	0.2	0.2	0.15	0.3	0.15	0.15	0.2
iii. Solar heat gain / absorption coefficient.	0.6	0.6	0.6	0.3	0.3	0.85	0.5	0.6
iv. Emissivity of external surface. Defined according to ISO 13790. / UNIT: [-]	0.94	0.94	0.94	0.84	0.09	0.94	0.95	0.94
v. Reflectance in the Red spectrum. Defined according Radiance. (long-wave) / UNIT: [-]	0.4	0.4	0.4	0.7	0.7	0.15	0.5	0.4
vii. Embodied emissions per m2 of roof. (entire building lifecycle) / UNIT: [kgCO2m2]	112	112	112	113	112	113	112	112

Wall								
i. Type	White paint over plaster over clay brick	White paint over plaster over clay brick	White paint over plaster over clay brick	Dark blue paint over plaster over clay brick	Dark paint over plaster over clay brick	Dark paint over plaster over clay brick	White paint over plaster over clay brick	White paint over plaster over clay brick
ii. Thermal transmittance including linear losses (+10%). UNIT: [-]	0.8	0.8	0.8	0.15	0.15	0.15	0.8	0.8
iii. Solar heat gain / absorption coefficient.	0.3	0.3	0.3	0.65	0.85	0.85	0.3	0.3
iv. Emissivity of external surface. Defined according to ISO 13790. / UNIT: [-]	0.84	0.84	0.84	0.9	0.94	0.94	0.84	0.84
v. Reflectance in the Red spectrum. Defined according Radiance. (long-wave) / UNIT: [-]	0.7	0.7	0.7	0.35	0.15	0.15	0.7	0.7
vi. Embodied emissions per m2 of wall. (entire building lifecycle) / UNIT: [kgCO2m2]	112	112	112	112	112	112	112	112

Floor								
i. Type	Concrete floors	Concrete floors	Concrete floors	Concrete floors	Concrete floors	Concrete floors	Concrete floors	Concrete floors
ii. Thermal transmittance including linear losses (+10%). UNIT: [-]	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
iii. Embodied emissions per m2 of wall. (entire building lifecycle) / UNIT: [kgCO2m2]	112	112	112	112	112	112	112	112
Shading device								
i. Type	None	None	None	Venetian blinds	Rollo	Rollo	Venetian blinds	Venetian blinds
ii. Shading coefficient when shading device is active. Defined according to ISO 13790. / UNIT: [-]				0.15	0.08	0.08	0.15	1.15

Cooling parameters	Baseline Scenario (2023)	BAU Scenario	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	Sustainable Building Envelope Scenario III	Green Roof-Floor Cooling Scenario	HVAC High Energy Efficiency Scenario
Cooling system								
i. Type	Mini split AC	Mini split AC	Mini split AC	Mini split AC	Mini split AC	Mini split AC	Floor cooling	Ceiling cooling
ii. Convective part of the power of the heating system in relation to the total power / UNIT: [-]	1	1	1	1	1	1	0.1	0.5
iii. Maximum heat flow permitted by cooling system per m2 gross floor area / UNIT: [W/m2]	150	150	150	150	150	150	100	500
iv. Set-point correction for space emission systems / UNIT: [C]	0.7	0.7	0.7	0.7	0.7	0.7	0.5	0.5
v. Nominal supply temperature of the water side of the air-recirculation	6.5	6.5	6.5	6.5	6.5	6.5	NA	NA
vi. Nominal temperature increase on the water side of the air-recirculation units / UNIT: [C]	9	9	9	9	9	9	NA	NA
vii. Supply air temperature of the air-recirculation units / UNIT: [C]	16	16	16	16	16	16	NA	NA
viii. Nominal supply temperature of the water side of the sensible cooling units / UNIT: [C]	NA	NA	NA	NA	NA	NA	18	18
ix. Nominal temperature increase on the water side of the sensible cooling units / UNIT: [C]	NA	NA	NA	NA	NA	NA	3	3
Setpoint temperature of cooling system	28 degrees celsius	28 degrees celsius	28 degrees celsius	28 degrees celsius	28 degrees celsius	28 degrees celsius	28 degrees celsius	26 degrees celsius
Setback temperature of cooling system	27 degrees celsius	27 degrees celsius	27 degrees celsius	27 degrees celsius	27 degrees celsius	27 degrees celsius	27 degrees celsius	24 degrees celsius
Relative Humidity	30-70%	30-70%	30-70%	30-70%	30-70%	30-70%	30-70%	30-50%
Minimum outdoor air ventilation rate per person for air quality (l/s/p)	10	10	10	10	10	10	10	

	Baseline Scenario (2023)	BAU Scenario	B1 Scenario	Sustainable Building Envelope Scenario I	Sustainable Building Envelope Scenario II	Sustainable Building Envelope Scenario III	Green Roof-Floor Cooling Scenario	HVAC High Energy Efficiency Scenario
HVAC controller								
i. Type	PI Controller	PI Controller	PI Controller	PI Controller	PI Controller	PI Controller	PI Controller	PI Controller
ii. Correction temperature of emission losses due to control system of heating /	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
iii. Correction temperature of emission losses due to control system of cooling /	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2
Ventilation								
i. Type	Window ventilation	Window ventilation	Window ventilation	Window ventilation	Window ventilation	Window ventilation	Window ventilation	Mechanical ventilation equipped with demand control and an economizer
on?	No	No	No	No	No	No	No	Yes
iii. Heat recovery on?	No	No	No	No	No	No	No	Yes
iv. Night flush on?	No	No	No	No	No	No	No	Yes
v. Economizer on?	No	No	No	No	No	No	No	Yes

Cooling System								
i. Type	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower	Vapour compression chiller and dry chilling tower
ii. Feedstock used by the the all in one system (refers to the FEEDSTOCK database) / UNIT: NA	Grid	Grid	Grid	Grid	Grid	Grid	Grid	Grid
iii. Scale at which the system is used / UNIT: NA	Building	Building	Building	Building	Building	Building	Building	Building
iv. efficiency of the all in one system / UNIT: [-]	2.746	2.746	2.746	2.746	2.746	2.746	2.746	2.746
v. Capital costs per kW / UNIT: [USD2015/kW]	710	710	710	710	710	710	710	710
vi. Lifetime of assembly / UNIT: [yr]	20	20	20	20	20	20	20	20
vii. Operation and maintenance cost factor (fraction of the investment	3	3	3	3	3	3	3	3
viii.Interest rate charged on the loan for the capital cost / UNIT: [5]	3	3	3	3	3	3	3	3

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