Techno-Economic Feasibility Study of District Cooling Systems in India

OZONE CELL

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

TECHNO-ECONOMIC FEASIBILITY STUDY OF DISTRICT COOLING SYSTEMS IN INDIA

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OZONE CELL

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(MoEF&CC)

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पर्यावरण, वन एवं जलवायु परिवर्तन
भारत सरकार

सत्यमेव जयते

भूपेन्द्र यादव
BHUPENDER YADAV

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

MESSAGE

With rapid urbanization and the resulting increase in cooling demand, District Cooling System (DCS) is increasingly gaining prominence due to their significant benefits in reducing energy consumption, refrigerant demand and enhancing energy efficiency. DCS systems are well-suited for large building projects and optimize space utilization by providing centralized cooling infrastructure for multiple buildings through a shared network of chilled water pipes.

DCS adoption in India is in its early stages but growing, with key projects coming up in airports, and large IT/commercial complexes. To meet the country's rising cooling demand, there is a significant growing potential for DCS adoption. High upfront capital costs, lack of awareness about the benefits among building developers, perceptions on economic viability are issues that need to be assessed.

The study on techno-economic feasibility of DCS aims to examine the techno economic feasibility of adoption of DCS vis-à-vis conventional cooling systems in different climatic zones of the country.

I congratulate all those involved in the preparation of this report.

(Bhupender Yadav)

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राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
विदेश मंत्रालय
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MESSAGE

Cooling systems, especially those using high global warming potential (GWP) refrigerants, are a significant source of greenhouse gas emissions. Reducing cooling demand is crucial for ensuring thermal comfort to all.

District cooling system (DCS) is a promising cooling solution because they are more energy-efficient, environmentally friendly, and cost-effective than conventional cooling systems. Through a centralized cooling system, DCS achieves economies of scale, reduce greenhouse gas emissions, and lower peak electricity demand. They also save space within buildings and can utilize renewable energy sources and recycled water, making them a sustainable solution for modern urban environments.

Adoption of DCS depends on balancing high initial capital costs, operational and life cycle costs, energy savings, and reduced environmental impact. While there are advantages like reduced capacity requirements due to load diversity, integration of renewable energy sources, leveraging thermal storage, high upfront investment and coordination at the city planning level needed detailed assessment. The Study on "Techno-Economic Feasibility of DCS in India" assesses the feasibility of DCS adoption in different climatic zones of the country.

The publication would serve as an important resource material and should be disseminated widely amongst all concerned stakeholders.

(Kirti Vardhan Singh)

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AND CLIMATE CHANGE

MESSAGE

India's cooling requirement is increasing rapidly due to rising temperatures, increasing household incomes, and rapid urbanization, leading to a greater demand for cooling infrastructure. This rise poses significant challenges, including higher energy consumption, and increased greenhouse gas emissions. Meeting this demand sustainably requires a shift towards energy-efficient cooling technologies, improved passive cooling building designs, and the integration of clean energy solutions.

District cooling is a viable solution due to its higher energy efficiency, lower operating costs and environmental impact by enabling larger, more efficient chillers and the integration of renewable energy sources like solar and utilization of waste heat recovery. It provides enhanced reliability for connected buildings and allows for better space utilization by reducing the number of individual cooling units required, improving urban aesthetics and reducing noise pollution. However, assessing the feasibility of District Cooling System is important to assess the technical viability, including meeting energy demands, as well as economic attractiveness, including cost savings for end-users and investors.

The Study assesses the techno-economic feasibility of DCS in the Indian context. I compliment the team associated with the preparation of this report.

(Tanmay Kumar)

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Abbreviations

AC	Air Conditioner
AHU	Air Handling Unit
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAU	Business-As-Usual
BF	Brownfield
BIS	Bureau of Indian Standards
BMS	Building Management System
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CBD	Central Business District
CCTS	Carbon Credit Trading Scheme
CEA	Central Electricity Authority
CPWD	Central Public Works Department
CO_2	Carbon Dioxide
CFC	Chlorofluorocarbon
COP	Coefficient of Performance
CTC	Carbon Tetrachloride
CaaS	Cooling-as-a-Service
Cr	Crore (₹10 million)
DCEZ	District Cooling Enabled Zone
DCPC	District Cooling Promotion Cell
DCS	District Cooling System
DCZ	District Cooling Zone
DHW	Domestic Hot Water
DPR	Detailed Project Report
ECBC	Energy Conservation Building Code
ETS	Energy Transfer Station
FAR	Floor Area Ratio
FCU	Fan Coil Unit
GF	Greenfield
GFA	Gross Floor Area
GHG	Greenhouse Gas
GIS	Geographic Information System
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HPMP	Hydrochlorofluorocarbon Phase-out Management Plan
HVAC	Heating, Ventilation, and Air Conditioning
ICAP	India Cooling Action Plan
IT	Information Technology
LCOC	Levelized Cost of Cooling
MEP	Mechanical, Electrical, and Plumbing
MTES	Mobile Thermal Energy Storage
MoEF&CC	Ministry of Environment, Forest and Climate Change
NPV	Net Present Value
OPEX	Operating Expenditure
PCM	Phase Change Material
PPP	Public-Private Partnership
QA	Quality Assurance
QC	Quality Control
RoW	Right of Way

SCADA	Supervisory Control and Data Acquisition
SEZ	Special Economic Zone
SLA	Service Level Agreement
SOP	Standard Operating Procedure
SPV	Special Purpose Vehicle
STP	Sewage Treatment Plant
TCO	Total Cost of Ownership (equivalent to Lifecycle Cost in this context)
TES	Thermal Energy Storage
TR	Tons of Refrigeration
TR-hr	Ton-Hour (unit of cooling delivered)
TSE	Treated Sewage Effluent
UCMC	Urban Cooling Monitoring Cell
UHI	Urban Heat Island
ULB	Urban Local Body
UNEP	United Nations Environment Programme
URCIS	Urban Retrofit Cooling Incentive Scheme
VGF	Viability Gap Funding
VRF	Variable Refrigerant Flow
kWh	Kilowatt-Hour
kg CO_2/kWh	Kilograms of Carbon Dioxide per Kilowatt-Hour

Executive Summary

India's fast-growing cities are experiencing a sharp surge in cooling demand, driven by rising populations, denser urban development, and increasing temperatures. Conventional cooling methods mainly split ACs and rooftop systems are struggling to keep pace. These decentralized systems are energy-intensive, place heavy loads on local power networks, and contribute to both greenhouse gas emissions and the urban heat island effect. In light of these challenges, this report examines the potential of District Cooling Systems (DCS) as a more sustainable and scalable solution for the Indian context. This report, prepared under the guidance of the Ozone Cell, Ministry of Environment, Forest and Climate Change (MoEF&CC), and aligned with the objectives of the India Cooling Action Plan (ICAP), the report presents a techno-economic feasibility study of DCS deployment across thirteen representative Indian cities. These urban clusters were strategically selected to capture the diversity of climatic zones, infrastructure maturity, and urban typologies, including both greenfield and brownfield developments.

This study applies a range of practical methods such as forecasting cooling demand, mapping spatial loads, assessing infrastructure, and analyzing costs to evaluate how District Cooling Systems (DCS) perform against conventional approaches. It draws on case studies from Singapore, Denmark, and Hungary, where DCS has been successfully implemented through innovative strategies such as seawater cooling, waste heat reuse, and thermal energy storage. The report also examines city-level opportunities for using alternative resources such as treated wastewater and renewables, and reviews refrigerant transitions aligned with the Kigali Amendment. In doing so, it identifies sector-specific strategies and highlights institutional and regulatory gaps that currently limit DCS adoption across Indian cities.

The findings highlight the growing potential for scalable District Cooling Systems (DCS) across Indian cities, demonstrating a replicable framework that supports the Montreal Protocol for transitioning to low GWP alternatives and promotes sustainable urban cooling.

1. Introduction

India is committed to environmental actions and is one among the few countries globally in the use of climate friendly technologies, that are non-ozone depleting and low Global Warming Potential (GWP). In the Montreal Protocol implementation, India has consciously chosen a path for environment friendly and energy efficient technologies while phasing out Ozone Depleting substances (ODSs). As a Party to the Montreal Protocol since 1992, India has successfully phased out Chlorofluorocarbons (CFCs), Halons, and Carbon Tetrachloride (CTC), and is currently implementing the accelerated phase-out schedule for Hydrochlorofluorocarbons (HCFCs). As of 1st January 2025, the use of HCFCs in new equipment manufacturing has been phased out, while servicing of existing HCFC-based systems will be permitted until 2040, in line with the Montreal Protocol Schedule.

The India Cooling Action Plan (ICAP), launched in 2019, positioned India as one of the first countries to develop a comprehensive, long-term strategy for addressing the issues in the cooling sector. Its broad goals over a period of 20-years' time horizon are to reduce cooling demand, refrigerant demand, and cooling energy consumption while simultaneously enhancing access to sustainable cooling and fostering innovation in the domestic cooling sector [1]. To support these goals, ICAP actively encourages the adoption of a diverse range of sustainable cooling technologies. This includes implementing passive design measures, enhancing the energy efficiency of refrigerant-based systems, and prioritizing the deployment of innovative Not-in-Kind (NIK) technologies. Specifically, ICAP advocates for the integration of systems such as trigeneration, district cooling, and thermal energy storage in the building sector to meet space cooling demands more efficiently and sustainably.

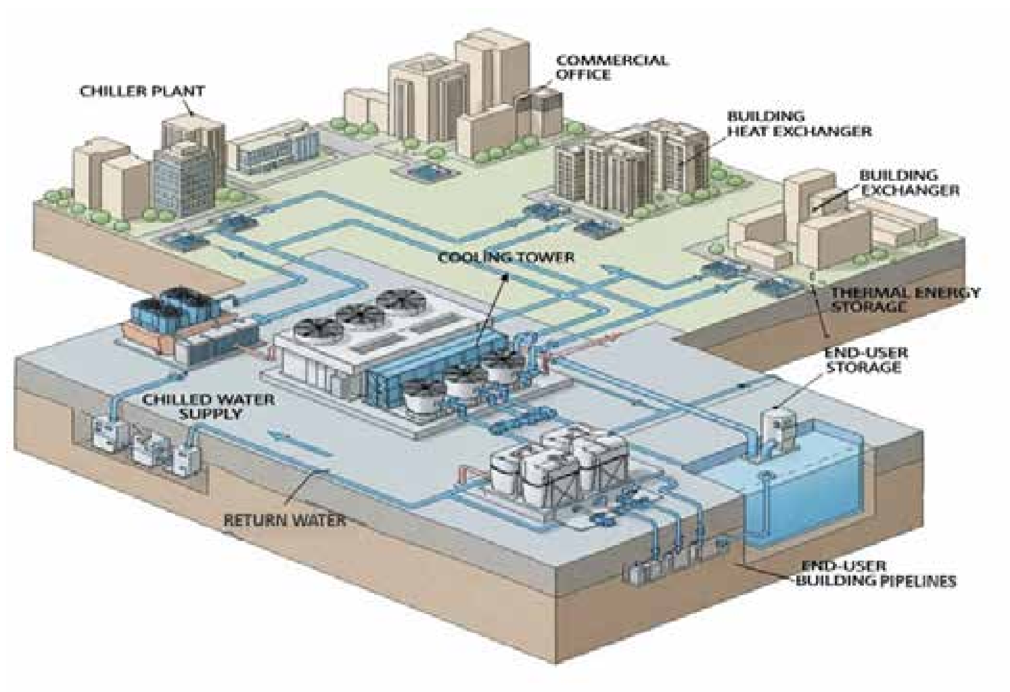


Fig. 1.1, District cooling system

District Cooling Systems (DCS) are centralized cooling technologies and NIK technology proposed in the ICAP (Fig. 1.1). By generating chilled water from a central plant and distributing it to multiple buildings, DCS leverages load diversity to require approximately 15% less installed capacity than conventional systems. This model supports the integration of diverse energy sources such as solar cooling, tri-generation, and waste heat recovery and enables large-scale thermal energy storage, thereby enhancing grid stability (Fig. 1.1). Crucially, by reducing reliance on individual refrigerant-based units, DCS supports ICAP's core objectives of reducing cooling and energy demand.

The urgent need for such sustainable alternatives is underscored by India's projected cooling demand in the coming years. India's rapid urbanization, marked by a projected rise in residential households from 272 million in 2017 to 386 million by 2037 and a near tripling of commercial built-up area from 1.2 billion m² to 3.1 billion m² by 2037, is rendering conventional cooling methods, termed as Business-As-Usual (BAU) systems increasingly inadequate and environmentally unsustainable. (Fig. 1.1). The projected rise in the penetration of room air conditioners from 7–9% in 2017 to nearly 40% by 2037) place immense strain on energy infrastructure and exacerbating urban heat islands underscores the urgency of transitioning toward scalable, low-carbon cooling infrastructure (Fig. 1.2).

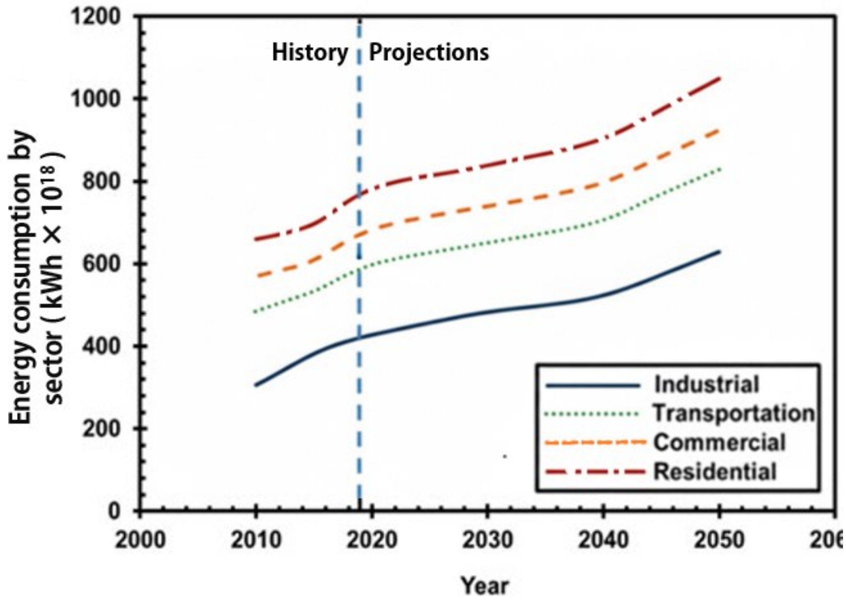


Fig. 1.2, Energy consumption scenario [2]

District Cooling Systems (DCS) have emerged as a promising alternative technology to address the rapidly growing demand for cooling in India’s urban and industrial centers. BAU systems not only contribute significantly to energy consumption and carbon emissions but also exacerbate peak load conditions, strain local electricity grids, and intensify the urban heat island effect [2]. This techno-economic feasibility study has been commissioned to evaluate the potential of DCS as a technically viable, economically competitive, and environmentally (feasible) alternative to BAU cooling methods in India. The study focuses on identifying and analyzing at 13 cities urban or industrial clusters both coastal and landlocked representing greenfield and brownfield projects, each with a minimum cooling demand of 10,000 TR.

These clusters were assessed in terms of current (2024) and projected (2034) cooling demand, using robust forecasting models [3]. An assessment of the technical feasibility, resource requirements (energy, water, refrigerants), capital and operating costs, and a detailed comparison of DCS performance against conventional systems was conducted. Enabling factors such as thermal energy storage, use of alternative heat sinks (e.g., sea water, recycled water), integration with renewables and waste heat, and the potential for reducing both peak electrical demand and GHG emissions were also considered. [4, 5].

Beyond technical and economic evaluation, this study identifies critical implementation barriers such as low cooling load diversity, distribution network inefficiencies, and the complexities of retrofitting existing urban infrastructure. To provide a global perspective, the study incorporates five international case studies from countries such as Denmark, Hungary, and Singapore. These examples highlight technical innovations like seawater and recycled water use for cooling, offering practical insights for adaptation in the Indian context. This study is being carried out as part of the enabling activities of the HCFC phase out Management Plan Stage-III (HPMP Stage-III), implemented by Ozone Cell of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, in close cooperation with UNEP, as implementing agency [6, 7].

2. Approach and Methodology

This study employed a systematic methodology to assess the techno-economic feasibility of District Cooling Systems (DCS) in India and benchmark them against conventional Business-As-Usual (BAU) cooling practices. The approach combined demand forecasting, technical and financial analysis, policy mapping, and stakeholder engagement (Fig. 2.1). The key methodological steps are outlined below.

2.1 Methodology

Thirteen urban and industrial clusters were identified using a multi-criteria framework covering climatic zones, urban typology, cooling load thresholds, infrastructure readiness, and policy alignment (Fig. 2.1). Both greenfield and brownfield developments were included, along with industrial zones to capture the diversity of urban India.

a) Cooling Demand Assessment

Cooling demand for the identified clusters was estimated for 2024 and projected to 2034 using a structured, four-step methodology. The approach ensured consistency across different urban typologies and climate zones, while accounting for city-specific growth trajectories and building practices.

- **Built-up Area Estimation:** Gross Floor Area (GFA) was calculated using GIS overlays, zoning regulations, city masterplans, and Floor Area Ratio (FAR) utilization norms. This provided the spatial baseline for demand estimation.
- **Application of Cooling Intensity:** Building-type-specific cooling intensities were applied based on the Energy Conservation Building Code (ECBC) and ASHRAE standards. Sectoral demand distribution was derived for residential, commercial, and institutional loads.
- **Load Profiling and Diversity Adjustment:** Hourly load profiles were developed, and diversity-adjusted peak loads were computed using coincidence factors in the range of 0.6–1. This reflected temporal and spatial variations in cooling demand across mixed-use clusters.
- **Growth Forecasting:** Demand was projected to 2034 using compound annual growth rates (CAGR) informed by urbanization patterns, Smart City developments, industrial corridors, and anticipated climate impacts.

The outputs included city-wise GFA, sectoral demand breakdown, hourly load curves, and diversity-adjusted peak TR values, forming the basis for subsequent DCS feasibility modeling.

b) Technical Feasibility Analysis

Existing BAU cooling systems were benchmarked in terms of efficiency, refrigerant use, and environmental impact. DCS configurations were then modelled for each cluster, incorporating:

i. Centralized chiller plants with modular configurations.
ii. Thermal Energy Storage (TES) for peak load shaving.
iii. Integration of seawater and recycled water where feasible.
iv. Transition to low-GWP refrigerants.

Comparisons focused on energy use, water savings, refrigerant transitions, and reduction of Urban Heat Island (UHI) effect.

c) Risk and Barrier Assessment

Risks such as load diversity limitations, retrofitting constraints, tariff structures, and network distribution losses were examined. Practical challenges such as building readiness, feasibility of underground distribution, and buyback of existing systems were also assessed.

d) Cost–Benefit Analysis

Lifecycle cost (LCC) modelling was undertaken to compare DCS with BAU systems. This included CAPEX, OPEX, energy cost savings, payback periods, and carbon credit benefits. City-level analyses quantified net savings, Levelized cost of cooling (LCOC), and emission reductions.

e) Current DCS Policies & Regulations

The regulatory landscape was mapped to identify barriers and enablers for DCS adoption. Recommendations were developed for tariff incentives, zoning guidelines, and public–private partnership (PPP) models. Both Indian and international case studies were examined to derive actionable insights.

f) Case Study Documentation

Five national and international case studies (e.g., Singapore, Denmark, Canada, India) were reviewed, with a focus on seawater and recycled water-based DCS models. These examples provided replicable strategies for Indian conditions

g) Stakeholder Consultations

Two structured consultations were organized in collaboration with the Ozone Cell, MoEF&CC, one after the Initial Assessment Report and another following the Draft Report. Feedback from stakeholders was incorporated in the study.

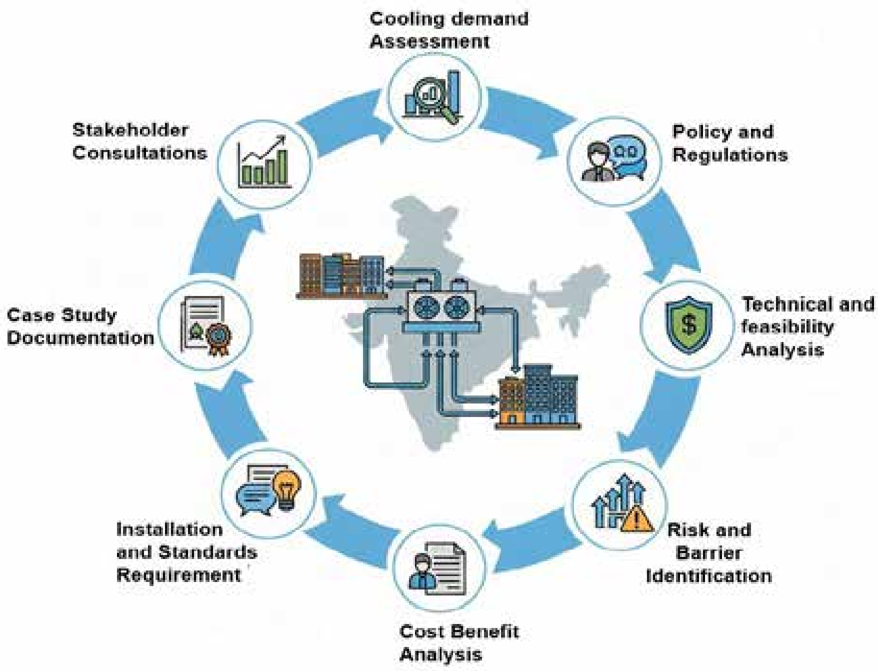


Fig. 2.1, Techno-economic evaluation of district cooling systems in India methodology

2.2 Cluster Identification

District Cooling Systems (DCS) are best suited for zones with dense and diverse cooling demands, reliable infrastructure, and long-term urban growth. Based on a multi-criteria evaluation, 13 clusters across India were identified, representing a balance of climatic conditions, development typologies, and load types.

The clusters span across **five climatic zones** coastal, composite, hot-dry, humid, and moderate ensuring diversity for the study. They also cover varied **development types**:

- **Greenfield:** Planned developments on new land parcels that allow seamless integration of district cooling with upcoming masterplans (e.g., Amaravati, Bhubaneswar, Visakhapatnam).
- **Brownfield:** Existing urban areas where retrofitting is required, yet high load densities provide significant emission reduction potential (e.g., Delhi NCR, Mumbai, Chennai).
- **Mixed-use Redevelopment:** Renewal of urban districts combining residential, commercial, and institutional functions for higher efficiency and land utilization (e.g., Bengaluru, Hyderabad, Pune).

The load types considered include commercial, institutional, residential, and industrial demand centers. This diversified mix enables robust feasibility modeling across use cases and policy scenarios in alignment with the India Cooling Action Plan (ICAP), the Kigali Amendment, and national Smart City goals. The cluster identification process drew on criteria outlined in the Inception Report and was guided by technical viability, geographic diversity, infrastructure readiness, and policy alignment. Thirteen urban and industrial clusters were shortlisted based on projected cooling loads, urban typology, and climatic variation. These include Mumbai, Delhi NCR, Bengaluru, Ahmedabad, Chennai, Kolkata, Hyderabad, Visakhapatnam, Bhubaneswar, Rourkela, Kochi, Guwahati, and Surat. Each reflects a unique combination of greenfield, brownfield, or mixed-use redevelopment potential, with varying infrastructure maturity such as treated sewage effluent (TSE) availability, underground utility corridors, and renewable energy integration [8].

2.3 Criteria Selection & Approach

A multi-criteria framework was adopted to identify and evaluate potential clusters for DCS feasibility analysis, ensuring strategic alignment with India's climate goals, urban development priorities, and infrastructure readiness (Table 2.1).

Table 2.1, Selection criteria of potential clusters/cities

Evaluation Criteria	Rationale
Cooling Load ≥10,000 TR	Threshold for DCS viability as per ToR
Urban Typology	Greenfield (planned), Brownfield (retrofit), and Industrial
Climatic Zone Coverage	Representing hot-dry, humid, composite, semi-arid, moderate, and coastal conditions
Infrastructure Readiness	Availability of STPs, ULB support, electrical grid, underground corridors
Current Policies and Regulations	Aligned with ICAP, Kigali, ECBC 2017, Eco-Niwas, Smart Cities, and AMRUT. State policies, DCR norms, and PPP/VGF enable DCS adoption

2.4 Finalized Clusters for District Cooling Feasibility

The estimation of cooling demand for 2024 and 2034 was carried out through a structured process that combined floor area calculations, benchmark cooling intensities, and urban growth projections. For each cluster, the gross floor area (GFA) for 2024 was derived from GIS overlays, zoning data, FAR norms, and city master plans. Projections for 2034 were obtained by applying expected population growth, Smart City development plans, and anticipated urban expansion. Building-type specific cooling intensities such as 180–250 W/m² for offices, 300–400 W/m² for hospitals, and 120–150 W/m² for residences were applied using ECBC 2017, ASHRAE standards, and BEE benchmarks. To reflect actual operating conditions, coincidence factors ranging from 0.6 for residential buildings to 1.0 for hospitals and data centers were used, accounting for the fact that not all buildings peak simultaneously. Hourly load variations were also considered, with daytime peaks from offices and institutions, evening surges from residential and retail activity, and constant base loads from hospitals, hotels, and data centers. These adjustments ensured diversity-adjusted demand estimates instead of oversized projections. The 2034 demand was then calculated by applying compound annual growth rates that captured population increases, commercial activity, and climate-related cooling degree days. The final values were expressed in Tons of Refrigeration (TR) using the formula:

Cooling Demand = GFA × Cooling Intensity × Coincidence Factor

Table 2.2, District cooling demand and initial phasing for Indian cities

City	Population (2024) (million)	Estimated DCS Demand (million TR)	Suggested Initial DCS	Estimated Initial phasing
Ahmedabad	9.2	0.6 – 1.2	GIFT City, Gandhinagar	80,000-100,000 TR
Mumbai	22.1	2 – 4	Navi Mumbai/BKC	100,000-150,000 TR
Kolkata	14.9	0.8 –1.5	NewTown Rajarhat/Salt Lake	60,000-90,000 TR
Delhi NCR	33.8	2.5-5	Aerocity/Noida/Gurugram	150,000- 200,000 TR
Hyderabad	12.7	1-2	HITEC City/Gachibowli	90,000-120,000 TR
Kochi	3.2	0.3-0.6	Smart City/Infopark	30,000-50,000 TR
Visakhapatnam	2.6	0.4-0.8	Smart City Core/Naval Base	25,000-40,000 TR
Chennai	12.2	1-2	OMR/Chennai Trade Centre	70,000-100,000 TR
Bhubaneswar	1.1	0.2-0.5	Info City/Kalinga Nagar	20,000-35,000 TR
Rourkela	0.7	0.1-0.3	RSP Township/NIT Campus	10,000-15,000 TR
Surat	8.0	0.6-1.0	Diamond Bourse/DREAM City	40,000-60,000 TR
Pune	7.5	1.0-1.5	Hinjewadi/Kharadi	60,000-90,000 TR
Guwahati	1.5	0.3-0.6	Dispur Secretariat/Smart Projects	20,000-30,000 TR

The 13 shortlisted cities and clusters represent the first wave of DCS deployment opportunities. (Table 2.2) summarizes their 2024 population [9], estimated overall DCS potential, suggested zones for initial implementation, and projected TR demand in the first phase. Large metropolitan regions such as Delhi NCR, Mumbai, and Kolkata demonstrate the highest demand, requiring between 90,000–200,000 TR in high-density zones like Aerocity, Navi Mumbai, and Rajarhat. Hyderabad, Chennai, Pune, and Ahmedabad also show strong prospects, each with initial demand of 60,000–120,000 TR concentrated in IT and financial districts such as HITEC City, OMR, and GIFT City. Emerging cities including Kochi, Bhubaneswar, Guwahati, and Rourkela are viable candidates for early DCS pilots, particularly in smart city precincts, government hubs, and industrial campuses, with initial demand ranging from 10,000–50,000 TR. A deeper assessment of these clusters (Table 2.3) highlights their geographic zones, typologies, demand growth, and implementation drivers. Densely developed regions like Delhi NCR, Mumbai, and Hyderabad show the highest initial TR loads (120,000–200,000 TR in 2024), driven by mixed-use density, high energy demand, and urban heat island effects. Ahmedabad (GIFT City) and Chennai (OMR) stand out as greenfield and coastal hubs with opportunities for STP reuse and integration of thermal energy storage (TES). Smaller clusters such as Rourkela's industrial belt and Visakhapatnam's port-institutional zone illustrate opportunities for industrial waste heat integration and port-linked synergy. Coastal and government-led clusters such as Kochi, Surat, and Guwahati show mid-scale demand (30,000–60,000 TR in 2024), with values expected to nearly double by 2034. For most cities, 2034 TR values scale with GFA growth at around 45,500 TR/Mm², while exceptions like Kolkata reflect land-use mix shifts that lower demand intensity.

Table 2.3, DCS demand and strategic highlights (2024–2034)

State	City/Cluster	Zone	Typology	TR Demand 2024	TR Demand 2034	Strategic Highlights
Gujarat	Ahmedabad – GIFT City, Gandhinagar	Hot-Dry	Greenfield	100000	196715	STP reuse, peak shaving
Maharashtra	Mumbai- Navi Mumbai/BKC	Coastal	Brownfield	150000	295072	Seawater cooling, retrofit complexity
West Bengal	Kolkata – New Town Rajarhat/Salt Lake	Humid	Brownfield	90000	177043	High commercial density, eastern humid climate
Delhi/UP	Delhi NCR — Aerocity/Noida/Gurugram	Composite	Brownfield	200000	393430	Mixed-use density, UHI reduction
Telangana	Hyderabad – ITEC City/Gachibowli	Semi-arid	Mixed-use	120000	236058	DCS case study location (My Home Abhra)
Kerala	Kochi — SmartCity/Infopark	Coastal	Greenfield	50000	98357	Seawater + recycled water synergy
Andhra Pradesh	Visakhapatnam – Smart City core/Naval Base	Coastal	Mixed-use	40000	78686	Port industry integration
Tamil Nadu	Chennai – OMR/Chennai Trade	Coastal	Brownfield	100000	196715	Seawater cooling, TES potential
Odisha	Bhubaneswar – Info City/Kalinga Nagar	Humid	Greenfield	35000	68850	Smart city DCS deployment ease

State	City/Cluster	Zone	Typology	TR Demand 2024	TR Demand 2034	Strategic Highlights
Odisha	Rourkela — RSP Township/NIT Campus	Hot-Dry	Industrial	15000	29507	Waste heat integration
Gujarat	Surat — Diamond Bourse/DREAM City	Coastal	Greenfield	60000	118029	Industry-led cooling demand
Maharashtra	Pune – Hinjewadi/Kharadi	Moderate	Mixed-use	9000	34000	IT + real estate expansion zones
Assam	Guwahati – Dispur Secretariat/Smart Projects	Humid	Brownfield	30000	59014	Government precinct & smart infra synergy

Note: Cooling demand estimated through population, floor area projections (FAR based), climatic cooling degree days (CDDs), and current building typologies

2.5 Key Features supporting DCS in the selected clusters

- **Coastal Cities (Mumbai, Kochi, Chennai)**: Potential for seawater cooling or heat sink integration.
- **Industrial Clusters (Rourkela, Visakhapatnam)**: Opportunities for integrating DCS with waste heat recovery.
- **Greenfield Smart Zones (Ahmedabad, Bhubaneswar)**: Ideal for integrated utility infrastructure planning.
- **Brownfield Retrofitting (Delhi, Mumbai, Chennai)**: Complex implementation but significant GHG abatement potential.

Fig. 2.2, Strategic assessment of District Cooling Systems in India

3. Cooling Demand Assessment

The purpose of this assessment is to determine the cooling demand for the present year (2024) and to project the demand for 2034 across selected urban and industrial clusters in India. Establishing this baseline is essential for evaluating the technical feasibility, economic viability, and long-term scalability of District Cooling Systems (DCS). To achieve this, cooling load intensities and coincidence factors for different building categories were derived from a combination of building energy standards, technical guidelines, and published studies. The primary references include the Energy Conservation Building Code (ECBC 2017, India) and ASHRAE design standards [10–14], which specify typical energy intensities for different building types such as offices, hospitals, retail, and residential complexes. For instance, cooling load ranges of 180–250 W/m² for offices and 300–400 W/m² for hospitals are directly informed by these standards.

These baseline values were then validated against benchmark studies, including the Bureau of Energy Efficiency's (BEE) Energy Performance Index for Indian buildings, as well as relevant international case studies. To ensure alignment with Indian operating conditions, the values were further calibrated using simulation tools, which incorporate local climate variations, occupancy schedules, and building usage patterns. The assignment of coincidence factors followed a similar process, drawing from ASHRAE guidelines and Indian building design handbooks. For example, residential buildings typically exhibit a lower coincidence factor of about 0.6 due to staggered peak usage, while hospitals and data centers operate near full load continuously and therefore assume a factor of 1.0.

Table 3.1 and Figure 3.1 summarize these inputs by presenting the building type-wise cooling load intensities and the corresponding peak coincidence factors applied in the analysis, providing the foundation for projecting cooling demand across the selected clusters. The peak coincidence factor is calibrated using the following Eq. 3.1.

$$\textbf{Peak Coincidence Factor} = \frac{\textbf{Sum of Individual Peak Demands (kW)}}{\textbf{Maximum Simultaneous Demand (kW)}} \qquad 3.1$$

Table 3.1, Building Type-wise Cooling Load and Coincidence Factor [11–14]

Building Type	Cooling Load (W/m²)	Peak Coincidence Factor
Offices	180 — 250	0.7
Retail	250 — 300	0.8
Hospitals / Labs	300 — 400	1.0
Data Centers	500 — 800	1.0
Residential	120 — 150	0.6
Hotels	250 — 350	0.9

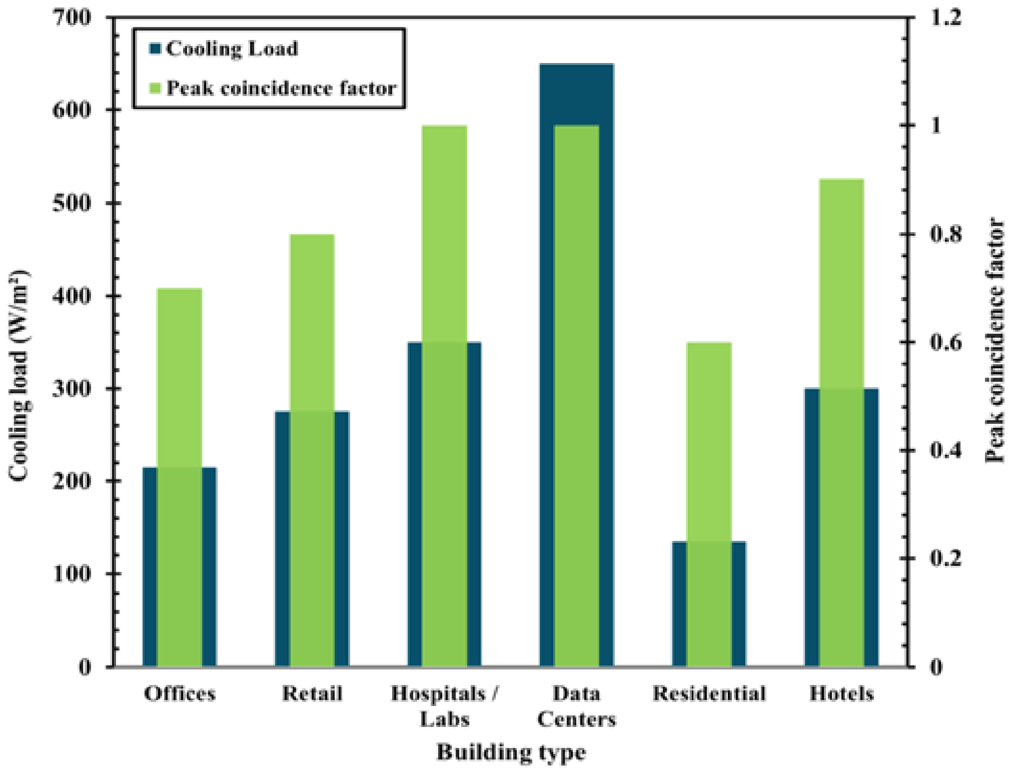


Fig. 3.1, Cooling Load and Coincidence Factor for Building Type-wise

Cooling demand characteristics vary significantly by building type, reflecting differences in occupancy, internal gains, and operational schedules.

- Offices usually need 180–250 W/m² of cooling. The demand is high during the day when people, lights, and computers are in use. However, not all offices reach their peak at the same time because of different working hours and building use. That is why the overall peak is about 70% of the total possible load.
- Retail spaces like malls and shopping centres need more cooling, about 250–300 W/m². This is because they have bright lighting, doors opening often, and heavy crowds during shopping hours. Since most shops are busy at similar times, especially on weekends, their peak demand is higher and more aligned, with about 80% overlap.
- Hospitals and laboratories need constant cooling, between 300–400 W/m², to maintain air quality, comfort, and safety for patients and staff. These facilities run 24×7 with no real breaks, so all areas usually require cooling at the same time. This makes their demand fully coincident, or 100%.
- Data centres require the most cooling of all, about 500–800 W/m², because computers and servers generate heat non-stop. They operate continuously, day and night, and must maintain strict temperature limits. Like hospitals, they are considered fully coincident at 100%.
- Residential buildings need less cooling, around 120–150 W/m². Their demand mainly rises in the evening and night when families are at home. Because households have different routines, the peaks do not all happen at the same time. This spreads out the load, so only about 60% of the peak overlaps.

- Hotels need 250–350 W/m² of cooling. Rooms, lobbies, restaurants, and event halls are cooled almost continuously. Demand peaks in the evenings and during events when activity levels are high. Since most hotel areas are used at similar times, their peak demand is close to 90% overlap.

Distinguishing cooling needs by building type makes it easier to estimate the total demand more accurately. It also helps in deciding the right size for district cooling systems, since not all buildings reach their peak use at the same time. By considering this diversity, the system can be designed to run more efficiently without oversizing. The figures shown in Table 3.1 were converted into Gross Floor Area (GFA) values using Eq. 3.2.

$$\text{Cooling Demand} = \text{GFA} \times \text{Cooling Load Intensity} \times \text{Peak Coincidence Factor} \qquad 3.2$$

3.1 City Cluster Demand Estimates (2024 & 2034)

Table 3.2, 2024 Cluster-Wise Cooling Load Baseline

State	City	Total GFA (Million m²)		Diversity Adjusted Peak TR		Type
		2024	2034	2024	2034	
Gujarat	Ahmedabad	2.2	4.32	100000	196715	Inland GF
Maharashtra	Mumbai	3.3	6.48	150000	295072	Coastal BF
West Bengal	Kolkata	1.2	3.89	90000	177043	Inland BF
Delhi/UP	Delhi NCR	4.4	8.64	200000	393430	Inland BF
Telangana	Hyderabad	2.63	5.18	120000	236058	Inland BF
Kerala	Kochi	1.1	2.16	50000	98357	Coastal GF
Andhra Pradesh	Visakhapatnam	0.87	1.72	40000	78686	Coastal GF
Tamil Nadu	Chennai	2.2	4.32	100000	196715	Coastal GF
Odisha	Bhubaneswar	0.76	1.51	35000	68850	Coastal GF
Odisha	Rourkela	0.32	0.64	15000	29507	Inland BF
Gujarat	Surat	1.31	2.64	60000	118029	Coastal GF
Maharashtra	Pune	0.19	0.74	9000	34000	Inland GF
Assam	Guwahati	0.65	1.3	30000	59014	Inland BF

Table 3.2 presents the projected cooling demand for selected urban clusters across India for the years 2024 and 2034. The data includes total gross floor area (GFA) in million square meters, diversity-adjusted peak cooling loads in tons of refrigeration (TR), and zone typologies.

- Delhi NCR records the highest values, with total GFA increasing from 4.4 M m² in 2024 to 8.64 M m² in 2034 and peak cooling demand reaching 393,430 TR.
- Mumbai follows, with 6.48 M m² GFA and 295,072 TR by 2034.
- Hyderabad, Ahmedabad, Chennai, and Kolkata also show strong demand, with their GFA nearly doubling over the decade and cooling needs exceeding 170,000 TR in each

case. Rapidly growing clusters like Surat, Kochi, and Bhubaneswar display moderate GFA growth with significant increases in peak TR, indicating rising urban density.

- Cities such as Visakhapatnam, Pune, and Guwahati represent emerging demand centers, while Rourkela remains the smallest cluster with a projected 0.64 M m² GFA and 29,507 TR by 2034.
- The final column classifies each location by its zone and development typology, ranging from inland and coastal settings to greenfield and brownfield types.
- This classification helps in aligning urban cooling strategies with infrastructure planning and regional conditions. The table provides a comprehensive foundation for estimating future cooling infrastructure needs across diverse city types.
- In the case of Kolkata, the projected TR for 2034 (177,043 TR) is comparatively lower when set against its GFA expansion. This is attributed to an expected land-use shift toward more residential and institutional developments with relatively lower cooling intensities, which results in a reduced TR density compared to other clusters.

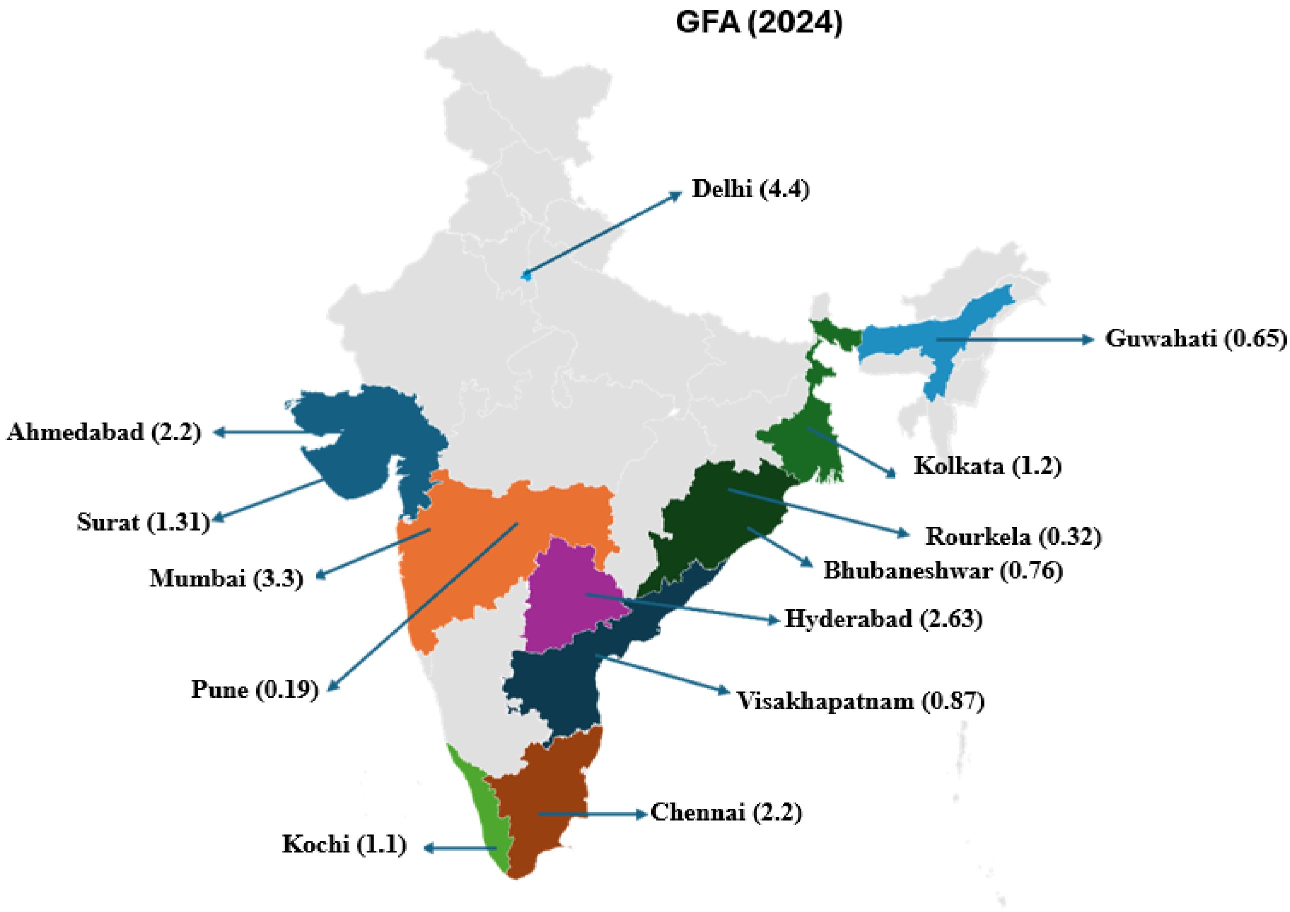


Fig. 3.2, Total Gross Floor Area (Mm^2) for 2024

Fig. 3.2 illustrates the projected Gross Floor Area (GFA) in million square meters for key Indian urban clusters in 2024. Delhi NCR leads with the highest GFA of 4.4 million m², reflecting its expansive urban footprint and dense commercial-residential mix. Mumbai follows with 3.3 million m², driven by its vertical real estate growth and coastal development. Hyderabad (2.63 million m²), Chennai (2.2 million m²), and Ahmedabad (2.2 million m²) represent major urban centers undergoing rapid infrastructure expansion. Cities like Kochi (1.1 million m²), Kolkata (1.2 million m²), and Surat (1.31 million m²) show moderate but steady growth. Comparatively, smaller cities such as Bhubaneswar (0.76 million m²), Guwahati (0.65 million m²), Rourkela (0.32 million m²), and Pune (0.19 million m²) contribute lower GFA values, aligned with their current urban density and development stages. These GFA values provide a spatial distribution snapshot of cooling demand potential based on built-up area.

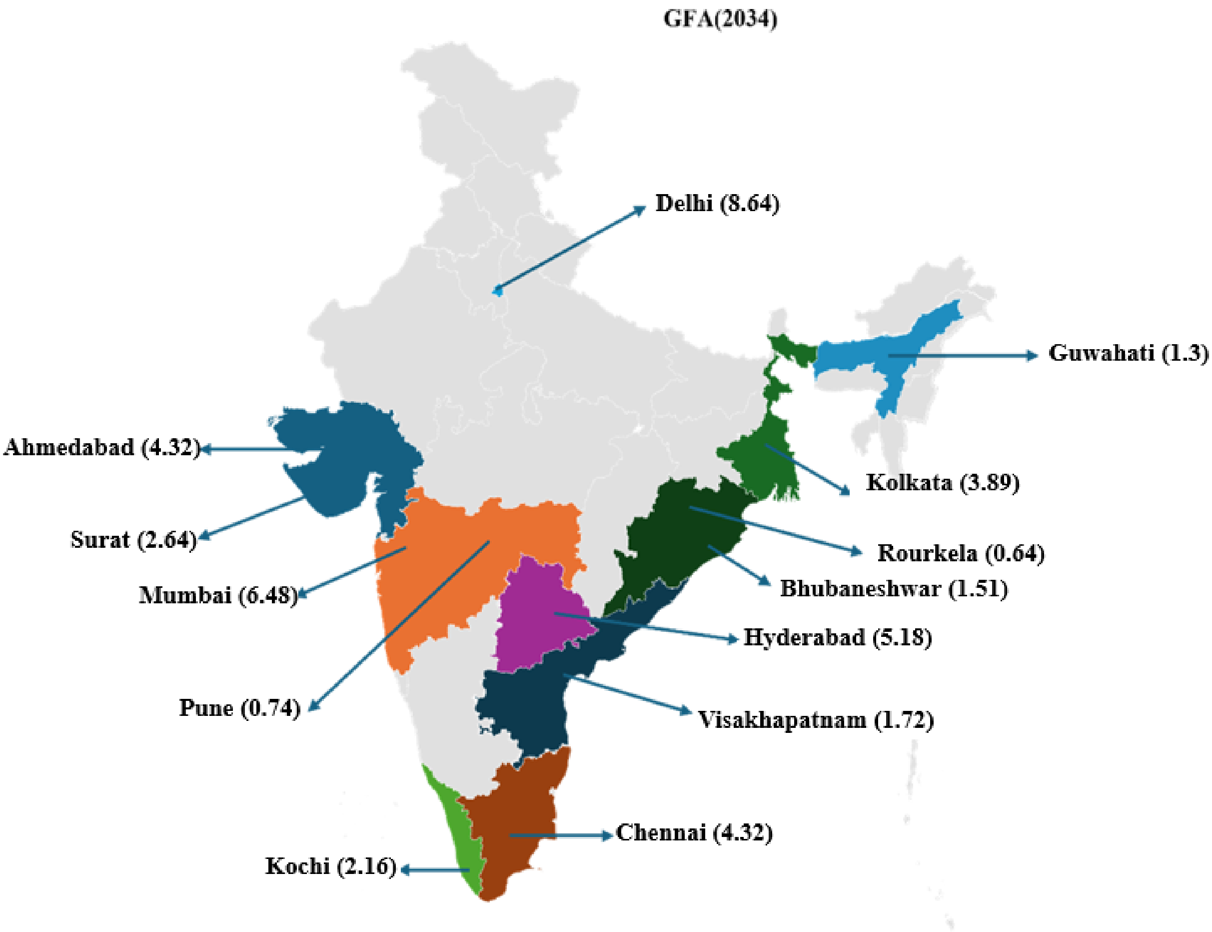


Fig. 3.3, Projected Gross Floor Area (Mm²) for 2034

Fig. 3.3 displays the projected Gross Floor Area (GFA) in million square meters for selected Indian cities in the year 2034. Delhi NCR shows the highest GFA at 8.64 million m², indicating a continued and substantial expansion of its built environment. Mumbai follows with 6.48 million m², almost doubling its 2024 GFA, which reflects sustained urban densification. Hyderabad (5.18 million m²), Chennai (4.32 million m²), and Ahmedabad (4.32 million m²) also witness considerable increases, signifying their emergence as major commercial and residential hubs. Kolkata records a sharp rise to 3.89 million m², while Surat (2.64 million m²), Kochi (2.16 million m²), and Guwahati (1.3 million m²) reflect medium-range growth. Smaller cities such as Rourkela (0.64 million m²), Bhubaneswar (1.51 million m²), Visakhapatnam (1.72 million m²), and Pune (0.74 million m²) exhibit moderate development. The increase in GFA across all cities highlights the rising urbanization trend and underlines the growing need for integrated cooling and infrastructure planning in the next decade.

3.2 Sectoral Demand Distribution

Sectoral analysis reveals that commercial and mixed-use areas account for 35–45% of total cooling demand, followed by residential (20–25%), institutional (15–20%), and hospitality or industrial segments (10–15% each) (Table 3.3). These sectors exhibit varied load profiles, with commercial and institutional buildings peaking during daytime hours and residential areas contributing to evening peaks. This diversity enhances the efficiency of DCS by enabling lower installed capacities due to staggered peaks. Here, mixed-use zoning in many cities contributes to high load diversity, which is ideal for centralized DCS operations.

Table 3.3, Sectoral Demand Distribution

Sector	Share of Cooling Load (%)	Usage Pattern
Commercial	35–45%	Peak from 10 AM-6 PM
Residential	20–25%	Evening/night peak
Institutional	15–20%	Continuous/day-loaded
Industrial	10–15%	Daytime, batch load
Hospitality	10–15%	Year-round base load

3.3 Hourly Load Profiling

A representative daily load profile shows that 30–40% of peak load persists during nighttime due to hospital and hospitality operations. Load starts ramping up by 7 AM and peaks between 11 AM and 4 PM. Evening cooling demand resurges between 5 PM and 9 PM due to residential usage. This non-uniform hourly distribution reinforces the benefit of central cooling plants using TES for peak shaving and energy arbitrage (Table 3.4 and Fig. 3.4) [11].

Table 3.4, Hourly Load Profiling (Typical Daily Profile)

Time Block	% of Peak Load	Observation
00:00 —06:00	30–40%	Base load from hospitals (24×7 operations) and hotels (guest rooms, lobbies, late-night use).
07:00 — 10:00	50–60%	Morning ramp-up as offices, schools, and retail outlets open; ventilation and equipment loads rise.
11:00 — 16:00	90–100%	Midday peak cooling demand from offices, retail, institutions, and hospitality running simultaneously.
17:00 — 21:00	60–75%	Evening demand from residential cooling, shopping activity, and continued hospitality use.
22:00 — 23:59	40–50%	Load decline as offices and retail shut; base load from residences, hospitals, and hotels remains.

3.4 Load Diversity and Coincidence

The clusters span multiple climate zones. Mumbai, Kochi, and Chennai fall within the warm-humid zone, necessitating higher latent cooling capacities. Delhi NCR and Ahmedabad fall under the composite or hot-dry zones where sensible cooling dominates. Bengaluru lies in a temperate zone with more moderate load profiles. These differences have implications for system design, refrigerant selection, and control strategies within DCS deployments (Table 3.5 and Fig. 3.4).

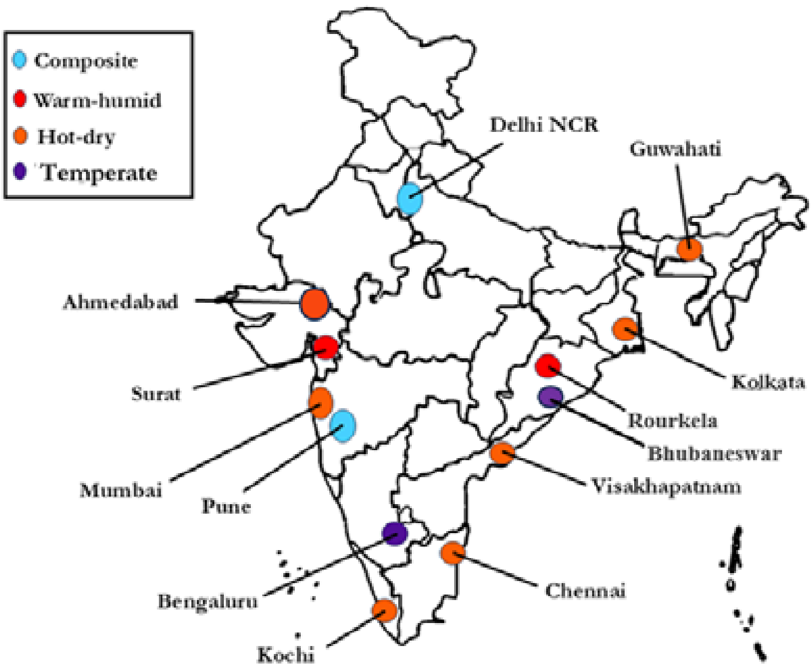


Fig. 3.4, Climate-Zone Based Load Factors

Table 3.5, Climate-Zone Based Load Factors

Climate Zone	Cities	Dominant Cooling Need
Composite	Delhi NCR, Ahmedabad, and Pune	Both temperature and humidity – cooling is needed for heat as well as moisture, especially in monsoon season.
Warm-Humid	Mumbai, Kochi, Chennai, Visakhapatnam, Guwahati, and Kolkata	Humidity control is the biggest challenge – air feels sticky, so systems must remove a lot of moisture.
Hot-Dry	Ahmedabad, Rourkela, and Surat	Mainly temperature control – the air is dry, so the focus is on bringing down the heat, not moisture.
Temperate	Bengaluru	Balanced needs – neither heat nor humidity is extreme, so cooling demand is moderate and mixed.

3.5 DCS Opportunity Matrix

Clusters were also analyzed for specific DCS-enabling features. Seawater-based cooling appears feasible in Mumbai, Chennai, and Kochi, while cities like Ahmedabad, Surat, and Visakhapatnam can integrate treated sewage (STP) recycled water for make-up needs. Trigeneration potential where a single fuel source is used to simultaneously produce electricity, heating, and cooling is especially strong in Delhi NCR, Hyderabad, and Bengaluru due to the close co-location of large power generation facilities and cooling demand centers. This allows waste heat from power plants to be converted into useful heating and cooling, improving overall efficiency. Cities like Pune and Bhubaneswar, on the other hand, demonstrate strong suitability for Thermal Energy Storage (TES) because of their distinct day and night load variations, enabling off-peak storage and on-peak deployment (Table 3.6) [12].

Table 3.6, DCS Opportunity Mapping

Feature	Cities Benefiting
Seawater Cooling Feasibility	Mumbai, Kochi, Chennai, Visakhapatnam
STP/Recycled Water Integration	Ahmedabad, Surat, Guwahati
Combined Cooling, Heat and Power Potential (Trigeneration Potential)	Bengaluru, Delhi NCR, Hyderabad
TES-Enabled Load Shifting	Pune, Bhubaneswar, Rourkela

3.6 Cooling Demand and Resource Assessment – City-wise Overview

To identify clusters suitable for District Cooling Systems (DCS), city-level datasets were analyzed across population, cooling demand, energy consumption, and techno-economic performance indicators. The following findings summarize the comparative evaluation:

a) Population

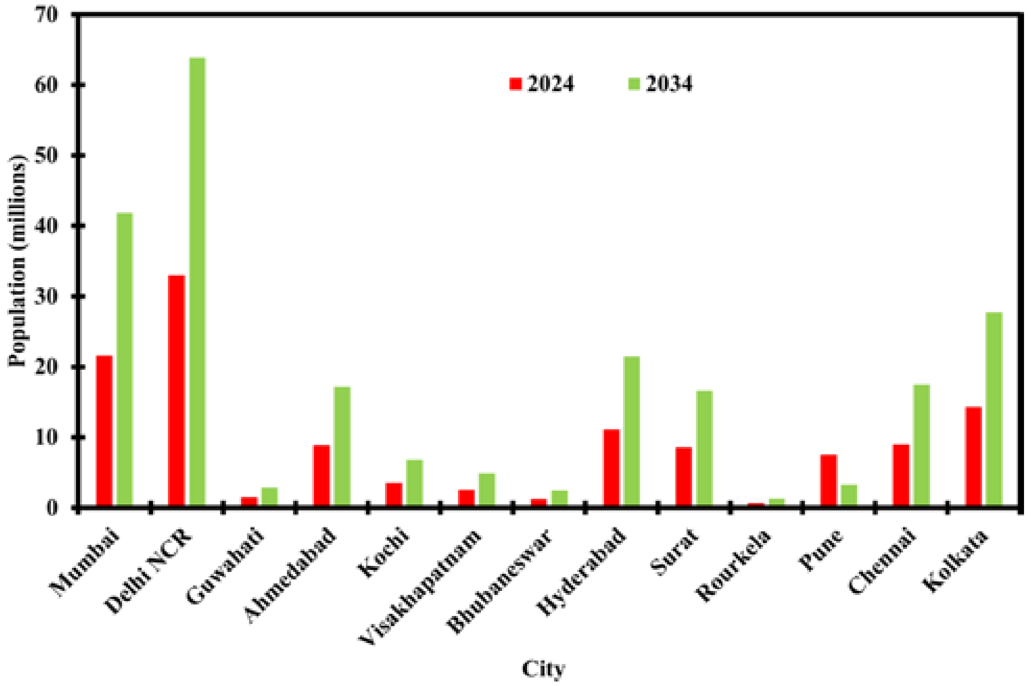


Fig. 3.5, Population Distribution across Selected Clusters

Fig. 3.5 presents a comparative overview of population across selected urban clusters for the years 2024 and 2034 [9]. Each cluster is represented by two bars: the red bar indicates the estimated population in 2024, while the green bar reflects projected figures for 2034. Among all clusters, Delhi NCR shows the highest growth, with its population increasing from approximately 33 million in 2024 to nearly 64 million by 2034. Mumbai also registers a significant rise, growing from 21.6 million to nearly 42 million over the same period. Other major cities such as Hyderabad, Kolkata, and Ahmedabad show moderate but steady growth, with each expected to add 7 to 13 million residents. In contrast, smaller clusters like Rourkela, Guwahati, Bhubaneswar, and Visakhapatnam display lower overall population figures, though each shows a proportional increase over the decade. Notably, cities like Surat, Pune, and Kochi reflect a trend of rapid urban expansion, nearly doubling their population base. This population trend highlights the increasing urban load on infrastructure, energy, and cooling systems, reinforcing the need for planned interventions such as district cooling in high-growth zones.

b) Cooling Demand

Fig. 3.6 compares the baseline cooling demand for thirteen urban clusters. Each city is plotted with two bars: the green bar shows its present requirement (2024) in tons of refrigeration, while the blue bar indicates the load expected by 2034. Delhi NCR tops the chart, rising from roughly 200 000 TR today to just under 400 000 TR within a decade. Mumbai follows, climbing from about 150000 TR to nearly 300000 TR. Hyderabad occupies third place, moving from 120 000 TR to more than 230000 TR. Mid-tier centers Ahmedabad, Chennai, and Kolkata each start near the 90000–100000 TR mark and approach 180000-200000 TR by 2034. In Kolkata's case, the 2034 projection reflects a greater share of residential development, which lowers the overall cooling intensity compared to other cities. Coastal and port-oriented clusters such as Kochi, Visakhapatnam, and Surat show more modest absolute figures (40000–60000 TR in 2024) yet almost double over the period. Smaller inland nodes—Guwahati, Bhubaneswar, Rourkela, and Pune remain below 35000 TR in 2024, but several exhibit the steepest proportional gains, particularly Pune and Rourkela. Overall, the graphic highlights two clear trends: the largest metropolitan areas will see the greatest absolute increase in cooling load, while fast-growing secondary cities experience the highest percentage growth, underscoring the need for early planning of efficient cooling infrastructure across the board.

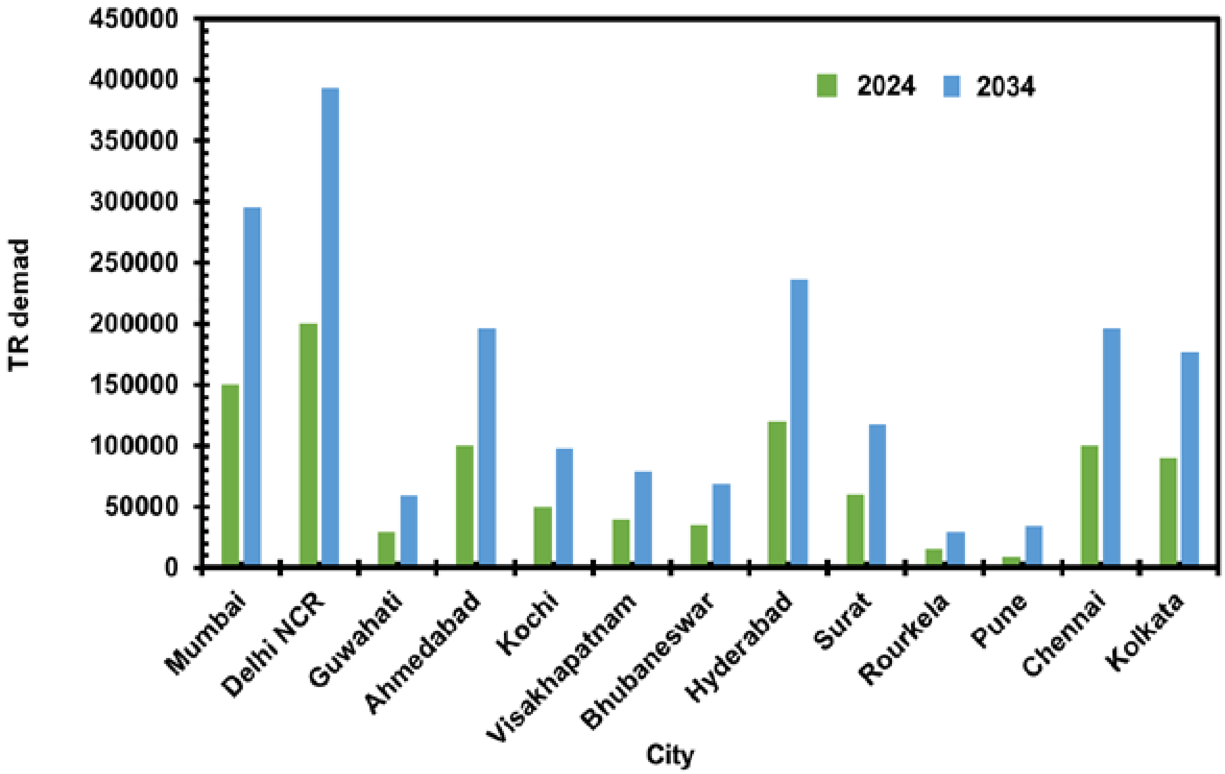


Fig. 3.6, Cooling Demand (TR) across Selected Cities (2024 Baseline)

c) Electricity Consumption per Capita

Fig. 3.7 illustrates the electricity consumption per million people across selected city clusters for the years 2024 and 2034, excluding appliance-related loads. The red bars represent 2024 data, while the green bars indicate projected values for 2034. The chart provides a comparative view of core cooling energy requirements normalized to population levels.

The calculation of these values is based on the following formula:

$$\textbf{Electricity Consumption (kW)} = \frac{\textbf{TR} \times \textbf{3.517}}{\boldsymbol{COP}} \quad (3.4)$$

In this calculation, TR refers to the total cooling demand expressed in tons of refrigeration, which quantifies the amount of heat energy that needs to be removed to maintain comfortable indoor conditions. The value is then converted into kilowatts using the standard conversion factor of 3.517, where one ton of refrigeration equals 3.517 kW of cooling output. To determine the actual electrical energy required, the converted value is divided by the system's coefficient of performance (COP), which reflects how efficiently the cooling system operates. For this assessment, a COP of 3.5 is used for the year 2024 to represent current system efficiency, while a more optimistic COP of 5.0 is applied for 2034 to account for expected technological improvements and energy-efficient practices.

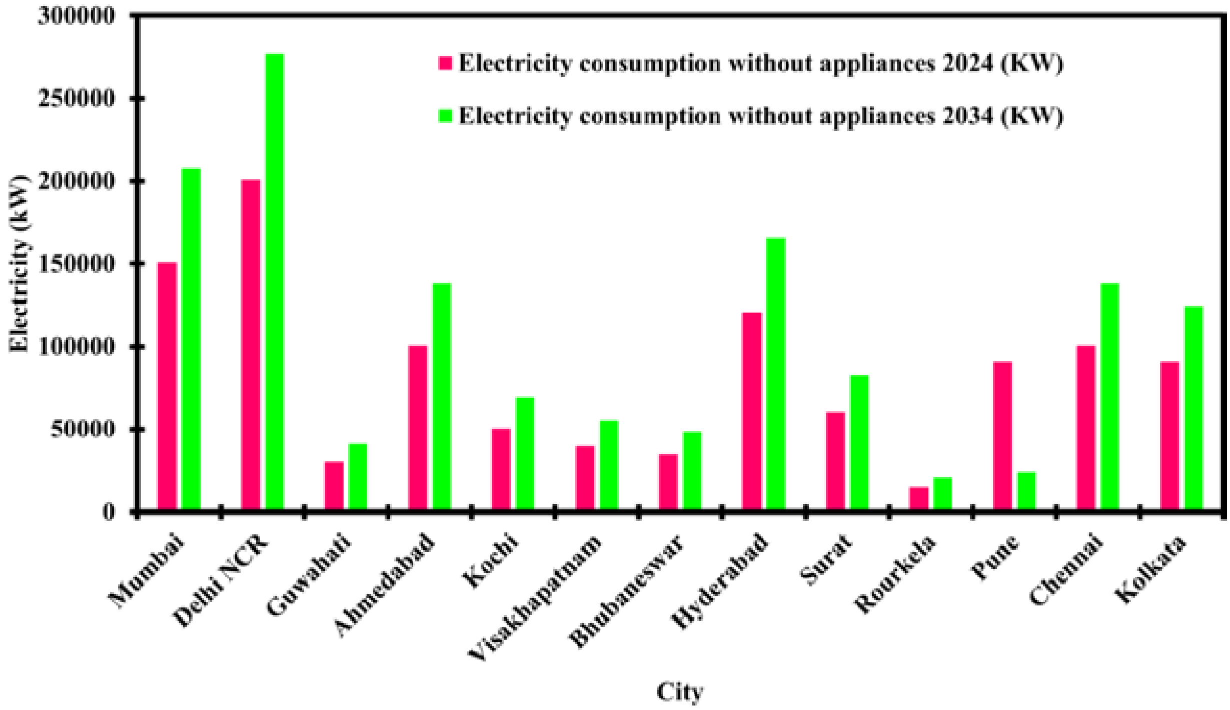


Fig. 3.7, Electricity Consumption per Capita (without Appliances) across Cities

Delhi NCR registers the highest demand in both years, followed by Mumbai, Hyderabad, and Chennai/Kolkata. All cities display a clear increase in consumption by 2034, with sharper rises seen in Delhi NCR, Hyderabad, and Kochi. Smaller cities such as Rourkela, Surat, and Bhubaneswar remain at the lower end of the demand spectrum. The comparison highlights the growing cooling energy requirement across urban centers, with the largest metropolitan regions dominating overall consumption.

d) Summary of Results: Cooling Demand Assessment

The assessment shows that cooling demand across Indian cities will rise sharply between 2024 and 2034. Delhi NCR estimates the highest requirement, almost doubling from 200,000 TR to nearly 393,000 TR. Mumbai follows, growing from 150,000 TR to around 295,000 TR. Hyderabad, Chennai, Ahmedabad, and Kolkata also show strong increases, each crossing 170,000–190,000 TR by 2034. Mid-sized cities such as Kochi, Surat, and Bhubaneswar demonstrate moderate growth, while smaller clusters like Pune and Rourkela remain at the lower end in absolute terms, though with high proportional gains.

By sector, commercial and mixed-use buildings contribute the largest share of demand at 35–45%, followed by residential (20–25%) and institutional facilities (15–20%). Hospitality and industrial segments together add about 20–30%. The daily load profile highlights the impact of diversity: offices and institutions peak during the day, residential areas in the evening, and hospitals, data centers, and hotels maintain round-the-clock loads. This mix enables central plants to optimize installed capacity through diversity gains.

Regional climate conditions play a major role. Coastal and warm-humid cities such as Mumbai, Chennai, and Kochi are dominated by latent loads, while inland composite and hot-dry cities such as Delhi NCR, Ahmedabad, and Rourkela are driven mainly by sensible loads. Bengaluru shows a balanced profile due to its temperate climate. Opportunities also differ across clusters—Mumbai, Chennai, and Kochi can utilize seawater cooling, Ahmedabad and Surat have potential for recycled water use, and Delhi NCR, Hyderabad, and Bengaluru offer strong prospects for trigeneration. Thermal energy storage is particularly well suited for Pune and Bhubaneswar.

Overall, the results suggest that while population growth remains a key driver, variations in urban typology, climatic zone, and system efficiency have a considerable impact on cooling demand intensity and electricity consumption. Also, the results point to two main patterns: larger metros will continue to drive the bulk of total cooling demand, making them prime candidates for large-scale district cooling, while smaller but fast-growing clusters show the steepest relative increase, requiring early planning to avoid inefficient, fragmented cooling solutions.

3.7 Insights on cooling demand assessment

Cooling demand across Indian cities will rise sharply by 2034. Delhi NCR nearly doubles (200,000 to 393,000 TR), Mumbai grows from 150,000 to 295,000 TR, while Hyderabad, Chennai, Ahmedabad, and Kolkata each ranges from 170,000 to 190,000 TR. Mid-sized cities (Kochi, Surat, Bhubaneswar) show moderate growth, and smaller clusters like Pune and Rourkela record high proportional gains. By sector, commercial and mixed-use buildings lead (35–45%), followed by residential (20–25%), institutional (15–20%), and hospitality/industrial (20–30%). Hourly profiling shows daytime peaks (offices/institutions), evening peaks (residential/retail), and constant loads (hospitals, hotels, data centres), allowing diversity gains for central plants. Climate zones shape demand: warm-humid cities face latent-heavy loads, hot-dry/composite zones are sensible-dominated, and temperate Bengaluru has a balanced profile. Cluster opportunities include seawater cooling (Mumbai, Chennai, Kochi), recycled water (Ahmedabad, Surat, Visakhapatnam), trigeneration (Delhi NCR, Hyderabad, Bengaluru), and TES (Pune, Bhubaneswar).

Two patterns emerge:

- Megacities will drive absolute cooling demand, best suited for public infrastructure-level service providers, similar to electricity, water, and natural gas utilities.
- Mid and small clusters grow fastest in relative terms, which will need modular/precinct-scale systems to avoid fragmented cooling.

Key Takeaways: Integrated DCS with TES, energy recovery, seawater/recycled water use, and renewables offers a scalable, climate-aligned solution in line with the India Cooling Action Plan.

4. DCS Technical Feasibility and Cost Benefit Analysis

4.1 Technical Feasibility

The technical assessment of DCS across 13 shortlisted urban and industrial clusters shows strong potential for both greenfield and brownfield applications compared to current Business-As-Usual (BAU) cooling scenarios. The analysis covers system inefficiencies, load management, resource use, refrigerant transitions, and readiness for innovation [13].

In the BAU case, most cities rely on standalone split ACs, VRF systems, rooftop chillers, and small central HVAC units. These are decentralized, energy-intensive, and often use high-GWP refrigerants (R-22, R-410a). They face frequent capacity mismatches, poor part-load performance, and contribute to urban heat island effects through scattered rooftop units. They also offer little scope for renewable integration, demand diversity, or advanced load management. By contrast, DCS modeling demonstrates higher efficiency, lower emissions, and better long-term cost-effectiveness. Four key interventions anchor the proposed architecture: Thermal Energy Storage (TES), seawater or recycled water use, centralized chiller plants, and modular Energy Transfer Stations (ETS). TES is particularly impactful in Delhi NCR, Bengaluru, Ahmedabad, and Hyderabad, where peak shaving of up to 30% is possible, enabling off-peak energy use and renewable integration [14]. Coastal cities such as Mumbai, Chennai, and Kochi are technically suited for seawater-based cooling, reducing freshwater demand and improving condenser efficiency. Cities like Ahmedabad, Bhubaneswar, and Visakhapatnam can utilize treated sewage or industrial effluent in cooling towers, supporting circular water use under Smart City and Jal Shakti initiatives. Centralized chiller plants are proposed for each cluster, using centrifugal machines for base loads, screw chillers for modulation, and, where feasible, absorption chillers powered by solar thermal or industrial waste heat. Focus is towards adoption of low-GWP alternatives including natural refrigerants (R-717, R-290) and HFOs. Centralization also improves safety, leakage control, and end-of-life refrigerant recovery. Distribution networks will employ pre-insulated conduits with variable-speed pumping, while ETS units at buildings provide hydraulic separation, energy metering, and predictive maintenance through SCADA and BMS integration. Feasibility varies by city. Mumbai and Kochi score highest due to coastal advantages and infrastructure. Bengaluru and Ahmedabad show strong potential through renewable integration and STP reuse. Delhi NCR, despite retrofit challenges, can adopt modular hybrid systems. Visakhapatnam and Rourkela offer synergy with waste heat from industry, while Hyderabad and Bhubaneswar need policy support and phased roll-outs. Surat and Pune present opportunities for TES linked with solar and recycled water [15].

Overall, the assessment indicates that DCS deployment could reduce cooling energy intensity by 30–40%, cut freshwater use by up to 90% (through seawater or STP reuse), and accelerate the transition to low-GWP refrigerants. TES and centralized plants enhance scalability, demand management, and resilience to rising urban loads. These findings will be refined in the next phase through lifecycle cost modeling, stakeholder engagement, and thermal performance simulations [16].

i. Observed Limitations in Business-As-Usual (BAU) Cooling Scenario

In the majority of selected clusters, Business-As-Usual (BAU) cooling is dominated by decentralized systems such as split ACs, rooftop chillers, and VRFs. These systems operate in isolation, often oversized or underutilized due to lack of load-sharing or demand aggregation. Their energy efficiency is significantly lower, with observed average COPs ranging from 2.5 to 3.2 and seasonal fluctuations. Additionally, widespread use of high-GWP refrigerants such as R-22 and R-410a poses environmental concerns. Maintenance is fragmented across buildings, leading to inconsistent performance and higher lifecycle costs. Furthermore, rooftop-mounted equipment adds to urban heat island (UHI) effects by radiating waste heat directly into the local environment. Freshwater is commonly used in cooling towers, with limited adoption of recycled sources. The important points observed for limitations in Business-As-Usual (BAU) Cooling Systems are as follows (Table 4.1 and Fig. 4.1):

- Decentralized systems dominate (split ACs, VRFs).
- Frequent oversizing or underutilization due to poor load matching.
- Low energy efficiency (COP 2.5–3.2).
- High-GWP refrigerants (R-22, R-410a) still prevalent.
- Lack of coordinated maintenance = poor lifecycle performance.
- High UHI impact from rooftop systems.
- Excessive freshwater use; minimal use of recycled water.

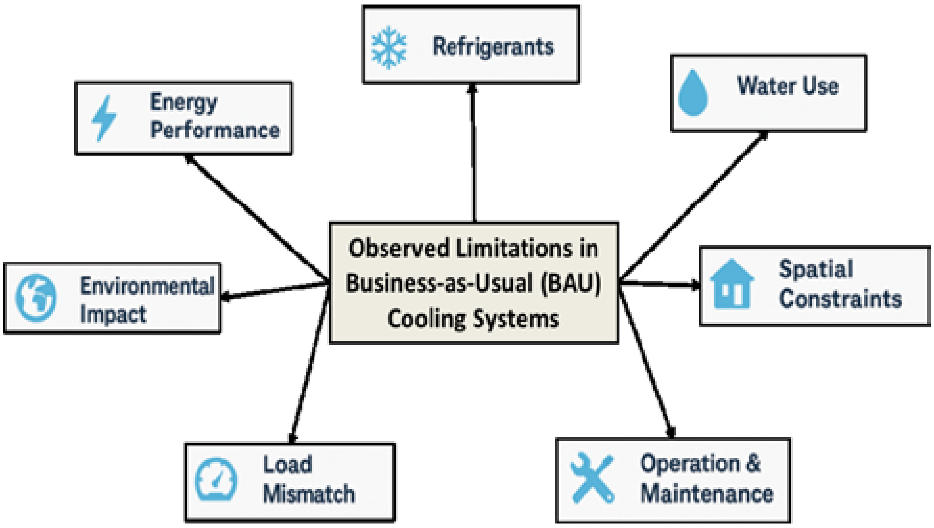


Fig. 4.1, Limitations of BAU Cooling Systems

Table 4.1, Observed Limitations in Business-As-Usual (BAU) Cooling Systems

Dimension	Observations in BAU Scenario
Energy Performance	Low part-load efficiency; high seasonal variation
Refrigerants	High-GWP refrigerants (R-22, R-410a); risk of leakage and phase-out incompatibility
Water Use	High freshwater demand in cooling towers without water reuse
Spatial Constraints	Rooftop congestion and limited HVAC zoning in older buildings
Operation & Maintenance	Disparate maintenance regimes; energy wastage and poor system health
Load Mismatch	Oversized or underutilized systems due to lack of diversity/load sharing
Environmental Impact	High GHG emissions; contribute to urban heat island effect via rooftop discharges

ii. High-Impact Interventions in DCS Scenario

Preliminary feasibility studies identified several high-impact interventions for deploying DCS in Indian urban contexts (Table 4.2 and Fig. 4.2). Thermal Energy Storage (TES), using chilled water or ice banks, enables load shifting and supports off-peak energy use especially suitable in cities with tiered electricity tariffs like Bengaluru and Delhi NCR. In coastal cities, seawater is proposed as a condenser cooling medium or even a direct heat sink, reducing dependence on freshwater and enhancing heat rejection efficiency. Integration of recycled water from STPs into cooling towers is viable in Ahmedabad, Bhubaneswar, and Visakhapatnam, aligning with circular economy principles. Centralized chiller plants using centrifugal or screw chillers are key to system scalability and refrigerant transition. All these technologies combine to create a resilient, efficient, and climate-aligned DCS network. The important points observed for high-impact interventions in DCS systems are as follows,

- TES enables peak shaving and better plant sizing.
- Seawater is used for condenser heat rejection in Mumbai, Chennai, Kochi.
- Utilizing treated STP water enables sustainable cooling solutions, particularly in water-scarce urban regions.
- Centralized chillers offer scale, better maintenance, and refrigerant flexibility.
- Systems are optimized for long-term refrigerant transitions (e.g., HFOs, R-717).

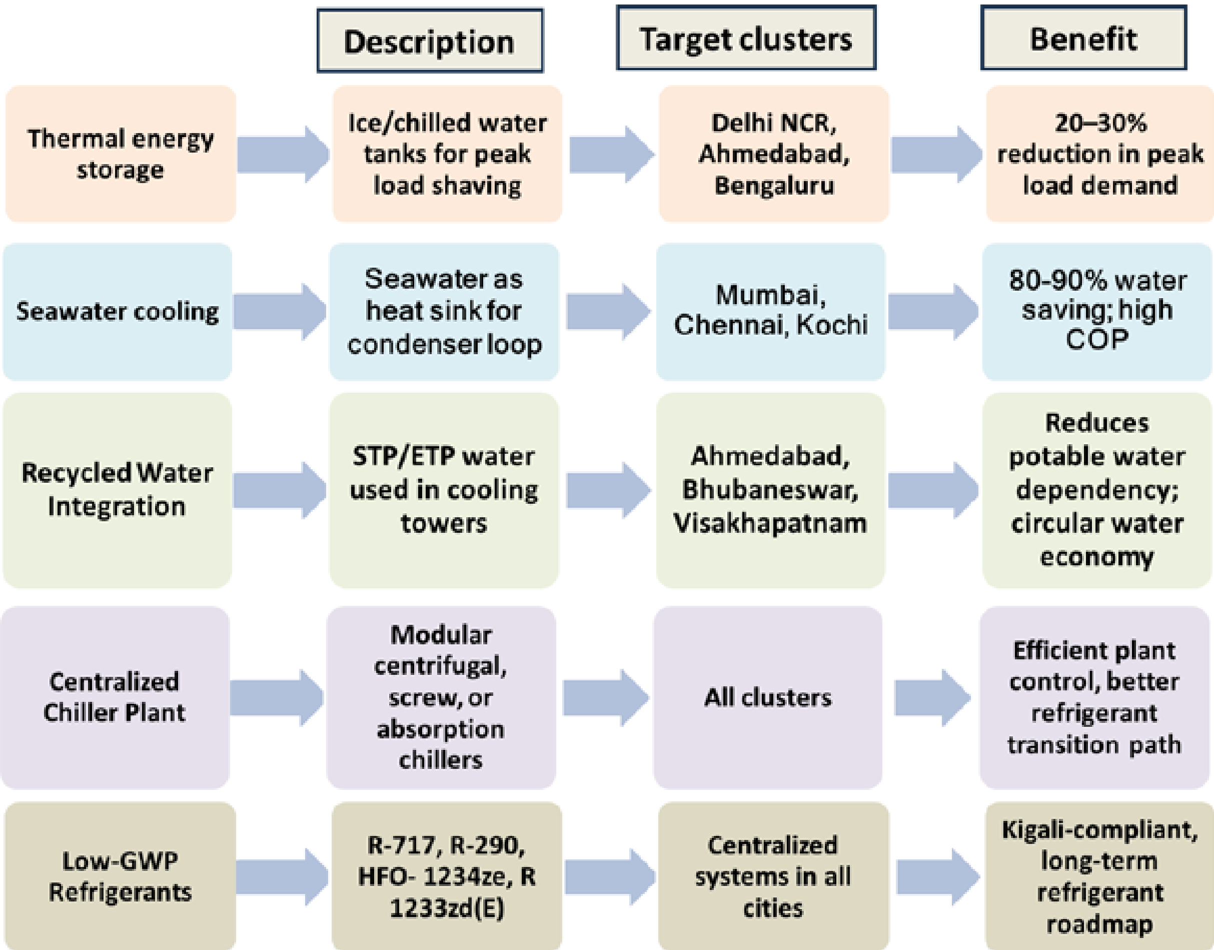


Fig. 4.2, Interventions Identified in DCS Systems

iii. Technical Benefits Comparison of BAU versus DCS Scenarios

The technical benefits of transitioning from BAU to DCS scenarios are substantial (Table 4.3 and Fig. 4.3). Energy consumption per TR is expected to fall by ~30–40%, with system-wide efficiency (COP) increasing from ~3.0 to >5.0. Water use is optimized via TES and STP reuse, reducing the requirement for potable water by over 50%. The switch to centralized systems supports the use of low-GWP refrigerants, many of which are not feasible in distributed units due to safety or O&M challenges. DCS also mitigates urban heat island effects by removing rooftop heat sources and shifting thermal discharge to controlled ground-level cooling towers. The important points observed for technical benefits comparison of BAU with DCS are as follows,

- Energy use drops from ~1.6 to 1.1 kWh/TR (30–40% savings).
- COP increases from ~3.0 (BAU) to >5.0 (DCS).
- Freshwater demand reduced by >50%.
- Enables safe use of low-GWP refrigerants (R-717, HFOs).
- Mitigates UHI by removing rooftop discharge sources.
- Longer system life (30–35 years vs. 15–20 years for BAU).

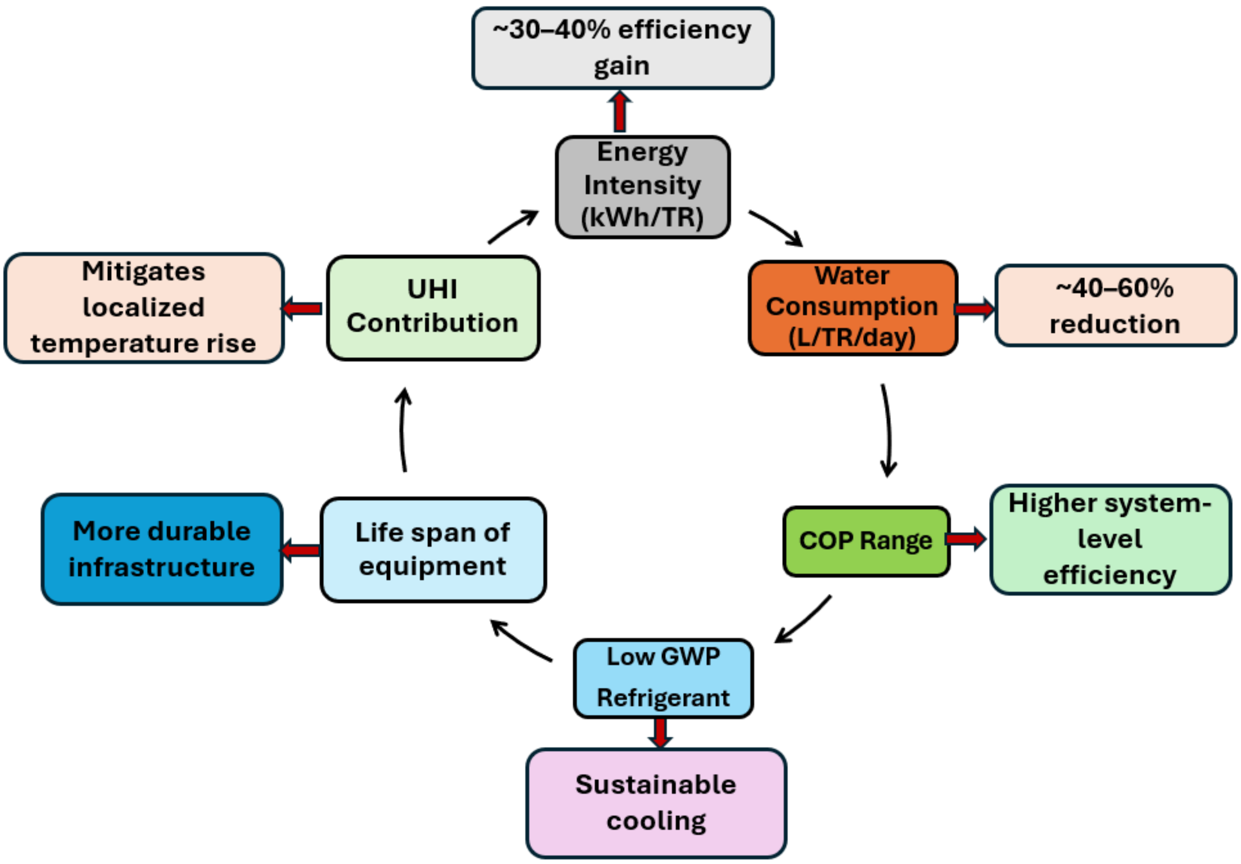


Fig. 4.3, Comparison of BAU Cooling and DCS scenarios

Table 4.2, Technical Benefits Comparison – BAU versus DCS

Parameter	BAU Cooling	DCS Cooling	Improvement
Energy Intensity (kWh/TR)	1.6–1.8	1.0–1.2	~30–40% efficiency gain
Water Consumption (L/TR/day)	3.0–4.0	1.5–2.2 (with reuse)	~40–60% reduction
COP Range	2.5–3.2	5.0–6.5	Higher system-level efficiency
Refrigerant GWP	High (1500–2000)	Low (<10 for HFO/Natural)	Supports Kigali Amendment targets
UHI Contribution	Significant (rooftop)	Minimal (central tower)	Mitigates localized temperature rise
Lifespan of Equipment	15–20 years	30–35 years	More durable infrastructure

a) Energy Consumption

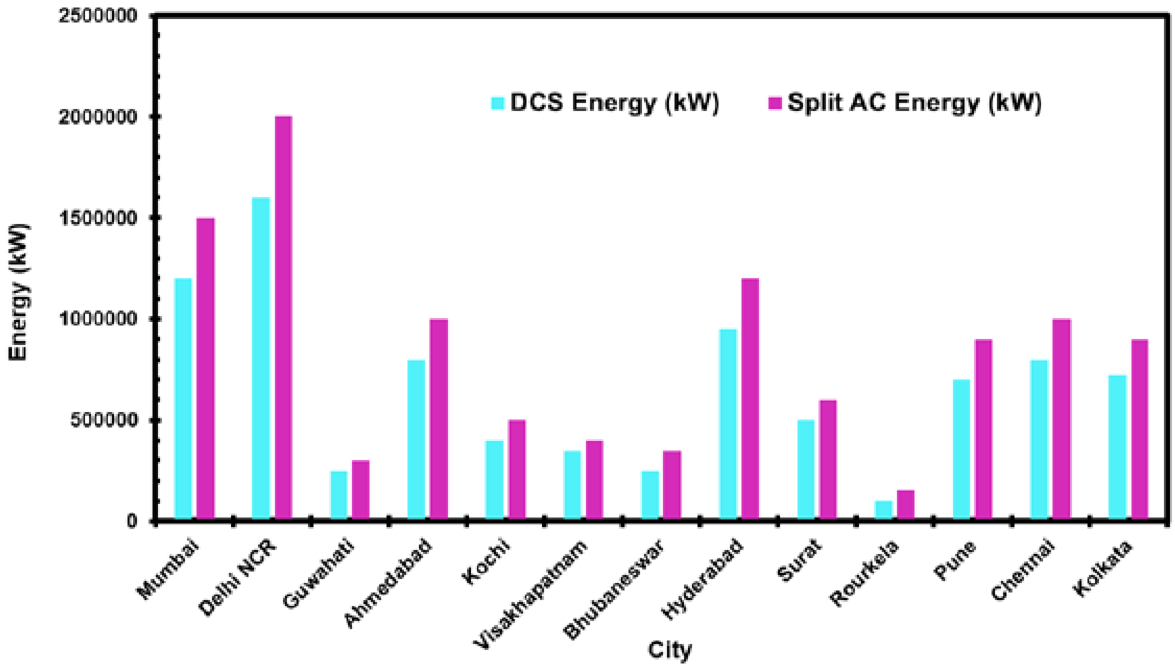


Fig. 4.4, Annual Energy Consumption across Cities (Cooling-related Load)

The bar chart compares the total annual cooling-related energy consumption (in kW) across major Indian cities for two systems: conventional Split Air Conditioning (Split AC) and District Cooling Systems (DCS) (Fig. 4.4). Overall, District Cooling Systems achieve greater energy savings by employing centralized chillers that operate at higher efficiencies than multiple individual split AC units.

Through optimized load sharing across buildings, they minimize oversizing and reduce overall energy consumption. Delhi NCR tops the chart with Split AC energy consumption at 2 million kW and DCS at approximately 1.6 million kW, highlighting the sheer scale of cooling demand driven by its large Gross Floor Area and high population density. Hyderabad, Mumbai, and Chennai follow as major energy consumers under both technologies. Cities like Rourkela, Guwahati, and Bhubaneswar show relatively lower energy consumption due to their smaller built environments and cooling demands.

For each city, the annual energy consumption for both systems is calculated using the formula:

$$\textit{Annual Energy Consumption } (kWh) = \frac{(\textit{Cooling Load } (TR) \times 3.517 \times \textit{Operating Hours})}{COP} \quad (4.1)$$

The energy consumption estimation is based on a standardized formula that enables fair comparison between Split ACs and District Cooling Systems (DCS) across different cities. In this method, the total cooling requirement, expressed in Tons of Refrigeration (TR), is first converted into kilowatts using a standard factor of 3.517. This conversion allows for direct calculation of electricity consumption. The annual energy usage is then obtained by multiplying the converted cooling load with the number of operating hours per year, typically ranging between 2,000 and 2,500 hours depending on the local climate conditions. To account for system efficiency, the resulting value is divided by the Coefficient of Performance (COP), which reflects how effectively the cooling system converts electrical energy into cooling output. For this analysis, a COP of 3.5 is assumed for Split ACs and 5.0 for DCS, aligning with their respective typical operational efficiencies. This formula ensures a consistent and realistic basis for comparing the energy demands of both technologies across various urban regions.

b) Cooling-Related Cost

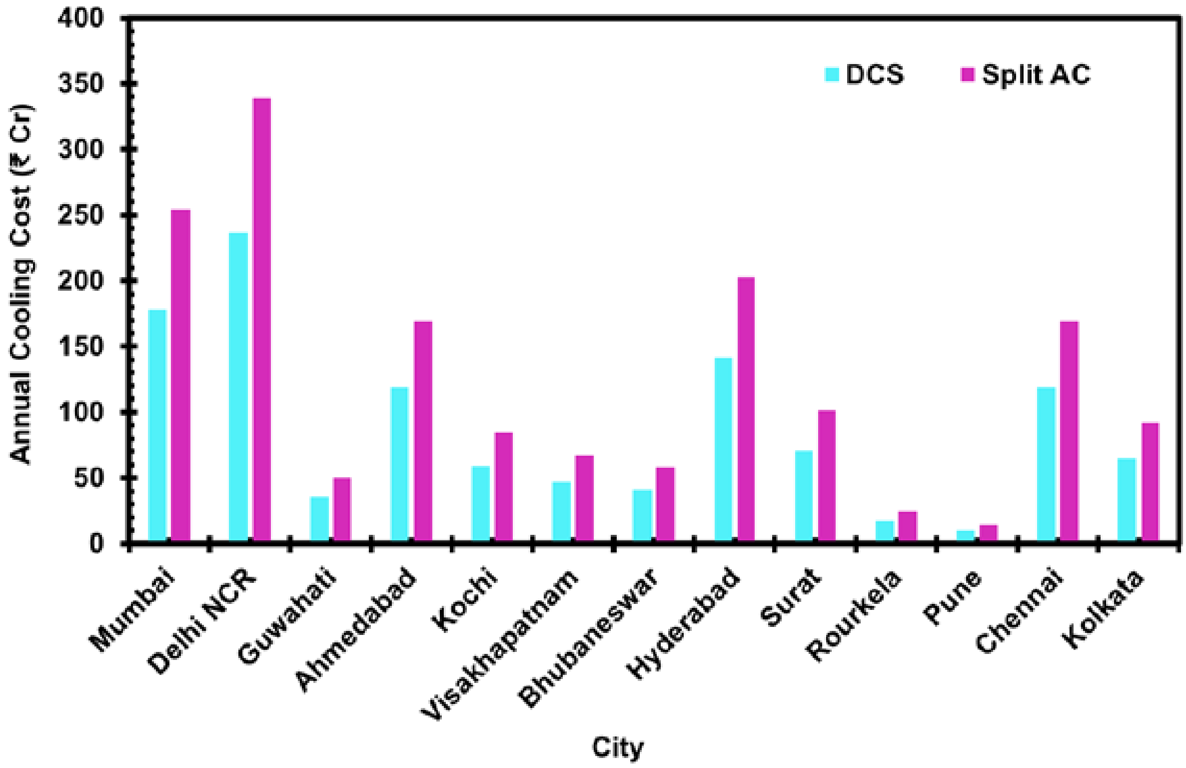


Fig. 4.5, Indicative Cooling Cost Comparison across Cities

The comparative analysis of annual cooling costs between District Cooling Systems (DCS) and conventional Split AC systems reveals significant cost-saving potential for cities adopting centralized cooling infrastructure for the year 2024 (Fig. 4.5). Across all evaluated cities, DCS demonstrates lower operational expenditure, underscoring its economic advantage over decentralized systems. Delhi NCR, for instance, shows the most dramatic differential, with Split AC systems incurring costs well above ₹350 Cr annually, compared to substantially lower values under DCS operation. Hyderabad, Guwahati, and Ahmedabad also exhibit considerable gaps, where DCS offers a more cost-efficient alternative despite high baseline cooling demand.

Mumbai, Visakhapatnam, Kochi, and Kolkata display moderate but consistent cost advantages in favor of DCS, reflecting the combined impact of higher energy efficiency and load diversity optimization. In cities like Surat, Rourkela, Pune, and Chennai, although the overall cooling load is lower, the savings trend remains positive, further validating the scalability of DCS even in Tier-2 contexts. Notably, Bhubaneswar presents a balanced case where DCS delivers competitive annual savings without compromising performance.

These findings reinforce the operational viability of DCS across varying urban profiles. Beyond capital investment considerations, the recurring cost advantage makes DCS a compelling solution for long-term urban cooling, particularly when integrated with smart city frameworks, green building norms, and renewable energy sources. Sample calculations supporting these trends have been provided in Annexure II, detailing the methodology used for estimating city-specific annual cooling costs under both DCS and BAU scenarios. This evidence supports prioritizing DCS in policy interventions and infrastructure planning for sustainable, low-cost urban climate control.

iv. Refrigerant Transitions in DCS

One of the core environmental advantages of DCS is its ability to support a safe and scalable transition to low-GWP refrigerants. Centralized chiller plants can accommodate refrigerants like R-717 (Ammonia), R-290 (Propane), and HFO blends like R-1233zd(E), which offer GWP values under 10. These refrigerants are either mildly flammable or toxic, making them unsuitable for decentralized systems but manageable in centralized, controlled environments. Scroll and modular systems can adopt R-32 or R-1234yf as interim solutions. Absorption chillers, which require no refrigerants, provide additional climate advantages and are particularly relevant for industrial clusters where waste heat is available. Table 4.4 and Fig. 4.6 presents the refrigerant transitions for centralized DCS plants. The important points observed for refrigerant transitions in DCS are as follows:

- Centralized plants can safely use R-717, R-290, HFOs with GWP < 10.
- BAU systems use R-22, R-410a (GWP 1800+), due for phase-out.
- Absorption chillers (LiBr-H_2O) offer refrigerant-free cooling using waste heat.
- Refrigerant Transition aligned with Kigali Amendment.
- Central O&M model ensures better refrigerant containment and lifecycle management.

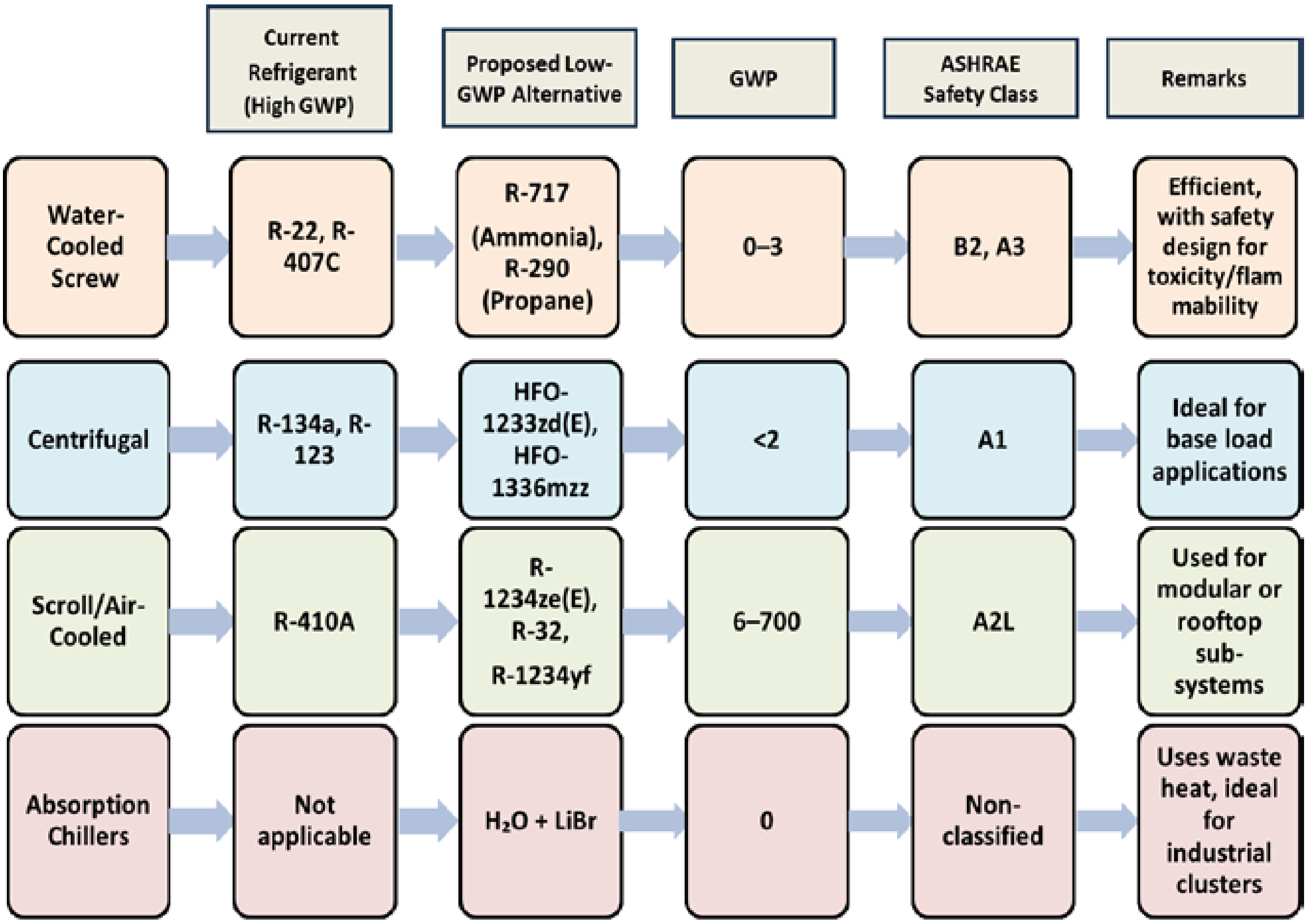


Fig. 4.6, Refrigerant Transitions for DCS

v. Cluster-Level Technical Feasibility Summary

The study assessed city-specific technical feasibility, factoring in climate, infrastructure, water resources, and load characteristics. Mumbai and Kochi show high feasibility for seawater-based DCS due to coastal geography and municipal support for marine discharges. Delhi NCR and Ahmedabad require modular and phased implementation due to brownfield constraints and underground utility limitations. Bengaluru offers high synergy with trigeneration due to its IT and industrial base. Each city was scored based on physical feasibility, utility engagement, water access, and integration readiness. Table 4.3 depicts the technical feasibility summary all the 13 cities considered.

Table 4.3, Technical Feasibility Summary – City Level

City	System Type	Cooling Source	Key Innovations	Technical Feasibility Score
Mumbai	Seawater + TES	Seawater + centrifugal chillers	Marine discharge licensing, deep seawater intake	★★★★★
Delhi NCR	Modular hybrid DCS	Grid + solar	Underground corridor retrofitting, brownfield layering	★★★★☆
Bengaluru	Trigeneration	Biogas + solar	SEZ-integrated microgrids, solar-assisted absorption	★★★★☆
Ahmedabad	Industrial reuse	STP + grid power	GIDC industrial tie-in, reclaimed water	★★★★☆
Chennai	Seawater + hybrid	Seawater + absorption chillers	Coastal air + seawater hybrid rejection system	★★★★☆
Kochi	Deep water cooling	Seawater + industrial waste heat	Floating chillers, marine synergy	★★★★★
Visakhapatnam	Industrial DCS	Waste heat + centrifugal chillers	Petrochemical/port zone integration	★★★★☆
Hyderabad	TES + Rooftop DCS	Grid electricity + ice TES	Rooftop ice storage for brownfield cooling	★★★☆☆
Bhubaneswar	Modular DCS	Grid + STP	Smart city pipeline corridors, plug-and-play ETS	★★★☆☆
Rourkela	Smart DCS retrofit	Grid + industrial waste heat	Integration with steel plant residual energy	★★★☆☆
Surat	STP-based TES	Treated sewage effluent	Circular economy model, microgrid alignment	★★★☆☆
Pune	TES + Solar Hybrid	Solar + absorption chillers	Decentralized TES with rooftop PV	★★★★☆
Kolkata	Seawater + hybrid	Seawater + absorption chillers	Coastal air + seawater hybrid rejection system	★★★★☆
Guwahati	Modular DCS + Solar TES	Grid + rooftop solar + Brahmaputra water	River-based indirect cooling potential, rooftop solar-assisted TES, smart zone retrofitting	★★★☆☆

4.2 Integrated District Cooling and Thermal Energy Recovery System

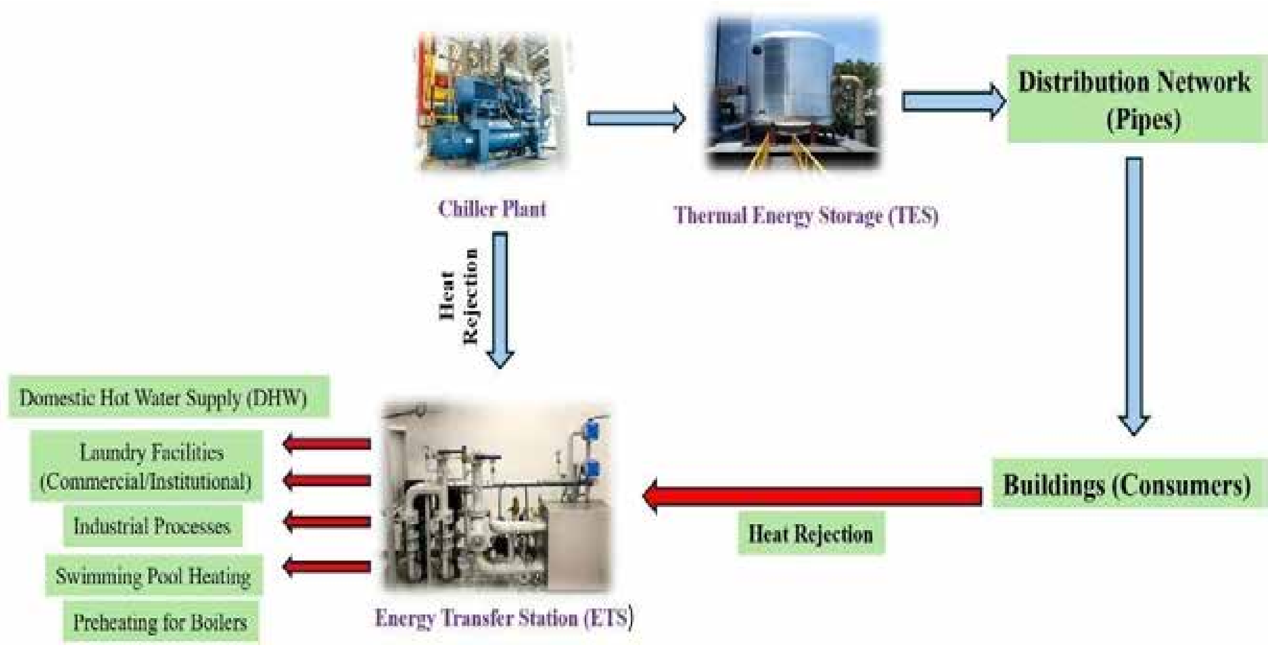


Fig. 4.7, Integrated district cooling system with TES and ETS for cooling and heat recovery

Fig. 4.7 illustrates a comprehensive schematic of a District Cooling System integrated with a Thermal Energy Storage (TES) unit and an Energy Transfer Station (ETS). At the heart of the system lies the Chiller Plant, which generates chilled water for cooling purposes. This chilled water is stored in the TES unit, enabling load shifting and peak demand management. The stored chilled water is then circulated through a Distribution Network (pipes) and supplied to various Buildings (Consumers), ensuring reliable cooling. Simultaneously, heat rejected from the chiller plant is redirected to the ETS, where it is efficiently utilized for multiple secondary applications such as Domestic Hot Water Supply (DHW), Laundry Facilities, Industrial Processes, Swimming Pool Heating, and Boiler Preheating. This dual-purpose system maximizes energy efficiency by repurposing waste heat and supporting both cooling and heating needs, embodying the principles of integrated thermal energy management and sustainable urban infrastructure.

i. Integrated Thermal Strategies for Sustainable District Cooling Systems

This section presents two complementary frameworks designed to enhance the operational efficiency and sustainability of district cooling networks. Fig. 4.8 depicts the schematic layout of a Mobile Thermal Energy Storage (MTES) system that facilitates thermal energy transport from a high-temperature source, such as the Rourkela Steel Plant, to a distant academic building. The system is composed of critical subcomponents, including a central desorption unit powered by waste steam, a mobile transport loop for strong and weak solution circulation, and on-site absorption and evaporation modules for chilled water generation. A detailed thermal model has been developed to evaluate the technical feasibility and thermal behavior of this setup, confirming its suitability for decentralized cooling in campuses or industrial clusters.

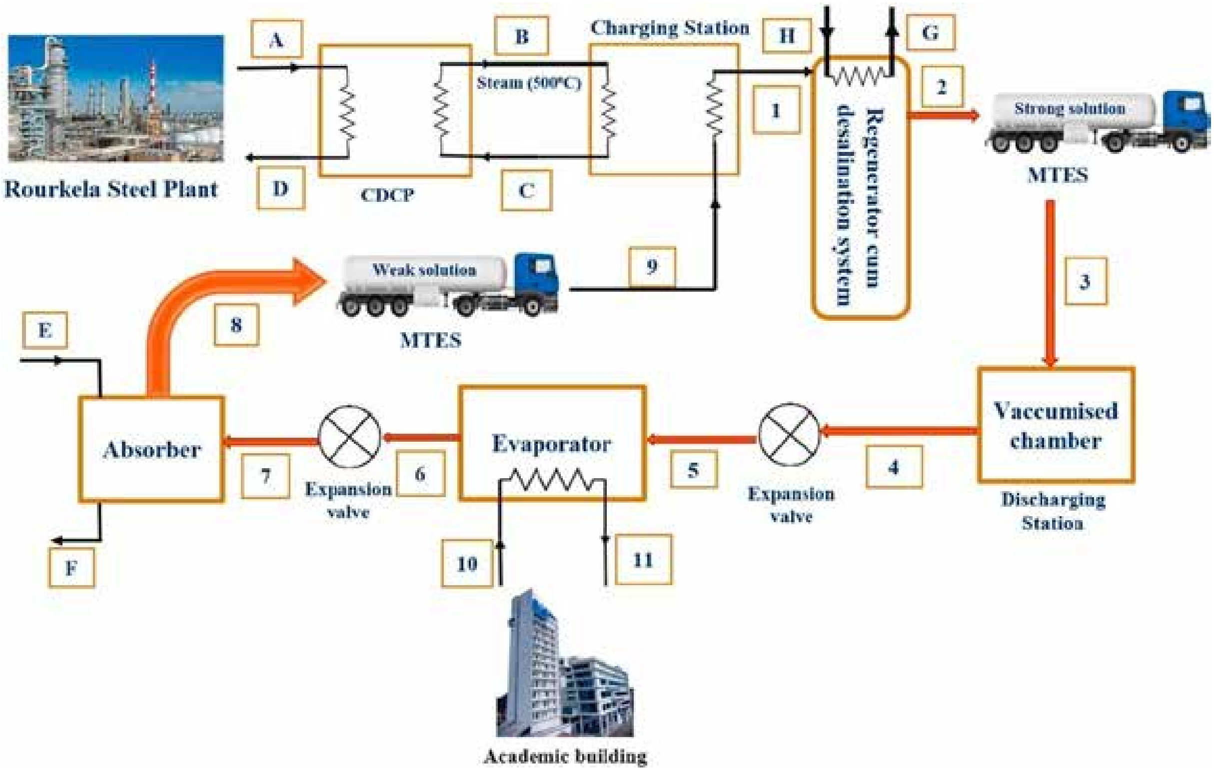


Fig. 4.8, Thermal model of MTES system [16]

Figs. 4.9 illustrates a set of integrated energy-saving strategies applied to a district cooling system. These include the use of solar panels to supply compressor power, night/weekend operations to leverage off-peak conditions, water conservation through efficient cooling towers, and seasonal thermal storage using low-temperature phase change materials (PCM). Through rigorous feasibility assessments and mathematical modelling, the study shows how these components can collectively improve system-level sustainability, reduce energy consumption, and lower the environmental footprint of urban cooling infrastructure.

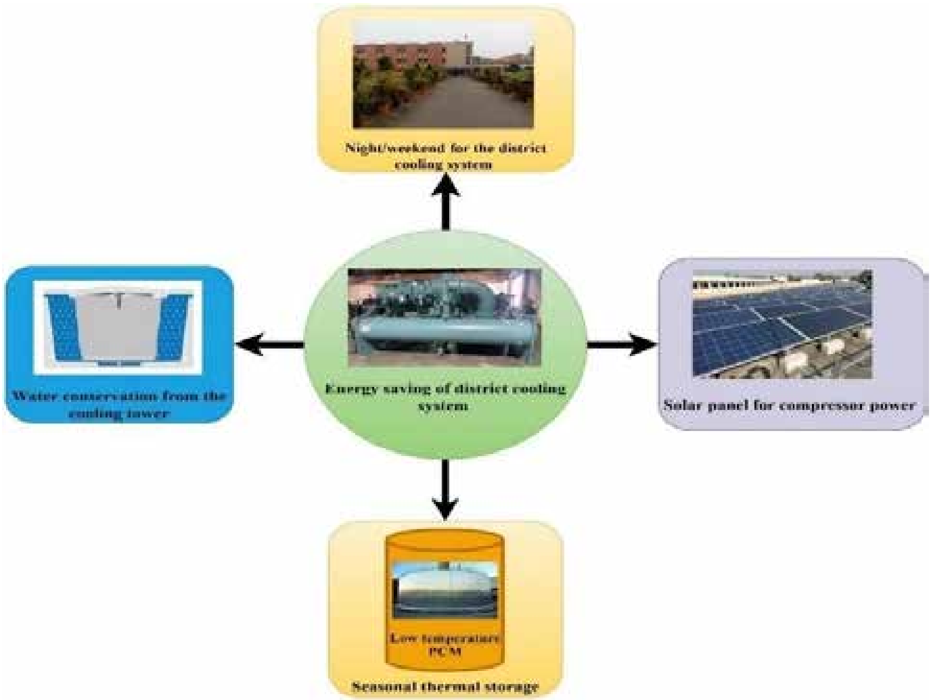


Fig. 4.9, Energy saving scenario of district cooling system [17]

4.3 Cost-Benefit Analysis

The lifecycle cost analysis for District Cooling Systems (DCS) follows a structured approach, covering all phases from capital investment to long-term operation and decommissioning. It begins with capital expenditure, which includes the full range of upfront costs necessary to plan and implement the system. These costs typically account for preliminary investigations, feasibility studies, detailed engineering, procurement of equipment such as chillers, pumps, and pipelines, as well as construction of the distribution network. In cities, this may also include land acquisition and site development, elements that often make the initial investment substantial [18].

Operating costs form the second key component. These are the recurring annual expenses incurred throughout the system's service life, which for DCS is considered to be 35 years. This includes electricity use, water treatment, staffing, maintenance, and system upkeep. Costs associated with mid-life component replacements, such as pumps and control systems, are also included, typically occurring every 10 to 15 years. End-of-life costs are accounted for as well, covering infrastructure dismantling and site restoration, usually estimated at 5 to 10 percent of the original capital cost. The model also factors in the benefits of DCS. These systems are designed for efficiency. Centralized control and thermal load diversity contribute to reduced electricity use, smoother load profiles, and lower peak demand. When compared to conventional decentralized cooling systems, these operational advantages can lead to substantial savings over time. Environmental benefits, including reduced refrigerant leakage and lower greenhouse gas emissions, are recognized as well. In this analysis, such environmental gains are monetized using standard carbon pricing benchmarks [19]. A key refinement in the cost analysis approach is ensuring a fair basis of comparison between district cooling and conventional systems. Most Business-As-Usual (BAU) setups are designed to last around 20 years, while district cooling systems are built for a longer operational life, typically spanning 35 years. To make the evaluation meaningful, the model assumes that BAU systems would be replaced once during the same period. This adjustment helps level the playing field and reflects how these systems would perform over a full project horizon. With this correction in place, the results clearly show that district cooling offers a strong economic advantage. In many cases, the savings extend beyond 50 percent when compared across the full lifecycle. These financial benefits are also accompanied by reductions in electricity use and carbon emissions, strengthening the case for DCS as a more sustainable and cost-effective solution over the long term.

To bring future costs and savings into present terms, the model uses discounted cash flow analysis, applying a discount rate of 6 percent. For comparative purposes, it also calculates the Levelized cost of cooling (LCOC), which expresses the total cost per ton-hour of cooling delivered. This allows different cooling technologies and system sizes to be compared on a common basis. Taken together, this lifecycle cost model provides a clear picture of both the investment requirements and the long-term benefits of DCS. By capturing all relevant costs and aligning them with operational and environmental outcomes, the framework supports more informed decision-making for infrastructure planning and sustainable urban development. Table 4.6 summarizes the main elements included in the cost modelling process for District Cooling Systems.

Table 4.4, Lifecycle Cost Components Summary

Component	Description
Capital Expenditure (CAPEX)	One-time investment covering infrastructure, equipment, civil works, and installation.
Operational Expenditure (OPEX)	Annual costs for energy consumption, water treatment, labor, and routine maintenance.
Replacement Costs	Mid-life replacement of mechanical components such as pumps, control units, and valves.
Decommissioning	End-of-life dismantling, material disposal, and site restoration at project closure.
Energy Savings	Reduction in electricity usage compared to conventional systems, based on TR and kWh/TR-hour benchmarks.
Emission Savings	Avoided CO_2 emissions monetized using applicable carbon pricing, if included.
Discount Rate	Used for calculating Net Present Value (NPV) and Levelized Cost of Cooling (LCOC); typically 6%.
System Lifetime	Assumed to be 35 years for DCS; BAU systems evaluated with two 20 years cycles for parity.
Total Cooling Delivered	Aggregate ton-hours of cooling used to compute LCOC and compare technology options.

i. Step-by-Step procedure used to perform the Lifecycle Cost Modeling and Levelized Cost of Cooling (LCOC) analysis for each city for DCS and BAU

To evaluate the viability of District Cooling Systems (DCS) in comparison to conventional cooling systems (BAU – Business as Usual) across selected Indian cities, a detailed lifecycle cost and Levelized Cost of Cooling (LCOC) assessment was carried out. The analysis was structured to account for both upfront capital investment and long-term operational, environmental, and replacement considerations over a full project lifecycle. For consistency, DCS installations were evaluated over a 35-year operational period, whereas BAU systems were modeled as two successive 20-year cycles to reflect real-world reinvestment requirements. A standardized cooling capacity of 100,000 TR operating for 2,500 hours annually was adopted, resulting in a total delivered cooling output of approximately 8.75 billion TR-hours over the DCS system's lifespan. A discount rate of 6% was applied to derive Net Present Values (NPV) for annualized expenditures. City-specific system performance parameters and state electricity tariffs were incorporated, with DCS COPs ranging from 4.2 to 4.6, and a baseline COP of 2.8 assumed for BAU. Electricity tariffs ranged between ₹6.0 and ₹7.1 per kWh, as per prevailing DISCOM rates. The assessment for each city covered the following components:

- **CAPEX:** Initial capital investment for infrastructure, equipment, installation, and civil works, derived from comparable Indian DCS deployments and scaled to account for local land and utility conditions.
  The capital costs (CAPEX) for all the cities are based on a standardized 100,000 TR capacity of DCS. The CAPEX has been assigned as per the verified cost data from existing District Cooling projects in India and then adjusted to account for local factors like land prices and construction complexity. The core equipment and technology for a standard-sized plant have a similar cost in any city. This is why the CAPEX for a project in a megacity like Delhi can appear comparable to

that of a smaller city like Rourkela.

- **OPEX**: Annual operational and maintenance costs including electricity, water treatment, staffing, and routine servicing, typically estimated at **4%–6% of CAPEX**.
- **Energy Costs**: Based on effective COPs and local tariffs, calculated from the total TR-hour demand.
- **Replacement Costs**: Modeled for BAU systems at mid-life (after 20 years), while DCS systems accounted only for essential mechanical refurbishments.
- **Emission Savings**: Quantified in terms of avoided CO_2 emissions from improved energy efficiency, and monetized using a **carbon price of ₹2,500 per ton**.
- **LCOC**: Computed as the total discounted lifecycle cost divided by cumulative cooling output, enabling fair and transparent comparison across technologies and locations.

This methodology offers a structured and transparent basis for comparing long-term cooling strategies in urban India, balancing financial performance with energy efficiency and carbon savings.

Table 4.5, Key Assumptions and Data Inputs for Lifecycle Cost Modeling and LCOC Analysis

Parameter	Assumption	Data Source / Justification
Project Lifetime	35 years for DCS; 2 × 20 years for BAU	DCS typically operate for 30–40 years with periodic retrofits, as reported by the International District Energy Association (IDEA) and global case studies (e.g., Tabreed, Copenhagen, Toronto). BAU generally last 15–20 years (ASHRAE standards, CPWD lifecycle norms). For comparability, BAU is evaluated over one full 20-year cycle and a partial 15-year cycle to align with the 35-year DCS horizon.
Discount Rate	6% (NPV factor ≈ 14.21 for 35 years)	Industry standard recommended by CEA, and commonly used for public infrastructure evaluation
Installed Capacity	100,000 TR per city	Assumed as Uniform baseline capacity for national comparability across climate zones and urban typologies
Annual Operating Hours	2,500 hrs/year	Typical utilization for large commercial/urban cooling systems
Total Cooling Output	8.75 × 10□ TR-hr (for 35 years)	Derived from capacity × hours × 35 years; consistent with LCOC calculation
CAPEX	₹1,200 – ₹1,800 Cr (city-specific)	Based on existing DCS pilots, CPWD/BIS cost indices, and land/infrastructure
OPEX	₹45 – ₹75 Cr/year	Based on equipment type, operational complexity, and local labour rates
Energy Cost	₹25 – ₹45 Cr/year	Calculated using cooling COP and city-specific electricity tariffs
Emission Factor	0.7 kg CO_2/kWh	As per Central Electricity Authority (CEA) and MoEF&CC guidelines
Carbon Price	₹2,500/ton CO_2	In line with global shadow pricing models and domestic carbon trading frameworks
Cooling Technology	Centralized DCS vs. Decentralized (BAU)	Differentiated by networked chilled water loops vs. standalone building-level chillers
Cost Escalation	Not included	All costs modelled in constant INR; conservative real-cost approach without inflationary effects

To evaluate the long-term viability of District Cooling Systems (DCS) in comparison with conventional Business-As-Usual (BAU) cooling methods across Indian cities, the net present value (NPV) of recurring operational costs was calculated over a 35-year analysis period. These recurring costs, comprising both OPEX and energy consumption, were discounted using a 6% rate and combined with initial capital expenditure (CAPEX) to determine the total lifecycle cost for each DCS installation. This total lifecycle cost was then divided by the cumulative cooling output estimated at 8.75 billion TR-hours over 35 years based on a standardized system capacity of 100,000 TR operating 2,500 hours annually to compute the Levelized Cost of Cooling (LCOC). The LCOC provided a uniform basis for comparing DCS systems across cities and against decentralized BAU alternatives, which included split systems, VRFs, and chiller units. For BAU systems, the analysis accounted for two full operational cycles of 20 years each, including full reinvestment after year twenty, to maintain parity with the 35-year DCS horizon. In addition to economic evaluation, environmental impacts were quantified. CO_2 emission reductions resulting from improved system efficiency were calculated using a grid emission factor of 0.7 kg CO_2 per kWh. These avoided emissions were monetized at ₹2,500 per ton of CO_2, reflecting prevailing carbon credit benchmarks. The resulting value was deducted from the total lifecycle cost to arrive at an adjusted lifecycle cost that internalized both financial and environmental benefits. All assumptions were customized to reflect city-specific parameters. CAPEX figures were adjusted for urban development maturity, infrastructure readiness, land values, and climatic conditions (e.g., hot-dry, composite, coastal zones). OPEX values varied based on regional factors, with coastal cities such as Kochi and Chennai incurring higher annual costs due to increased requirements for corrosion protection, water treatment, and preventive maintenance. Electricity tariffs and local cooling demand profiles further influenced annual energy expenditure. This methodology integrated discounted financial modeling with technical system performance and environmental valuation. It offers practical guidance for agencies considering the deployment of centralized cooling infrastructure. Findings from this analysis are intended to support informed decision-making by policymakers, urban planners, infrastructure developers, and financial institutions involved in sustainable urban development. The complete stepwise calculation methodology is illustrated in Figure 4.10, with full datasets and comparative results presented in Annexure–III.

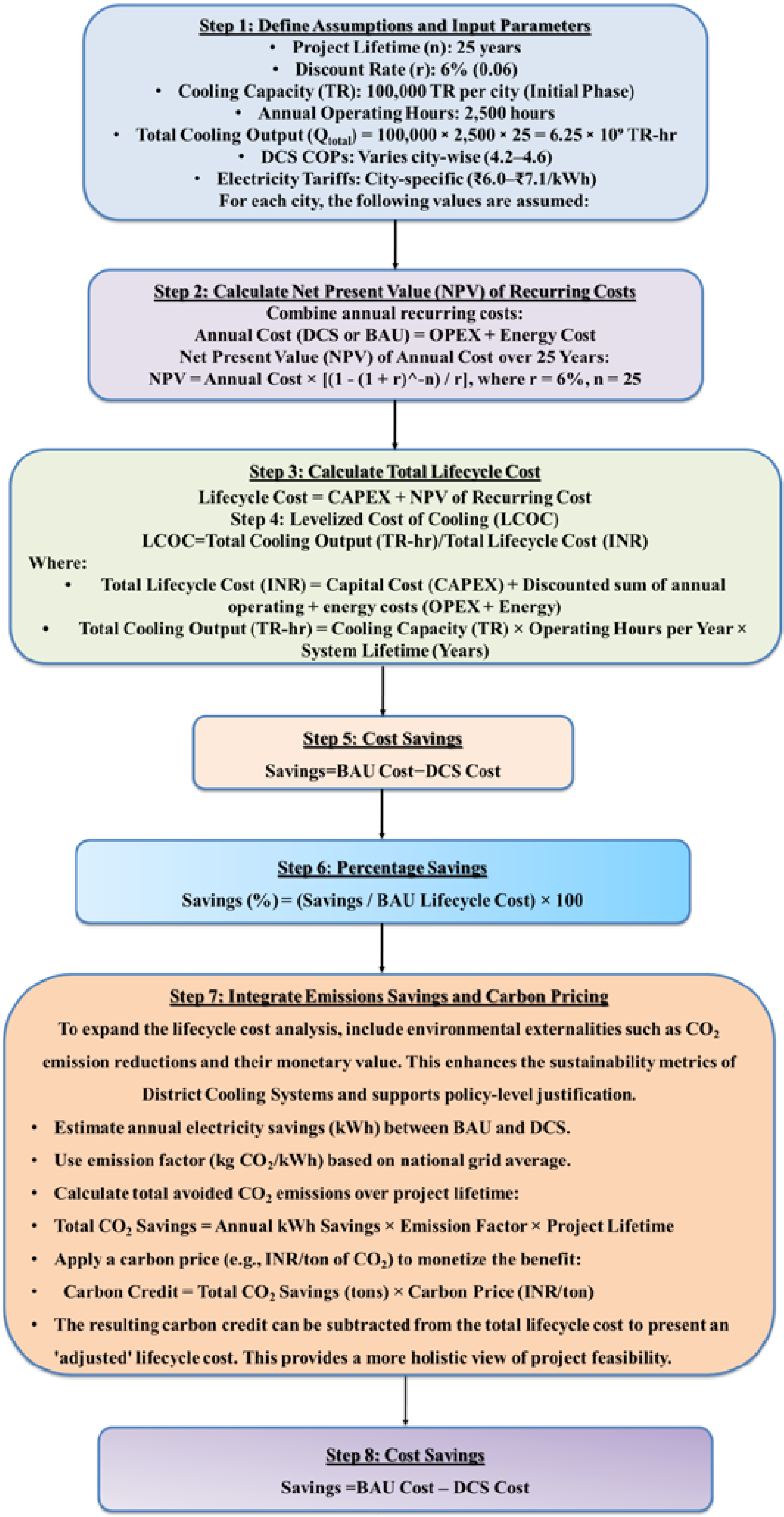


Fig. 4.10, LCC flow diagram for DCS analysis

ii. Step-by-Step Procedure for Each City

Sources and rationale implemented for assuming the CAPEX, OPEX, and Energy Costs are as follows,

i. CAPEX - Initial Infrastructure Cost (₹ Cr)

- Existing/planned DCS projects in India and Southeast Asia (~₹1.2–1.6 lakh per TR).
- Scaled to 100,000 TR capacity: Typical CAPEX=Unit Cost per TR×100,000
- Adjusted for:

a) Land value (higher in metros like Mumbai/Delhi)
b) Civil + utility work complexity
c) Source cooling water availability (lower for desert cities → higher cost)
d) Grid connectivity

ii. OPEX – Annual Operations & Maintenance Cost (₹ Cr/year)

- Based on norms: **4%–6% of CAPEX per year**
- Included:

✓ Manpower
✓ Equipment maintenance
✓ Utility charges excluding power
✓ Administration & SLAs

- Adjusted by:

❖ Local labor cost
❖ Maintenance intensity due to humidity or corrosiveness (e.g., Kochi is higher)

iii. Energy Cost – Annual Electricity Consumption (₹ Cr/year)

- Estimated from total cooling load and **Coefficient of Performance (COP)**: Total Energy (kWh) = (Cooling Load (TR) X Operating Hours)/COP
- Applied average **commercial tariff** (₹6.5–7.5/kWh)

Adjusted for:

➢ Regional electricity tariffs
➢ Seasonal variation and part-load operations
➢ DCS COP assumed = 4.5 (efficient)
➢ BAU COP = 2.8

Table 4.6, Lifecycle Cost analysis of selected clusters

City	CAPEX (Cr INR)	OPEX (Cr INR/year)	Energy Cost (Cr INR/year)	NPV of Recurring Cost (Cr INR)	Total Lifecycle Cost (Cr INR)	LCOC (INR/TR-hr)	CO_2, Savings (tons)	Carbon Credit (Cr INR)	Adjusted Lifecycle Cost (Cr INR)	Adjusted LCOC (INR/TR-hr)	BAU Lifecycle Cost (Cr INR)	Cost Savings vs BAU (Cr INR)	Percentage Savings vs BAU (%)
Ahmedabad	1300.00	65.00	35.56	1457.94	2757.94	3.15	691468	172.87	2585.07	2.95	4692.45	2107.38	44.91
Mumbai	1500.00	77.50	41.28	1722.10	3222.10	3.68	638497	159.62	3062.48	3.50	5864.39	2801.91	47.78
Delhi NCR	1500.00	77.50	41.28	1722.10	3222.10	3.68	610119	152.53	3069.57	3.51	5685.58	2616.00	46.01
Kolkata	1300.00	67.50	35.80	1497.67	2797.67	3.20	665584	166.40	2631.27	3.01	5130.90	2499.62	48.72
Hyderabad	1450.00	72.50	38.64	1611.34	3061.34	3.50	665584	166.40	2894.94	3.31	5517.63	2622.69	47.53
Kochi	1300.00	66.50	36.00	1486.07	2786.07	3.18	688000	172.00	2614.07	2.99	4692.45	2078.38	44.29
Visakhapatnam	1300.00	67.50	36.11	1502.16	2802.16	3.20	691468	172.87	2629.29	3.00	4734.82	2105.52	44.47
Chennai	1500.00	75.00	39.50	1660.05	3160.05	3.61	638497	159.62	3000.43	3.43	5417.21	2416.78	44.61
Bhubaneswar	1300.00	65.00	35.80	1461.42	2761.42	3.16	665584	166.40	2595.02	2.97	5130.90	2535.87	49.42
Rourkela	1300.00	62.50	33.50	1391.83	2691.83	3.08	691468	172.87	2518.96	2.88	4935.79	2416.83	48.97
Surat	1400.00	70.00	36.60	1545.51	2945.51	3.37	691468	172.87	2772.64	3.17	5146.54	2373.90	46.13
Pune	1450.00	72.50	39.20	1619.45	3069.45	3.51	665584	166.40	2903.05	3.32	5537.60	2634.54	47.58
Guwahati	1500.00	75.00	34.88	1593.07	3093.07	3.53	638497	159.62	2933.45	3.35	5501.25	2567.80	46.68

iii. Economic Feasibility Analysis

The comparative analysis of lifecycle cost savings from District Cooling Systems (DCS) across thirteen Indian cities reveals notable absolute gains, with Mumbai emerging as the highest contributor, achieving savings nearing ₹2800 Cr. This is followed closely by Pune, Guwahati, Hyderabad, and Delhi NCR, each registering savings in the range of ₹2700–2750 Cr, driven by high cooling demand densities and significant performance differentials between DCS and conventional Business-As-Usual (BAU) scenarios. Mid-tier cities such as Kolkata, Chennai, Bhubaneswar, Rourkela, and Surat fall within the next band (₹2600–2700 Cr), reflecting favorable DCS economics even in non-metro or coastal urban regions with moderate thermal loads. On the lower end, Ahmedabad, Kochi, and Visakhapatnam record comparatively lower cost reductions (~₹2300–2400 Cr), indicating either lesser demand aggregation, lower tariff differential, or relatively competitive performance from BAU systems. These absolute cost trends underscore the importance of contextual parameters such as energy prices, system efficiency (COP), and operational runtime in influencing DCS viability (Fig. 4.11). Although all cities show a positive economic outlook for DCS deployment, the scale of returns suggests that cities like Mumbai, Pune, and Hyderabad present high-priority zones for investment. Meanwhile, cities with smaller margins may still benefit substantially if supported through enabling mechanisms such as concessional tariffs, green financing, or carbon credit integration to bridge the economic gap with BAU alternatives.

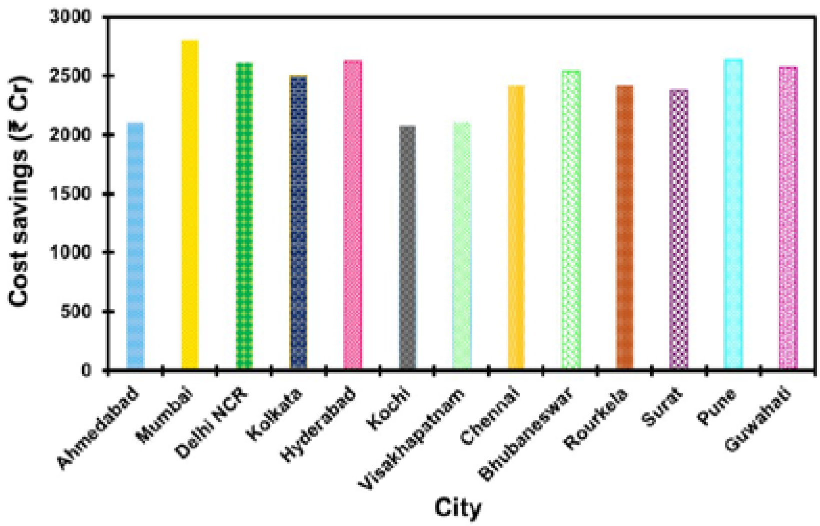


Fig. 4.11, Lifecycle Cost Savings Comparison across Cities

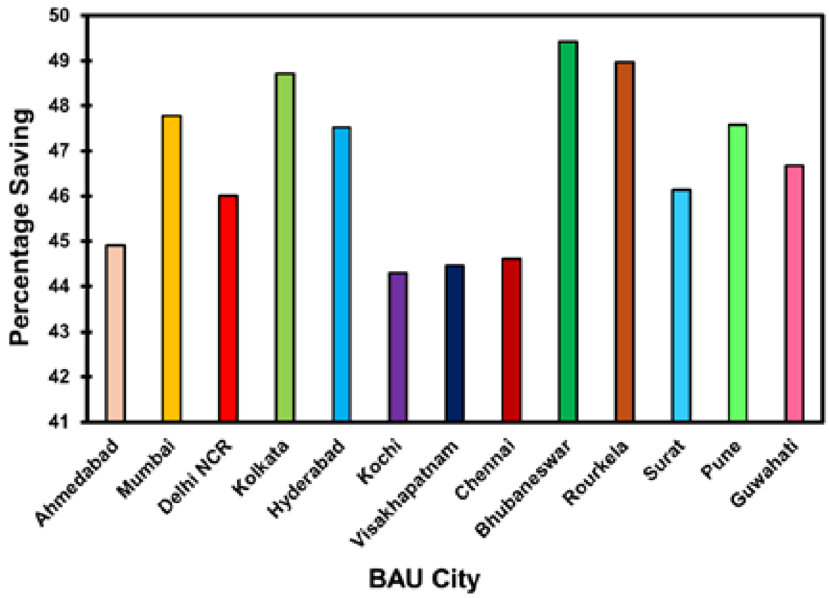
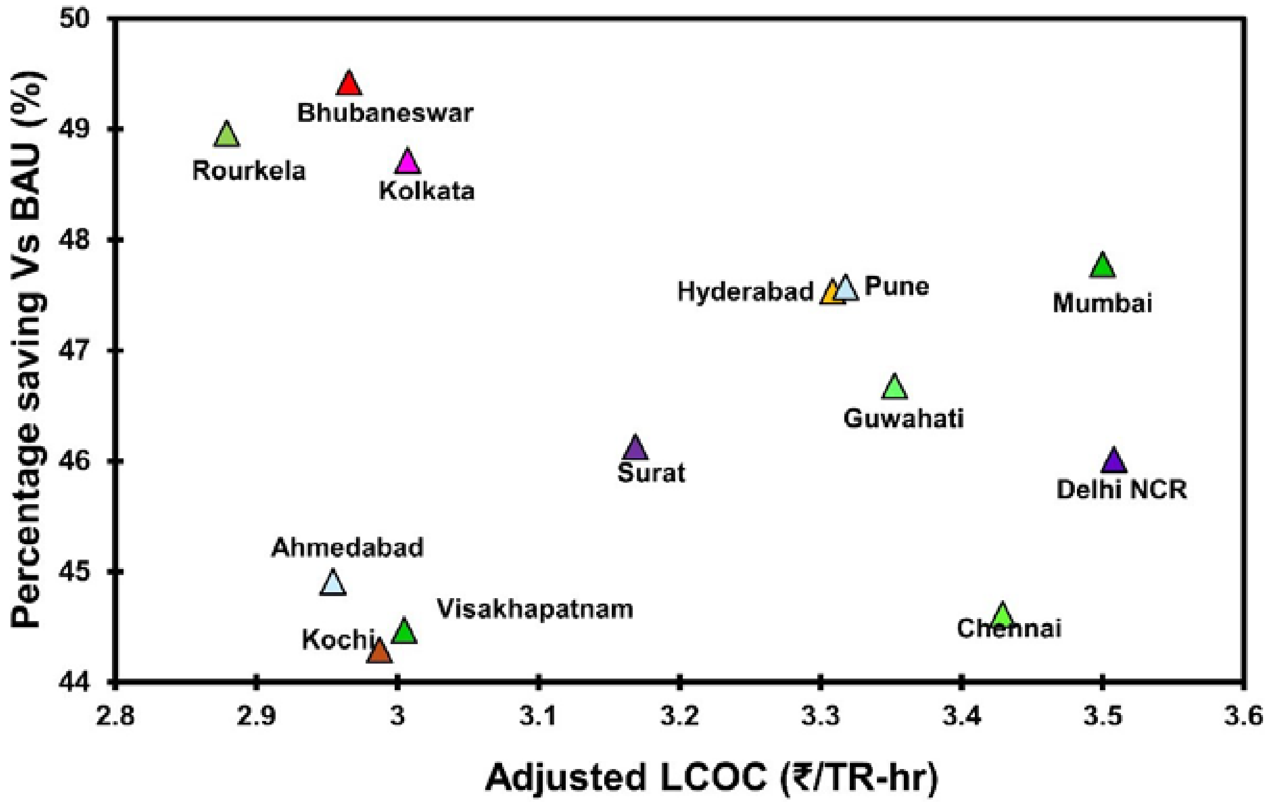


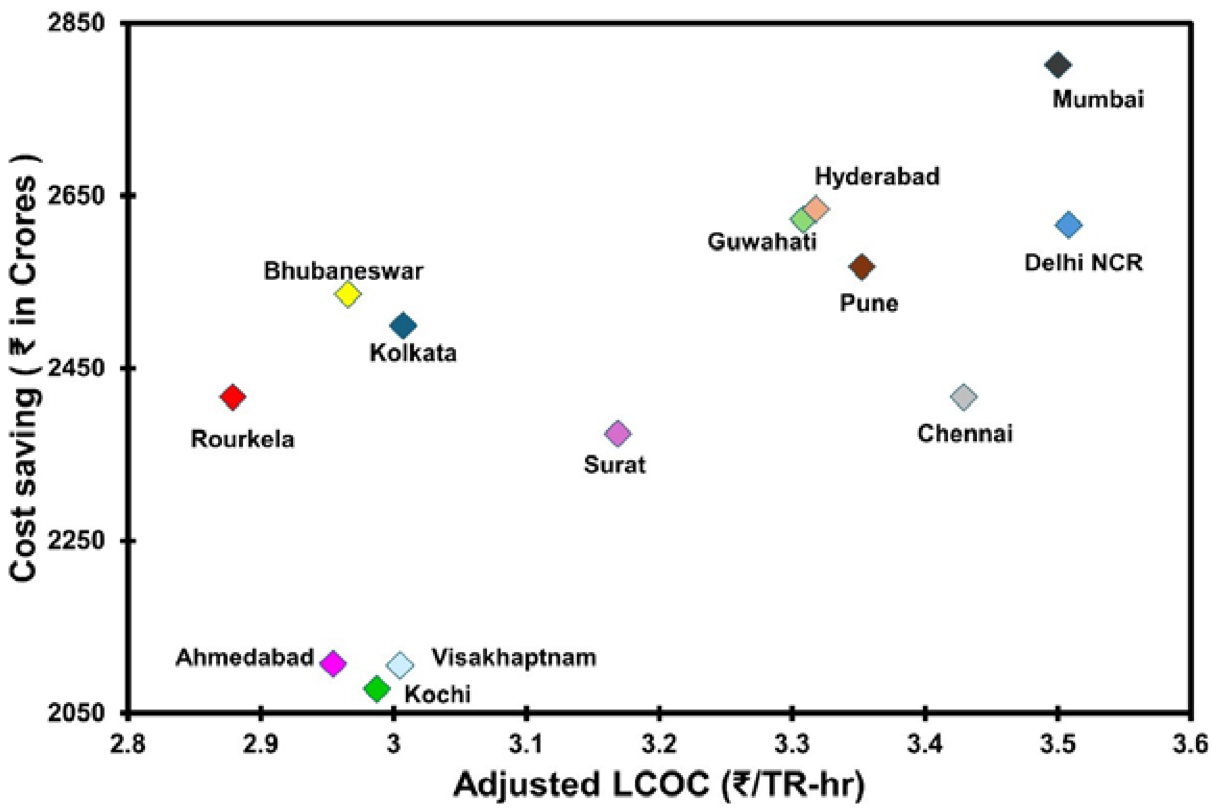
Fig. 4.12, Percentage Lifecycle Cost Savings over BAU

The percentage savings analysis reinforces the strong case for District Cooling Systems (DCS) across all evaluated cities, showcasing consistent advantages over conventional Business-As-Usual (BAU) systems (Fig. 4.12). Cities such as Rourkela, Bhubaneswar, and Kolkata emerge as frontrunners, achieving percentage savings close to 49–50%, demonstrating the exceptional lifecycle efficiency of DCS in these regions. These results indicate that not only are the absolute cost reductions substantial, but the proportional benefits are also highly compelling making these cities ideal candidates for early adoption and large-scale rollout. Hyderabad, Delhi NCR, and Mumbai also exhibit strong performance, with savings ranging from 47–48%, confirming the economic soundness of DCS even in dense urban environments with high cooling demand. Pune, Guwahati, and Surat fall within a healthy mid-range (46–47%), offering reliable returns and presenting viable models for replication in similar Tier-2 urban centres. While Ahmedabad, Kochi, Visakhapatnam, and Chennai report slightly lower percentage savings (44–45%), the figures still reflect meaningful improvements over existing systems, reinforcing the universal applicability of DCS as a sustainable cooling strategy. Overall, the consistently high percentage savings across diverse climatic and urban profiles reaffirm that DCS offers a scalable and future-ready solution, with particularly attractive opportunities in cities demonstrating both high relative and absolute benefits. Strategic policy support, tariff incentives, and carbon credit integration can further accelerate adoption in cities with moderate differentials, ensuring widespread transition to efficient and climate-aligned cooling infrastructure.

The integrated analysis of adjusted Levelized Cost of Cooling (LCOC) and percentage savings versus BAU cooling solutions reveals clear city-wise distinctions in the feasibility and benefits of adopting District Cooling Systems (DCS) as shown in Fig, 4.13. Bhubaneswar, Rourkela, and Kolkata exhibit the strongest overall performance, achieving high cost savings (exceeding 48%) coupled with the lowest adjusted LCOC values, around ₹2.9–3.0 per TR-hr. These cities demonstrate a favourable economic profile for DCS implementation due to their higher baseline BAU lifecycle costs, which amplify both the percentage and absolute financial gains of switching to centralized cooling infrastructure. Mumbai and Delhi NCR, while showing relatively higher adjusted LCOC values in the range of ₹3.4–3.5 per TR-hr, report substantial cost savings in absolute terms (₹2000–₹2700 Cr), making them highly attractive from an investment and policy standpoint. Pune, Hyderabad, and Guwahati fall within a mid-performing cluster, with LCOC values around ₹3.2–3.3 per TR-hr and consistent percentage savings near 46–47%, indicating viable conditions for DCS rollout under suitable aggregation and financing models. Ahmedabad, Kochi, Visakhapatnam, and Chennai report adjusted LCOC values between ₹3.0–3.4 per TR-hr, accompanied by savings in the range of 44–45% (Fig. 4.13). While the relative benefits in these cities appear more modest, they still present viable opportunities for DCS deployment particularly when integrated with waste-heat recovery or renewable energy systems in mixed-use or institutional developments. Surat, despite a fair LCOC range, registers slightly lower savings percentages, suggesting that demand concentration and cooling load density should be optimized to improve overall viability.



(a) Evaluation of percentage savings with adjusted LCOC



(b) Evaluation of cost savings with adjusted LCOC

Fig. 4.13, Multidimensional evaluation of DCS feasibility for different cities in India

The comparison of capital expenditure (CAPEX) and the Net Present Value (NPV) of recurring costs across cities provides an important perspective on the long-term economic dynamics of District Cooling System (DCS) implementation is depicted in Fig. 4.14. The chart clearly shows that in every city, the NPV of recurring costs exceeds the initial CAPEX, emphasizing that operational efficiency and lifecycle performance are just as critical as upfront investment decisions. Among the metropolitan centres, Mumbai and Delhi NCR stand out with both the highest CAPEX and recurring cost profiles, with recurring costs surpassing ₹1700 crores. This is consistent with their scale of demand and energy intensity, but it also highlights the need for stronger energy optimization strategies and demand aggregation mechanisms to ensure sustainable operations. Similarly, cities like Chennai, Kolkata, and Hyderabad also register substantial recurring costs in the ₹1500–1600 crores range, reflecting the large-scale benefits that can be unlocked through centralized cooling. In contrast, medium-sized cities such as Rourkela, Surat, and Kochi show a more balanced cost structure, with CAPEX and recurring costs at relatively lower levels (Fig. 4.14). This indicates that while the scale of investment is smaller, the overall economic risk is reduced, making them suitable for early-stage or pilot DCS deployments. Bhubaneswar and Visakhapatnam also demonstrate favourable cost ratios, suggesting that investment in DCS can be recovered more effectively when combined with appropriate tariff structures and supportive policies. Therefore, the analysis reinforces that while CAPEX is a critical starting point, the long-term recurring costs dominate the economic feasibility of DCS projects. Policymakers and investors should therefore focus on lifecycle optimization, energy pricing strategies, and integration with carbon-saving mechanisms to maximize the return on investment across both large metropolitan areas and emerging urban clusters.

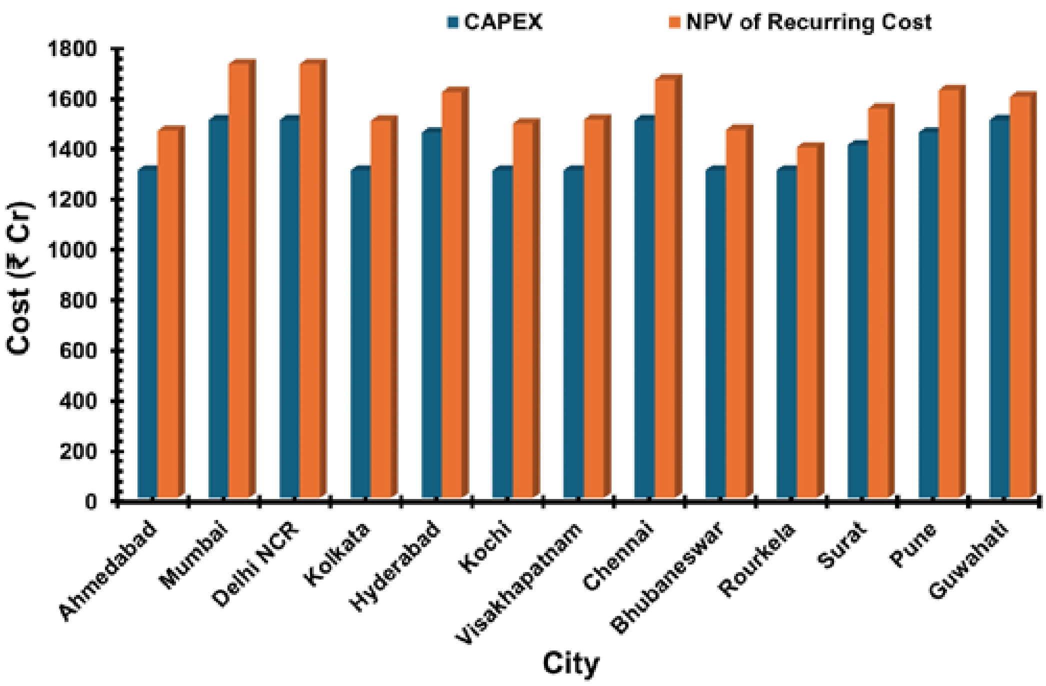


Fig. 4.14, Lifecycle Cost Composition: CAPEX, OPEX, and Carbon Credit

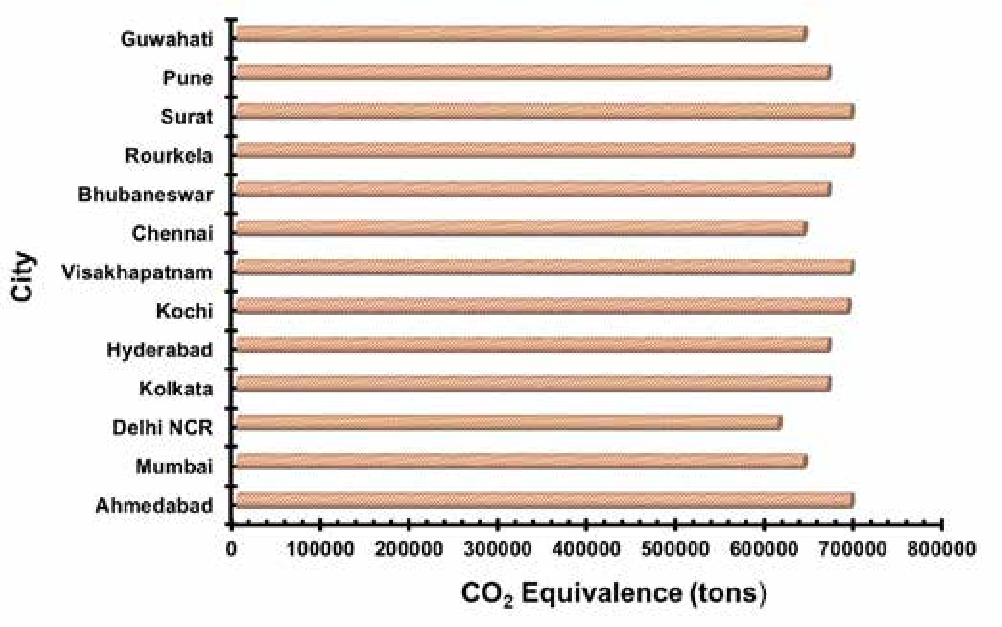


Fig. 4.15, Environmental Impact on CO_2 Equivalence

The comparative assessment of CO_2 equivalence across cities provides strong evidence of the environmental benefits achievable through District Cooling Systems (DCS) in Fig. 4.15. All cities exhibit significant reductions, with savings ranging between 600,000 and 700,000 tons of CO_2, underlining the effectiveness of DCS as a large-scale climate mitigation strategy. Ahmedabad and Visakhapatnam emerge as top performers, approaching the 700,000-ton mark, reflecting their substantial cooling demand and the corresponding efficiency gains from centralized systems. Kochi, Hyderabad, Chennai, Bhubaneswar, and Rourkela also demonstrate strong results, each delivering savings above 650,000 tons, reinforcing the case for DCS deployment in both metropolitan and medium-sized urban centres. Meanwhile, Guwahati, Pune, and Surat, while slightly lower in absolute terms, still achieve over 600,000 tons of savings, showing that even emerging cities can contribute meaningfully to national decarbonisation targets (Fig. 4.15). The uniformity of results across different geographies indicates that DCS adoption not only ensures cost efficiency but also consistently reduces emissions regardless of city size or climatic profile. By integrating such systems into urban planning, these savings can be scaled further, aligning with India's net-zero commitments and enhancing local air quality. This analysis confirms that prioritizing DCS adoption offers a dual advantage lower operating costs for cities and significant contributions to climate resilience and sustainability.

4.4 DCS Installation and Standards Requirement

The installation of a District Cooling System involves setting up a central chilled water plant and a distribution network to serve multiple buildings from a single location. This process includes site preparation, equipment installation, piping and insulation works, electrical and control system integration, and thorough testing before commissioning. Coordination between civil, mechanical, and electrical teams is critical to ensure all components function as a unified system [20]. Compliance with established standards and codes is essential throughout the installation phase. Key references include ASHRAE Standards (90.1 for energy efficiency, 62.1 for ventilation, 15 for refrigerant safety), ISO 50001 for energy management, and NFPA codes for fire protection. Local regulations covering building safety, environmental impact, water usage, and refrigerant management must also be observed. Adhering to these requirements ensures that the DCS operates efficiently, safely, and in line with both environmental and performance expectations. The detailed before, during, after installation standards, procedures and safety protocols required is provided in following sections.

Before Installation – Planning, Design, and Approvals

Before a District Cooling System (DCS) can be built, it is essential to carry out detailed planning and secure all necessary approvals (Tables 4.8 and 4.9). This stage sets the foundation for reliable and efficient operation by confirming the technical feasibility, finalizing the system design, and ensuring compliance with relevant standards and regulations. The table below summarizes the main activities and considerations during the planning, design, and approval stage, helping to avoid delays and ensure a smooth transition to the installation phase [21].

Table 4.7, DCS Pre-Installation Planning, Design, and Approval Requirements

Category	Detailed Requirements
Feasibility & Demand Assessment	• Conduct cooling load profiling (seasonal & hourly). • Determine peak load (TR/RT) & annual cooling energy (kWh/TRh). • Identify customer base and building connection capacities. • Compare electric, absorption, or hybrid systems. • Perform life cycle cost (LCC) analysis & sensitivity analysis for tariff changes.
System Concept Development	• Select DCS model: centralized, modular, or distributed plants. • Choose network configuration: primary-secondary, primary-variable, or direct primary. • Define loop length, pipe diameters, and routing to minimize losses. • Plan thermal energy storage (TES) – ice or chilled water – for off-peak operation.
Design & Engineering Specifications	• Size chillers with redundancy configuration (e.g., N+1, where *N* is the number of chillers required to meet the peak load, and +1 means one additional standby chiller for backup in case of maintenance or failure). • Specify COP, EER, and part-load performance. • Define equipment specs for pumps, cooling towers, valves, strainers, dosing systems. • Specify make-up water quality to avoid corrosion/scaling. • Plan BMS/SCADA control systems for real-time optimization.
Site & Utility Assessment	• Select plant site near load centres with minimal noise/vibration impact. • Confirm electrical grid capacity and backup power requirements. • Verify make-up water supply. • Secure rights-of-way for underground chilled water piping.
Environmental & Regulatory Compliance	• Conduct Environmental Impact Assessment (EIA). • Obtain local municipal and utility clearances. • Secure water use permits. • Ensure refrigerant compliance with ASHRAE 34, Kigali Amendment, and local GWP/ODP norms. • Meet fire & safety codes (NFPA, local rules).
Financial & Contractual Framework	• Choose business model: BOOT, ESCO, PPP, or utility operated. • Prepare CAPEX/OPEX estimates with contingencies. • Define tariff structures (fixed + variable). • Pre-qualify EPC contractors & equipment vendors.
Standards & Codes Compliance	• Comply with ASHRAE 90.1, 189.1, ISO 50001, and relevant IS codes • Follow OSHA-based safety planning. • Adhere to AHRI 550/590 (chiller performance), ASME (pressure vessels), ASTM (piping materials).

h) Pre-Installation Standards & Protocols

Table 4.8, DCS Pre-Installation Quality Management System [21]

Sl. No.	Item	
1. Compliance & Standards		
1.1	Quality Management compliance	ISO 9001:2015
1.2	Occupational Health & Safety compliance	ISO 45001:2018 / OSHA
1.3	Environmental Management compliance	ISO 14001:2015
1.4	HVAC safety requirements	ASHRAE 15, ASHRAE 34, EN 378
1.5	Energy efficiency compliance	ASHRAE 90.1 / ECBC India
1.6	Piping & pressure vessel compliance	ASME B31.1 / B31.3 / IS codes
1.7	Electrical system compliance	IEC 60364, NFPA 70, IEEE 1584
1.8	Household and Similar Electrical Appliances - Safety - Particular Requirements for Commercial Refrigerating Appliances and Ice-Makers with an Incorporated or Remote Refrigerant Unit or Motor-Compressor (IEC 60335-2-89: 2019, MOD)	IS18689:2024
1.9	Safety of Household and Similar Electrical Appliances Part 2 Particular Requirements Sec 40 Electrical Heat Pumps, Air- Conditioners and Dehumidifiers (IEC 60335-2-40: 2022, MOD)	IS 302 (Part 2/Sec 40):2025
1.10	Refrigerants - Designation and safety classification	IS 16656: 2017 / ISO 817: 2014
1.11	Refrigerating systems and heat pumps - Safety and environmental requirements	IS 16678 (Part 1 to 4) / ISO 5149-1 to 4
1.12	Refrigerating systems and heat pumps - Competence of personnel	IS 18847:2024 / ISO 22712: 2023
2. Site Readiness		
2.1	Site survey completed (soil test, load analysis)	Project Specs
2.2	Foundation constructed, cured, and load-tested	NBC / IS standards
2.3	Access roads and pathways cleared	Safety Manual
2.4	Utility connections ready (power, water, drainage)	Design Specs
3. Documentation & Approvals		
3.1	Drawings and P&ID reviewed & approved	Project Docs
3.2	Environmental & regulatory clearances obtained	Govt. Guidelines
3.3	Vendor documents reviewed (datasheets, MTC)	Quality Assurance (QA)/Quality control (QC)
3.4	HAZOP / FMEA conducted & signed off	Safety Protocol
4. Material Handling & Storage		
4.1	Visual inspection on receipt (no damage)	QA/QC
4.2	Verification against PO & packing list	QA/QC
4.3	Protective covers installed on open ports	Storage Protocol
4.4	Climate-controlled storage for sensitive items	Storage Protocol
5. Pre-Installation Testing		
5.1	Factory Acceptance Test (FAT) report reviewed	Vendor Docs
5.2	Incoming Quality Check (IQC) completed	QA/QC
5.3	Electrical insulation resistance test done	IEC 60364
5.4	Hydrostatic / pneumatic test completed for piping	ASME / IS Codes
6. Safety & Access		
6.1	PPE compliance ensured for all workers	ISO 45001
6.2	Scaffolding & fall protection ready	OSHA / NBC
6.3	Emergency evacuation routes marked	NBC / Safety Plan

ii. During Installation – Construction, Testing, and Commissioning

The pre-installation stage of a District Cooling System (DCS) is a decisive phase that lays the groundwork for efficient execution and reliable operation (Tables 4.10–4.11). It covers all preparatory activities under pre-construction readiness, pre-testing preparation, and pre-commissioning planning. This includes completion of detailed engineering designs, securing statutory clearances, coordinating procurement and logistics, and establishing safety and quality assurance frameworks prior to site mobilization. Testing protocols, acceptance criteria, instrumentation arrangements, and water treatment strategies are defined to ensure operational integrity. Commissioning plans, baseline performance targets, control integration procedures, and emergency measures are finalised with stakeholder concurrence. These measures collectively ensure a smooth transition to the construction, testing, and commissioning phases, reducing risks, avoiding delays, and ensuring compliance with technical and environmental standards [22].

a) Pre-Construction Readiness

Table 4.9, Pre-constructions readiness detailed requirements

Sub-Area	Detailed Requirements
Detailed Engineering Design	Finalize all mechanical, electrical, and civil drawings; hydraulic modelling of chilled water network; plant layout optimization; thermal storage sizing; redundancy provisions.
Material & Equipment Procurement Planning	Issue purchase orders for chillers, pumps, cooling towers, TES tanks, electrical gear; ensure lead times match construction schedule; confirm vendor factory acceptance test (FAT) plans.
Site Survey & Layout Approval	Detailed topographic and geotechnical survey; underground utility detection; environmental baseline measurement (noise, dust, water quality).
Construction Permits	Obtain excavation permits, road closure permissions for pipe laying, plant construction clearances, hazardous material handling licenses (for refrigerants).
Logistics Planning	Route surveys for transporting large components; temporary storage and laydown area planning; crane placement zones.
Safety Planning	Preparation of Construction Safety Plan (aligned to OSHA/IS standards), hazard identification, and risk assessment for each major task.
Quality Assurance (QA) Planning	Develop Inspection & Test Plan (ITP), welding procedure specifications (WPS), material acceptance criteria, and NDT scope.

b) Pre-Testing Preparation

Table 4.10, Pre- testing preparation detailed requirements

Sub-Area	Detailed Requirements
Testing Standards Finalization	Define test methods and acceptance criteria per ASME, AHRI, ISO, and local codes for chillers, piping, pumps, and cooling towers.
Factory Acceptance Test (FAT) Schedule	Coordinate with manufacturers for witnessing performance and mechanical tests at their facilities before shipment.
Test Equipment Planning	Ensure procurement or rental of calibrated test instruments (flow meters, temperature sensors, pressure gauges, vibration analysers).
Water Quality Plan	Define chemical treatment requirements for system flushing, cleaning, and passivation before commissioning.
Training Before Testing	Pre-commissioning training for operators on how to handle test runs, monitoring, and emergency shutdowns.

c) Pre-Commissioning Planning

Table 4.11, Pre-commissioning planning detailed requirements

Sub-Area	Detailed Requirements
Commissioning Plan	Prepare a step-by-step commissioning sequence for each subsystem (chillers, TES, pumping, controls, end-user interface).
Performance Targets	Establish baseline KPIs — Coefficient of Performance (COP), ΔT across network, pump efficiency, water loss percentage.
Control & BMS Integration Plan	Define how equipment will be linked to SCADA/BMS; finalize control logic diagrams, sensor mapping, and software testing procedures.
Emergency Preparedness	Draft and circulate emergency start-up/shutdown SOPs, refrigerant leak protocols, and fire response measures.
Handover Documentation Templates	Pre-create forms for as-built drawings, warranty certificates, performance guarantees, and spare parts lists.
Stakeholder Sign-Off	Obtain client and consultant approval on commissioning checklist and readiness plan.

d) Standards and Installation Activity Compliance Matrix

Table 4.12, During installation standards and installation activity compliance

Installation Activity	Relevant Standards / Codes	Compliance Requirement	Verification Method
1. Site Preparation & Civil Works	IS 456 (Concrete), IS 800 (Steel), ISO 9001 (Quality Management)	Foundation dimensions, load-bearing capacity, surface levelling as per approved drawings	Site inspection, measurement check
2. Chiller Installation	ASHRAE 15, ASHRAE 90.1, AHRI 550/590	Positioning, vibration isolation, refrigerant safety compliance, COP as per design	Installation checklist, performance test
3. Cooling Tower Installation	CTI STD-201, ASHRAE Guidelines, IS 11329:2018	Correct alignment, water basin sealing, drift eliminators installed	Visual inspection, water test
4. Pump Installation	ISO 5199 (Centrifugal pumps), ISO 9906 (Hydraulic performance), IS 325 (Motors)	Alignment, foundation grouting, proper coupling guard, performance match to datasheet	Alignment report, test run
5. Chilled Water & Condenser Water Piping	ASME B31.3, ASME B31.9, ASTM A106/A53	Pipe schedule, welding quality, hydrostatic testing	Welding inspection, hydro test report
6. Pipe Insulation	ASHRAE Handbook – HVAC Systems, ASTM C534	Closed-cell insulation, vapour barrier, thickness as per design	Material certificate, visual inspection
7. Electrical Installation	IEC 60364, IS 732, NFPA 70	Earthing, cable sizing, circuit protection	Insulation resistance test, continuity test
8. Instrumentation & Controls (BMS)	BACnet/IP Protocol, ISO 16484 (Building automation)	Sensor calibration, proper control logic integration, redundancy checks	BMS functional test, calibration certificates
9. Water Treatment System	ISO 15748-1, ASHRAE Guidelines	Dosing pumps, filtration, corrosion inhibitor system operational	Water quality analysis
10. Safety Systems	ISO 45001, NFPA 70E, IS 5216 (Electrical safety)	Fire suppression, emergency shutdowns, safety signage	Safety inspection, mock drills
11. Testing & Commissioning	ASHRAE 202, ISO 50001	Functional & performance testing, energy efficiency validation	Test run report, energy audit
12. Documentation & Handover	ISO 9001, Client Specifications	As-built drawings, O&M manuals, warranties submitted	Document verification checklist

iii. After Installation – Operation, Maintenance, and Monitoring

The following table outlines the structured schedule of operational, preventive, and performance-related activities to be carried out after the commissioning of the District Cooling System (DCS) (Tables 4.13 and 4.14). These activities are organized by frequency to ensure efficient operation, extended equipment life, regulatory compliance, and sustained energy and water efficiency throughout the system's service life [23].

Table 4.13, After installation operation, maintenance, and monitoring activity

Frequency	Activity	Details / Parameters	Responsible Team
Daily	Chiller operation check	Monitor inlet/outlet temperatures, pressures, vibration levels, oil/refrigerant levels	Plant Operators
	Pump operation check	Verify flow rates, pressures, bearing noise, and leaks	Mechanical Team
	Cooling tower inspection	Check fan operation, drift eliminators, basin water level	Mechanical Team
	BMS/SCADA monitoring	Review real-time dashboards for alarms, ΔT, COP, kWh/RT	Control Room
	Water treatment dosing	Test pH, TDS, hardness, chlorine levels	Water Treatment Team
	Record keeping	Log energy & water consumption, incidents, maintenance	Plant Operators
Weekly	Strainer/mesh cleaning	Clean strainers in pump suction lines	Mechanical Team
	Safety equipment check	Inspect fire extinguishers, safety alarms, PPE availability	Safety Officer
	TES tank status	Check temperature stratification, insulation integrity	Mechanical Team
Monthly	Chiller preventive maintenance	Inspect condenser/evaporator tubes, clean if needed	Mechanical Team
	Pump/motor maintenance	Lubricate bearings, check alignment, inspect seals	Mechanical Team
	Cooling tower deep cleaning	Remove debris, algae, scale	Mechanical & Water Team
	Energy performance report	Compile COP, kWh/RT, ΔT analysis	Energy Manager
	Refrigerant leak detection	Check with electronic leak detectors	Mechanical Team
Quarterly	VFD & control system inspection	Test drives, sensors, and BMS control logic	Electrical/Controls Team
	Hydraulic balancing	Check and adjust flow rates in primary/secondary loops	Mechanical Team
	Emergency drill	Conduct fire/refrigerant leak response drill	Safety Officer
Bi-Annual	Tube bundle inspection	Inspect and clean condenser & evaporator bundles	Mechanical Team
	Vibration analysis	Analyze motors, compressors for predictive maintenance	Mechanical Team
	Water treatment audit	Third-party analysis of cooling water chemistry	Water Treatment Contractor
Yearly	Full performance test	COP, kWh/RT, ΔT, flow rate verification	Energy & Mechanical Teams
	Insulation audit	Check piping & TES tank insulation for damage	Mechanical Team
	Environmental compliance audit	Refrigerant logs, GWP compliance, EIA follow-up	Compliance Officer
	Control system upgrade review	Evaluate AI-based optimization, load management upgrades	Controls Team
	Capacity expansion feasibility	Assess connection of new buildings or TES units	Planning Team

a) **Post-Installation Compliance Matrix**

Table 4.14, post-installation standard and protocols

Area	Standard / Reference	Protocol / Action	Frequency	Responsible Team
Commissioning & Handover	ISO 50001	Verify design parameters (flow, temperature, capacity); record baseline energy use; handover O&M manuals and as-built drawings	Once (post-installation)	Commissioning Engineer / O&M Lead
System Performance Testing	ASHRAE 551/552,	Integrated Systems Testing (IST) to confirm plant efficiency and reliability	Once + annual re-verification	Testing & Commissioning Team
Energy Efficiency Monitoring	ISO 50001	Log kW/TR, ΔT, and plant load factor in BMS; track against baseline	Daily / Monthly report	Energy Manager / O&M Team
Water Quality & Treatment	CTI WTB-148, ASHRAE Guideline 12, IS 10500	Test chemical dosing, pH, TDS, microbial count; adjust treatment plan	Weekly	Water Treatment Specialist
Refrigerant Management	ASHRAE 15	Leak detection, recovery, and safe handling; maintain refrigerant logbook	Quarterly	HVAC Technician / Safety Officer
Preventive Maintenance	NFPA 70B, OEM O&M Manual	Inspect pumps, motors, strainers, valves; lubricate moving parts	Monthly	Maintenance Team
Cooling Tower Inspection	ASHRAE 188, CTI Guidelines	Check drift eliminators, fan belts, water distribution, scaling	Monthly	Maintenance / Water Treatment Team
Chiller Tube Cleaning	OEM Manual, Eurovent Standards	Brush clean condenser & evaporator tubes; inspect for fouling	Annually	HVAC Technician
Control System Calibration	ISO 9001, OEM Specs	Calibrate temperature, pressure, and flow sensors in BMS	Semi-annual	Controls Engineer
HSE Compliance	ISO 45001, OSHA 29 CFR 1910	Permit-to-Work (PTW) for maintenance; PPE compliance	Daily	Safety Officer
Legionella Risk Management	ASHRAE 188	Risk assessment and sampling; implement control measures	Annually	HSE Officer / Water Specialist
Emergency Response Preparedness	NFPA Standards	Conduct drills for refrigerant leaks, fire, and power failure scenarios	Semi-annual	HSE & Operations Team
Documentation & Reporting	ISO 14001, ISO 50001	Maintain logs of energy, water, maintenance, and incidents; submit compliance reports	Monthly / Quarterly	Facility Manager

4.5 Retrofitting of Existing District Cooling Systems (DCS)

Retrofitting existing District Cooling Systems involves upgrading chillers, pumps, cooling towers, piping, and control systems to improve performance, meet updated safety standards, or transition to low-GWP refrigerants. Retrofit projects are more complex than new installations as they must be executed without disrupting ongoing cooling services. Detailed planning, staged execution, and strict adherence to codes and standards are essential (Tables 4.15 – 4.17).

i. Pre-Retrofit Assessment and Planning

Table 4.15, Pre-Retrofit Planning and Assessment Requirements

Category	Detailed Requirements
System Audit	• Conduct energy audit (kW/TR, COP, ΔT). • Inspect plant equipment and network condition. • Identify obsolete controls and sensors.
Load Review	• Update demand profile with current and projected loads. • Verify building connection capacities.
Refrigerant Transition	• Identify existing refrigerants (R-22, R-134a, R-410A). • Assess low-GWP alternatives (R-513A, R-1234ze, R-290) or full chiller replacement.
Safety & Compliance	• Review ASHRAE 15, ASHRAE 34, IS 16590, NFPA 70. • Check structural and electrical readiness for retrofit.
Financial Analysis	• Compare retrofit and replacement costs. • Prepare lifecycle cost estimates.
Stakeholder Planning	• Secure building-owner approval. • Define phasing to avoid service disruption.

ii. Retrofit Execution – Replacement, Integration, and Testing

Table 4.16, Retrofit Execution and Standards Compliance

Activity	Standards / References	Compliance Protocol
Chiller Replacement	AHRI 550/590, ASHRAE 90.1	Install high-efficiency chillers with redundancy. Verify COP/EER.
Refrigerant Conversion	ASHRAE 15, MoEF&CC ODS Rules	Recover and dispose of old refrigerants. Charge with approved low-GWP refrigerant. Maintain logbook.
Pump and Piping	ASME B31.3, ASTM A106/A53	Replace undersized pumps. Hydrostatic testing after piping modifications.
Cooling Tower	CTI STD-201, ASHRAE 188	Upgrade fan drives, water distribution, and drift eliminators.
TES System	IS 2825, Eurovent Standards	Inspect TES tanks, insulation, and stratification.
Controls & BMS	ISO 16484, BACnet/IP	Retrofit sensors. Integrate with SCADA/BMS. Recalibrate system logic.
Electrical Systems	IEC 60364, NFPA 70	Upgrade switchgear and VFDs. Test earthing and backup systems.
Water Treatment	ASHRAE Guideline 12, IS 10500	Flush and clean old piping. Commission with corrosion inhibitors.

iii. Post-Retrofit Operation, Maintenance, and Monitoring

Table 4.17, Post-Retrofit Operation, Maintenance, and Monitoring Protocols

Frequency	Activity	Standards / Reference	Responsible Team
Daily	Monitor chiller COP, ΔT, and refrigerant levels.	ISO 50001	Plant Operators
Weekly	Verify BMS alarms, leak detection, and safety devices.	ASHRAE 15	Controls & Safety Officer
Monthly	Update refrigerant logbook. Prepare energy reports.	ASHRAE 34	O&M Team
Quarterly	Test emergency power and fire safety systems.	NFPA 70/70E	Electrical & Safety Team
Bi-Annual	Vibration analysis for compressors and pumps.	ISO 10816	Mechanical Team
Yearly	Full energy audit and TES inspection.	ECBC, ISO 50001	Energy Manager
Biennial	Review retrofit ROI and standards compliance.	BIS/BEE Codes	Audit & Compliance Team

Key Notes

- Retrofit provides a 20–30% lower cost option compared to full replacement when equipment life permits.
- Transition to A2L/A3 refrigerants must include additional fire safety and leak detection measures.
- Retrofitting is an opportunity to integrate smart controls, IoT, and AI-based optimization.
- Compliance with MoEF&CC refrigerant rules, BIS codes, ASHRAE, ISO, and NFPA standards is mandatory.

5. Current DCS Policies and Regulations

The India Cooling Action Plan (ICAP, 2019) proposes district cooling as an alternate cooling technologies. The Energy Conservation Building Code (ECBC 2017) of the Bureau of Energy Efficiency (BEE) establishes minimum energy performance standards for commercial buildings including building envelope, HVAC, lighting, and electrical systems[i] and the Eco-Niwas Samhita (ENS), launched in 2018 as the ECBC-R, mandates minimum standards for residential building envelopes and aims to integrate electro-mechanical systems and renewable energy provisions in subsequent updates [24-28]. Although both ECBC (2017) and Eco-Niwas Samhita currently focus on individual buildings, they lay the groundwork for advancing system-level solutions like District Cooling. By establishing minimum performance standards for commercial and residential buildings, these codes create base towards energy efficiency that makes shared infrastructure more viable in high-density developments. Importantly, the framework can be expanded in future revisions to include provisions for centralized cooling networks, thereby linking building-level efficiency mandates with district-scale energy solutions.

On the urban development side, national missions such as the Smart Cities Mission and the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) promote integrated infrastructure planning, where district energy systems can be embedded in city master plans and service delivery frameworks. A few states and cities are beginning to recognize this potential: for instance, Amaravati in Andhra Pradesh integrated district cooling into its city planning framework, while Thane Municipal Corporation in Maharashtra has explored feasibility studies for large-scale cooling networks.

In addition, provisions under the Bureau of Energy Efficiency (BEE) create pathways to align DCS with energy efficiency and sustainable water use objectives. Taking together, these initiatives provide a strong policy signal and institutional foundation for district cooling. The scope for strengthening DCS in policies and regulations and Current policies, guidelines and regulation related to DCS are shown in Table 5.1 and Fig. 5.1, respectively.

5.1 Key Challenges and Opportunities

The initiatives proposed above lay a strong foundation for advancing energy efficiency at the building level. Looking ahead, there is an opportunity to build on this momentum by extending the focus to district-scale solutions. With further strengthening and refinement, policies and regulations can play a pivotal role in enabling the widespread adoption of District Cooling Systems (DCS) in the country.

Current Development Control Regulations (DCRs) and master plans primarily address stand-alone building systems. Provisions for DCS-related infrastructure such as space for underground pipelines, energy transfer station (ETS) rooms, or central cooling plants can be embedded in planning frameworks, which may limit the ease of integrating DCS into future urban growth. The ECBC and Eco-Niwas Samhita should include opportunities for introducing DCS-readiness norms, thereby enabling shared infrastructure in high-density precincts such as central business districts, large residential townships, IT/industrial parks, and transit-oriented developments.

Today, underground corridors (the planned spaces where utilities such as water pipelines, sewer lines, electricity cables, and telecom ducts are laid) are managed by multiple agencies, such as Urban Local Bodies (ULBs) for water supply and sewage, State Public Works Departments (PWDs) for roads, state electricity distribution companies (DISCOMs) for power, and telecom operators for communication ducts. A standard checklist for coordinating district cooling assets with these utilities could reduce project delays and provide coordination, thereby creating confidence among developers and investors.

There is also growing interest in retrofitting existing high-density areas, where DCS can bring long-term efficiency and resilience. Technical feasibility has been demonstrated in several studies, which supported by planning norms or targeted incentives could promote wider adoption of DCS. Developing regulatory guidance for heritage zones, redevelopment projects, and commercial complexes could help capture this potential.

Water reuse and discharge regulations, currently overseen by State Pollution Control Boards and municipal water utilities, present an opportunity for greater alignment with cooling needs. While treated sewage effluent (TSE) from Sewage Treatment Plants (STPs) or Effluent Treatment Plants (ETPs) could serve as a reliable source for cooling tower makeup water, specific mandates or incentives encouraging its use in DCS can be promoted and embedding such provisions would allow cities to connect district cooling with broader circular economy and water conservation goals.

On the financial side, cooling tariffs and business models are still evolving. Concepts like 'Cooling-as-a-Service,' a subscription-based cooling model where users pay only for the cooling they consume, are being tested globally. Provisions such as differentiated cooling tariffs, incentives for thermal energy storage, or accelerated depreciation benefits for district assets could strengthen the investment case. In addition, DCS has yet to find a place in mainstream initiatives State Urban Missions, Smart City guidelines, or PPP frameworks. Dedicated mechanisms like Viability Gap Funding (VGF) or targeted capital subsidies could help offset the higher upfront costs, particularly in retrofit scenarios, making it easier to attract private participation and scale projects through blended financing models.

Finally, at the state policy level, district cooling needs to be promoted across climate action plans, smart city guidelines, or urban missions. As national strategies already recognize the role of DCS, mainstreaming the concept in state-level policies and schemes could significantly accelerate adoption.

In summary, India has laid a strong foundation for energy-efficient and sustainable cooling. Building this foundation by incorporating district cooling into codes, utility frameworks, and state-level policies would create an enabling environment that supports large-scale implementation. This would align well with the country's broader vision of promoting energy efficient cooling and sustainable urban development.

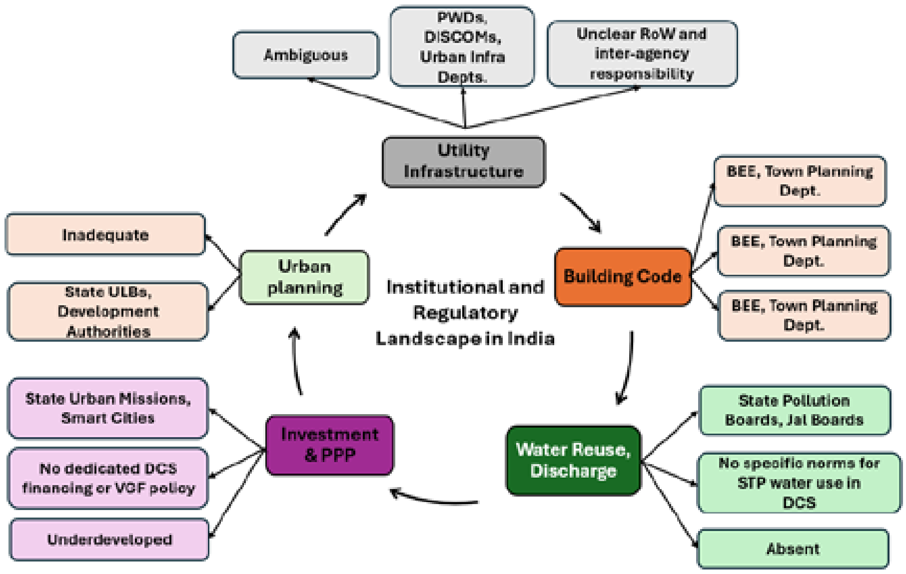


Figure 5.1.: Current policies, guidelines and regulation related to DCS

Table 5.1, Scope for Strengthening DCS in Policies and Regulations

Key Area	Current Situation	Possible Opportunities
Building and Urban Codes	• Most DCRs and masterplans focus on individual cooling systems • ECBC 2017 sets efficiency norms for stand-alone buildings but does not cover shared systems or load aggregation.	• Add DCS-readiness features in codes (like rooftop solar, EV charging) • Encourage shared solutions in high-density areas.
Coordination with Utilities & Ownership	• DCS networks must fit into existing corridors for water, power, sewerage, telecom. • No standard Right-of-Way (RoW) checklist. • Roles in ownership and O&M are not clearly defined.	• Right-of-Way (RoW) checklist for faster permission • Clarify whether utilities, private operators, or SPVs will manage systems.
Retrofitting in Existing Areas	• Good potential in busy commercial, residential areas and redevelopment zones. • Retrofitting needs space for pipes, mechanical rooms, and HVAC adjustments. • Limited guidance for heritage or renewal projects.	• Provide policy support or small incentives for retrofits. • Share guidelines for heritage and urban renewal contexts.
Business Models & Tariffs	• Models like Cooling-as-a-Service (CaaS) are being tried globally but not yet in state rules. • Tariff structures for storage or depreciation benefits are not common.	• Try differentiated tariffs or incentives for storage. • Allow depreciation benefits or reliability-based pricing.
State-Level Policy Alignment	• ICAP mentions DCS, but state-level plans, smart city manuals, and missions like AMRUT 2.0/PMAY-U give little space. • Nodal agencies for planning and permits are not identified.	• Consider ways to reflect DCS more clearly in state policies and city guidelines. • Explore the option of designating nodal agencies that could help coordinate planning and approvals.

5.2. Case Studies on Implementation of DCS

To better understand the practical alignment between district cooling implementation and the prevailing regulatory landscape, the project team has analyzed both Indian and international case studies. These examples offer valuable insight into how policy frameworks or the lack thereof can either enable or hinder DCS deployment.

5.2.2 Global Case Studies on District Cooling System

District Cooling Systems (DCS) have achieved remarkable success in global cities where long-term infrastructure development is closely aligned with urban planning, environmental regulation, and utility governance. The following case studies from diverse international contexts reveal a recurring theme: the presence of clear mandates, supportive policies, and strategic institutional roles is critical for such systems to flourish.

1. Singapore: Mandatory Connection and Green Building Integration

In Singapore's Marina Bay district [29], the Urban Redevelopment Authority (URA) mandates that all new buildings in designated zones connect to the centralized cooling system. This requirement is integrated with the nation's Green Mark building rating system, creating a robust demand base (Fig. 5.2 and Table 5.2).

Key Learning: Regulatory mandates for building connection are a powerful tool to ensure demand aggregation from the outset. Coupling this with green building policies creates a synergistic effect, driving both efficiency and market adoption through a public-private implementation model.

2. Vienna, Austria: Climate Policy and Waste Heat Utilization

Vienna has embedded district cooling into its broader Vienna Climate Protection Program (KLIP) [30]. The municipal utility, Wien Energies, operates the network using waste heat from incineration plants to run absorption chillers, with performance regulated under EMAS II environmental certification (Fig. 5.3 and Table 5.2).

Key Learning: Integrating DCS within a city's overarching climate action plan provides a strong strategic foundation. Utilizing waste heat transforms a waste product into a valuable resource, enhancing sustainability. A strong, municipally-led utility model is effective for managing this integration.

3. Budapest, Hungary: Modernizing Legacy Infrastructure under EU Policy

Budapest is transitioning its district heating infrastructure toward cooling applications in response to EU climate targets [31]. The use of Danube River water for heat rejection is approved under specific discharge regulations, aligning with the EU's Fit-for-55 package (Fig. 5.4 and Table 5.2).

Key Learning: Existing thermal energy infrastructure can be modernized and adapted for cooling. Supra-national policy frameworks (like the EU's) can provide the impetus and funding for member states to modernize legacy systems and invest in low-carbon infrastructure.

4. Copenhagen, Denmark: Legislative Mandates and Natural Resource Use

Copenhagen's Climate Plan 2025 includes district cooling managed by utility HOFOR [32–36], which uses seawater from the city's harbor for free cooling. Environmental permits regulate the water intake and discharge, and there is a legal requirement for buildings in selected areas to connect (Fig. 5.5 and Table 5.2).

Key Learning: A clear legal framework can simultaneously mandate connections (ensuring viability) and strictly regulate the use of natural resources (ensuring sustainability). This dual approach guarantees high utilization rates while protecting the local environment.

5. Qatar and Saudi Arabia: Master Planning and Utility Frameworks

In projects like Qatar's Pearl Island and Riyadh's King Abdullah Financial District (KAFD) [33], DCS was embedded directly into the urban master plan. These systems received regulatory approval for seawater use and included cooling tariffs within the utility billing framework.

Key Learning: Incorporating DCS into the initial urban master plan is the most effective way to ensure its integration. Establishing clear technical standards (e.g., for seawater use) and an approved tariff model within the utility framework from the beginning provides certainty for investors and developers.

As summarized in Table 5.2 and Fig. 5.6, these global examples underscore that successful DCS deployment hinges on a combination of clear mandates, environmental approvals, and utility integration.

Fig. 5.2, Underground district cooling network at Marina Bay

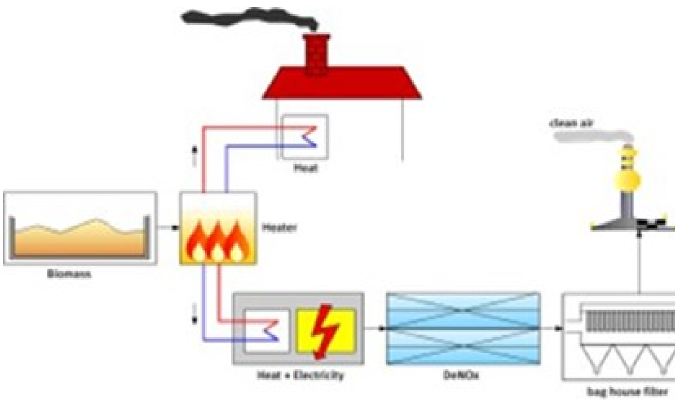


Fig. 5.3, Biomass CHP plant in Vienna

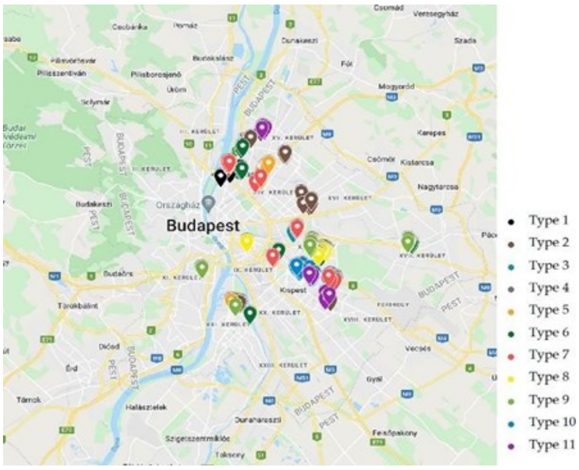


Fig. 5.4, District heating patterns for Budapest residential buildings

Fig. 5.5, Copenhagen District Heating System

Table 5.2: Global Best Practices and Their Application for District Cooling in India

Theme	Regulatory Examples	DCS Impact	India Applicability
Zoning-based DCS Enforcement	Singapore, Vienna, GIFT City	Ensures demand aggregation and system viability	Integrate into ECBC and ULB master plans
Water Reuse Policy Integration	GIFT City, Mumbai, Copenhagen, Qatar	Minimizes freshwater use and reduces operational costs (OPEX)	Enable CPCB-approved treated sewage effluent (TSE) reuse norms at city level
Smart City & Urban Planning Alignment	Pune, GIFT City, Budapest	Accelerates implementation through planning synergy	Embed DCS in Smart Cities Mission 2.0 and AMRUT+ guidelines
Climate Target Convergence	Vienna (KLIP), Copenhagen, ICAP	Links DCS to Net-Zero goals and refrigerant phase-out	Set DCS milestones in State Action Plans on Climate Change (SAPCCs)
Utility-Led or PPP Financing Models	Copenhagen (HOFOR), GIFT City, Vienna	Ensures service continuity and tariff stability	Develop ESCO/PPP models under NIIF or UDAY 2.0 frameworks
Tri-Generation & Waste Heat Recovery	Vienna, Riyadh, Pune MIDC	Enables deep carbon savings and reduces grid stress	Map heat-rich zones and promote integration with solid waste management (SWM) New chat

Fig. 5.6. Key insights from International cases for DCS adoption in India

5.2.3 District Cooling in India

India's approach to DCS is evolving, with several pioneering cities demonstrating how to align infrastructure projects with state policies, utility reforms, and climate action strategies. These early initiatives provide a crucial blueprint for scaling district cooling in diverse Indian conditions.

1. GIFT City, Gujarat: Integrated Zoning and Utility-Led Model

Gujarat International Finance Tec-City (GIFT) has implemented DCS through integrated urban planning. The city's zoning bylaws mandate connection for all buildings in the designated area, and a dedicated utility manages the system. A key feature is its use of treated sewage water, approved under state water reuse norms. This ensures both water sustainability and reduced operating costs (Fig. 5.7).

2. Mumbai (Bandra-Kurla Complex): Development Control & Climate Planning

In Mumbai, the Bandra-Kurla Complex (BKC) has been identified as a suitable location for DCS integration under the city's Development Control Regulations (DCR 2034) [36]. The availability of treated sewage water from the Bandra STP creates an opportunity for water reuse in cooling applications. This aligns well with the Maharashtra State Action Plan on Climate Change, which emphasizes the importance of sustainable urban services.

3. Hyderabad, Telangana: Fast-Track Approvals for Private Development

The My Home Abhra development in Hyderabad showcases a private sector-led DCS model. It was facilitated by Telangana's TS-iPASS policy, which provides fast-track clearances for large projects. The system's use of recycled water was further encouraged by the Greater Hyderabad Municipal Corporation's (GHMC) green building compliance policies.

4. Pimpri-Chinchwad (Pune): Smart City Policy and Industrial Integration

The Pimpri-Chinchwad Smart City proposal and the Maharashtra Industrial Development Corporation (MIDC) policy explore innovative DCS models. These include using industrial waste heat and treated water reuse, with financing explored through Energy Service Company (ESCO) models under municipal contracts.

As summarized in Table 5.3 and Figs. 5.7 & 5.8, these early Indian examples demonstrate that successful DCS deployment is possible through a combination of zoning mandates, water reuse permissions, fast-track approvals, and innovative financing.

(a) DCS Chiller (b) DCS chiller piping network

Fig. 5.7, GIFT City Ahmedabad DCS chiller and piping network.

Fig. 5.8, Indian Case Study Alignment with DCS Regulatory Frameworks

Table 5.3: Key Insights from Pioneering District Cooling Projects in India

City/Region	Project/Initiative	Regulatory & Policy Drivers	Key Features of the DCS Model	Primary Learning
GIFT City, Gujarat	Utility-led DCS implementation	Smart City zoning bylaws, SEZ norms, State water reuse policies	Mandatory building connections, Dedicated utility Use of treated sewage water	Mandatory connection clauses and a dedicated utility structure ensure demand and clear governance. Integration with water reuse strategy enhances sustainability and reduces costs.
Mumbai (BKC)	Bandra-Kurla Complex planning	Development Control Regulations (DCR) 2034, Maharashtra Climate Action Plan	Designated high-density zone Planned use of treated effluent from Bandra STP	Master plans can proactively zone areas for DCS. Securing a source of alternative water (e.g., treated sewage) at the planning stage is critical for feasibility and climate alignment.
Hyderabad, Telangana	My Home Abhra private development	TS-iPASS (fast-track approvals), GHMC green building policies	Private sector-led model, Use of recycled water Driven by real estate development	Streamlined single-window clearances incentivize private investment. Coupling with green building norms creates a strong business case for developers.
Pimpri-Chinchwad, Pune	Smart City & Industrial proposal	Smart City mission, MIDC industrial & water reuse policy	Exploration of waste heat recovery Treated water reuse, ESCO-based financing models	Smart City and industrial policies can pilot innovative solutions using waste resources. ESCO models help overcome capital barriers and attract private investment.

5.3 Way Forward for Scaling District Cooling Implementation in India

India's push for sustainable cooling hinges not just on technology, but on adaptive policies and city governance. Pilot projects show DCS works, but scaling up demands clearing policy and regulatory bottlenecks. Key priorities ahead are as follows:

1. Break the Utility Permission Gridlock
In cities like Delhi NCR, Kolkata, and Mumbai, fragmented permissions from multiple agencies slow down DCS deployment. The lack of a shared utility corridor framework and unclear ownership of underground infrastructure makes laying chilled water pipelines unnecessarily complex. A unified clearance process and clear rights-of-way (RoW) policies could cut years off project timelines.

2. Treat Greenfield and Brownfield Differently
New urban districts such as GIFT City and Visakhapatnam Smart City zones are showing that with Special Planning Authorities (SPAs), DCS can be integrated from day one. But in dense, older areas like central Delhi **or** South Mumbai, retrofits need their own policy toolkit: easement rights for utility passage, thermal zoning overlays, and mandatory load-sharing provisions between buildings.

3. Update ECBC for Cooling Networks
ECBC should include provisions like dedicated space for Energy Transfer Stations (ETS), pipe corridors for chilled water networks, and incentives for developers connecting to third-party cooling suppliers [27]. Future versions should introduce DCS-readiness provisions—like dedicated space for **Energy Transfer Stations (ETS)**, pipe corridors for chilled water networks, and incentives for developers who connect to third-party cooling suppliers.

4. Recognize Cooling as a Utility
Under current State Electricity Regulatory Commissions (SERCs), cooling services should consider tariff structure for DCS have a defined tariff structure. Introducing cooling tariffs, along with special rates for thermal energy storage, could unlock private investment and make DCS financially attractive.

5. Harness Coastal and Vertical City Advantages
Cities such as Mumbai, Chennai, Kochi, and Kolkata have huge technical potential for seawater cooling and STP (sewage treatment plant) water reuse which should be promoted.

6. Map Before You Build
Use of digitalized utility map should be promoted to save time, reduce risks, and avoid costly rework by investing in citywide underground utility mapping and GIS-based RoW planning before the first pipe is laid.

5.4 Strategy to Build Grassroots-Level Adoption for District Cooling Systems (DCS)

Bringing DCS to India's cities isn't just about installing infrastructure, it's about making it relatable, trusted, and part of daily life.

1. Speak the Local Language

Explain DCS with familiar comparisons, "one big AC for the whole colony" and translate into local idioms. Simple, culturally rooted messaging helps people connect emotionally.

2. Involve Communities

Host neighborhood workshops, "cooling clinics" to show savings, and use local champions (teachers, RWAs, ASHA workers) to spread awareness. Make it interactive with stories, drawings, and open Q&A.

3. Demonstration Zone

Create "Cooling Lighthouses" in visible public spaces like schools or clinics. Show real-time temperature and energy savings, display testimonials, and share videos via QR codes—so people can see benefits firsthand.

4. Explain Costs Simply

Frame pricing in relatable terms "₹2/day for 24x7 cooling, cheaper than chai." Use visuals to compare lifetime savings and emphasize collective affordability with no upfront costs.

5. Engage Youth

Launch "Cool School" programs where students track temperatures, make models, and run "How cool is your colony?" challenges bringing DCS conversations into homes.

6. Link to Existing Initiatives

Position DCS within ongoing sustainability drives water reuse, clean air, heat action plans showing it as part of a bigger solution for health, comfort, and resilience.

7. Customize by City

Tailor messages to local priorities: quiet and space-saving in Mumbai, health-focused in Delhi NCR, flood-resilient in Kochi, heritage-aligned in Bhubaneswar.

Expanding district cooling is key to meeting India's growing urban cooling demand. The table below outlines recommendations, regulations, and incentives for large-scale DCS, based on technical studies, stakeholder inputs, and global best practices.

6. Key Findings and Conclusion

The Assessment of District Cooling Systems (DCS) presented in the report indicates DCS as a sustainable, energy-efficient alternative to conventional decentralized cooling in India. In the coming years, DCS is likely to emerge as a viable alternative cooling solution to cater the increased demand for air-conditioning, driven by rising temperatures, increasing urbanization, growing middle-class incomes, and expansion of residential and commercial sectors, besides achieving the goals of ICAP relating to reduction in cooling and refrigerant demand. The following findings are presented from the study:

(a) DCS appears to be a viable option for integration into urban planning, especially in the upcoming large scale infrastructure projects including smart cities. Towards this, there is a need to associate town planning departments, urban local bodies and other related stakeholders in the development of city master plans.

(b) There is need to promote awareness and develop capacity of all concerned stakeholders relating to DCS. These include officials associated with development of city master plans, building developers, associations like GRIHA, RERA, etc. Building local technical expertise through training programs for urban planners, engineers, and policymakers helps demystify the technology and promotes smoother adoption of DCS. In addition, there is a need to develop personnel for operation and maintenance of DCS. This should include certification programmes for operation and maintenance personnel.

(c) There is a need to standardize business models for DCS which also includes standard contracting procedures, standard leasing agreements and roles of different stakeholders. The model/procedures should include the following depending upon the climatic zone and the area identified for installation of DCS:

   (i) Use of Thermal energy storage (TES) to reduce installation costs, decrease operational expenses by avoiding high electricity tariffs, leading to improvement in system efficiency by running chillers at higher efficiency during cooler off-peak times. TES can reduce peak power demand up to 30%. TES also decreases operational expenses by avoiding high electricity tariffs, and improves system efficiency by running chillers at higher efficiency during cooler off-peak times

   (ii) Waste heat recovery through capturing excess heat from sources like industrial processes, data centers and wastewater plants, and channeling it through networked pipes to provide thermal energy for multiple buildings is a viable solution for DCS. This sustainable approach significantly improves energy efficiency, reduces the reliance on fossil fuels, and lowers greenhouse gas emissions.

   (iii) Design of Closed-loop configurations can reduce cooling water usage by 15–25% (equivalent to 20–40 million litres/year for large deployments).

   (iv) Use of seawater in coastal areas is an energy efficient method, which eliminates the need for potable water for cooling, reduces operational costs, and lowers electricity consumption and CO_2 emissions, making it an eco-friendly solution.

   (v) Use of recycled water from wastewater treatment plant, which is an increasingly viable source for district cooling systems, offering significant water conservation by reducing reliance on potable water, especially for large facilities like data centers and convention centers. The recycled water can be used through lime softening and catalytic decomposition of impurities, before it enters the cooling system to enable higher cycles of concentration and improving overall sustainability.

(vi) Centralized designs of DCS reduce refrigerant charge requirements by 40–60%, lowering leakage risks and environmental impacts.

(vii) Promote use of low GWP and climate friendly refrigerants, where needed in line with the compliance obligations under the Montreal Protocol including the Kigali Amendment to the Montreal protocol.

(d) Indian standards should be developed for DCS related infrastructure wherever needed.

(e) Area Development Project Authorities should encourage the adoption of DCS for large infrastructure projects.

(f) Financial incentives for promoting district cooling comprising subsidies, tax breaks, concessional loans should be explored. In addition, public-private partnership (PPP) models which aim to reduce upfront costs and improve the economic viability of these systems should be explored.

(g) Develop frameworks for ensuring a consistent and cost-effective electricity supply since this is paramount, as it directly impacts the economic competitiveness of district cooling compared to traditional AC systems. Integration of waste heat recovery or renewable energy may be explored to reduce the energy and electricity consumption requirement.

(h) Integration with renewable energy sources (solar PV, solar thermal, trigeneration) will lower the carbon intensity of cooling.

(i) By eliminating rooftop units, DCS significantly reduces urban heat island effect, especially when combined with green corridors and reflective materials.

(j) Smart monitoring through IoT, AI, and SCADA/BMS integration ensures predictive maintenance, reduces downtime, and optimizes performance.

(k) DCS adoption needs to be socially inclusive, extending to public hospitals, educational campuses, and affordable housing, strengthening community resilience.

(l) District Cooling Systems (DCS) emerge as a climate-smart solution cutting costs, reducing carbon emissions, and conserving water while ensuring reliable, inclusive, and sustainable cooling.

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Annexure – I

Draft Time-of-Day Cooling Tariff Schedule for District Cooling Systems

(Model Regulation for Adoption by State Electricity Regulatory Commissions)

1. Preamble

This regulation establishes a differential cooling tariff structure for District Cooling System (DCS) operators and consumers based on Time-of-Day (ToD) metering. The objective is to promote energy-efficient cooling practices, encourage off-peak usage through thermal energy storage (TES), and reduce the stress on the power grid during peak hours.

This schedule may be adopted by State Electricity Regulatory Commissions (SERCs) under their existing powers to regulate supply and tariff structures under the Electricity Act, 2003, particularly under Sections 61 (c), (h), and 86 (1)(a).

2. Definitions

- District Cooling System (DCS): A centralized system that produces and distributes chilled water to multiple buildings through a network of insulated pipes.
- Cooling-as-a-Service (CaaS): A model under which the consumer pays for cooling consumption (kWh-thermal or TR-hour).
- ToD Tariff: A tariff structure where rates vary according to the time of day.
- Thermal Energy Storage (TES): A system that stores chilled water or ice during off-peak hours and discharges cooling during peak hours.

3. Applicability

This tariff schedule applies to:

- Licensed DCS operators under CaaS or third-party utility models.
- Bulk consumers connected to a centralized DCS network.
- Pilot DCS systems approved by relevant state or municipal bodies.

4. Cooling Tariff Schedule (ToD-Based)

Time Slot	Cooling Tariff (₹ / TR-hour)	Cooling Tariff (₹ / kWh-th)	Remarks
Off-Peak (10 PM - 6 AM)	₹ 2.50 – ₹ 3.00	₹ 1.20 – ₹ 1.50	Encourages TES charging
Normal (6 AM - 10 AM, 6 PM – 10 PM)	₹ 4.00 – ₹ 4.50	₹ 2.00 – ₹ 2.20	Moderate load periods
Peak (10 AM - 6 PM)	₹ 6.00 – ₹ 7.00	₹ 2.80 – ₹ 3.50	Reflects system-wide energy stress

Note:

- Prices may be reviewed annually.
- Chiller COP is assumed at 5.0 for conversion.

5. Incentives for TES-Enabled DCS Operators

- 25-30% rebate on electricity tariff for off-peak TES operation.
- ₹ 0.50/TR-hour rebate for peak shaving above 500 TR.
- TES capacity >1,000 TR may qualify for additional incentives.

6. Metering and Billing Provisions

- ETS connections must have thermal energy meters.
- DCS operators must submit hourly consumption profiles quarterly.
- Billing shall be based on time-tagged thermal energy use.

7. Quality of Supply

- Supply temperature to be maintained between 6-7°C ±1°C.
- Deviations for more than 3 days may attract a 10% tariff reduction.

8. Validity and Review

- Valid for 5 years from issuance.
- Subject to annual review by the Regulatory Commission.

9. Model Justification Note

This tariff model facilitates:

- Load management and grid stability.
- Economic viability of DCS through optimized energy use.
- Promotion of TES and decarbonized cooling.

Appendix: Sample Bill Format (For CaaS Consumers)

Date	Time Slot	TR-hour Consumed	Applicable Rate (₹/TR-hr)	Amount (₹)
02-Aug	10:00 AM - 11:00 AM	25	₹ 6.50	₹ 162.50
02-Aug	10:00 PM - 11:00 PM	18	₹ 2.75	₹ 49.50
	Total	43		₹ 212.00

Annexure II

Worked Example: Annual Cooling Cost Calculation for Ahmedabad

This example illustrates how cooling demand (in Tons of Refrigeration, TR) and annual cooling cost are calculated for Ahmedabad in 2024 using the District Cooling Systems (DCS) feasibility study methodology.

Assumptions

Gross Floor Area (GFA, 2024) = 2.2 million m^2
Cooling Load Intensity = 220 W/m^2
Coincidence Factor = 0.7
Annual Operating Hours = 2,500 h
Electricity Tariff = ₹7/kWh
COP (BAU) = 3.5
COP (DCS) = 5.0
Conversion factor: 1 TR = 3.517 kW, ₹1 Cr = ₹1×10^7

Step 1. Peak Cooling Load (kW)

Load (kW) = (GFA × Intensity × Coincidence) / 1000

= (2.2×10^6 × 220 × 0.7) / 1000 = 338,800 kW

Step 2. Convert kW → TR

TR = 338,800 ÷ 3.517 ≈ 96,332 TR

Step 3. Annual Cooling Requirement (TR-hr)

Annual TR-hr = 96,332 × 2,500 = 240.83 million TR-hr

Step 4. Annual Electricity Use (kWh)

BAU (COP = 3.5): Power = 338,800 ÷ 3.5 = 96,800 kW → Annual kWh = 96,800 × 2,500 = 242.0 million kWh

DCS (COP = 5.0): Power = 338,800 ÷ 5.0 = 67,760 kW → Annual kWh = 67,760 × 2,500 = 169.4 million kWh

Step 5. Annual Cooling Cost (₹)

BAU: 242.0 million kWh × ₹7 = ₹1,694 million = ₹169.4 Cr

DCS: 169.4 million kWh × ₹7 = ₹1,185.8 million = ₹118.6 Cr

Final Result (Ahmedabad, 2024)

- Annual Cost (BAU): ₹169.4 Cr
- Annual Cost (DCS): ₹118.6 Cr

Annexure – III

Calculation procedure for economic feasibility of implementing District Cooling Systems (DCS) or BAU across different cities of India

Step 1: Define Assumptions and Input Parameters

- Project Lifetime (n): 35 years

- Project Lifetime (BAU): 20 years (replaced once in 40 years)

- Discount Rate (r): 6% (0.06)

- Cooling Capacity (TR): 100,000 TR per city (Initial Phase)

- Annual Operating Hours: 2,500 hours

- Total Cooling Output (Q_{total}) = 100,000 TR × 2500 hrs/year × 35 years = 8.75×10^9 TR-hr

-DCS COPs: Varies city-wise (4.2-4.6)

- Electricity Tariffs: City-specific (₹6.0-₹7.1/kWh)

For each city, the following values are assumed:

- **CAPEX:** Initial infrastructure cost (in Cr INR)
- **OPEX:** Annual operation & maintenance cost (in Cr INR)
- **Energy Cost:** Annual electricity cost (in Cr INR)

Step 2: Calculate Net Present Value (NPV) of Recurring Costs

Combine annual recurring costs:

Annual Cost (DCS or BAU) = OPEX + Energy Cost

Net Present Value (NPV) of Annual Cost over project lifetime:

NPV = Annual Cost × [(1 - (1 + r)^-n) / r], where r = 6%, n = project lifetime (DCS = 35 yrs, BAU = 20 yrs)

Step 3: Calculate Total Lifecycle Cost

Lifecycle Cost = CAPEX + NPV of Recurring Cost
For DCS = CAPEX + NPV of DCS
For BAU 40yr = 2 × (CAPEX + NPV of BAU)
Scaled to 35 years BAU 35yr = BAU 40yr × (35 / 40)

Step 4: Levelized Cost of Cooling (LCOC)

LCOC=Total Cooling Output (TR-hr)/Total Lifecycle Cost (INR)
Where:
- Total Lifecycle Cost (INR) = Capital Cost (CAPEX) + Discounted sum of annual operating + energy costs (OPEX + Energy)

- Total Cooling Output (TR-hr) = Cooling Capacity (TR) × Operating Hours per Year × System Lifetime (Years)

Step 5: Cost Savings

Savings=BAU Cost−DCS Cost

Step 6: Percentage Savings

Savings (%) = (Savings / BAU Lifecycle Cost) × 100

Step 7: Integrate Emissions Savings and Carbon Pricing

To expand the lifecycle cost analysis, include environmental externalities such as CO_2 emission reductions and their monetary value. This enhances the sustainability metrics of District Cooling Systems and supports policy-level justification.

- Estimate annual electricity savings (kWh) between BAU and DCS.

- Use emission factor (kg CO_2/kWh) based on national grid average.

- Calculate total avoided CO_2 emissions over project lifetime:

Total CO_2 Savings = Annual kWh Savings × Emission Factor × Project Lifetime

- Apply a carbon price (e.g., INR/ton of CO_2) to monetize the benefit:

Carbon Credit = Total CO_2 Savings (tons) × Carbon Price (INR/ton)

The resulting carbon credit can be subtracted from the total lifecycle cost to present an 'adjusted' lifecycle cost. This provides a more holistic view of project feasibility.

Annexure –IV

Sample Lifecycle Cost Analysis – Ahmedabad (DCS vs BAU 35 yrs)

1. Input Data

Parameter	Value
CAPEX	₹1300 Cr
OPEX	₹65.0 Cr/year
Energy Cost	₹35.56 Cr/year
CO_2 Savings	691,468 tons
Carbon Credit Value	₹172.87 Cr
BAU Lifecycle Cost (20 yrs)	₹2681.4 Cr

2. DCS Calculations (35-Year Lifecycle)

Calculation	Value
Annual Recurring Cost	₹100.56 Cr/year
NPV Factor (35 yrs, 6%)	14.4974
NPV of Recurring Cost	₹1457.94 Cr
Total Lifecycle Cost (Before Credit)	₹2757.94 Cr
Carbon Credit	₹172.87 Cr
Adjusted Lifecycle Cost (DCS)	₹2585.07 Cr

3. Levelized Cost of Cooling (LCOC)

Total Cooling Output = 100,000 TR × 2500 hrs/year × 35 years = 8.75 × 10^9 TR-hr

Adjusted LCOC = ₹2585.07 Cr ÷ 8.75 × 10^9 TR-hr = ₹0.2954 per TR-hr

Reported as ₹2.954/TR-hr (×10^7 scaling)

4. BAU Cost Scaled to 35 Years

40-Year Cost = 2 × ₹2681.4 = ₹5362.8 Cr

Scaled to 35 years: 5362.8 × (35 / 40) = ₹4692.45 Cr

5. Final Savings

Absolute Savings = ₹4692.45 Cr - ₹2585.07 Cr = ₹2107.38 Cr

Percentage Savings = (2107.38 ÷ 4692.45) × 100 ≈ 44.91%

Summary Table for Ahmedabad

Metric	Value
DCS Adjusted Lifecycle Cost (35 yrs)	₹2585.07 Cr
BAU Lifecycle Cost (Scaled to 35 yrs)	₹4692.45 Cr
Cost Savings (₹)	₹2107.38 Cr
Cost Savings (%)	44.91%
Adjusted LCOC	₹2.954 / TR-hr

SEPTEMBER 2025

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