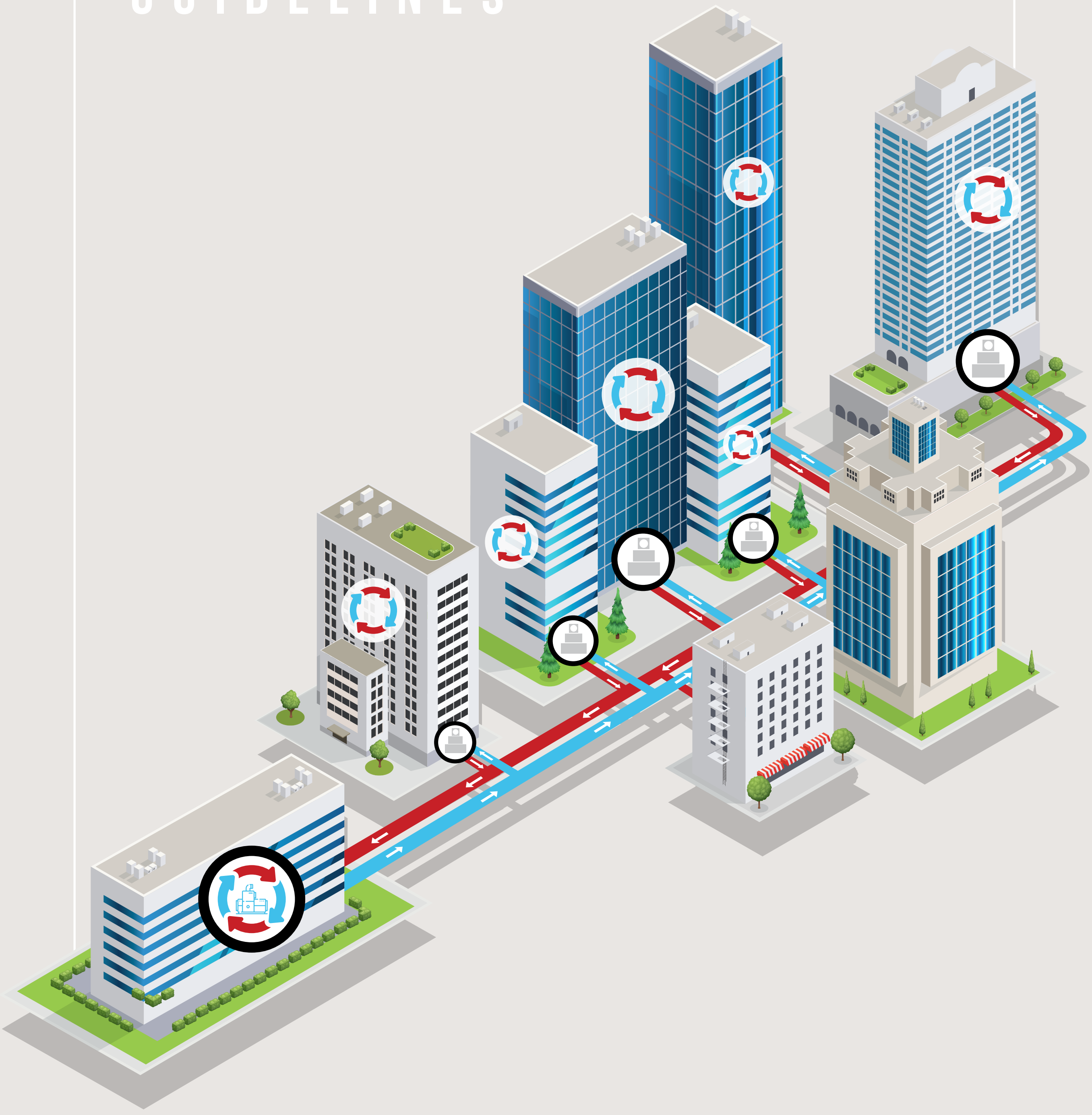
On behalf of
Federal Ministry
for Economic Affairs
and Climate Action
of the Federal Government of Germany

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

DISTRICT COOLING

GUIDELINES



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BEE
Energy is Life, Conserve it

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DISTRICT COOLING GUIDELINES

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सत्यमेव जयते

Azadi Ka Amrit Mahotsav

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(विद्युत मंत्रालय, भारत सरकार)
BUREAU OF ENERGY EFFICIENCY
(Ministry of Power, Government of India)

Foreword

Cooling requirement is cross sectoral and an essential part for economic growth. The cooling demand is set to rise in the future. Addressing the rising cooling requirement is both a challenge as well as a unique opportunity, necessitating synergies in policies and actions to address the cooling requirement across sectors even while making cooling sustainable and accessible to all.

In addition to various policy interventions undertaken by the Government to tackle the growing energy demand from current technologies, alternate cooling technologies need to be explored with an objective to achieve updated Nationally Determined Contributions (NDCs).

To combat the rising growing cooling demand while reducing its adverse environmental impacts, India Cooling Action Plan (ICAP) promotes the adoption and implementation of several not-in-kind cooling technologies including District Cooling Systems (DCS). DCS is an alternative to traditional standalone cooling system. It is a modern and efficient way to air-condition clusters of buildings in cities and on campuses with high cooling density.

DCS has entered the Indian market very recently and is proven to reduce GHG emissions and contribute in achieveing India's energy efficiency goals. One of the successful implementation of the DCS technology has already been demonstrated at the GIFT City, Ahemdabad.

In accordance with the directions of Governemnt of India, to foster the implementation of DCS, a document titled "District Cooling Guidelines" has been prepared with the joint efforts of Bureau of Energy Effciciency, Research & Development organisations, Academic Institutions, Experts, and Think tanks. This guideline provides complete information on various crucial aspects of installing a DCS technology covering planning, construction, business models, measurement, billing system and also outlines potential advantages of installing DCS in India.

This document will act as a guidebook for all stakeholders involved in making DCS, a utility in India. It also defines the possible roles and responsibilities of key stakeholders towards unlocking the District Cooling market potential in India. I appreciate the guidance and cooperation provided by each member of the committee involved in developing DCS Guidelines.

I hope this first step will initiate further dialogue and actions to help address the key challenges associated with District Cooling implementation in India including high initial investment, technical expertise, policy-level support, and favourable business and finance mechanisms.

I congratulate everyone for their valuable contribution in development of District Cooling Guidelines as this will pave the way for further action and would play a significant role towards democratising access to cooling in India.

स्वहित एवं राष्ट्रहित में ऊर्जा बचाएँ Save Energy for Benefit of self and Nation

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स्वच्छ भारत
एक कदम स्वच्छता की ओर

PREFACE FROM GIZ

India has increased its climate ambition through the Panchamrit Commitments made by Honorable Prime Minister Shri Narendra Modi at COP 26 held in Glasgow, UK. In addition, India's vision is to become a 5 trillion-dollar economy and has already surpassed several developed nations and now stands as 5^{th} biggest economy in the world. Balancing between mitigating the climate crisis and ensuring sustained economic development requires accelerating the energy transition and identifying advanced technologies and solutions for a climate-resilient and energy-secure future.

India has been one of the front runners in developing robust standards, policies and mechanisms for energy efficiency and reducing the energy demand. India has developed various successful policies to promote energy efficiency such as the Energy Conservation Building Code, the India Cooling Action Plan, the Standards and Labelling Programme and the PAT scheme. Almost 35% of the overall energy demand in India arises from the built environment, of which around 40% can be accounted for cooling. With the rise in temperatures, cooling will not be a luxury but a dire necessity. If thermal comfort is to be ensured for more than a billion lives in India and considering the fact that India has still very low access to cooling, cooling energy demand will increase exponentially. Thus, tackling the growing cooling demand is a priority for India.

Under the leadership of Shri R K Singh, Honorable Minister of Power & NRE, Government of India and supported by the Federal Ministry for Economic Affairs and Climate Action of Germany (BMWK), Shri Abhay Bakre, Director General, Bureau of Energy Efficiency with support from GIZ India initiated a project to promote sustainable and energy efficient cooling solutions that can contribute significantly towards accelerating the energy transition and enable economic and industrial development. District cooling was identified as one of the key technologies that, if scaled up, can reap multiple benefits of reducing the energy demand, supporting refrigerant transition in line with the Montreal Protocol and unlocking a new cooling service industry leading to multiple job creation. On top, district heating could use solar electricity only while thermal storage is so much cheaper and ease electricity peak demand of the country.

Alliance for an Energy Efficient Economy (AEEE), along with partners including KPMG, Danish Technical University (DTU), and United Nations Environment Program (UNEP), have been working together since 2021 to bring consensus amongst various stakeholders regarding the District Cooling technology and have developed a District Cooling Guideline for India.

The main objective of developing this guide was to provide overall guidance on all major aspects of District Cooling Systems (DCS) and create an information handbook to be used by a range of stakeholders, including state and city development authorities, developers and investors and provide a comprehensive reference document to those who wish to implement DCS in upcoming projects.

On behalf of the GIZ India team and the EE-Cool Project PMU, I thank the Ministry of Power & MNRE and Bureau of Energy Efficiency for their guidance and support. I hope this guideline will help initiate dialogues and actions to address the critical challenges associated with DCS implementation and upscale in India, support unlocking the potential of DCS and enable cooling as a service industry in India through innovative business models and finance mechanisms.

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The development of the District Cooling (DC) Guidelines has been a multi-stakeholder effort, with inputs from the Technical Committee members and individual subject matter experts, representing various Government Ministries/Departments/Organizations, industry associations, think tanks, academia, and research & development institutions.

The Bureau of Energy Efficiency (BEE) would like to acknowledge the role of the Project Management Unit (PMU) of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH led by Mr Markus Wypior of GIZ and Dr Satish Kumar of Alliance for an Energy Efficient Economy (AEEE). The key team members of the PMU involved in the development of these guidelines included Dr Bhaskar Natarajan, Mr. Akhil Singhal, Mr Sandeep Kachhawa, and Mr Vibhu Saxena from AEEE, Ms Sohini Ghosh Mukherjee from KPMG, India and Dr Zhuolun Chen from UNEP Copenhagen Climate Centre. Mr Tarun Garg, Ms Sneha Sachar, Mr Akash Vajpai, and Mr Gautam Nagar were part of the PMU team and are acknowledged for their support in preparing the initial draft of the DC Guidelines.

BEE would also like to acknowledge the active participation and invaluable contributions of the following organisations representing the Technical Committee.

- NITI Aayog
- Ministry of Housing and Urban Affairs
- Central Public Works Department (CPWD)
- Ozone Cell
- Department of Science and Technology (DST)
- Energy Efficiency Services Limited (EESL)
- Bureau of Indian Standards (BIS)
- Gujarat International Finance Tec-City (GIFT City)
- The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE)
- National Institute of Urban Affairs (NIUA)
- India Smart Grid Forum (ISGF)
- Refrigeration and Air-conditioning Manufacturers Association (RAMA)
- Confederation of Real Estate Developers' Association of India (CREDAI)
- Shakti Sustainable Energy Foundation
- United Nations Environment Programme (UNEP)
- CLASP
- Tata Power
- Indian Institute of Technology (IIT), Delhi
- Malaviya National Institute of Technology (MNIT), Jaipur
- Plaksha University, Mohali
- Centre for Environmental Planning and Technology (CEPT) University, Ahmedabad
- UNEP Copenhagen Climate Centre
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
- Alliance for an Energy Efficient Economy (AEEE)
- KPMG, India

The DC Guidelines benefitted immensely from the thorough review of multiple versions, excellent technical inputs and extensive edits provided by Mr Vijay Kumar Mattoo. Our sincere gratitude towards Mr Rajeev Sharma for providing the various operational details for the GIFT City DC System case study. The DC Guidelines also benefitted from the careful review of Mr Prabhat Goel who provided invaluable inputs on various key aspects related to DC design and operation. Various technical inputs received from the industry including Carrier, Danfoss, and Tabreed are duly acknowledged. Detailed review comments provided by UNEP during the development of guidelines are sincerely appreciated.

We recognise the contributions of the Foundation for ISHRAE team comprising Prof. Vishal Garg, Prof. Jyotirmay Mathur, Mr C. Subramaniam, Mr Srinivas Valluri, Mr Gaurang Patel, Mr Pramod Prabhakar, Mr Madhan Kumar K, and Mr Vikram Murthy who played a key role in editing the guideline, compiling a case study of an operational DC System in Hyderabad, and preparing normative references for the design and operation of various DC systems and equipment.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

°C	Degree Celsius
°F	Degree Fahrenheit
4DHG	4th Generation of Smart District Heating Systems
A1	Article 1
A5	Article 5
AC	Air Conditioner
ADB	Asian Development Bank
AEEE	Alliance For an Energy Efficient Economy
AHU	Air Handling Unit
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
BAU	Business as Usual
BEE	Bureau of Energy Efficiency
BESCOM	Bangalore Electricity Supply Company Limited
BFV	Butterfly Valve
BIS	Bureau of Indian Standards
BMS	Building Management System
BOD	Biochemical Oxygen Demand
BOT	Build-Operate-Transfer
BTU	British Thermal Unit
C2E2	Climate Change, Energy and Environment Commission
$CaCO_3$	Calcium Carbonate
CAPEX	Capital Expenditure
CBD	Central Business District
CCHP	Combined Cooling, Heat, and Power
CDD	Cooling Degree Day
CDM	Clean Development Mechanism
CDW	Condenser Water
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFC	Chlorofluorocarbon
CHP	Combined Heat and Power
CHW	Chilled Water
cm	Centimetre
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COP	Coefficient of Performance
COP26	Conference of the Parties 26
CPWD	Central Public Works Department
CSA	Customer Supply Agreement
CHWS	Chilled Water Supply
CHWR	Chilled Water Return
CT	Cooling Tower
CTI	Cooling Technology Institute
CUF	Capacity Utilisation Factor
DBEIS	Department for Business, Energy & Industrial Strategy
DC	District Cooling
DCC	District Cooling Company
DCICS	District Cooling Instrumentation and Control System
DCR	Development Control Regulations
DCS	District Cooling Systems
DDC	Direct Digital Controller
DES	District Energy Service
DEWATS	Decentralised Wastewater Treatment System
DG	Diesel Generator
DHC	District Heating and Cooling
DHS	Direct Heating System
DISCOM	Electricity Distribution Company
DLF	Delhi Land & Finance
DHW	Domestic Hot Water
DPR	Detailed Project Report
DR	Demand Response
EC Act	Energy Conservation Act, 2001
ECBC	Energy Conservation Building Code
EESL	Energy Efficiency Services Limited
EIA	Environmental Impact Assessment
EPC	Engineering, Procurement, & Construction
ESCO	Energy Service Company
ETP	Effluent Treatment Plant

ETS	Energy Transfer Station
FAR	Floor Area Ratio
FCU	Fan Coil Unit
FDI	Foreign Direct Investment
FM	Flow Meter
fps	Feet per Second
FSI	Floor Space Index
ft	Feet
FTU	Formazin Turbidity Unit
F-Gas	Freon Gas
GFA	Gross Floor Area
GHG	Greenhouse Gas
GHGP	Greenhouse Gas Protocol
GIFT City	Gujarat International Finance Tec-City
GIFTCL	Gujarat International Finance Tec-City Company Limited
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOM	Government of Maharashtra
GPCL	GIFT Power Company Limited
GWh	Gigawatt-Hour
GWP	Global Warming Potential
h	Hour
H_2O	Water
H_2O-NH_3	Water-Ammonia
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HT	High Tension
HVAC	Heating, Ventilation, and Air Conditioning
HX	Heat Exchanger
ICAP	India Cooling Action Plan
IDCP	Integrated District Cooling Plant
IDEA	International District Energy Association
IEA	International Energy Agency
ikW	Input Kilowatt
INR	Indian Rupee
IoT	Internet of Things
IRR	Internal Rate of Return
IT	Information Technology
km	Kilometre
km^2	Square Kilometre
kPa	Kilopascal
KPMG	Klynveld Peat Marwick Goerdeler
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-Hour
Li-Br	Lithium Bromide
LNG	Liquefied Natural Gas
LSI	Langelier Saturation Index
µS	Microsiemen
m	Metre
m^2	Square Metre
MBTUs	Million British Thermal Units
MF	Mutual Fund
mm	Millimetre
MoHUA	Ministry of Housing and Urban Affairs
MoEF&CC	Ministry of Environment, Forest and Climate Change
MRV	Measurement, Reporting, and Verification
MW	Megawatt
NA	Not Available
NBCC	National Buildings Construction Corporation
NCT	National Capital Territory of Delhi
NDC	Nationally Determined Contribution
NHAI	National Highways Authority of India
NPV	Net Present Value
O&M	Operations and Maintenance
ODP	Ozone Depleting Potential
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditure
PBT	Payback Time
pH Value	Potential of Hydrogen Value
PHE / PHEX	Plate Heat Exchanger
PIBCV	Pressure Independent Balancing Control Valve
PICV	Pressure Independent Control Valve
PID	Proportional Integral Differential
PLC	Programmable Logic Controller
PNG	Piped Natural Gas
PPA	Power Purchase Agreement
ppm	Parts per Million
PPP	Public-Private Partnership
PSU	Public Sector Undertaking
PV	Photovoltaic
RA	Rapid Assessment

RE	Renewable Energy
RES	Renewable Energy Source
RFP	Request for Proposals
RfS	Request for Solution
RH	Relative Humidity
ROI	Return on Investment
RTD	Resistance Temperature Detector
s	Second
S&L	Standards and Labelling
SD	Sustainable Development
SDG	Sustainable Development Goal
SPV	Special Purpose Vehicle
STP	Sewage Treatment Plant
T	Temperature
TCPO	Town And Country Planning Organisation
TDS	Total Dissolved Solids
TES	Thermal Energy Storage
TFA	Trifluoroacetic Acid
TR	Tonne of Refrigeration
TR-h	Ton hour of Refrigeration
TSE	Treated Sewage Effluent
TSS	Total Suspended Solids
TWh	Terawatt-Hour
UDA	Urban Development Authority
ULB	Urban Local Body
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States
USA	United States of America
USD	United States Dollar
V	Volt
VFD	Variable Frequency Drive
VGF	Viability Gap Funding
YST	Y Strainer

INDIA IS ONE OF THE FASTEST GROWING ECONOMIES IN THE WORLD, AND BY 2027-28, IT IS PROJECTED THAT IT WILL HAVE ABOUT 1.78 BILLION M^2 OF COMMERCIAL BUILDING FLOOR AREA

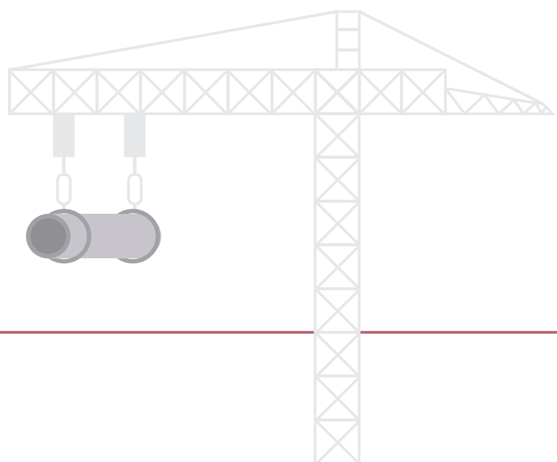
ABOUT THE
DISTRICT COOLING GUIDELINES

The objective of this document is to provide overall guidance on all major aspects of DCS related to scope, planning, construction, business models, and measurement and billing systems. This guide should act as an information handbook and is intended to be used by a range of stakeholders, including state and city development authorities, developers, and investors, as a comprehensive reference on district cooling (DC) system implementation. At the same time, this guide is not to be used as a design reference; normative references on technical specifications related to design aspects are provided throughout the document and should be accessed for design guidance.

This guide has been developed with the intent of defining DCS and identifying the associated potential benefits of implementing DCS in India. This guide provides information on DC system technology and associated benefits, key DC system components, and operations and maintenance (O&M) requirements. The guide strives to capture the roles and responsibilities of stakeholders involved in decision-making throughout the different stages of the DC project cycle, such as project planning, execution & operations, and evaluation. Furthermore, the guidelines provide information on the relevant DC system business models that have been successfully applied globally.

This document aims to:

1. Define the DCS specific to India's context, and its associated environmental, societal and economic benefits
2. Provide an overview of the key DC system components and technologies
3. Present information on different stakeholders' roles and level of involvement
4. Discuss the selection criteria and prerequisites for a DC project
5. Provide information on the different project development cycle stages
6. Discuss the economics of DCS, business models, and enabling mechanisms
7. Present bidding choices that can be adopted for the execution of DC projects
8. Recommend state-level actions that can be adopted to promote DCS.



The development process of the DC Guidelines took into account documents prepared by key associations dealing with heating, ventilation, and air conditioning (HVAC) and DCS, such as American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) and International District Energy Association (IDEA), respectively.

The guidelines should be read along with the following complementary documents, which include best practice guides, standards, and codes:

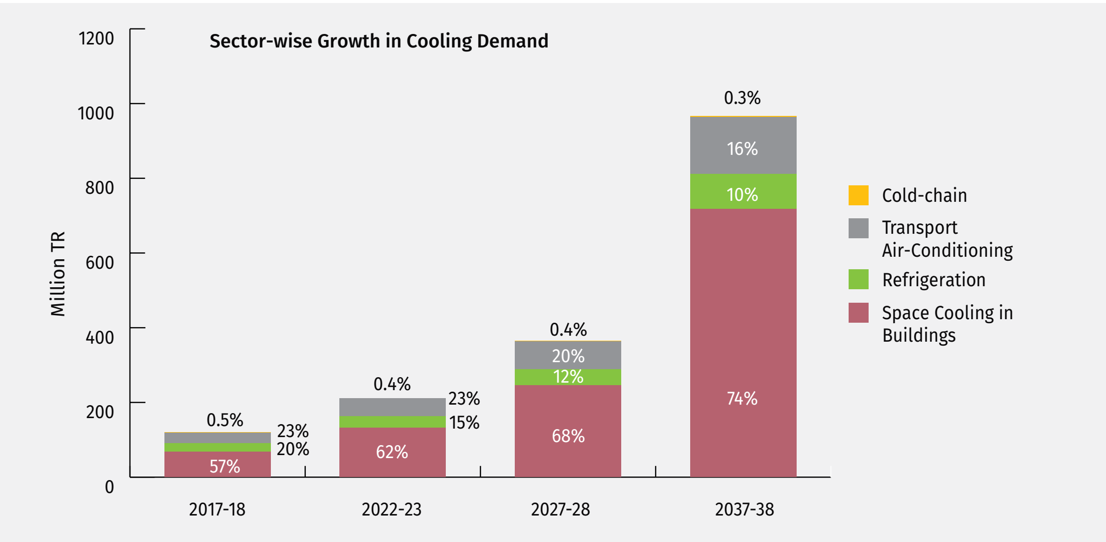
- ASHRAE District Cooling Guide, Second Edition – for technical specifications wherever mentioned in the report
- ASHRAE Owner's Guide for Buildings Served by District Cooling – for building owner-specific information wherever mentioned in the guidelines
- Bureau of Energy Efficiency's (BEE) Energy Conservation Building Code (ECBC) 2017 – for equipment selection and specifications
- BEE's Standards & Labeling (S&L) Programme Manual – for performance-specific standards of electrical equipment
- IDEA District Cooling Best Practice Guide – for detailed and comprehensive information on DCS.

In addition, the work carried out under the District Energy in Cities Initiative by United Nations Environment Programme (UNEP) and Energy Efficiency Services Limited (EESL) has also provided valuable insights and information that have been referenced throughout this guide.

1 OVERVIEW OF DISTRICT COOLING IN INDIA

The requirement for comfort cooling is increasingly recognised as a development need worldwide, especially in meeting the Sustainable Development Goals (SDGs), SDG 3 on good health, SDG 7 on energy access, and SDG 8 on decent work and economic growth. However, the growth in cooling demand is also driving an increase in electricity consumption and is thus linked to SDG 7 on affordable and clean energy and critically affecting efforts to meet SDG 13 on taking urgent action to combat climate change and its impacts. The criticality of addressing India's space cooling challenge becomes even more apparent against the backdrop of international climate change agreements such as the Paris Agreement and Montreal Protocol.

Figure 1: Sector Wise Growth in Cooling Demand (ICAP, 2019)



India is one of the fastest growing economies in the world, and by 2027-28, it is projected that it will have about 1.78 billion square metres (m^2) of commercial building floor area[1] and around 320 million units in housing stock. Moreover, with a population of 1.3 billion, over 3,000 annual cooling degree days (CDDs), and 5-10% air conditioner (AC) penetration, it is very vulnerable to the impacts of rising and extreme temperatures. Increasing urbanisation and resulting cooling demand, coupled with the urgent requirement to meet climate targets, necessitate the promotion of sustainable space cooling solutions driven by institutional and policy support.

In March 2019, India escalated cooling opportunities and challenges to a national priority level through the India Cooling Action

1 Satish Kumar et al., "Estimating India's Commercial Building Stock to Address the Energy Data Challenge," *Building Research & Information* 47, no. 1 (January 2, 2019): 24–37, https://doi.org/10.1080/09613218.2018.1515304.

Plan (ICAP) – a flagship initiative of the Ministry of Environment, Forest & Climate Change (MoEF&CC). As per ICAP[2], the building sector's cooling demand shows the most significant projected growth, at nearly 11 times the 2017-18 baseline by 2037-38, as depicted in Figure 1. The energy consumption from space cooling in buildings is estimated to be ~135 terawatt-hours (TWh) in 2017-18. Projections show that this will increase up to 4 times (~585 TWh) over the next two decades. Moreover, in 2021, during the Conference of the Parties 26 (COP 26), India further heightened its climate pledges, committing to becoming Net Zero by 2070 and declaring enhanced national determined contributions (NDCs) with respect to energy intensity and carbon emission reduction. Furthermore, India ratified the Kigali Amendment to the Montreal Protocol in August 2021, wherein India agreed to phase down hydrofluorocarbon (HFC) production and consumption from 2032 until 2047.

The current push towards climate action and net zero commitments calls for abatement of greenhouse gas (GHG) emissions, meaning that sustainable solutions to meeting the rising cooling demand are required. In India, DCS provides opportunities for reducing energy demand by 6100 megawatts (MW) and annual energy savings of around 7850 gigawatt-hours (GWh), leading to an annual reduction of 6.6 million tonnes of annual carbon dioxide (CO_2) emissions up to 2037[3]. DCS has huge potential to help smoothen the cooling-related electrical load curve and defer the addition of power generation capacity to meet peak demand. Furthermore, DCS provides possibilities for sector coupling approaches, integration of renewable energy sources, and the use of environmentally friendly low global warming potential (GWP) refrigerants. Therefore, DCS is increasingly generating interest among policy makers and regulators across India.

1.1 INTRODUCTION TO DISTRICT COOLING SYSTEMS

The concept of district cooling was introduced in the 1800s when plans were made to distribute clean, cold air to buildings through underground pipes. However, it was not until the 1960s that the first DC system was installed in the USA in a non-residential area. Subsequently, Europe's first DC system was introduced in 1967, in Paris, supplying heating and cooling as a service to the La Défense office complex. Currently, the largest DC plant in operation, called the Integrated District Cooling Plant (IDCP) and commissioned in Qatar in 2010, serves a cooling demand of 130,000 tonnes of refrigeration (TR) and provides chilled water to a cluster of buildings[4].

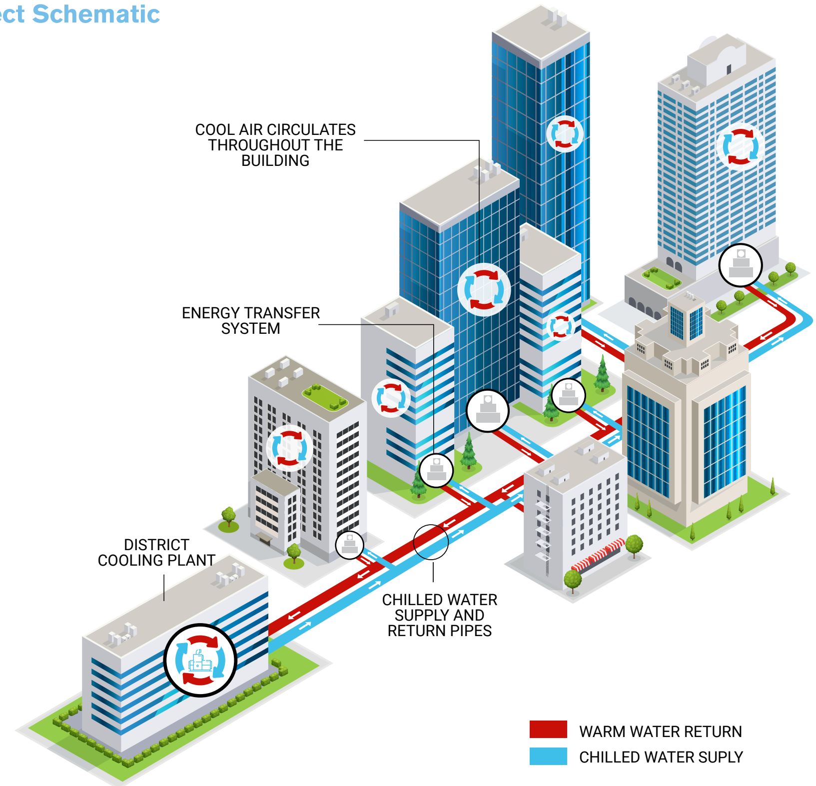
In India as well, there have been DC pilot projects such as Gujarat International Finance Tec-City (GIFT City), which is being developed on 886 acres of land with a planned built-up area of 62 million square feet, including commercial, residential, and community buildings such as hotels, clubs, malls, and hospitals. It has a total demand of 270,000 TR, which will be met by a plant with 180,000 TR capacity when the DC system is fully installed, which is expected to reduce the power demand by 150 MW. As of 2022, only 10,000 TR of chilled water system, augmented by 10,000 TR-hours (h) of thermal energy storage (TES), has been installed in the GIFT City. Apart from this, some mega projects having large chilled water plants ranging from 5000 TR to 20,000 TR upwards, such as international airports, information technology (IT) campuses, educational institutions, and hospitals, both in the private and public sectors have also come up in India.

1.2 ABOUT DCS

DCS use a network of subterranean pipes to deliver cooling capacity in the form of chilled water or another medium from a central source to numerous buildings for use in space and process cooling[5]. It is the modern and efficient way to air-condition clusters of buildings in cities and on campuses. In a district cooling system, a large central plant produces chilled water for supply to multiple buildings through an insulated closed-loop underground piping network. Traditional AC systems create over 50% of a building's peak electricity demand, usually at peak cost[6]. With district cooling, peak demand on the grid, as well as operating energy consumption, decreases. It also avoids the capital costs of installing chillers and cooling towers and associated mechanical and electrical equipment at the building level and frees up valuable rooftop and building space. By aggregating the cooling needs of multiple buildings, district cooling generates

2 MoEF&CC, "India Cooling Action Plan," 2019, http://ozonecell.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf.
3 UNEP's District Energy in Cities Initiative, "National District Cooling Potential Study for India," 2021.
4 FlowCon International, "District Cooling Plant, Qatar Pearl", 2016.
5 Werner, S. (no date) District Cooling System, District Cooling System - an overview | ScienceDirect Topics. Available at: https://www.sciencedirect.com/topics/engineering/district-cooling-system (Accessed: November 15, 2022).
6 Ibrahim Dincer and Azzam Abu-Rayash, "Community Energy Systems," in *Energy Sustainability* (Elsevier, 2020), 101–18, https://doi.org/10.1016/B978-0-12-819556-7.00005-X.

Figure 2: DC Project Schematic



economies of scale. The system can serve a single user for captive use such as in airports, campuses, malls, hospitals, etc., or the service provider can provide cooling to multiple types of buildings together, e.g. in high-density commercial developments, hospitals, schools, residential buildings, etc.

DCS can utilise renewable energy sources (RES) and excess energy from entropic processes, significantly contributing to the decarbonisation of the heating and cooling sector. A DC system usually makes use of TES to meet peak cooling demand during warm summer days. Thus, in the future, DCS will offer increasingly valuable flexibility to the electricity grid, which makes them economically appealing and attractive from a national and regional energy planning perspective.

The application and size of DCS can vary significantly, from covering multiple buildings in a region to a whole city. DCS can cater to a wide variety of customers, including the commercial, residential, public, and industrial segments. DCS are generally commercially viable for both greenfield and brownfield developments when there is a high density i.e. high cooling requirement (TR) per square kilometer (km) of the built space as well as high diversity i.e. non-coincidence of cooling loads.

In India, DCS finds applicability in:

1. Mixed-use development or redevelopment projects with residential and commercial (offices, retail, hotels, hospitals, convention centres, entertainment) spaces
2. Large infrastructure projects such as aero cities (including airport terminals, logistics and other commercial facilities) and industrial clusters such as pharma cities, etc.
3. Campuses of large educational institutions with academic and hostel blocks
4. IT parks with offices, call centres, data centres, etc., and
5. Smart city projects and other similar real estate or industrial development projects.

Different organisations and countries have modified the definition of DCS by introducing terms depending on their local context & applicability and understanding of the solution:

ASHRAE defines DCS as "a concept of providing and distributing, from a central plant, cooling energy to a surrounding area (district) of tenants or clients (residences, commercial businesses, or institutional sites)." [7]

China defines DCS as "one cooling network, distributing chilled water to more than one building." [8]

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7 Steve Tredinnick, Gary Phetteplace, and P Brian; Kirk, *Owner's Guide for Buildings Served by District Cooling* (ASHRAE, 2019).

8 Asian Development Bank. (2017). District Cooling in the People's Republic of China: Status and Development Potential. https://doi.org/10.22617/RPT168582-2

UNEP describes the process in the following way: "A district cooling system distributes (supplies and collects back) cooling energy in the form of chilled water from a central district cooling plant to multiple buildings through a distribution network of insulated, underground pipes for space and process cooling. Individual users purchase chilled water for their own building from the operator of the district cooling system and do not need to install their own chillers or cooling towers. A district cooling system varies significantly in size globally from serving multiple buildings to serving an entire city."[9]

For India, a succinct definition of DCS has been developed with inputs from the Technical Committee constituted in India to look at DC implementation:

> **"One single cooling network, distributing chilled water to a cluster of buildings as a self-sustaining service"**

Since it is a single cooling network that is operated as a service, the chilled water service provider shall be called the "district cooling service provider". Several benefits can be achieved through the use of DCS. DC through the service provider can also be an enabler for creating job opportunities and aggregating efficiency gains and various societal benefits beyond just monetary gains, as discussed in the following section.

1.3 BENEFITS OF DCS

In order to meet India's climate commitments, fossil fuel-based cooling energy consumption needs to be reduced. A district cooling system can also be viewed as a public service, alongside piped natural gas (PNG), electricity, and water. Thus, there is a business case for utilities and service providers who want to provide cooling as a service. As mentioned above, DC service providers can cater to a variety of end-users, and DCS can be developed at different scales. DCS provide several economic benefits to end-users, including reduced capital and operating costs, less frequent maintenance, space savings, and lower electricity usage than in more traditional AC systems.[10] DCS offer the unique advantage of making use of diversity factors of cooling loads in multiple buildings in a cluster and ensure that the cooling systems can operate at maximum efficiency over the complete load profile of space cooling requirements, in contrast to individual smaller systems that operate at reduced efficiency. In addition, DCS are large-scale new infrastructures, that require a specialised team and skill deployment. In addition, DCS are large-scale systems that require a labour pool and could lead to local job creation and skill deployment. In general, there are benefits of DCS for society, project owners, and service providers that can be categorised into environmental, social, and economic benefits, as shown in Figure 3:

Figure 3: District Cooling System Benefits

ENVIROMENTAL

- Energy saving
- Peak energy demand reduction
- Carbon and GHG emission saving
- Enabling transition to low or zero GWP refrigerants
- Water conservation
- Improved micro-climatic conditions by reduced urban Heat Island Effect
- Improved Air quality

SOCIETAL

- Enhanced aesthetics
- Local business devlopment
- Skill Development and improved employability
- Security of supply for cooling
- Access to affordable cooling for achieving thermal comfort
- Improved quality of life
- Reduced noise from cooling equipment

ECONOMIC

For DCS service providers/investors:

- New business venture with competitive advantage
- Long-term stable and profitable revenues
- Employment generation Avoided investments in summer electricity peak production, transmission, and distribution Higher energy and resource utilisation\

For end-users of DCS:

- Avoided CAPEX and space requirement for cooling equipment like chillers and cooling towers and related costs
- Reduced O&M cost

9 UNEP's District Energy in Cities Initiative, "National District Cooling Potential Study for India," 2021.
10 Steve Tredinnick, Gary Phetteplace, and P Brian; Kirk, *Owner's Guide for Buildings Served by District Cooling* (ASHRAE, 2019).

1.3.1 Environmental Benefits

DCS are designed and installed more efficiently than traditional systems, thus resulting in higher energy savings, reduced energy demand, and enhanced energy and resource utilisation, which impacts the financial investments in infrastructure and thus generates economic benefits. However, there are several other environmental benefits beyond energy efficiency:

Supporting the refrigerant transition

Cooling involves some form of refrigeration to extract heat from the working fluid (chilled water), which is distributed to provide cooling to the end-user and requires refrigerant. Early in the history of refrigeration, refrigerant fluids were naturally occurring compounds such as ammonia, and in certain specialised applications, these remain in use today. Then, to better serve a wider range of applications efficiently and safely, several chemical compounds were developed to serve as refrigerants. However, many of the refrigerants were found to have high ozone-depleting properties and contribute to global warming. One of the solutions identified over time was to transition to refrigerants with zero ozone depleting potential (ODP) and low GWP (e.g. natural refrigerants). The issue with this approach is that some of these refrigerants operate at a higher temperature or have safety concerns, which limits their use in the business-as-usual (BAU) scenario. Nonetheless, DCS can support the transition to natural refrigerants and thus reduce direct and indirect GHG emissions throughout the project lifecycle. A study estimates that in India if DCS are deployed to their full potential, it can lead to a reduction of approx. 1100 tonnes refrigerant consumption[11].

DCS will also help in limiting the 'Refrigerants' to a place away from the buildings and thus improving the possibility of using mildly inflammable refrigerants and in some places allowing Propane and Ammonia to be considered safely. Refrigerant removal and storage units also reduce the additional refrigerant quantity used during the service life of the chillers.

Water Savings

In the present scenario, individual building-level chiller plants mostly use recycled treated water from the Sewage Treatment Plants (STP) or Effluent Treatment Plants (ETP) and any shortfall is augmented with borewell /municipal water. This may lead to significant fresh water usage. To address this, DCS can be designed to use recycled water from sewage treatment plants (STPs) or effluent treatment plants (ETP) or decentralised wastewater treatment systems (DEWATS)[12].

According to a UNEP report[13] under an optimistic scenario, a DCS installed capacity of 12.57 million TR cooling capacity can potentially save approximately 78850 million litres of water by the year 2037-38 if installed at full capacity across India. Considering the water shortages across the country, as well as globally, this is a significant amount and will contribute towards a more sustainable future.

Enabling the transition to alternative lower climate impact technologies

- DCS may also take advantage of technologies that are often out of reach for onsite installations. For example, TES, which is often included in DCS, decreases the electricity expenditure associated with the increased refrigeration capacity required at on-peak times by shifting cooling production to off-peak times. Free cooling can significantly reduce a plant's electricity demand, assuming the ambient conditions are compatible.
- In certain settings, the ability to use seawater or fresh surface water for heat rejection directly can also be deployed, although subject to applicable laws. Furthermore, in some instances, deep sea water or deep fresh surface water if available at 8°C and below can be utilised to provide cooling directly without the use of refrigeration equipment (also subject to local laws), thus greatly reducing electricity demand and consumption. For example, deep sea/lake cooling is possible with water sourced at relevant depths after checking the hourly temperatures of water year-round to determine the feasibility These conditions exist in coastal areas of the Middle East on the Arabian/Indian sea, the Red Sea, and the Mediterranean, but not the Gulf, where depths are only 300 to 400 ft (90 to 120 m)[14].
- Large central plants, including those that also produce district heating, can, in certain situations, generate cooling from a heat source through a process known as absorption refrigeration. Waste

11 UNEP's District Energy in Cities Initiative, "National District Cooling Potential Study for India," 2021.

12 DEWATS is a technical approach to wastewater treatment in developing communities. The passive design uses physical and biological treatment mechanisms such as sedimentation, floatation, and aerobic and anaerobic treatment to treat both domestic and industrial wastewater.

13 UNEP's District Energy in Cities Initiative, "National District Cooling Potential Study for India," 2021.

14 District Cooling Guidelines, ASHRAE

heat from industrial processes or electric power generation, along with geothermal energy, is a potential energy source for heat-driven refrigeration. Such heat sources are much easier to use on the scale of a district cooling system, as opposed to the smaller, building-level cooling equipment.

- In addition, DCS also can use recycled treated water from sewage effluent as cooling tower makeup water. Municipalities can be involved in providing recycled water/raw sewage for in-house treatment to overcome any shortage in make-up water. This can also help in initiating water circularity initiatives for cities.
- The disposal of used compressor oil is possible in a more environment-friendly manner with professional O&M in DCS. Under poor O&M conditions with no accounting for used oil, it usually ends up in drains ultimately polluting water bodies.
- The cooling towers bleed-off which contain harmful chemicals can be disposed of in an environmentally conscious manner with DCS. The cooling tower bleed-off can be used for washing hard surfaces thus promoting evaporation and avoiding percolation into the ground.

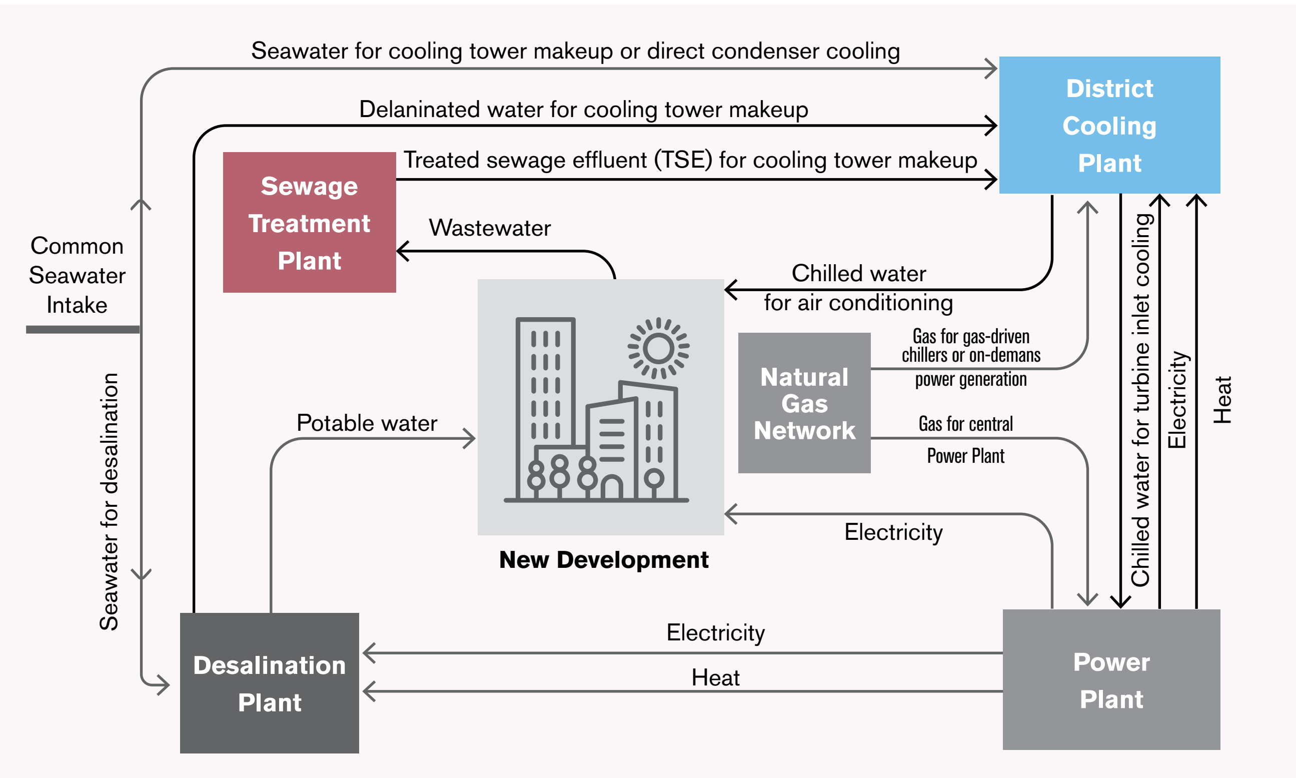
1.3.2 Societal Benefits

DCS can help eliminate dependence on individual/standalone room air conditioners (RACs) at the building level, which generates the urban heat island effect, and thus improve the air and environmental quality and overall microclimatic conditions, while simultaneously contributing to increasing the aesthetic value of the community/district. In addition, establishing a DC system can lead to local business development, skill development and improved employability of community members. Switching to DCS can also help ensure uninterrupted cooling supply at affordable prices to end-users, enabling improved quality of life. Lastly, it shall also help in reducing the noise from the outdoor units, cooling towers and other cooling equipment.

Heat island effects

In general, the use of air-cooled chilled water systems in residential/commercial buildings which create massive urban heat island effects. DCS can substantially reduce these hot pockets closer to the built space. With water-cooled chilled water systems at a centralised location farther away from the built environment, DCS will avoid the adverse impacts of distributed air conditioning on the micro-climate, thereby providing much better environmental conditions. Furthermore, DCS provide

Figure 4: Options for Utility Integration



(Source: IDEA. 2008. District cooling best practices guide. International District Energy Association)

unparalleled reliability of chilled water supply due to equipment redundancy and the high level of operational supervision and maintenance, thus ensuring uninterrupted cooling services to end-users, with high uptime.

1.3.3 Economic Benefits

There are several economic benefits of DCS for service providers/investors, as well as end-users, recognised across the world. Many economic as well as environmental benefits can be drawn from integrating planning for energy and water utilities. While there can be multiple options for potential utility integration, as depicted in Figure 4, not all will be applicable for all scenarios.

The other major economic benefits of the DCS are listed below:

New investment opportunities

For businesses and investors, DCS can be a new business venture with a competitive advantage, as there are very few entities that provide cooling as a service with long-term and stable revenue. Furthermore, it also enables the service providers to avoid investments to meet summer peak loads and enhanced energy utilisation. It also leads to betterment of economic conditions in the region, as it generates employment in the community/district. As per EESL's report on district cooling potential in India, the technology could bring in Indian Rupee (INR) 13.5 billion in investment by 2037-38 for 300 new plants.

Capital cost benefits

The most significant capital cost savings associated with DC come from the elimination of high-side equipment costs at the building level for end-users for cooling provision. This includes chillers, cooling towers, pumps, water treatment systems, and other electrical infrastructure. In addition, the space that the high-side equipment would occupy can be used by end-users for other purposes.

Furthermore, in-building chiller plants require significant electrical power, and to provide it, the service utility usually imposes bulk electricity charges, and additional charges are imposed on the building owners. Moreover, there is electrical switchgear required for the chillers, pumps, and cooling tower fans, whose cost can be eliminated for the building owner when DC is chosen for the building. In addition to the direct cost offsetting benefits, DCS provide indirect cost benefits such as a reduction in the required installation time for building-level cooling infrastructure.

For buildings that have critical cooling needs, such as data centres or medical facilities, redundancy of chilled water generating equipment is required, further increasing the system cost to ensure the uninterrupted operation of the building. When DC is chosen, all of the required redundancy is provided by the DC service provider, who is able to do this at a much lower cost than a building owner, as their central plants have multiple chillers, cooling towers, pumps, etc. to meet the varying demand of the DC system's aggregated customer base, thus yielding high levels of reliability in the supply of chilled water.

Standby requirements for electrical equipment can also be eliminated in the case of DCS. The diesel generator (DG) sizing can be significantly reduced in the buildings, resulting in benefits like savings in terms of space and associated infrastructure. Along with that, electrical infrastructure can also be downsized. Modular expansion of chiller capacity can be facilitated through the integration of easy plug & play systems to cover the additional required capacity.

The large chillers typically used in DCS come with High Tension (HT) motors for running the compressors. This eliminates many step-down transformers and also reduces cabling costs.

Operating cost benefits for end-users

One of the most significant operating cost advantages of subscribing to a DC service is typically the shifting of the cost to the system operator of operating the in-building chillers, pumps, and cooling tower fans to just paying for the required amount of cooling, similar to PNG or electricity. The difference for the DC system operator lies in the economies of scale, increased equipment efficiency for larger equipment, and being able to closely match the load while operating equipment at near-maximum efficiency. Second only to energy cost savings is the savings from reducing the number of qualified building O&M staff. This includes not having to deal with additional employee costs such as workplace safety and training, which for an in-building chiller plant may be entirely foreign to the building owner's existing employees.

In addition, during the building life cycle, it is normally necessary to replace equipment that has been provided to generate chilled water on site—the major items are chillers, cooling towers, and pumps. The life of this equipment can be less certain, especially when maintenance practices are not optimal, and significant costs may be incurred that cannot be scheduled with any degree of certainty. With DC, future costs can be contractually set, taking most of the uncertainty out of the significant building operating expenditure (OPEX) required for cooling. The end-user will still need to maintain their side of the HVAC system on an ongoing basis. This includes diligent inspection, maintenance, and housekeeping, primarily of airside heat transfer surfaces (coil fins, pumping and control at the building level, etc.), upkeep of HVAC filters, and tertiary pumping system and controls in the case of multiple/ high-rise buildings. However, these maintenance costs can be eliminated by drawing up a contract with clauses that include provisions supporting the maintenance of end-user HVAC systems.

In order to realise the benefits associated with DCS, it is essential to understand the key DC system components and align key stakeholders towards a common goal of DC system implementation in greenfield and brownfield projects in India. Information on key components and stakeholder roles and responsibilities in DC system implementation are covered in the subsequent chapters.

2 KEY COMPONENTS OF DCS

A DC system is a centralised cooling system consisting of an underground insulated pipe network filled with chilled water (CHW) and cooling sources (chillers or residual heat). The chilled water is circulated by pumps from the cooling plant to the users and then back again to the cooling sources through a distribution network. A typical DC system comprises the following key components:

District Cooling Plant (DCP)

to generate, and many times store as well, chilled water and reject heat into the surroundings

Distribution Network

to distribute chilled water to buildings through insulated chilled water piping

Energy Transfer Station (ETS)

interface with buildings' AC circuits which depending upon the scale of the project, may include heat exchangers and tertiary chilled water pumping network on the customer side

Instrumentation, Monitoring, and Control System

to monitor and control the entire DC system

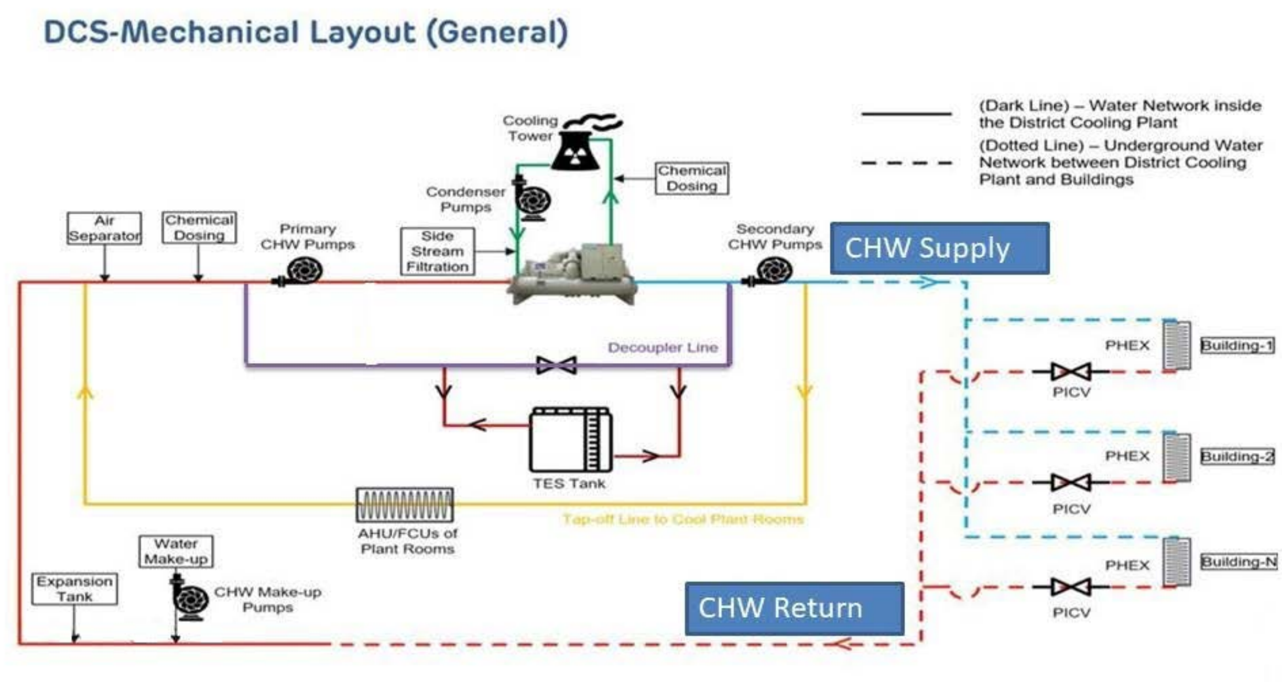
Measurement and Billing System

to measure the cooling energy generation and associated energy expenditure at the DCP, and cooling energy consumption at the customer's end to generate cooling bills.

Normative references covering various relevant national and international codes, standards, and guidelines are provided in Chapter 10 for reference on the design, selection, and operation of various DCS and equipment.

Figure 5 below depicts the general layout of a DC system.

Figure 5: General DC System Layout



2.1 DISTRICT COOLING PLANT

The primary function of a District Cooling Plant (DCP) is to generate chilled water to provide the cooling services. It includes chillers, cooling towers (heat rejection), chilled water (CHW) and condenser water (CDW) pumping, and other auxiliary systems including air separators and filtration systems. TES to augment the chiller capacity also forms an integral part of the DCS, especially to utilise the benefits of differential tariff wherever available. TES details are provided in Chapter 5.

2.1.1 Chiller

The chiller is the main driving force of a DC system; it enables the transfer of energy from a low temperature (chilled water temperature) to a high-temperature sink (usually surroundings). This energy transfer is done mainly via vapour compression (and can also be achieved through the use of vapour absorption or a mix of systems to achieve optimal efficiencies depending upon the energy sources available), which is achieved through various methods depending upon the type of energy available, cost, and CHW temperature requirement.

DCS typically utilise chillers with high delta temperatures (T) of 9°C and upwards. For higher capacity DCS, high delta T of series and counter flow configurations are preferred. This ensures high operational efficiency for the chiller, as well as the entire system.

Chillers can be categorised as vapour compression or vapour absorption/adsorption types. Vapour compression chillers use an electrically driven mechanical compressor to force a refrigerant around the system. These are the most common types of chillers. These chillers are further classified into various categories based on heat rejection and compression technologies, as described below.

Classification based on heat rejection

Chillers can be classified as either air-cooled or water-cooled. The working principle for both air-cooled and water-cooled chillers is the same. The only difference is that with an air-cooled chiller, heat is expelled into the air using fined tube heat exchangers, whereas in water-cooled chillers, heat is expelled into water in a shell and tube heat exchanger (HX). In a water-cooled chiller, (condenser) water carrying the expelled heat from the chiller is further cooled in a cooling tower. The pros and cons of water- and air-cooled chillers are given below in Table 1.

Table 1: Pros and Cons of Water- and Air-Cooled Chillers[15]

Water-cooled chillers	Air-cooled chillers
Pros	
These are more efficient, especially for large cooling loads due to a lower pressure difference across the compressor. Water also has a higher heat capacity than air, leading to a relatively smaller condenser size. For water-cooled chillers, the ambient air wet-bulb temperature is the limiting condition for condensing temperature, whereas air-cooled chillers have the ambient air dry bulb temperature as the limiting condition. On dry summer days in India, this can lead to an advantage of a 15-20°C lower condensing temperature for water-cooled chillers. Water-cooled chillers are more compact than air-cooled chillers and can be accommodated in covered utility areas. However, it should be noted that the cooling tower does require additional outdoor space. These may last longer, because they operate under more controlled conditions and are often installed inside the building and protected from weather effects.	Air-cooled chillers cost less to install because they have fewer components. Air-cooled chillers do not require any water and are therefore ideal in a scenario where water availability and cost are significant constraints. Air-cooled chillers do not require makeup water, which is an essential requirement for the operation of cooling towers associated with water-cooled chillers. Hence, they are preferred over water-cooled chillers where there is water scarcity. Air-cooled chillers are installed outdoors and hence do not require covered space for installation. The indoor space saved can be used for other purposes. Air-cooled chillers require less maintenance compared to water-cooled chillers, as there is no cooling tower or water pumps.
Cons	
These use cooling towers and require a constant supply of treated makeup water. If the chiller is going to be installed in an area with water restrictions, then this type of chiller is not advised. Water-cooled chillers are located inside the building and are very large machines, so depending on the compressor technology used, they can create a lot of noise and vibration inside the building, which is why they are usually located in the basement. Water-cooled chillers cost more to install and maintain. Water-cooled chillers take up space within the building; they need a mechanical plant room, more pumps, cooling towers, and water treatment. This space can therefore not be used for commercial purposes.	Air-cooled chillers sit outside the building, and their fans and compressors create noise that surrounding areas might be able to hear, although certain measures can be implemented to mitigate this issue. This noise should be compared to the noise generated by cooling tower fans and pumps in air-cooled chillers. Air-cooled chillers typically do not have as long of a service life as water-cooled chillers, because they are exposed to the sun, rain, and wind, which deteriorate the materials. Air-cooled chillers have a larger footprint and hence require substantial open space, either on the ground or terrace. Air-cooled chillers lose their effectiveness due to clogging of fins and the possibility of fin corrosion. Their energy efficiency is poor compared to that of water-cooled chillers. The operating life of air-cooled chillers is much less than water-cooled chillers.

15 Paul Evans, "Chiller Types And Application Guide - The Engineering Mindset," The Engineering Mindset.com, 2018, https://theengineeringmindset.com/chiller-types-and-application-guidelines/.

Classification based on compression technologies

Vapour compression chillers suitable for DC application come with either screw or centrifugal compression technology, both of which are summarised in Table 2.

Table 2: Different types of compressor technologies suitable for DCS

Centrifugal chiller	Screw chiller
• Mostly water-cooled	• Air or water-cooled chillers
• Used in medium to large cooling loads	• Used in small to medium cooling loads
• Typically available in 150-6,000 TR cooling capacities[3]	• Typically, 70-600 TR, 250-2,100 kW3
• Water-cooled coefficient of power (COP) of 5.8-7.1 (values vary depending upon the ambient conditions and chiller selection)	• Air-cooled COP: 2.9-4.15 Water-cooled COP: 4.7-6.07 (values vary depending upon the ambient conditions and chiller selection)
• Usually one compressor is used - sometimes two compressors are used for large capacities	
• Bigger capacity compressors typically come with HT motors	

2.1.1.1 Absorption Chillers

Absorption chillers differ from vapour compression chillers in terms of the type of input energy used to create a thermal lift to transfer heat from a low temperature to a high temperature. In absorption chillers, heat is the primary source of energy. The refrigerant is absorbed in a solution after evaporation and then pumped to a generator using a liquid pump, unlike in a vapour compressor. In the generator, heat is used to separate refrigerant vapour from the liquid solution. Refrigerant vapour flows to the condenser, where it undergoes change from vapour to liquid phase by expelling its latent heat to water from a cooling tower. Most commercial absorption chillers use lithium bromide (Li-Br) as absorbent, with water as a refrigerant. The absence of the need for electric power makes them particularly suitable for waste heat utilisation. The absorption chillers are available in multiple/higher capacities and the COP varies from 0.6 to 1.92[16]. However, due to the high cost of heat energy in the form of high-speed diesel (HSD) and PNG, this option may be rendered economically unviable, as the operating cost per TR increases multi-fold in comparison with electrically operated chillers. Hence, life-cycle cost analysis should be performed considering long-term contracted fuel costs.

Absorption chillers and high-temperature fuel cells can be coupled for cooling, heating, hydrogen, and power. Polygeneration provides more than three energy utilities from a single integrated facility.

2.1.1.2 Adsorption Chillers

Adsorption chillers differ from absorption chillers in that they use a solid sorbate instead of a liquid absorbent. These chillers have very different operational and performance characteristics due to the need for two different beds to be simultaneously charged and discharged and then swapped.

2.1.2 Thermal Energy Storage

Another successfully applied alternative energy source is TES, which can help in reducing peak electricity demand from cooling and even reduce installed chiller plant capacity, thereby reducing net capital costs. Chillers can make either ice or chilled water during times of lower electricity costs. This ice or chilled water is stored in insulated tanks and then discharged to satisfy the cooling loads during times of high electricity costs, thus taking advantage of the differential electricity tariffs wherever applicable. The total TES capacity is directly related to the hourly cooling demand, baseload and peak load pattern. Based on the demand profile, the TES tank capacity can be selected for peak load shaving, partial load shaving, or as a battery for smaller night loads. One must consider the peak/off-peak tariffs, chiller investment, plant structure and space, OPEX, and total system efficiency to calculate TES's cost-effectiveness. In general, based on the experience from existing DC systems, the total TES ratio normally accounts for approximately 25-35% of the peak load requirement. Increasing the storage capacity reduces the OPEX when there is cooling demand in the first 5-7 years; the total load is relatively low, and stored energy can cover most of the load in peak periods.

16 American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), *District Cooling Guide, Second Edition* (ASHRAE, 2019).

2.1.2.1 Types of Thermal Energy Storage

Two major types of TES include 1) CHW TES, and 2) Ice TES

2.1.2.1.1 Chilled-water thermal energy storage

This is the most common and simplest form of TES which employs concrete or steel tanks to store chilled water at 3.9-5.6°C, generated by conventional chillers. During the discharge cycle of the TES tanks, CHW is supplied from the bottom of the tank while an equal amount of warm water is returned to the top of the tank. A natural stratification of water is maintained due to different densities of water at different temperatures. CHW TES is more cost-effective where space is easily available.

2.1.2.1.2 Ice thermal energy storage

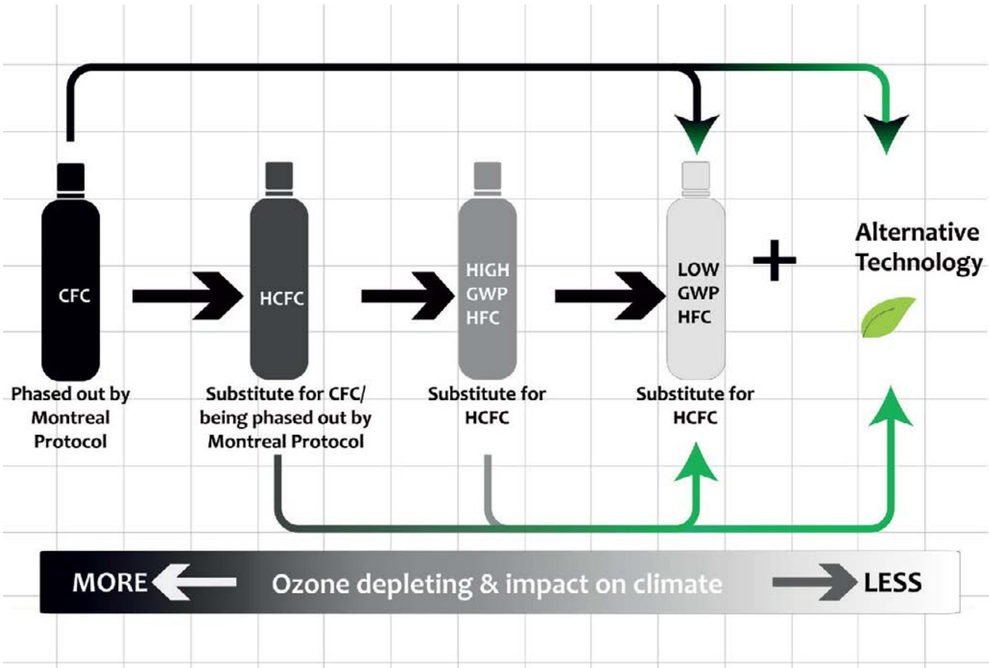
Ice TES requires specialised ice generation and storage technology. During discharging of the ice TES tanks, ice is blended with water to produce CHW supply temperatures of around 1.1-4.4°C. Ice TES is much more compact as compared to CHW TES as the volume of ice storage is 75-85% less compared to CHW storage for the same cooling capacity. Hence ice TES is more cost-effective where land is expensive. [17]

2.1.3 Refrigerant Selection

Refrigerants are substances with low boiling points and large latent heat at pressures above atmospheric pressure. At present, various HFCs, hydrofluoroolefins (HFOs), and natural refrigerants such as R-290 (propane), R-600a (isobutane), R-717 (ammonia), R-718 (water), R-744 (CO2), and R-1270 (refrigerant grade propylene or propene) are used in HVAC and refrigeration systems as alternative refrigerants to chlorofluorocarbons (CFCs) (which are already banned under the Montreal Protocol) and HCFCs (for which clear phase-out plans have been agreed upon), as they have zero ODP. However, to meet the targets as per India's recent ratification of the Kigali Amendment to the Montreal Protocol, HFCs need to be phased down by increasing the use of refrigerants with low GWP wherever applicable starting from 2032, as depicted in Figure 6 and further detailed in Table 3.

Subsequently, freon gas (F-gas) regulations are in place in many countries. As per the European Union (EU) F-gas regulation introduced in 2015, the total amount of potent F-gases that can be sold in the EU is limited, and they will be phased down in steps to 20% of 2014 sales by 2030. Furthermore, the use of F-gases in any new types of equipment where more environmentally-friendly options are available is banned, and F-gas emissions from existing appliances need to be prevented by having

Figure 6: ODS Substance Phase-Out[18]



17 IDEA. 2008. District cooling best practices guide. International District Energy Association
18 Ozone Cell MoEF&CC, "HCFC Phase-Out and Energy Efficiency in Buildings," 2017.

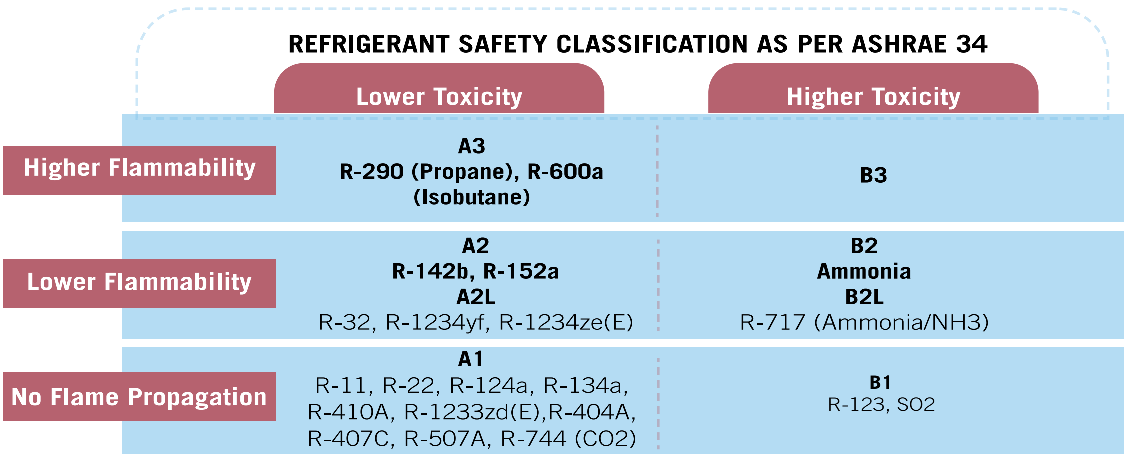
Table 3: HFC Phase-Down under Kigali Amendment [19]

	Non-Article 5 (developed countries)	Article 5 (developing countries)	Article 5 (developing countries)
Baseline years	2011-2013	2020-2022	2024-2026
Baseline calculation	Average production/consumption of HFCs in 2011, 2012, and 2013 plus 15% of HCFC baseline production/ consumption	Average production/ consumption of HFCs in 2020, 2021, and 2022 plus 65% of HCFC baseline production/consumption	Average production/ consumption of HFCs in 2024, 2025, and 2026 plus 65% of HCFC baseline production/consumption
Freeze	-	2024	2028
1st step	2019 -10%	2029 -10%	2032 -10%
2nd step	2024 -40%	2035 -30%	2037 -20%
3rd step	2029 -70%	2040 -50%	2042 -30%
4th step	2034 -80%	-	-
5th step	2036 -85%	2045 -80%	2047 -85%
	For Belarus, the Russian Federation, Kazakhstan, Tajikistan, and Uzbekistan. 25% of HCFC baseline production/ consumption. First two steps are later: 5% in 2020 and 35% in 2025.		Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates

checks, proper servicing, and recovery of the gases at the end of the equipment's life.

Given the fact that HFCs are being phased down 85% by 2047 compared to the 2024-26 baseline, and looking at a lifecycle of about 30 years[20] for a chiller, it is recommended that the HFC refrigerant route should be avoided already. For DCS, the situation is the same, as with all large chillers, refrigerant alternatives are available, and the overall challenge is safety during operations and while replacing or recharging these systems with alternative refrigerants. An ideal refrigerant should have zero ODP, low or zero GWP, and a medium pressure range with evaporating pressure above atmospheric pressure to avoid air intake into the system and be safe, i.e. non-toxic & non-flammable. Figure 7 below explains the different safety groups (A1 – B3)[21]:

Figure 7: ASHRAE's 2018 Refrigerant Safety Group Classification



19 ISHRAE Position Documents on "Refrigerants for Indian Refrigeration and Air Conditioning Industries- Challenges and Responsibilities" 2021
20 2020 ASHRAE Handbook – HVAC System and Equipment
21 ASHRAE, "Designation and Safety Classification of Refrigerants," 2018.

DCS can enable the transition to low or no GWP and natural refrigerants, such as ammonia, as the cooling plant operates at an offsite facility away from the building and thus reduces any safety risks to the end-users. It is therefore strongly recommended to start integrating non-HFCs, HFOs, natural refrigerants, and low-GWP alternatives as refrigerants in DCS. When using ammonia as a refrigerant, safety standards[22] [23] must be followed.

The possible refrigerant alternatives with low GWP that can be used in large cooling technologies such as DCS have been mapped in Table 4 below. Since DCS are located in separate utility areas, it is easier to handle the logistics of upgrading the chillers with the newer refrigerants that may come in from time to time due to environmental regulations and code compliance.

Table 4: Refrigerant Alternatives for Chillers[24] [25]

Chiller Type	Approximate Capacity Range (kW)	Current Refrigerant Used	Proposed Refrigerant Alternative - Potential Refrigerant (GWP), **Safety Class**	Additional Requirements
Screw water-cooled	100-7000	HCFC-22	Medium Pressure: -HFO-1234yf (<1); **A2L** -HFO-1234ze (<1) **A2L** -R-513A (600); **A1** - R744 – CO2 (1); **A1** - R717 – Ammonia (0); **A2L**	To shift to HFOs, there is a need to upgrade existing compressors that are compatible with specific HFOs to ensure efficiency gains (see comment above). To use CO2 as a refrigerant in DCS, more research is required to make it commercially viable. Ammonia chillers have higher efficiency. However, they require additional systems for air density control to ensure safety.
Screw, scroll, and reciprocating air-cooled	10-1800	HCFC-22,		
Centrifugal water-cooled	200-21,000	HCFC-123, HFC-134a	Low Pressure: -HFO-1233 zd (1); **A1** -HFO-1336mzz (2); **A1** Medium Pressure: -HFO-1234yf (<1); **A2L** -HFO-1234ze (<1); **A2L** - R-514A (1.7); B1 - R717 – Ammonia (0); **A2L** - R290 – Propane **(0.02); A3**	- Ammonia chillers have higher efficiency. However, they require additional systems for air density control to ensure safety. - Larger quantities of propane cannot be used in the building due to its higher flammability (specific safety measures are required). For use in DCS, more research is required.
Absorption (water-lithium bromide – shell and tube)	140-18000	R-718 (Water)	-	-
Absorption (water-lithium bromide – shell and coil)	17-120	R-718 (Water)	-	-

22 ASHRAE. 2013b. ANSI/ASHRAE Standard 15, Safety standard for refrigeration systems and designation and classification of refrigerants
23 ISO 5149-1:2014, Refrigerating systems and heat pumps — Safety and environmental requirements — Part 1: Definitions, classification and selection criteria
24 EPA, "Significant New Alternatives Policy (SNAP) Program," n.d.
25 IPCC, Climate Change 2021, The Physical Science Basis, Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

2.1.4 Heat Rejection Systems

Heat rejection systems, mostly cooling towers, form an integral part of DCS.

Cooling Towers

In a cooling tower, air and water are brought into direct contact with each other to enable heat rejection, which reduces the water temperature. The cooling tower is designed according to the amount of heat to be expelled, wet bulb temperature of the ambient air and the approach temperature. During this process, a small volume of water is evaporated, reducing the temperature of the water being circulated through the tower.

The performance of the mechanical draft cooling towers also depends upon the airflow arrangements. The flow arrangements used in the cooling towers include:

- Counter flow induced draft
- Counter flow forced draft
- Cross flow induced draft

Depending upon the application and site location, the most appropriate cooling tower can be selected by the consultants.

2.1.5 Pumps and Pumping Systems in Plant Rooms

A DC system consists of a chilled water distribution network within the chiller plant, as well as distributed network piping connected to the building on the load side. The system also has a condenser water distribution system (in the case of water-cooled systems) connecting the chillers, cooling towers, and condenser water pumps.

Several types of pumps can be used in fluid transfer, but centrifugal pumps are most common in DC applications.

2.1.5.1 Types of Pumping Systems

The water pumping systems can be a once-through or recirculating type. In a once-through system, water passes through the equipment only once and is discharged. The once-through system may be applicable when integrating DCS with a sea, lake, river, wastewater stream, or other similar water body or stream for either heat rejection or free cooling. In a recirculating system (which is the most typical pumping system), water is not discharged but flows in a repeating circuit. Both types are further classified as open- or closed-loop systems. A closed-loop system is one in which the flow of water is not exposed to the atmosphere at any point. This system usually incorporates an expansion tank to enable the expansion of water. In closed-loop systems, static elevation is not accounted for in head pressure calculations. CHW pumping circuits are typically closed-loop systems. An open-loop system is defined as a system having a pipe that is open to the atmosphere. The CDW pumping circuits are open-loop systems, as cooling tower spray nozzles are open to the atmosphere.

When selecting a pump for closed-loop systems (chilled water distribution), several factors should be considered, such as pressure losses associated with the total horizontal and vertical length of piping, piping elbows and tees (fittings), valves in the system, miscellaneous piping accessories, a pressure drop through the chiller's evaporator and heat exchanger/equipment coils, the minimum system pressure to be maintained, and net positive suction head required (if applicable). To calculate the pressure losses associated with the piping, a value of approximately 0.6-0.9 m per 100 m of piping is typically used as a pressure loss to maintain a maximum velocity of 2.5 to 3 m per second (s). Piping erosion can occur if the velocity is too high. However, the design pressure losses and water velocities should be set based on the available technology options and other design considerations.

2.1.5.2 Pump System Configurations & Types of Chilled Water Systems

Several configurations can be used in pumping systems. Pumps can be arranged in a dedicated manner or headered in a primary/secondary pumping configuration.

In one of the chilled water distribution methods, distribution piping is decoupled from chiller piping and is known as the primary-secondary or decoupled system. There is constant primary flow through the operating chiller(s) and variable secondary flow through the loads. A bypass pipe between the two balances the primary flow with the secondary flow. The bypass line is sized to handle the flow through the maximum capacity chiller. The secondary pumps maintain variable flow on the load side based on the changes in cooling demand through two-way motorised valves on the chilled water cooling coils. Deficit or excess flow between the primary side and secondary side flows through the decoupler line between the supply and demand side of the chilled water. DCS can be designed with primary and secondary pumping systems or with the advanced technology of variable primary flow only pumping systems. This is possible due to the stable operation of chillers that handle the variable flow and primary pumps through variable frequency drives (VFDs). However, proper control systems should be in place to ensure stable and proper system operation in the case of variable primary flow systems. Through VFDs, the flow rate of the primary pumps and the cooling produced by the chiller are modulated according to the load on the DC system. Variable primary flow systems have lower infrastructure costs due to the avoidance of secondary pumps and associated electrical switchgear, as well as space savings.

2.1.5.3 Pump Selection

When selecting a pump, several factors must be considered. Once the building DC system load profiles have been finalised, the chilled water flow rate required to meet the cooling loads can be established. After the flow rate is set, the pressure losses of the system have to be calculated.

Once the flow rate and pressure head are determined, the pump that can operate at the highest possible efficiency at the known flow rate and pressure head should be selected. This selection is done by matching the system operating curve with the pump curve.

2.1.6 Air Separators and Air Elimination Devices

Dissolved oxygen gets released from water when the temperature increases, creating air bubbles in the water. Air bubbles cause corrosion in systems and pipes. The bubbles also adhere to heat transfer surfaces and reduce the heat permeability, causing efficiency losses. This is one of the causes of failures in pumps due to cavitation & pressure fluctuation.

Several devices are used to eliminate the presence of gas in CHW systems. Gas exists within the system in three forms: stagnant bubbles, gas entrained within the flow, and dissolved gases. The large stagnant bubbles can be removed via manual or automatic venting if enough pressure is available. Air vents are effective for the elimination of stagnant bubbles that are separated from the flow and not totally dissolved in it, if the air vent passage is big enough to avoid a capillary problem. Removal effectiveness is greater in locations with lower velocity, such as plant headers.

Large bubbles and microbubbles in DC systems are separated in water by baffle separators, centrifugal separators, or wire mesh separators. The separators are ideally suited for continuous gas venting in district plants. However, air vents and separators are not effective tools for the separation and removal of microbubbles. Degassers could be employed to remove and separate such gas bubbles.

In the air elimination method, a flexible diaphragm, or bladder, physically separates the water and air cushion. The entire water circuit piping, heat sink, and chiller are completely purged of air during the initial fill, and any free air introduced later is separated in the air separator and vented to the atmosphere.

2.1.6.1 Expansion Tanks

Expansion tanks are required in a closed-loop heating or chilled water HVAC system to absorb the expanding fluid and limit the pressure within a heating or cooling system. A properly sized expansion or compression tank can accommodate the expansion of the system fluid during the heating or cooling cycle without allowing the system to exceed the system's critical pressure limits. The expansion tank uses compressed air to maintain system pressures by accepting and expelling the changing volume of water as it heats and cools. Some tank designs incorporate a diaphragm or bladder to isolate the expanded water from the pressure-controlling air cushion. As water expands, it is contained in the bladder, preventing potential tank corrosion and water logging. The pressure-controlling air cushion is pre-charged at the factory and can be adjusted in the field to meet critical system requirements. An expansion tank is critical to maintaining the pressure limits by accommodating the expansion of fluid during the cooling cycle. There are various types of expansion tanks adopted in chilled water systems, e.g. ones with bladders or membranes.

Generally, multiple expansion tanks, depending upon the DCS capacity, are installed within the DCP and at the ETS.

2.1.7 Chilled/Condenser Water Filtration Systems

Water filtration is one of the vital elements for maintaining clean and clear chilled water pipes and avoiding operational performance losses in AC systems. Filtration of chilled- and condenser-water systems in DCS is important to maintain clean chiller tubes and thus avoid degrading chiller performance. The chilled water system network typically gets filled with dirt particles, construction debris, and dust. It is important to flush them out before commencing the system operations. Flushing is required at the start of DCS and may also be required if there are periodic developments and building (consumer) connections are taking place from time to time, so that cross-contamination from new connections to existing connections can be avoided. As per ASHRAE District Cooling Guidelines[26], a minimum water velocity of 0.9 to 1.5 m/s (3 to 5 feet per second (fps)) must be achieved to have adequate force to flush pebble-sized debris from piping. Hence, a separate pumping source may be required during construction and start-up to provide adequate flow to drive the flush of debris.

2.1.7.1 Chemical Treatment

The quality of water used in DCS directly impacts the system-level efficiency, operational cost, and life. In the primary circuit, the DC service provider has to take various steps to maintain the desired quality of water used in both CHW and CDW circuits. More specifically, the desired levels of total dissolved solids (TDS), potential of hydrogen (pH), hardness, saturation index, etc. must be maintained.

- Calcium hardness, magnesium hardness, & total bacterial count are also critical to the smooth functioning of the water systems.
- Total suspended solids (TSS) - TSS refers to waterborne particles that exceed 2 microns in size. Any particle that is smaller than 2 microns, on the other hand, is considered TDS.
- BOD / COD / Organic Matter - Biochemical oxygen demand (BOD) is the amount of oxygen microorganisms require to break down organic materials. In contrast, chemical oxygen demand (COD) is the amount of oxygen required to break down organic material via oxidation.

There are various technologies available to treat the water to enhance the efficiency and life of the system. These technologies help end-users and system operators maintain the desired quality of water from primary sources, as well as makeup water.

TDS

conductivity of water is correlated with the amount of dissolved solids in water. Pure distilled water has very low conductivity, whereas seawater has high conductivity. The presence of solids dissolved in water results in the formation of insoluble mineral precipitates on the heat transfer surfaces, generally called scale. Scale sticks to the pipe surface and starts negatively imapcting heat transfer and water pressure. Thus, the main aim of reducing TDS is to prevent scaling on the pipe surfaces.

pH

This is the measure of the acidity of water, on a scale of 0-14, with 7 being neutral. When the pH moves towards the acidic environment, the chances of corrosion increase, and when it moves towards an alkaline environment, the chances of scaling increase. Therefore, it is important to maintain optimal pH levels to avoid both corrosion and scaling.

Hardness

The amount of calcium and magnesium dissolved in water determines its hardness. Total hardness is divided into two types: carbonate (temporary) and non-carbonate (permanent) hardness. Temporary hardness is harmful to AC applications, as it causes sedimentation of calcium carbonate scale in pipes and equipment.

Saturation index (Langelier Saturation Index (LSI))

This is a measure of the stability of water involved in scale formation. When LSI is positive, water tends to scale, and when it is negative, water tends to erode.

In addition to the above, monitoring and control of the following parameters also plays a huge role in ensuring good quality of water in the CHW and CDW circuits, which, in turn, determines the efficiency of the DCS at the design level.

As water availability is one of the main challenges in the Indian context, local authorities always insist on the use of treated recycled water from STPs (sometimes referred to as TSE) for make-up in the cooling towers. The TSE water requires treatment prior to its use, and the treatment process is dependent upon the TSE water

26 American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), District Cooling Guide, Second Edition.

quality. In the Indian context, the TSE water parameters should be defined so that the treated water can be used in DC applications. The various water quality parameters must be maintained within the set limits specified by the chiller original equipment manufacturer (OEM).

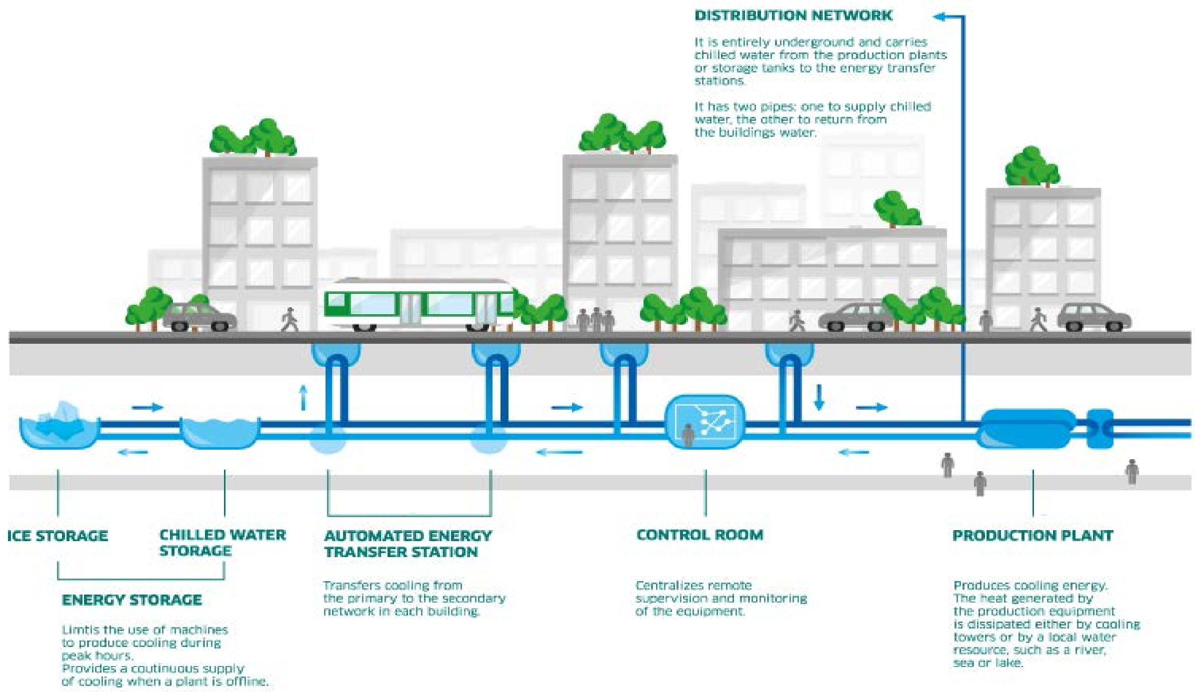
In the secondary/tertiary circuit, generally, end-users (buildings) are responsible for filling the secondary side chilled water system, along with providing break tanks of suitable capacities and expansion tanks/ pressurisation units. The water treatment system must include manual feed chemical dosing pots with rust inhibitors and biocides for testing, commissioning, and operation. It is recommended to engage a specialised professional company to handle the water treatment system. The consumer should provide an analysis of the physicochemical characteristics of the water in the secondary circuit to the DC service provider company before commencing commercial operation of the ETS.

Regarding operational safety, the main concern in water treatment is Legionella pneumophila bacterium, which may cause Legionnaires' disease. This bacteria can be deadly if inhaled in the form of aerosols, which can happen where cooling towers are used. According to ASHRAE, experience shows that wet cooling towers can transmit bacteria over a distance of up to 3.2 km[27]. To mitigate the risk of Legionella disease from DCS, the wet cooling towers and basins must be kept clean and chemical treatment provided regularly to inhibit the growth of Legionella bacteria.

2.2 DISTRIBUTION NETWORK

On basis of aesthetics, ease of operation, geographical constraints, safety, and applications, there are two kinds of distribution networks: underground and above-ground pre-insulated chilled water distribution systems. For both types, stress analysis is required to be done as per relevant Bureau of Indian Standards (BIS) / American Society of Mechanical Engineers (ASME) codes. Carbon Steel or Mild Steel pipes should be used for chilled water and condenser water distribution piping (as per IS Standards), with proper protective coating wrap. Pre-insulated pipe insulation is designed based on a temperature loss of a maximum of 0.5°C in chilled water distribution. Depending on the length of distribution chilled water piping, the appropriate insulation thickness should be determined to limit the rise of supply chilled water temperature to a value of 0.5°C. Pre-insulated pipes incorporate an auto¬mated leak detection system to detect the exact location of the leakage point so that rectification, if required, can be done in minimal

Figure 8: Placement of Distribution Network in DC System



(image source: engie.com)

27 American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), *District Cooling Guide, Second Edition.*

time. The technical challenges, like maintaining supply and return temperatures, can be addressed with the various technologies available, e.g. insulation. However, in different types of distribution networks, the cost varies due to investment technology interventions to achieve desired DC system outputs. An schematic of the typical components in a DC distribution network is given in Figure 8.

It is the responsibility of the DC service provider to design, construct, install, operate, and maintain the distribution network, which consists of insulated pipes (supply and return) and a pumping system. A well-designed and well-maintained distribution network results in smooth and energy-efficient DC system operations.

In the Indian context, an indicative DC system design (including the distribution system) is presented below. However, the actual design specifications may vary depending on a multitude of factors.

- Ambient temperature (for design): based on where the DC system/consumer is located
- Chilled water supply temperature at DCP: 5±1°C
- Temperature rise in the chilled water supply distribution network: 0.5-1°C
- Approach across ETS: 1.1°C
- Chilled water supply temperature at consumer end: 6±1°C
- Chilled water return temperature at consumer end: 15±1°C
- Temperature drop in the chilled water return distribution network: 0.5-1°C
- Chilled water return temperature at DCP: 14±1°C
- Design pressure of the chilled water distribution network: 5-15 bar (g) (depends on the overall DCS design and building elevation)

To establish the distribution network, the local city government (urban local body (ULB) in the Indian context) provides the land and permissions to the DC service provider (unless it is on private land or a township). It provides dedicated corridors/space in trenches for a chilled water distribution network (supply and return) up to the ETSs (including trenches required for last-mile connectivity to plots) and other services. The chilled water piping distribution network is laid in the utility tunnel with proper provisions for future tappings.

The successful implementation of district cooling systems depends greatly on the ability of the system to obtain high-temperature differentials i.e. delta Temperatures (T) between the supply and return water. It is crucial to ensure that the district cooling system can operate with reasonable size distribution piping and pumps to minimize the pumping energy requirements. Generally, it is most cost-effective to design for a high delta T in the district cooling system because this allows for smaller pipe sizes in the distribution system. A large delta T allows for the use of smaller pipes, which reduces the capital investment for the construction of the system. The system operating efficiency also increases with an increased delta T due to the reduced pumping requirements caused by the reduced flow rates and the reduced heat gains/losses in the distribution system.

The system's delta T is typically limited to 8-11°C. The maximum allowable flow velocities are governed by pressure drop constraints and critical system disturbances caused by transient phenomena (i.e. water hammer effects). Generally, velocities higher than 2.5-3.0 m/s should be avoided unless the system is specifically designed and protected to allow for higher flow velocities.

The pipe sizing is governed by four key factors:

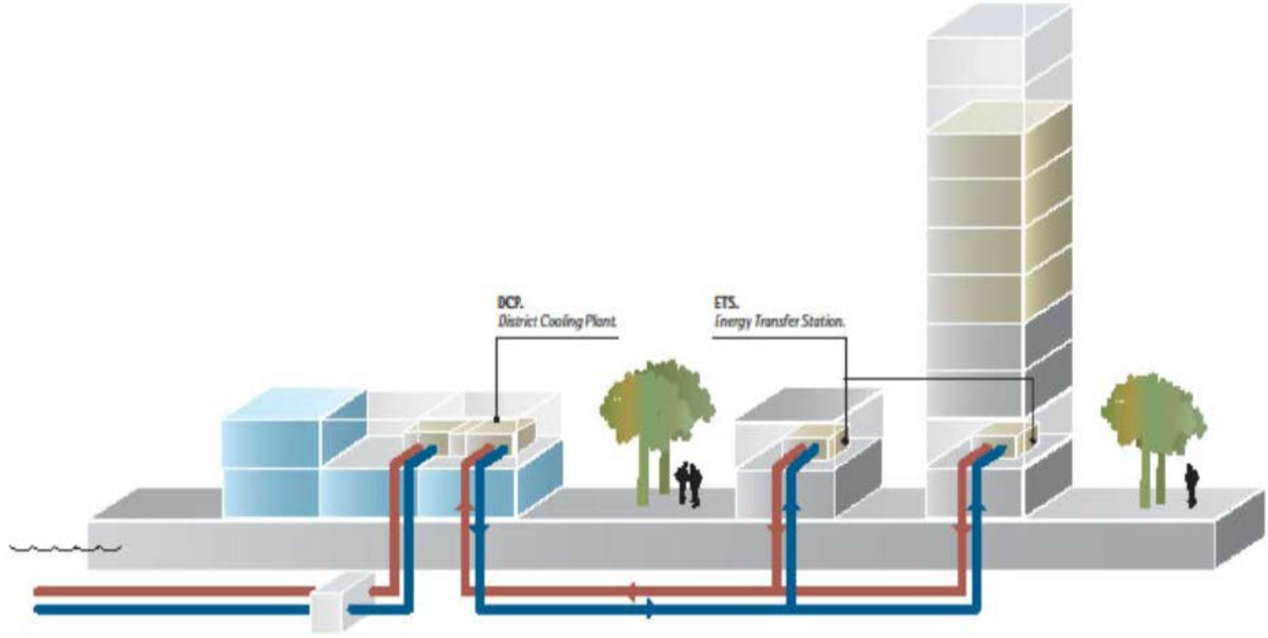
- The system's delta T
- Maximum allowable flow velocity
- Distribution network pressure at the design load conditions
- Minimum differential pressure requirements to service the most remote customers.

Please refer to ASHRAE District Cooling Guide, Second Edition for detailed guidelines to design a distribution system that consists of pipe materials, insulations, testing, valves, leakage, and soil properties.

2.3 ENERGY TRANSFER STATIONS

An energy transfer station is an interface between the DC service and the consumer's AC system to transfer thermal energy generated at the plant level to the buildings or consumers. This transferred thermal energy is used for space conditioning in buildings (or consumers) where building owners can install heat exchangers. An ETS, as depicted in Figure 9, serves as a boundary between a DC company and building (consumers), which differentiates ownership, responsibility, and maintenance of equipment. In the ETS, a revenue-grade flow meter and temperature sensors packaged together are used to calculate cooling energy consumption and demand for consumer billing. This is

Figure 9: Placement of ETS in DC System



(Image Source: Lusail development, Qatar)

referred to as a thermal energy meter or BTU meter, which is used for monitoring the incoming and outgoing chilled water temperature and cooling (TR) available.

A typical ETS consists of heat exchangers, pumps, isolation valves, control valves, thermal/British Thermal Unit (BTU) meters, and field devices like temperature sensors and pressure transducers and controllers as the primary mechanical equipment and control elements. Various types of heat exchangers, e.g. plate and frame and brazed types, can be used for energy transfer applications in a typical DC plant. The consumer has to provide a suitable space to install the ETS in accordance with the preliminary and final designs supplied by the DC service provider. HX sizing should be based on meeting the cooling demand without redundancy. However, based on the criticality of the application, the number and size of HXs should be aligned with the maintenance and downtime criteria. Space can also be provided for capacity expansion at a later date.

Space must be provided for equipment, maintenance access, service lines, interconnecting pipes, lighting, AC with makeup air, floor drains, and potable water piping. Consideration should be given to transport and access, so that repair, replacement, etc. can be carried out quickly and easily. If the consumer does not allow free passage through the building, a separate access door from the outside must be arranged. The transport pathway to the ETS plant room, including all doors, must enable access to the heat exchanger(s) without any need for disassembly. Adequate space should be provided so that equipment can be accessed for maintenance.

In general, to design the ETS, the DC service provider provides the design guidelines, requirements, and specifications to the consumers. The design guidelines generally cover major materials like temperature and differential pressure transmitters, flow/energy meters, plate heat exchangers (PHEs), programmable logic controllers (PLCs), pressure independent control valves (PICVs), welded isolation ball valves, and pressure safety relief and operational parameters in line with DC plant design. In return, the DC service provider expects the consumers to abide by the guidelines and submit the documents for design and materials, demonstrating compliance with the guidelines. For instance it is worth noting that proper selection of PICVs and other controls on the consumer side of the ETS (secondary side) can help maintain desired (high) delta Temperatures (T) thus ensuring desired system-level efficiency as well as avoid any non-compliance penalties on the consumers.

In the ETS room, there are various components that have shared roles and responsibilities. Typically, the primary side is DC service providers' full responsibility whereas the secondary side is consumers' (buildings) full responsibility. A tentative list of these components and their roles and responsibilities is given in Table 5. However, the actual roles and responsibilities may vary from project to project, depending upon the preferences of project developers and perceived customer requirements.

Table 5: Roles and Responsibilities in ETS Room (Indicative)

ETS Room (indicative list)			
Description	Supplied by	Installed by	Cable transmitted by
Lighting, electrical supply, air conditioning, fire detection, floor drain, potable water supply, wall, and floor penetrations	Consumer (buildings)	Consumer (buildings)	NA
Equipment (indicative list)			
Heat exchangers	DC service provider	Consumer (buildings)	NA
Secondary pumps, pressurisation system, expansion tank, water treatment	Consumer (buildings)	Consumer (buildings)	NA
Instruments (indicative list)			
Primary side temperature transmitters, flowmeter, energy meter, secondary side temperature transmitters, PICVs for primary side, PLC, etc.	DC service provider	Consumer (buildings)	DC service provider
Piping components (indicative list)			
Primary side isolation ball valves, HX pressure relief valves	DC service provider	Consumer (buildings)	NA
Primary side pipe, fittings, flanges, vent and drain valves, Threadolets for instruments for both primary and secondary side, spool pieces to replace the meter, control valve, heat exchanger, etc.	DC service provider	Consumer (buildings)	NA
Testing and commissioning (indicative list)			
Hydrostatic testing, flushing, and chemical treatment (primary and secondary sides)	Consumer (buildings)		NA
Commissioning PLC system, installing energy meter, and integrating communication between the ETS and the DCP for both fibre optic and wireless communications	DC service provider		NA

The number of PHEs is dependent on the total requested cooling capacity by the consumers. The DC service provider designs and supplies the PHE to the ETS. If a consumer wants additional heat exchangers or redundant capacity, the DC service provider can supply them at an additional cost based on the requirements and application. There is a tertiary pumping system on the consumer side of the ETS, from where the building load is connected to a separate chilled water distribution network with its own controls.

2.3.1 Connection Types

In DCS, there are two possible types of connections for the distribution of thermal energy to consumers: direct or indirect. In a direct system, the cooling water comes directly into contact with the internal piping system of buildings (consumers). The chilled water that circulates within the DC system is the same as that which circulates inside the buildings. In an indirect system, a heat exchanger separates the internal piping from the external system. DCS provide chilled water to the HXs located in the ETS, and there is a separate chilled water piping distribution network on the customer's building side that supplies chilled water to the air handling units (AHUs) on the load side. There are various benefits to both systems, as summarised below.

Indirect system:

- The line of responsibility is clearer between the DC service provider and consumer, and the regulations and sales are easier to monitor, with clear boundaries
- Relevant when the DC service provider wants to have a separate boundary line between the DC system and customer's building
- With separate circuits, customers may experience fewer fluctuations and disturbances in the case of system expansion and maintenance
- The static head of the customer's building increases the system return pressure or risks increasing the operating pressure of the DC piping system
- From the maintenance point of view, the system ensures trouble-free operations
- No risk of contamination of chilled water, as there is no water exchange
- Leakages are easier to detect, and even if one does occur, it creates minimal damage

Direct system

- Relevant where the static head of chilled water can be kept at a relatively lower value, where the DC service provider and end-user are either same or have a strong working relationship
- Water quality issues between the building level and DC system level can be easily addressed, since the same water is being used at both levels
- Applicable where there is limited space on the consumer's site to accommodate ETS, etc.
- Can be used where the customer's building's static head never exerts a static pressure on the distribution network that is greater than the system return pressure
- Applicable where there is ease of operations from the point of view of makeup water.

Independent of the connection type, the DC service provider needs to ensure proper CHW supply temperature control at the consumer level. It is equally important for consumers to deliver high-return water temperature to the central plant.

A comparison of direct and indirect connections is presented in Table 6 :

Table 6: Direct vs. Indirect Connections

S.No.	Feature	Direct connection	Indirect connection
1	Achieving high delta T in circuit distribution	No cooling loss at heat exchangers. Greater delta T in building, hence better humidity control	HXs need 1-2°C approach, reduced delta T in building
3	Chilled water quality control	No isolation between CHW production & distribution, and end-user; quality control must be rigorously maintained	Isolation between CHW production, distribution, and end-user; quality control easier to maintain
4	Division of responsibilities	The contractual battery limits between the DC service provider and end-users are not clear. May cause conflict when disputes arise	Battery limits are clearer contractually. Helps minimise disputes between service providers and users
5	Cost	Lower capital cost	Higher capital cost
6	Retrofitting existing system	Easier to use in applications where DC is introduced into an existing development	Harder to use in retrofit applications
7	Independent pressure in buildings	Isolation is achieved by applying pressure, isolation techniques for tall buildings, and high DC operational pressure differentials	Isolation of pressure exists between the DC system and buildings
8	One DC user	Maybe preferable for one user/customer applications	Can be used for one customer but becomes more expensive

S.No.	Feature	Direct connection	Indirect connection
9	Space requirements for in-building mechanical rooms	Requires less space for in-building mechanical rooms	Requires more space for in-building mechanical rooms
10	Need for in-building pumps in adjacent buildings	Building near the DC plant may not need a CHW pump	All buildings need CHW pumps

(source: District cooling theory and practice by Alaa A Olama)

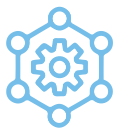
2.4 INSTRUMENTATION, MONITORING, AND CONTROL SYSTEM

A DC instrumentation and control system must be designed, installed, and commissioned to monitor and control various system components and enhance the operational efficiency of the DC system. The main components of an instrumentation and control system are a PLC, human machine interface (HMI), and distribution control system. The control system is designed to maintain the entire DC plant operations and functionality, and it is integrated with ETSs to maintain transparency in operations. The control system monitors chiller plant parameters, cooling tower parameters, TES parameters, chemical treatment equipment parameters, building management system (BMS) of the DC plant building, firefighting status of the plant building, etc. All the respective energy meters and BTU/thermal meters should be connected to the BMS to enable customer billing. All electrical energy meters should also be connected to the BMS to enable quick calculation of the utility billing costs for tenants. All Mechanical Electrical and Plumbing (MEP) equipment in DCS should have connectivity with the BMS at a soft integration level wherever possible. The rest of the equipment and systems should be hardwired to the BMS.

The robustness and quality of the control system ensure quality and accuracy in accounting for building cooling use, as well as remote monitoring, metering, and control of the building and ETS operations when system components are not owned by a common entity (DC service provider).

There are four layers in a control and monitoring system for DC applications[28]:

Management layer: It has a central operator workstation(s) or a server (depending upon the size of the DC system) to assess the parameters of various connected equipment in a system. It monitors and controls system controllers for the complete chiller plant, fire alarm systems, and BMS of the DC plant. Workstation software is installed in the server and workstations, and graphics of the entire DC system are displayed for monitoring by the operations team. Industry open standard protocols (ASHRAE Standard 135) should be implemented for proper communication between the various systems at the different layers. Moreover, it is recommended to have a system compatible with cloud connectivity, since a lot of data analysis is required to enhance system performance and efficiency.



System layer: This layer may have system controllers, and it connects with all the direct digital controllers (DDCs) and ensures the system-level functionalities and logic are being programmed to enable the smooth functioning of the DC system. Network cabling is carried out with redundancy to ensure communication between the controllers and this layer. The operator at the management layer can also analyse the dynamic events happening at the ETS level. The main systems components like the chillers and other subsystems are directly connected to this layer through soft integration.

Automation layer: It comprises microprocessor PLC controllers with ancillaries with a redundant stand-alone capability when a connection to the management level fails. DDCs are located for the effective automatic functioning of the sequence of operations of the various subsystems. This layer ensures all the field-level devices and instruments are captured.

28 District cooling theory and practice by Alaa A Olama

Instrument layer: It comprises all industrial-grade field instruments, including flow meters, actuators, temperature transducers, motorised valves, etc.; these must be selected with high accuracy levels for stable and reliable operations. Provisions should be made for connecting the system with newer technology like internet of things (IoT)-enabled devices.

The control system is used to optimise plant operations. It is recommended to design and install a control system to achieve certain strategies to ensure efficient plant operations, a few of which are listed in Table 7[29].

IoT-based monitoring and control solutions can predictively and proactively preempt equipment failure and help curtail service downtimes which is extremely important for critical cooling loads such as hospitals and data centres.

Artificial Intelligence (A.I.) enabled software can help design DC networks from scratch. Digital twins can simulate "what if?" scenarios on planned maintenance or future expansion in the distribution network, thus improving pumping efficiency and better production planning.

2.5 MEASUREMENT AND BILLING SYSTEM

Infrastructure for continuous measurement and logging of the cooling production and consumption (TR-h) and complete break-down of all associated power demand (kW- Voltage, Ampere, Power Factor) and energy consumption (kWh) at chillers, chilled & condenser water pumps, cooling tower fans, etc. is the single most important component of a DC system. Separate BTU meters for each cooling consumer, installed at the ETS, are used for generating the monthly cooling bills for each end-user. It is recommendable as much as possible to individualise the BTU metering by consumer/ apartment (whenever applicable) so the end user holds responsibility for the thermal energy consumption. The BTU meters must be sized appropriately to accurately measure the entire range of operation from partial to full cooling loads. The thermal metering can be optimised by selecting BTU meters with maximum accuracy at average operating cooling load rather than full (design) load conditions. Thus, the BTU meter can measure the cooling delivery with satisfactory accuracy over the entire range of cooling load variation by the customer buildings. DCS are recommended to have a well-designed customer billing system that can be customized for every application.

Table 7: Recommended Strategies to Control DC System Operations

Strategy	Description
Chilled water supply and return temperature	Continuous monitoring/control of supply and return chilled water temperatures in the plant room and at every building entry/exit point to help achieve design parameters and avoid low delta T syndrome.
Chiller monitoring and control	Ensure stability of chilled water temperature and allow cycling and sequencing safely and efficiently. Make sure critical parameters are being monitored continuously to ensure trouble-free operations and facilitate predictive maintenance. Chiller parameters should be continuously monitored to optimise chiller performance.
Cooling towers: monitoring and operations	Monitor and control the cooling tower operations as per the design intent. Control operation of make-up water for the condenser water, blowdown, and evaporation. Monitor chemical dosing to ensure optimum cooling tower performance. The chemical dosing system and water treatment parameters should be continuously monitored for efficient use of the heat rejection circuit.
Chiller sequencing	Based on load, application, and diversity, chiller modules (in the case of more than one chiller) can be operated and controlled. Based on the design CHW supply temperature, the chiller plant sequence of operations can be enabled. Proper add/subtract logic of chillers, along with associated equipment like CHW pumps, CDW pumps, and cooling towers will ensure optimum energy consumption at the chiller plant level.
ETS	Continuous monitoring of CHW flow to the buildings at the ETS and information for customer billing. Maintain required flow to customers and record individual customer energy consumption. Monitor energy flow meters by communicating with energy meters and displaying flow rates. Measure energy consumption at the building level by the ETS.

29 District cooling theory and practice by Alaa A Olama

3 KEY STAKEHOLDERS IN DCS IN INDIA

To ensure successful implementation and avail of the identified benefits of DCS, effective support and coordination is required from various institutions across the globe, including policy makers and implementors at the central and state/city level, design consultants, technology providers, system integrators, financial institutions, and real estate developers. In the Indian context, the various stakeholders involved in establishing DC can be broadly categorised into three segments—government, facilitators, and implementors. Their indicative roles are mapped in the following sections.

3.1 GOVERNMENTAL INSTITUTIONS

Governmental institutions play a vital role in implementing any policy/programme in India. For the adoption and implementation of DCS in India, it is essential to understand the present policy, regulatory, and institutional landscape, along with the role of DC service providers in DC project design, development, and operations.

The following points should be considered by appropriate government institutions:

1. **Considering DC as a utility:** One of the most important enabling actions by the government would be to consider designating DC service as a utility. It would be best if any applicable tax and incentives for DCS be treated on par with other public utilities such as PNG, electricity, and water. A regulatory mechanism can help propel the adoption of DCS in India.

2. **Fairness and transparency in DC tariffs for Cooling as a Service (CaaS):** The government should consider providing concrete guidance on DC tariffs to ensure fairness and transparency for all three key players, i.e., end-customers, real estate developers, and DC service providers.

3. **Competitive electricity and water tariffs for DCS:** The electricity and water tariffs for the DC companies serving both commercial and residential buildings should be commensurate with prevailing tariffs for similar category of consumers. It maybe appropriate to make DCS a separate consumer category for deciding on tariffs.

4. **Considering sustainable cooling as a basic necessity:** Laying out policy mandates for consideration of cooling in large infrastructural projects through municipal norms, environmental clearance regulations and issuing policies for the provision of cooling in residential developments.

Specific ministries Table 8 highlights the key list of government institutions, along with their potential role in DC.

Table 8: Governmental Institutions & Their Roles in DC

<table>
<tr><th>Organisation name</th><th>Possible role in district cooling</th></tr>
<tr><td>Bureau of Energy Efficiency</td><td>BEE was set up as a statutory body at the central level to facilitate the Energy Conservation Act's implementation. It acts as the nodal agency to coordinate and develop robust energy efficiency strategies and programmes to encourage sustainable energy use in all sectors of the Indian economy. It also plays a critical role in creating awareness and disseminating information on energy efficiency and conservation measures and formulating/facilitating the implementation of pilot projects and demonstration projects on different concepts. In the past, BEE has implemented various programmes in the building and appliance sectors, e.g. standards & labelling of equipment and appliances, Energy Conservation Building Code (ECBC), and energy consumption norms for energy-intensive industries. [30]

The role of BEE is to support rapid implementation of DCS through various means, including:
1. Development of design and operating guidelines for DCS in India
2. Development of technical design codes (such as a DC system code) and the setting of service standards (key performance indicators) for the operational performance of DCS in India.
3. Demonstration of DCS in pilot projects in India
4. Development/updating of the S&L programme on chillers, pumps, and other equipment and appliances used in DCS.</td></tr>
<tr><td>Ministry of Housing and Urban Affairs (MoHUA)</td><td>MoHUA is the executive authority that looks after the formulation and administration of the rules, regulations, and laws related to India's housing (national housing policy) and urban development (town and country planning). It is the nodal agency responsible for housing provision across the country under various flagship programmes. MoHUA comprises programmes and departments such as the Town and Country Planning Organisation (TCPO), district development authorities, ULBs, and Central Public Works Department (CPWD), which could play a key role in the implementation of DCS at the state level. In addition, MoHUA has launched the Smart City Mission and developed smart city cells in several states in India. 31

The role of MoHUA is to facilitate the rapid implementation of DCS through various means, including:
1. Accelerating the implementation of DCS by incorporating them into the urban planning process and ensuring they are a part of the smart city plans and master plans of cities; designating appropriate zones of sufficiently high cooling density for district cooling.
2. Sensitising TCPO by generating awareness on the appropriateness and relevance of DCS at the urban development level.
3. Guiding different departments and missions, including Smart Cities Mission, Urban Development Departments, Central and State Public Works Departments, National Buildings Construction Corporation (NBCC), etc. in promoting and adopting the use of DCS in India.
4. Supporting BEE in the development of the DC system code and specifying DC requirements for India.
5. Supporting BEE in the pilot demonstration and implementation of DCS by identifying appropriate smart cities.</td></tr>
</table>

30 Akhil Singhal and Karan Chouksey, "Country Guide - Implemented Policy: Bureau of Energy Efficiency & State Designated Agencies · BigEE - Your Guide to Energy Efficiency in Buildings.," 2016, http://www.bigee.net/en/country/in/implemented-policies/66/#references.

31 Anukriti Pathak, Tarun Garg, and Satish Kumar, "A Policy Strategy for Decarbonising the Building Sector: Facilitating ENS Implementation in Affordable Housing. AEEE, CRDF, GBPN." (New Delhi, 2020).

<table>
<tr><th>Organisation name</th><th>Possible role in district cooling</th></tr>
<tr><td>Central Public Works Department and National Buildings Construction Corporation Limited</td><td>CPWD is a governmental construction and maintenance management agency under the umbrella of MoHUA. It is responsible for executing building & infrastructure projects and manages various activities, including planning, design, construction, and maintenance management. It also plays a critical role in facilitating the implementation of policies for sustainable development and transparency in governance, along with the assimilation of knowledge and experience. NBCC is the national body for architectural design and real estate development in India.

The role of CPWD and NBCC is to fast-track the rapid implementation of DCS through various means, including:
1. Supporting BEE in the development of the DC system code and specifying DC requirements for India
2. Supporting MoHUA in the development and adoption of policies on thermal comfort and cooling in the built environment and new technologies such as DCS
3. Leading/supporting BEE in the demonstration of DC technology through pilot projects and supporting the development of evidence-based case studies in India
4. Facilitating the inclusion of DCS in the schedule of rates and providing necessary assistance to MoHUA and BEE in laying the groundwork for rapid deployment of DCS.</td></tr>
<tr><td>Ministry of Environment Forest and Climate Change (MoEF&CC) – Ozone Cell</td><td>An initiative of the Ozone Cell (MoEF&CC), ICAP was released on 8 March 2019 and was a turning point in the advancement of the future of cooling in India. In August 2021, India ratified the Kigali Amendment to freeze its HCFC production and consumption by 2030 (India will phase down HFCs from 2032 until 2047). The Ozone Cell is responsible for all the work related to ozone layer protection and implementation of the Montreal Protocol. They are engaged in the accelerated phase-out of production and consumption of HCFCs in India as per HCFC Phase-out Management Plan (HPMP Stage I and Stage II).

The role of MoEF&CC and Ozone Cell is to support fast track adoption of sustainable DCS in India through various means, including:
1. Supporting BEE in the development of the DC system code and specifying DC requirements for India, including the use of low or no GWP refrigerants.
2. Modifying the environmental clearance requirement and feasibility of DCS in large developments</td></tr>
<tr><td>State Level Development Authorities and Urban Local Bodies</td><td>State level development authorities and ULBs are bodies that administer or govern a state, city, or a town of a specified population. They are vested with a long list of functions related to public health, welfare, regulatory functions, public safety, public infrastructure works, and development activities.

The role of state level development authorities and ULBs (municipal corporations/ municipalities) is to facilitate the rapid implementation of DCS at the city/state level through various means, including:
1. Creating an enabling environment and policies at the city/state level, including easement planning for chilled water network, to ensure the connection, service, and metering of the systems and encouraging investment
2. Supporting BEE in the development of the DC system code and specifying DC requirements for India
3. Taking the lead in demonstrating DC technology through pilot projects and providing support in the development of evidence-based case studies in India
4. Showcasing the business model of providing cooling as a public service, like PNG, electricity, and water.</td></tr>
</table>

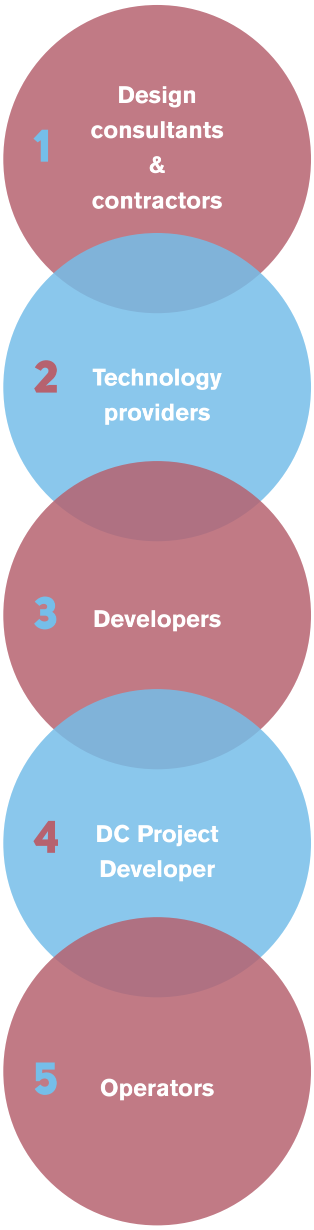
Organisation name	Possible role in district cooling
Electricity Distribution Companies (DISCOMs)	DISCOMs are responsible for the supply and distribution of electricity to consumers for industrial, commercial, agricultural, and domestic use32. DC could help DISCOMs reduce peak loads and potentially also enable them to provide cooling as a service. Under Electricity Act, 2003, DISCOMs can provide subsidised electricity for sustainable projects with the approval of state designated agencies (SDAs) under power purchase agreements (PPAs) for the DCS. **The role of DISCOMs is to facilitate the rapid implementation of DCS at the city/state level through various means, including:** 1. Supporting municipalities in the demonstration of DC technology through pilot projects and providing cooling as a service to end-users 2. Supporting the development of evidence-based case studies in India 3. Supporting municipalities in showcasing the business model of providing cooling as a public service 4. Supporting municipalities in ensuring price regulations on cooling as a public service.
Energy Efficiency Services Limited	EESL is a public sector undertaking (PSU) formed with the objective of implementing energy efficiency solutions by providing technical advisory services, measurement and verification, regulations on equipment/process/system performance assessment, and procurement of energy-efficient technologies. **EESL is already working on several DC initiatives and can play a key role in the market uptake of DCS by developing viable business models, establishing credit lines, and creating a measurement and verification protocol for the energy performance assessment of DCS.**

32 "India's Power Distribution Sector: An Assesment of Financial and Operational Sustainability," accessed January 4, 2021, https://www.brookings.edu/research/indias-power-sector-distribution/.

3.2 IMPLEMENTORS

To fast-track DC system implementation and leapfrog to DCS from conventional centralised cooling systems, private entities could play a key role in providing tailor-made solutions specific to India's geographic location. Moreover, these private players could help identify the boundary conditions and minimum threshold criteria before initiating DC system implementation. The following section provides brief information about the types of stakeholders required in a DC project, such as design consultants and contractors, technology providers, developers, DC project developers, and operators, as shown in Figure 10 below.

Figure 10: Indicative Implementor Categories



3.2.1 Design Consultants and Contractors

Design consultants are essential to conceptualise a project and provide guidance on the overall approach to be taken in the project. The design team requires varied expertise, ranging from engineering and architecture to cooling system design and commissioning. Thus, it is important to identify the organisations that can provide these services. Design consultants provide design and planning documents to the developers, technology providers, and system integrators, in order to translate the conceptualised design into a workable system.

In addition, MEP and Civil Contractors are an integral part of DC project development, as they help implement the design on the ground, commission the system, and ensure compliance with standards and codes, along with system performance.

3.2.2 Technology Providers

Technology providers help develop technical solutions and deliver the equipment needed for DCS, such as chillers, pumps, drives, and control systems. Several technology providers are working in the cooling domain in India.

3.2.3 Developers

Real estate developers are the companies that make the conceptual design a reality and develop space to integrate technologies on the ground. They are responsible for various activities, including purchase, infrastructure, construction, permissions, clearances, and operations. In India, as of 2019, the real estate market was valued at around United States Dollar (USD) 1.72 billion and is projected to grow to USD 1 trillion by 2030[33]. India has numerous real estate developers. The potential role that the real estate sector can play is adopting DCS in their construction projects, providing sustainable cooling solutions, and partnering with other stakeholders to develop viable business models to provide cooling as a service to end-users.

3.2.4 DC Project Developer or DC Service Provider

DC project developers or DC service providers take different types of equipment from various technology providers and integrate them to form a workable, effective system. They are an integral part of the DC

33 "Indian Real Estate Industry: Overview, Market Size, Growth, Investments", IBEF, accessed December 28, 2020, https://www.ibef.org/industry/real-estate-india.aspx.

ecosystem, as they have the knowledge and expertise in interlinking different systems and maximising overall system efficiency and performance. Depending on the project structure and business model, take on the responsibility either wholly or partially for the integration of different systems such as cooling equipment, piping, and pumping and ensuring the provision of cooling as a utility service. They may also support in designing, building, financing, executing, commissioning and operating DCS and other associated components.

3.2.5 Operators

Operators are the organisations that come last but remain for the longest time in the DC project cycle and play the biggest role in ensuring the provision of cost and energy-efficient cooling. The operators are responsible for ensuring efficient and uninterrupted system operations. Operators are expected to maintain high service quality, set up tariff structures, ensure timely billing, monitor and improve the performance of the DCS, and develop and adhere to measurement and verification protocols. These organisations act as an interface between end-users and investors. In several examples globally, DC Service Providers also act as operators.

3.3 FACILITATORS

Facilitators are the set of stakeholders that can provide the technical and financial backing to implement DCS. Their role is to facilitate the implementation of the DC project and creation of enabling conditions, tools, and resources for the adoption of DCS.

3.3.1 Investors

Globally, DC is seen as a utility business and is thus a key area of interest for investors, as it provides a stable source of return on investment (around 10% over 15 years). There are three types of business models usually adopted: 1) fully public, 2) hybrid - public and private, and 3) fully private business model, further detailed in the chapter on "Economics of DCS".

3.3.2 Multilateral/Bilateral Institutions

Pilot demonstration and uptake of any innovative technology requires the involvement of multilateral and bilateral institutions to bridge any funding gaps and occasionally provide capital expenditure (CAPEX) in the form of credit lines to government organisations/ developers.

3.3.3 Knowledge Partners and Associations

Raising awareness about technologies, developing verification frameworks to showcase the impact of DCS, and piquing national and international organisations' interest in district cooling requires documentation and coordination among various agencies. The organisations that can facilitate these aspects fall under the category of knowledge partners and associations. The knowledge partners can for instance work with the green building rating agencies to incentivise real estate developers who wish to adopt DCS. This can be done by incorporating appropriate credits for DCS within the rating systems.

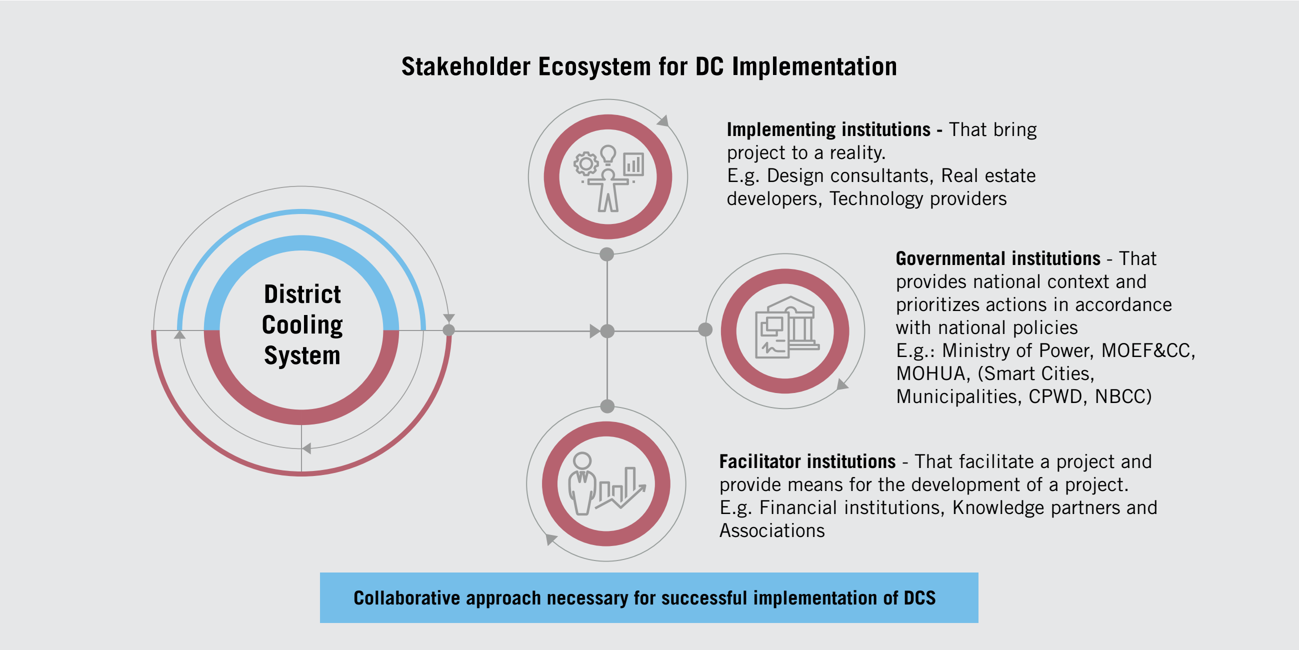
3.4 STAKEHOLDER ALIGNMENT

DCS are comparable to any large-scale infrastructure projects, and, as mentioned above, there are multiple types of stakeholders involved in the development of DCS. A clear understanding of the power and authority that different categories of stakeholders have is important. A snapshot of how each stakeholder category can align with a different set of stakeholders to make DCS a reality in India is presented in Figure 11.

As DCS represent a new technology, confidence development, capacity building, and sensitisation are needed before the systems can be mainstreamed and used by the majority of end-users, similar to PNG, electricity, and water. DC project implementation requires a collaborative approach and alignment of the three categories of stakeholders in terms of enabling governmental policy frameworks, provision of knowledge tools and financing instruments by facilitator institutions, and the application of professional and technical resources from the implementing institutions to introduce the concept, benefits, and operation of DCS to end-users. Furthermore, these stakeholders have to come together to implement DCS on the ground in terms of DC plant ownership and shareholding. More information on the ownership and business model are presented in Chapter 6. Further details on how national-level codes and guides can be translated into implementable directives at the state level by state-level development authorities and municipal corporations are given in Chapter 8.

Site selection is one of the critical parameters in defining the extent of the project's impact, as the relation of the site to its surroundings significantly affects the performance of the proposed infrastructure. The purpose of site selection is to identify the site with the best possible combination of features in the desired predefined region. Site requirements for infrastructure depend on the nature of the infrastructure; for example, a site that is suitable for laying out a utility line may or may not be suitable for building construction. Selecting an unsuitable site may have consequences, ranging from lower project output to its complete failure. The objective of this chapter is to define the site selection criteria for DCS.

Figure 11: Stakeholder Ecosystem for Successful DCS



4 PROJECT EVALUATION CRITERIA FOR DCS

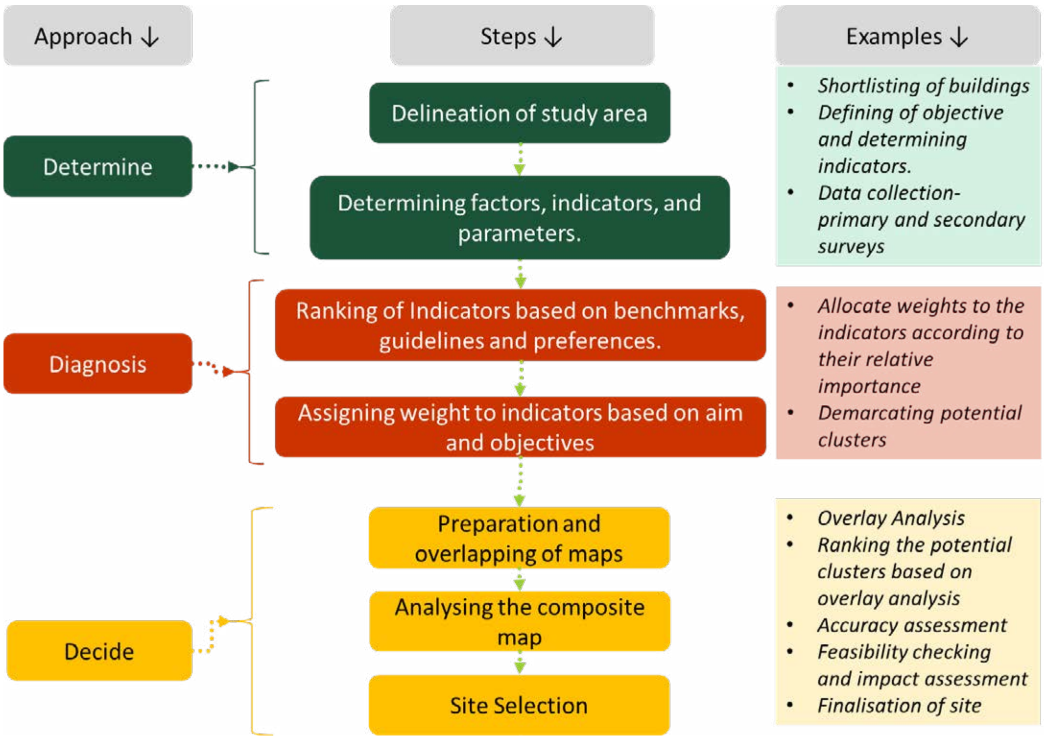
4.1 SITE SELECTION CRITERIA

Site selection involves careful evaluation of various aspects with different degrees of importance. A methodology should be prepared to ensure that the critical aspects are not overlooked. The aim is to define a set of criteria that helps in shortlisting the most optimum site, which has the following characteristics:

- Resource-efficient
- Minimum environmental impact
- Cost-effective
- Adequate in terms of logistics
- Ensures maximum efficiency
- Offers possibility of easy future expansion.

Figure 22 shows the indicative methodology for site selection. These steps may be modified based on the nature of the development. A project can be greenfield (new development) or brownfield (existing development) or a mix of both (extension to existing development). Brownfield development would need to consider more parameters than greenfield development to accommodate and adjust to the existing scenario. These key parameters are listed in Figure 12.

Figure 12: Indicative Site Selection Method



The first stage of site selection is determining the study area and indicators. The second stage involves the diagnosis process, wherein indicators are ranked and weighted according to benchmarks, guidelines, and preferences. Furthermore, this stage involves analysis of data collected for various indicators. The last stage is decision-making, where potential sites are ranked, followed by the development of a feasibility plan. The process can take place via the traditional method of site suitability analysis or using computer-based applications.

4.2 STEP 1: DELINEATION OF THE STUDY AREA

The first step is to finalise the project city/region and determine the study area within that region. To do this, one should consider the existing plans, programmes, and missions (such as building bye-laws, development control regulations, regional plans, and master plans) that can either facilitate or hinder DC system implementation. Furthermore, aspects like real estate scenarios, stakeholder consultations, & expert advice (from decision makers, local government officials, town planners, architects, developers, and owners) should also be taken into consideration before finalising the area.

In the case of greenfield development, the analyst can go on to the next step after identifying the area; however, for brownfield development, once the study area is finalised, the next task is to shortlist potential buildings.

To ensure economic viability, the load density should be in the prescribed range as mentioned in the DC design guidelines.

In order to ensure maximum use of the DCS, it is recommended to select buildings that can average load over different times of the day, week, and month. By the end of this step, a list of buildings, out of which buildings with maximum potential can be termed 'anchor' buildings, is prepared.

In the case of greenfield development, the entire project can be designed to accommodate the DC system requirements. Such a project would not need to consider the building design and use category in the next stage, whereas brownfield projects would entail considering all parameters.

4.3 STEP 2: DETERMINING FACTORS, INDICATORS, & PARAMETERS

At the beginning of this stage, there could be multiple sites that fulfil the prerequisite criteria. Determining the correct set of factors, indicators, and parameters is crucial for the analysis. The factors can be classified into the below-mentioned categories as mentioned in Figure 13. Each of these categories and subcategories should be marked against their preferred range as the indicators.

Figure 13: Major Factors Influencing DC System Implementation

Building design and use	Building energy demand	Local context	Resource requirement	Policy and governance
Availability of space for distribution centre or possibility of extension	Peak demand	Topography	Financial assistance	Existing policies, programmes, and missions
Floor Area Ratio or Floor Space Index	Demand density	Slope and contours	Capital Investment	Proactiveness of local government
Carpet area	Delivery density	Existing and proposed utility lines	Rate of return	Administrative capacity
Total floor area	Time distribution of energy demand over days, weeks, months, and years.	Water	Payback period	Ease of getting permissions and clearances
Diverse use of buildings	Potential future cooling demand	Drainage	Labour and other resources	
Ownership		Telecom, PNG line, electricity line, etc.	Availability of skilled labourers	
Availability of water and power to meet current and future demand		Access to natural cold-water body	Availability of machinery	
Electricity & Water Cost		Access to renewable energy and/or waste energy source	Time	
		Road network	Project timeline	

4.3.1 Building Design and Use

The analyst should assess the context based on parameters like the size of buildings, their function, location, and the possibility of extensions. The building's function holds maximum importance in a DC system, as it determines the overall demand and impact. For example, unlike residential buildings, commercial buildings (e.g. offices, shopping malls, & supermarkets) have high cooling loads for regular AC on weekdays. On the other hand, shopping malls require significant cooling energy throughout the week, with peak loads during weekends and evenings (especially in the summer). Industrial complexes have high cooling demand (for processing and office space) for both AC and process applications. Hotels have varied energy demand throughout the year depending on tourism. Unlike all of the above examples, hospitals do not have a fixed peak load timing and therefore require constant energy supply across all seasons.

DC system planning should start right at the building design stage, as this helps ensure the best use of the available space in a building. It also helps reduce any wastage of area/free space by smoothly planning the different rooms and compartments required for DCS. The advantages of this area optimisation exercise can also be understood in economic terms. The smaller the area absorbed under the DC system, the lower the construction load, manpower, material usage, and construction time. Early planning can also enable better system engineering between components, e.g. through the following:

- Design to reduce the distance between interconnections within the system, thereby reducing its cost
- Correct selection of the system and technology to ensure maximum efficiency
- Reduced footprint requirement through improvement in the overall use of the building and its multiple spaces by eliminating area wastage in the form of large corridors, complicated designs, etc., thereby ensuring high land use efficiency.

4.3.2 Building Cooling Energy Demand Estimation

Local energy demand has parameters like cooling peak demand (TR), cooling demand density (TR/km^2), and cooling delivery density (TR/km^2). It is vital to estimate the optimum demand and density to ensure a successful DC project. Inaccurate estimation may lead to incorrect system sizing, network design, and business model design and consequently negatively impact the project's financial viability. The assessment (calculation) sheet has a predefined weightage for each parameter. Based on the minimum requirement, the scoring is done.

Once cooling energy demand is calculated, it is important to estimate the precise cooling load of the DC system. Regarding space cooling applications, the cooling capacities and usage patterns of different end-users (i.e. residential, commercial, institutional, transport, and industrial buildings) can differ significantly and require detailed analysis, as the cooling load is often considered the most critical input for the design, performance, and economic viability analysis of DCS. The safety coefficients and seasonality over the day or along the year may make the DC plant run on partial loads most of the time. Hence, proper dynamic balancing on both primary side i.e. before the ETS and secondary side i.e. after the ETS is extremely important.

4.3.3 Local Context

Since district cooling is a city-led initiative, it is important to cater to urban-level parameters. The topographic nature of the land, its elevation, contours, depressions, and other geographical aspects have a major impact on the ease of installation, accessibility, and O&M of the project in the selected site. The existing features should be least disturbed before establishing a DC system; hence, a utility map road network should be considered in the site selection process.

4.3.4 Resource Requirement

The resource requirement is another important parameter in DCS implementation, as it defines the feasibility based on the required investment and time. For site prioritisation, capital investment, internal rate of return (IRR), payback period, energy tariffs, pipeline investment, and heat loss through the pipeline are considered. Capital investment is mostly dependent on the technology selection, network length, and land cost. Based on the capital investment and plant size, IRR and payback are calculated. One should be careful in selecting feasible technologies to achieve optimum IRR and net present value (NPV) in the project. Along with the cost, factors like time and labour availability also hold high importance.

4.3.5 Policy and Governance

Obtaining local government permits for construction and permits from parastatal agencies to make modifications in the electricity supply, draw freshwater, and discharge water is time-consuming, and, if denied, the lack of these permissions can halt the project for an indefinite amount of time. Thus, assessing the governance scenarios, policy landscape, and ease of doing business is crucial.

4.4 STEP 3: RANKING OF INDICATORS BASED ON GUIDELINES AND PREFERENCES

Some of the factors listed above are more relevant to DC projects than others. Table 9 highlights the recommended prioritisation of the different factors and their possible data sources. Factors like peak cooling demand, existing and proposed utility lines, road networks, and ease of getting permissions & clearances hold maximum importance when selecting a site for a DC system, whereas other factors like access to a renewable energy source and/or waste energy source are favourable, but the project can be implemented without them. These priorities may vary from project to project; thus, analysts can define their own ranking and weightage according to their main objectives.

Table 9: Key Parameters & Possible Data Sources

Sl. No.	Category	Factor	Data Sources
	Building design and use	Availability of space for distribution centre or possibility of extension	• Building design • Neighbourhood plan • Primary survey
		Floor Area Ratio or Floor Space Index	• Building design • Master plan of the city • Primary survey
		Carpet area Total floor area	• Building design • Primary survey
		Diverse use of buildings	
		Ownership	• Municipal land records • Primary survey
	Building energy demand	Cooling peak demand Cooling demand density and delivery density Cooling demand diversity Potential future cooling energy demand	• Electricity consumption data from DISCOMs • User survey on the cooling load • Area population projections from master plan • Calculation and forecasting of future energy demand and cooling load

Sl. No.	Category	Factor	Data Sources
	Local context	Topography Slope and contours	• Elevation map from CPWD • Site design
		Existing and proposed utility lines	• Water distribution system map, electricity distribution system map, drainage system map, PNG distribution system map, etc. from respective departments.
		Access to free cooling from sources such rivers, other water bodies, or groundwater	• Satellite image • Primary survey
		Access to renewable energy source and/or waste energy source	• Department of Renewable Energy • Primary survey
		Road network	• Transport Department • Primary survey • Satellite imagery • Local area development plan
	Resource Requirements	Investment, time, material, and labour	• Calculation by project team
	Policy and Governance	Existing policies, programmes, and missions	• Government stakeholder consultation • Expert recommendations • Review of policy documents
		Proactiveness of local government Administrative capacity	• Stakeholder consultations
		Ease of getting permissions and clearances	• Statutory documents, rules, and regulations • Stakeholder consultations

Legend: Highest Priority → Lowest Priority

4.5 STEP 4: ASSIGNING INDICATOR WEIGHTS

The weighting of indicators should be done cautiously, as these weights have a major impact on the assessment and final results. A numerical weight should be assigned to each factor according to its priority. This process may involve stakeholder consultations and expert evaluation of the prioritisation of indicators.

4.6 STEP 5: OVERLAY ANALYSIS OR ASSESSMENT MATRIX

Considering all parameters, an overlay analysis or assessment matrix could be developed, which would provide an overall holistic preview of the context. Each parameter has its own weightage, and if attributes meet the minimum requirement, it gets a score. Based on the overall score achieved as per the overlay map or assessment matrix, the site should be finalised as a potential site for the DC project.

4.7 STEP 6: ANALYSIS OF COMPOSITE MAP/ MATRIX AND SITE SELECTION

The analyst is able to make an informed decision based on the overlay map or assessment matrix analysis. The result provides a point-based ranking among multiple sites, and one can decide which site can be converted into a potential site for a DC project. Furthermore, it enables a comparison of feasibility between two or more sites, which helps investors make decisions. Once the site is finalised, the analyst may consider conducting a socioeconomic and environmental impact assessment before proceeding further with DC system design.

5 DISTRICT COOLING PROJECT CYCLE

Once the site is evaluated for the DC project, further investigation in the form of a rapid site assessment should be conducted to establish the district cooling potential. This is followed by an in-depth assessment and project development, as depicted in Figure 14. The general idea is, to begin with, a rough assessment of the DC potential to analyse the viability of multiple options and then select the most financially and environmentally appealing option to take forward to the design, construction, and implementation stages, followed by market expansion in the future.

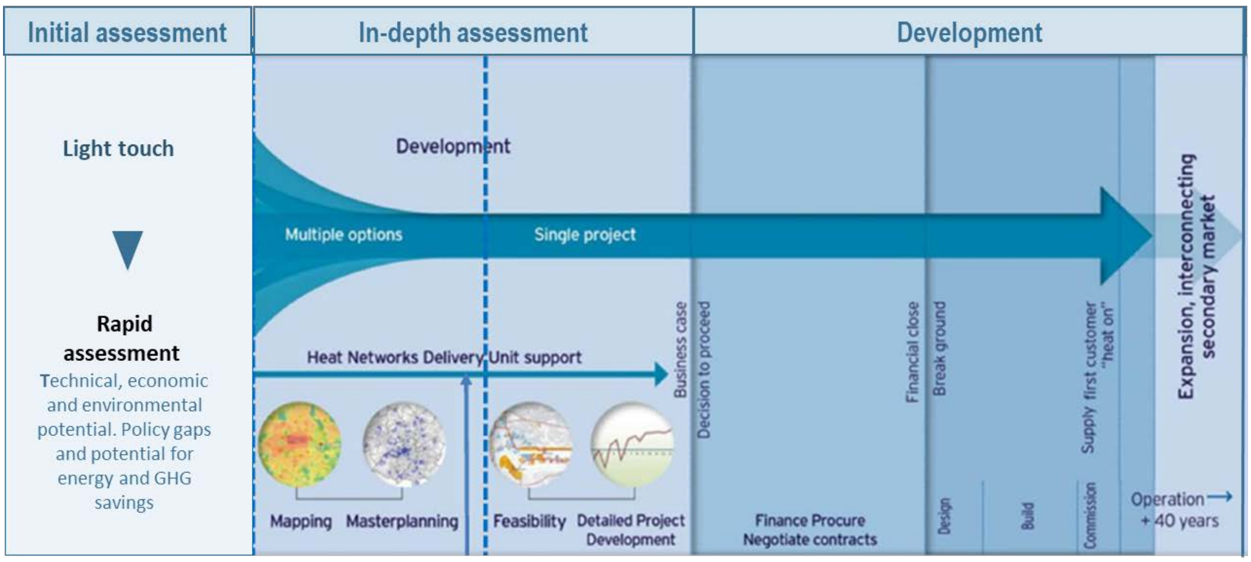
5.1 CONCEPT & PLANNING

5.1.1 General Procedures for Prefeasibility Project Development

There are usually three stages until the complete feasibility study for a project is undertaken, as highlighted in Figure 15:

Figure 15: Prefeasibility Project Stages

Figure 14: Project Development Lifecycle



(Source: DBEIS Heat Networks Delivery Unit)

5.1.1.1 Stage 1: Light Touch/Rapid Assessment at the City Level for Site Selection

Light touch or rapid assessments (RAs) are the first steps in project development, as they require very few resources and can help identify high-potential areas for DC project development in the later stages. Rapid assessment is performed to analyse whether the technical, economic, and environmental potential of a certain DC scheme is significant enough to justify advancing to a deeper analysis, which could be a citywide analysis and/or prefeasibility study for the considered scheme. The steps involved in the rapid assessment are depicted in Figure 16:

Initial approach: At the city level, local contact points should be established, mainly with planning authorities, to ensure the necessary approvals are obtained to conduct the assessments. In general, the key stakeholders to be engaged in this step include the city´s planning and policy-relevant programme, real estate, property developers, and related institutions, architecture and civil engineering firms, DISCOMs, state-designated energy agencies, the regional pollution control board, industry-related institutions, designers, manufacturers, and installation contractors for chillers and cooling systems, etc.

Advanced communication: Tailored requests are sent to the relevant stakeholders in a city to collect readily available data and information. The data request should include the necessary details to carry out the rapid assessment and emphasise the fact that if specific data is unavailable, then related information, including considered estimates, would also be useful. Such data is useful in getting a general overview of the local conditions regarding the natural environment, socioeconomic status, and energy development.

City visit planning: In this step, city visits and interviews are planned to achieve a better understanding of local conditions and project-specific details on the ground. Based on the assessment of data and information received in Step 2, city visits are planned. The city visits include selected stakeholder interviews (mainly with municipalities and utility companies) and data collection. The interviews are planned in advance, ensuring appropriate actors are available, and information is provided on the likely content of the interviews.

City visit: Site visits are conducted in cities to meet local actors such as the municipality, utility, national representatives, etc. to obtain the required information and explore potential/existing sites.

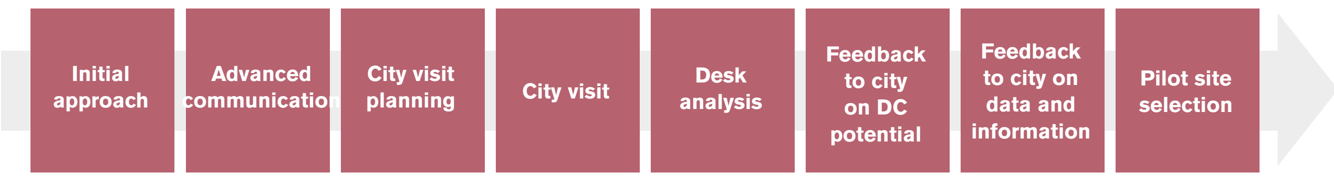
Additional data and contextual information that can be provided by the city is gathered by conducting interviews with relevant municipal departments and other stakeholders. In addition, by physically being in the city, consultants are able to collect data and information that may be difficult to access remotely.

As well as meeting stakeholders to obtain data and information points, consultants are able to get a ‘feeling’ for the status and potential of district cooling in a city by visiting specific areas of the city to gather the following information:

- Buildings in a central business district (CBD) to gather information on current cooling technology (centralised or not, chiller age, etc.), approximate floor area, spacing between buildings, & availability of land for an energy centre
- Areas where large new developments are in progress, in order to visually link development plans with the actual site.

Desk analysis: All of the data and information collected is analysed to assess the potential of a district cooling demonstration project. Pilot project sites in the city are selected after discussions with the relevant municipal corporations. As mentioned above, rapid assessment tools (e.g. the rapid assessment toolkit developed by UNEP District Energy in Cities Initiative) are employed to determine whether district cooling’s potential in the area is sufficient to justify moving forward in the project cycle. In this step, the DC policy framework is evaluated by performing policy scanning related to clean cooling and green buildings. The following parameters, among others, are recommended to be analysed in this step:

Figure 16: Steps Involved in Rapid Assessment of a City



1. Technical parameters: cooling demand (peak, hourly demand on design day), potential connection built-up area, building types, pipeline routine and length, total cooling capacity, annual electricity and water consumption for proposed DC system, potential cooling sources, phasing of systems
2. Economic parameters: total investment (CAPEX), OPEX, chilled water tariff, IRR
3. Environmental parameters: electricity and water savings, reduction in GHG emission and refrigerants

Feedback to the city on DC potential: The results of the analysis should be shared with the relevant urban development stakeholders. The analysis concludes whether district cooling is a commercially viable option for the analysed areas, with a rough estimation of reasonable IRR, considering both short-term and long-term implementation. A short report summarising the results of the desk study and potential next steps is developed and shared with the cities. This includes improvements in policy, technology, and institutional development.

Feedback to the city on data and information: Feedback is provided to the cities on the ease of obtaining data and information, and recommendations on low-cost data collection strategies are shared, along with remarks on how the city should intervene to make the data and information more available and relevant. This is useful in gathering detailed data points required for in-depth/deep dive studies, prefeasibility studies, etc.

Pilot site selection within the cities: After performing the rapid assessments of pilot sites, a report is developed on the results of the analysis. It also includes information such as the city's background and key relevant features, stakeholder mapping, city strategies and initiatives, local policies and legal framework, applicable business models, barrier analysis for project implementation, current status and opportunities for DC, and recommended next steps for the city.

5.1.1.2 Stage 2: Site-Specific Deep Dive Assessment

An in-depth or deep dive assessment builds on the rapid assessment and moves towards a deeper prefeasibility analysis. It is a preliminary study that can be used to determine the best business scenarios for district cooling in the pilot city. Along with the economics, the technical requirements and environmental impact can also be assessed.

The analysis performed is focused on assessment of the existing project conditions, such as setting the BAU scenario. This is done by identifying the existing cooling demand and technical level and efficiencies in existing individual cooling generation and distribution technologies, along with their operational costs, and emissions levels. The analysis can then assess the financial and emission savings potential DC could bring to improve the citizens' conditions. In this way, the analysis should further evaluate the potential of the DC technology for the district, city, or region assessed. In general, the deep dive assessment requires more detailed data collection at the specific site. For the analysis of cooling demand in different building types, it is recommended to use either real measured data from the site or nearby regions or benchmarking data with energy simulations. One of the key data sources to look at is the development plan or master plan in the region, in order to determine the required size and phases of the DC cooling system.

5.1.1.3 Stage 3: Further Development: Feasibility Study

The feasibility study takes the deep dive assessment further and incorporates more details. The cooling demand is estimated based on the available data, and the methods of production, financing, business model, and organisation are solidified. Technical considerations such as distribution temperature, network layout, design pressure, and preliminary layout with specifications on the dimension, length, and type of installations per stretch are usually examined in the feasibility study. Normally, there should be two separate reports for a feasibility study, on technical feasibility and commercial feasibility. In the technical feasibility study, a more detailed design (e.g. conceptual design) for the DC system should be included, with a detailed analysis on CAPEX and OPEX. The commercial feasibility should be analysed based on the results of the technical feasibility study and include a more detailed business model and recommendations for business plans for DC project implementation.

The outputs, such as the NPV, IRR, and payback time (PBT) are indicators of the project's profitability and enable estimation of the emission, electricity, and water savings potential.

In the Indian context, the feasibility study should be linked to the detailed project report (DPR).

The DC service provider must prepare a DPR highlighting various aspects related to the deployment of the DC system. The report should be comprehensive and include, but not be limited to, the following points:

Indicative Contents of the DPR

1. General project information
2. Background and experience of the project promoters
3. Market analysis and project justification
4. Social & political aspects of the project
5. Details of the proposed project:
    a. Project stakeholder mapping
    b. Plant capacity
    c. Project design brief
    d. Details of land, buildings, and plant and machinery
    e. Government approvals, local body consent, and statutory permissions
    f. Mode of construction execution and O&M strategy
    g. Details of infrastructural facilities (power, water supply, transport facilities, etc.)
    h. Raw material requirement/availability
    i. Effluents produced by the project & treatment procedures adopted
    j. Labour requirement and availability
    k. Project schedules/timelines
    l. Cooling offtaker tariff structure
    m. Project CAPEX & OPEX
    n. Working capital requirement/arrangements made
    o. Profitability and cash flow estimates
    p. Mode of loan repayment
    q. Details of collateral security that can be offered to financial institutions
    r. Marketing and selling arrangements
    s. Contribution of the project in terms of environmental, social, and governance (ESG) benefits
    t. List of project benefits over the project lifecycle.

5.1.2 Business Case Development

The design, development, and operation of DCS must be approached as a long-term utility service business and not as a contracting job.[34] The series of steps to be followed for business case development are mentioned below:

- System architecture and technology options
- Initial market assessment
- Stakeholder identification
- Risks and required permit identification
- Identification of business models/ownership models
- Rough order of magnitude key financial figures

5.1.2.1 System Architecture and Technology Options

A range of technologies can be used to generate chilled water in the energy centre. Multiple scenarios can be created considering different modes of sourcing, production, and distribution of centralised chilled water, with the constraint being that the technology selected for analysis should be able to deliver the required demand with high efficiency.

5.1.2.2 Initial Market Assessment

A market assessment is a comprehensive analysis of competitors, consumers, and other industry stakeholders. A market assessment enables the cooling provider to understand the need and demand for cooling in the market. Such an assessment is required to identify potential customers, the size of the target market, customers' willingness to pay for the service, competitors, etc. For this exercise, data is gathered from multiple sources, such as building and real estate registers, refrigerant registers, electricity demand profiles, and climate databases, where available.

5.1.2.3 Stakeholder Identification

DC projects are inherently large and complex, as they involve various stakeholders who are impacted by the project outcomes or have a role to play in their delivery. Hence, it is important to identify all the relevant players and build a strong coordination framework to deploy the project in an organised manner without suffering any unforeseen delays. Stakeholder groups, organisations, and individuals are identified according to their role, interest, and influence in the project. The stakeholders in DC projects comprise public authorities, investors/capital providers, utility companies, building developers,

34 District Cooling Best Practice Guide, International District Energy Association (IDEA)

customers, and residents. The stakeholder list can be regularly updated and refined as the project progresses.

5.1.2.4 Risks and Permit Identification

Risk management involves risk identification, evaluation, and prioritisation. It helps developers mobilise the required resources in order to minimise, monitor, and control the risks such as that of inadequate number of cooling consumers.

Permitting is an especially time-consuming process for DC projects, given their size and complexity. By identifying the permits needed to carry out such projects in the early stages, unnecessary delays can be avoided during the development phase, which can otherwise result in high costs and/or the project being stalled. The time required can be greatly reduced by engaging the right stakeholders at the local and national levels.

This is followed by the identification of possible business/ownership models, such as fully private, fully public, or hybrid, and the development of rough order magnitude financial key figures, considering lifecycle costs.

5.2 DEVELOPMENT, DESIGN, CONSTRUCTION, AND COMMISSIONING

5.2.1 Project Development

Project development after the assessments involves securing contracts at all ends of the project, such as customer contracts, financing, operation and construction, etc. The main activities include structuring ownership and stakeholders, project management, engineering, procurement/contracting, permitting, securing land rights, financing, marketing and sales, and risk management. Business models are further developed to fit risk allocation and control requirements.

The various aspects of project development include the following:

- Contracting alternatives
- Engineering
- Procurement/Contracting
- Permitting
- Financing
- Developing customer concept and contracts
- Marketing and sales

A rough estimate of the duration of each stage in project development is given in Table 10 below. The timeline may differ greatly due to data availability, system size, etc. It should be noted that some of the stages can be executed in parallel. For a 10,000 TR project, the total time required is approx. 15-18 months.

Table 10: Estimated timelines for project development

Stage	Estimated timeline (months)
Engineering design	4-6 months for detailed design
Permits and regulatory approvals	3-4 months
Construction	6-10 months
Procurement	6-8 months
Testing, precommissioning, & commissioning	1-2 months
Marketing and sales	Entire project period

5.2.1.1 Contracting Alternatives

Existing markets offer various options for DC project structuring and construction. Several well-defined contracting alternatives are available. There are two common alternatives that are usually implemented:

- The first alternative is a contract with a third party to design and build the DC facilities, called an engineering, procurement, & construction (EPC) contract. This kind of contract transfers the design and construction risk to a third party.
- Another frequently used model is build-operate-transfer (BOT). BOT refers to a contract wherein a third party designs, builds, and operates the DC facility for a defined period. The key driver is to transfer the operating risk, in addition to the design and construction risk.

5.2.1.2 Engineering

The level of engineering is based on the selected ownership structure and contracting alternatives.

Typically, the engineering is divided into the following scopes: production plant, pipeline routing, and customer connections. At the same time, O&M and health, safety, & environment (HSE) plans should be developed for the further implementation of the system.

5.2.1.3 Procurement/Contracting

Procurement is the process of finding and agreeing to terms and acquiring goods, services, or works from an external source, often via a tendering or competitive bidding process. Procurement and contracting include the preparation of bid package documents, qualification documents, general terms and conditions documents, bid issuing procedures, site visits, bid opening procedures, bid evaluation and analyses, clarifications, and selection criteria.

5.2.1.4 Permitting

In this stage of the project, if not sooner, all previous permit studies and permitting preparations should result in various permit applications being presented to the relevant identified authorities, such as ULBs in cities. Permitting activities include meetings with different departments to inform them and get approvals on environmental impact assessment (EIA) studies, shore and territorial permits and consents, building permits, easements, and land lease agreements. Other permits that should be prepared and approved include working permits during construction and operation.

5.2.1.5 Financing

Development and construction financing includes activities such as financial structure and financial model update, tax structure update, other subsidies (e.g. subsidies on land costs for DC plant and main pipelines), and tax facilities updates. Financing also includes loan arrangement, equity arrangement, and other direct agreements with contractors, clients, governments, etc. and can be divided into private (private sector debt, equity, financing from DC providers, venture capital, and business angels) and public (grants, public debt at low interest rates, development bank loans at low interest rates, city level subsidies, and energy revolving funds) sector financing.

5.2.1.6 Developing Customer Concepts and Contracts

A customer supply agreement (CSA) that defines a pricing structure is an important aspect of project design. Price regulation mechanisms need to be established by policymakers at different levels, e.g. municipality, state government, and national government, so that the DC developer does not take advantage of the natural monopolies that are usually created. In this phase, the contractual aspects, including the conditions of the sale of cooling to customers, are developed. The CSA is typically a 10-20-year contract between two parties that describes the terms and conditions for the supply of DC (provider) and its usage (customer).

It is important to define the delivery/supply border. Typically, DC is delivered upstream of ETSs, but depending on local conditions and customers' technical and financial capabilities, the point of delivery can also be downstream of the ETS. When introducing DC on a new market, ETSs are sometimes operated and maintained by the DC provider during the first few years of operation.

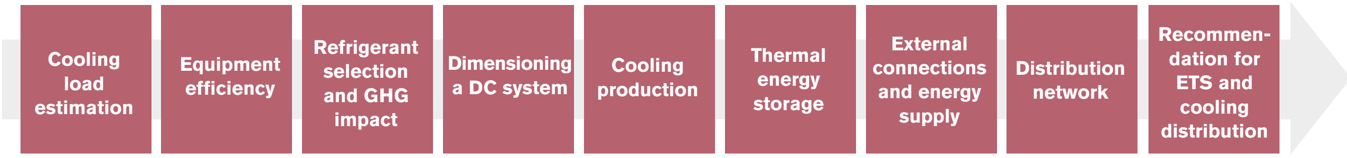
5.2.1.7 Marketing and Sales

The success of any DC project depends on the provider's ability to secure a good customer base. Marketing and sales activities help inform the public about the project and secure potential connections. These activities need to be carried out before the investment decision and construction finance are finalised. DC is a capital-intensive business with high upfront CAPEX; hence, a fair share of the market potential has to be secured by a number of signed CSAs to reduce the investment risk. Approaching large consumers such as commercial complexes and public buildings and securing anchor loads such as swimming pools can be a good starting point for DC projects.

An important aspect of marketing a DC project is to present the total lifecycle value and costs of a DC system compared to those of other options.

5.2.2 Project Design

The main stages of project design are the following:



Normative references covering various relevant national and international codes, standards, and guidelines are provided in Chapter 10 for reference on the design, selection, and operation of various DCS and equipment.

5.2.2.1 Cooling Load Estimation

Introduction

Cooling load is governed by environmental factors such as solar radiation, outdoor temperature, infiltration, and ventilation and internal factors such as appliances, occupancy rate, etc. For a large brownfield project (city-scale), this can be determined either based on electricity bills or cooling degree days. Another option is to use energy simulation software to calculate the hourly cooling demand in one year for different building types. For greenfield projects, space-by-space hourly heat load calculations are recommended.

Some of the factors that need to be considered during the estimation include: background (building age, layout, construction, planned changes, etc.), floor areas and building plans/schematics, maintained space cooling temperatures (per zone), technical specifications of installed AC plant, cooling consumption data (e.g. hourly cooling output, flow & return temperatures, etc.), total site electricity consumption data, operating hours, and energy efficiency (implemented or planned measures).

First approach based on electricity bills

There are three steps in determining the cooling load based on electricity bills.

- **Calculation of monthly electricity consumption based on electricity bills:** These bills are collected ideally over a span of several years, which takes into consider the variation in weather conditions.
- **Identification of share of electricity consumed for cooling purposes:** The amount of electricity consumed for cooling purposes needs to be determined from the consumption data. In cases where cooling is required year-round and diverse typologies of buildings such as residential, offices, commercial, etc. are being analysed, electricity consumption for cooling needs to be determined on a case-by-case basis, depending on the cooling patterns of the buildings.
- **Cooling demand estimation by assessing cooling system efficiency:** Finally, the cooling demand is determined by multiplying the amount of electricity consumed for cooling purposes by the cooling system energy efficiency. This coefficient is based on the type of cooling system installed. Various factors influence this coefficient such as the effect of condensation temperature variation, partial load effect, solar irradiation effect, maintenance and ageing, etc. For instance, in the case of Thane, a COP of 2.5 in the cooling season was considered.

Second approach based on cooling degree days

In cases where data on electricity bills is not available, the cooling demand can be estimated based on cooling degree days by following three steps.

- **Estimation of the number of CDDs:** Initially, the number of CDDs is estimated based on a base temperature. This base temperature represents the desired level of indoor thermal comfort. The number of CDDs is calculated as a difference between the daily mean temperature and the selected base temperature. For example, the total number of CDDs for Thane is 2,150, considering a base temperature of 23°C.

- **Estimation of cooling demand intensity:** The number of CDDs has to be converted into an average cooling demand intensity with a unit of kilowatt-hours (kWh)/m^2/year. For this calculation, several approaches have been developed in various regions around the world. However, for a more precise estimation of the cooling demand, the cooling intensity could be estimated based on the different types of buildings considered in the district, since residential buildings, hotels, schools, offices, and shops are all likely to have different cooling needs. Recommendations for cooling demand calculations for different building types under ECBC Code in India are mentioned in Table 11 below:
- **Estimation of cooling demand:** Finally, the cooling demand is estimated by multiplying the cooling intensity by the floor area of the buildings being analysed.

Table 11: Recommendations for Cooling Demand Calculations for Different Building Types under ECBC Code in India

Cooling density	Hotel	Office	Shopping mall	Hospital	Residential apartment	Campus building
W/m^2	100-180	160-250	150-350	130-220	75-145	65-220

The key factor in selecting an approach to estimate cooling demand depends on the availability of data. Ideally, a combination of a bottom-up approach (based on electricity bills) and a top-down approach (based on CDDs) and the consideration of the district's specific characteristics (types of buildings, consumption patterns, etc.) will enable estimation of the cooling demand range in the district.

5.2.2.2 Equipment Efficiency

At present, most AC loads are met by onsite cooling technologies consisting of either window or room ACs or central air-cooled or water-cooled chillers powered by the electricity grid. The efficiency and refrigerant selection of onsite cooling equipment varies significantly depending on the product, building and cooling system design, O&M, and even the building's ownership structure. In general, in dense urban areas, energy and refrigerant use for air conditioning is far lower if clusters of buildings and even entire townships are connected to a DC system. Global experience, detailed analyses, and existing projects in countries like India show that these systems are also more reliable and cost-effective and would be highly beneficial in strengthening and supporting urban power grids, especially through cheap thermal storage and trigeneration. Much of the energy efficiency advantage of DCS results from combining many diverse load profiles, which allows the DC plant equipment to operate at high load factors, with resultingly higher levels of efficiency. Selection of specific electrical equipment such as chillers, pumps, motors, and any other equipment that BEE's S&L Programme covers should be referred to or complied with the highest efficiency levels (or even beyond) as per the applicable regulations. In case any equipment or appliance is not covered under the S&L Programme, it should adhere to the highest performance levels (or even beyond) recommended in the most recent version of ECBC or ASHRAE. In general, the system efficiency of a DC chiller plant can be in the range of 0.8-0.85 input kilowatts per TR (ikW/TR). However, depending on system size and detailed economic analysis, there are opportunities to improve the efficiency levels of DCS.

5.2.2.3 Dimensioning a DC System

5.2.2.3.1 Cooling Production

Several parameters affect the selection of technical solutions in a DC system and the output temperature of the chilled water:

- Energy supply options, including possible access to electricity (high voltage), steam, natural gas, renewable energy, waste heat & free cooling, etc.
- Recommendations for urban energy planning and guidance on regulations and policies
- CAPEX & OPEX
- Location and size of DC system
- Regardless of which cooling technology is selected, reliability, economic viability, and sustainability remain the top priorities.

Indicative cooling production of different cooling technologies, along with their advantages/disadvantages, are summarised in Table 12.

Table 12: Cooling Production Technologies (Handbook of Heating, Ventilation, Air-conditioning, Cooling and Refrigerating, ISBN 9787112097494)

Energy source	Cooling source	Chilled water temperature: supply/return (°C)	Advantages/disadvantages
Electricity	Electric screw or centrifugal chillers (415 V/6.6 kV/11 kV)	5-6 / 13-15	Low initial investment, simple management and maintenance
	Electric chillers with thermal storage	1.1-3 / 13-15	Lower initial investment for electricity supply system and distribution network, less distribution energy consumption, higher energy consumption for chillers, complicated operations, peak electric load shifting
Natural gas, oil	Direct-fired absorption chiller	6.5-7 / 13-15	Requires steady supply (price and quantity) of primary energy
Access heat from power plants (steam or hot water)	Absorption chiller	6.5-7 / 13-15	Has to be combined with the energy system in power plants for higher primary energy efficiency
	Steam-driven centrifugal/ chillers	3-4 / 13-15	Suitable for areas with abundant natural gas supply at lower tariffs and lack of electrical power supply
Geothermal Free cooling	Ground-source/water-source chillers	6.5-7 / 13-15	Relatively higher initial investment
Multiple energy sources	Combination of absorption chillers and electric chillers, free cooling, etc.	3-4 / 13-15	Requires operational mode to benefit from the incentive tariffs for different energy sources to reduce OPEX

5.2.2.3.2 Distribution Network

The district cooling network typically operates as a closed circuit with a supply temperature of approximately 5°C and a return chilled water temperature of 12-16°C. DCS are designed for high delta temperatures (the difference between the supply and return chilled water temperatures) upwards of 9°C. Since the flow is inversely proportional to the delta T, a high delta T system requires lower flow and thus lower pumping energy and equipment (pumps, pipes, valves, fittings, and heat exchangers) capacity to satisfy the cooling requirements. Hence, the higher the return temperature, the more cost-effective the cooling network will be, but achieving temperatures above 12°C would normally involve some additional investment in the buildings themselves (e.g. larger AHU coils or use of chilled beams). Although heat gains from the environment will be relatively small, especially with the buried pipe, it is normally necessary to insulate the pipes. To prevent condensation on the pipes, the insulation needs to be vapour sealed. A common solution is to use pre-insulated pipe. This consists of sections of steel pipe in polyurethane foam insulation and a high-density polyethylene outer casing. The pipes are delivered in 12 m lengths and welded together on site. An outer casing joint closure is formed over the weld, and foam insulation is injected into the cavity. This provides an efficient system that is sealed against water ingress, resulting in a long life. These pipes also incorporate wires that detect the ingress of water either from the ground or chilled water and provide an early warning of any faults, so that repairs can be made before any corrosion damage or significant loss occurs. An alternative is to use polyethylene or polybutylene for the carrier pipe; however, these pipe systems are typically more expensive at the larger diameters required for district cooling. Furthermore, nitrile rubber material can be used for the insulation of chilled water pipes within the buildings.

As summarised by the Handbook of Heating, Ventilation, and Air Conditioning, the investigation of over 50 DC projects in Asian-Pacific countries shows that the investment in the distribution network accounts for approximately 10-20% of CAPEX, while the electricity consumed by distribution pumps accounts for about

15% of OPEX. It is very important to optimise the distribution system to achieve high energy efficiency and sustainability for the entire system.

It is possible to increase the network capacity by increasing the temperature differences between supply and return chilled water. For example, it is possible to reduce the supply temperature to as low as 1.1°C by using steel ice coils in ice storage systems. This kind of TES technology is used globally in DC projects, especially for those with limited space for DC systems but high required cooling capacity, like in Japan, China, and Singapore.

Distribution pipelines should be designed for a life expectancy of a minimum of forty years, which is the global best practice.

5.2.2.3.3 Recommendations for the Design of ETS and Building-Level HVAC Systems

There are several options to define the boundary between the DC system and the customer's cooling distribution. This boundary can relate to the initial investment, future management, and operations. One common option is to set the boundary at the ETS. The advantage of this option is that the DC service provider can more easily assure the energy efficiency and effectiveness of ETS and its control systems. Another option is to consider the building basement wall as the boundary to reduce the DC service provider's CAPEX. It is recommended to set ETS as a boundary between DC and internal cooling systems.

It is also recommended to have abundant backup capacity for the heat exchangers in the ETS. There are several innovative technologies and designs in heat exchangers to enhance heat transfer. The efficiency of heat transfer should not be less than 90 percent. The temperature difference for heat transfer between hot and chilled water is recommended to be less than 0.8°C. In some of the best practices of DC systems worldwide, the temperature difference of heat exchangers can be as low as 0.5°C.

When choosing the location of the DC ETS (normally in the building), the maximum working pressure that the valves and pipelines in the DC system can withstand should be considered, which is usually 160 or 200 kilopascals (kPa) and should be verified against the distribution pump shutoff pressure. The ETS is located somewhere within the building based on the height of the building. If the number of floors is above twenty (20), additional ETS needs to be placed at an intermediate level of the building to moderate the hydraulic pressure of piping networks at the lower level.

The DC service provider should develop and provide guidelines to the individual (customer) building developers on the installation and O&M of the in-building HVAC systems to be connected to the DCS system. The purpose of the guidelines is to illustrate how to install metering and control systems for the ETS and design their own internal AC systems (such as AHUs and fan coil units (FCUs)) to operate in a compatible way with the DC system, assuring good energy efficiency. The design and operation of internal AC systems should be in line with the supply and return temperature of chilled water, pressure, and other requirements of DC systems. To operate the AHUs and FCUs with high delta T, special consideration should be paid to the cooling coil design. For the supply CHW to pick-up heat at more than 9°C delta T, a lower water flow rate and larger coil size are required than those of traditional coils that operate at a standard delta T of 5°C. Hence, the AHUs and FCUs should be specifically designed, optimised, tested, and verified for low-flow and high delta T operation.

Delta T is both a key design parameter and operational energy efficiency parameter indicating total system performance. Non-compliance penalties and compliance bonuses embedded in the cooling tariffs (i.e., the CSA) are effective tools to enable customers to make sound economic decisions in their buildings to enhance their delta T performance.

5.2.3 Construction

5.2.3.1 General

Construction of various physical infrastructure within the DC system such as the central DC plant buildings, cooling network, substations, etc. is the main activity in this phase. Some of the key activities in this phase are mentioned in the following section.

5.2.3.2 Key Activities

During the construction phase, the impacts that have been identified while carrying out the EIA need to be carefully monitored. Management and staff required to operate and maintain the system are recruited. Normally, a certain level of customer commitment is required pre-construction, but marketing and sales activities need to be continued throughout construction to secure as much revenue as possible as soon as the DC system becomes operational. In the construction phase, there is a good opportunity to attain interest from previously doubtful potential customers, since at this point there is evidence that the system is being implemented. It is also relatively easy for all parties to foresee when the service will become operational, thereby managing connected risks.

5.2.3.3 Success Factors

Key success factors include keeping track of the overall schedule and profitability goals and continuing to evaluate proposed changes and improvements from a lifecycle costing, project profitability perspective. The quality control of underground and sub-surface installations including construction and forging of pipes is critical to the functioning and lifetime of the installations. During construction, there is disturbance, not only to the environment, but also to stakeholders and traffic. Communication of long-term benefits to stakeholders and the community helps drive greater acceptance of temporary disturbances during construction. It is often a challenge for customers to procure and correctly install ETS. Therefore, it can be worthwhile to make resources available to assist customers or even offer turnkey solutions through third parties.

5.2.4 Testing, Precommissioning, & Commissioning

5.2.4.1 Objective of Testing, Precommissioning, and Commissioning

System testing & commissioning is important for DC projects to achieve design functions, ensure operational efficiency, and achieve sustainable, optimal operation throughout the lifecycle of the DCS.

The major objectives of commissioning are as follows:

1. Verify that the model and performance parameters of the equipment meet the design requirements.
2. Verify that equipment and systems are installed in the correct location.
3. Before the commissioning process, necessary precommissioning shall be carried out as per the manufacturer's installation, operation, and maintenance (IOM) documents; this is an important process that is required for proper system testing.
4. Verify that the installation quality of equipment and systems meets the specific requirements of relevant regulations.
5. Ensure that the actual operating state and performance of equipment and systems meet the design requirements.
6. Ensure the safety, reliability, and efficiency of equipment and system operations.
7. Optimise O&M by providing comprehensive quality training and operating instructions to the owner's operators.

5.2.4.2 Testing, Precommissioning, and Commissioning Plan

Once the DC system is installed, the same shall be tested as per the relevant processes for every piece of equipment and subsystem.

Necessary hydro testing shall be carried out for the distribution network. The distribution pipes should be subjected to pressure testing as per the design specifications and guidelines approved by the owner and their design consultants' representatives. Where required for certain equipment like chillers, factory testing will be required to ensure design conditions are being complied with. Once the individual equipment is all put together as a system, proper testing of the complete system should be carried out.

Various parameters should be monitored during the trial run, during which the systems need to be adjusted and balanced as per site performance. While doing the system balancing, it should be verified that the equipment runs in the configuration it is intended to. Setpoints of critical parameters should be obtained, e.g., differential pressure setpoints between the chilled water supply and return headers. For every piece of equipment, control loops should be defined, and these setpoint values should be used in the BMS controllers for proper auto-mode operation of the system.

A detailed commissioning plan is an important guarantee to ensure the smooth development of the commissioning work. The formulation of the commissioning plan should be based on the actual project needs and match the project duration. When there is a situation that does not match the project duration, it is necessary to communicate with relevant parties and propose solutions. The commissioning plan generally includes commissioning participants and responsibilities, objectives, the commissioning process, content, scope, personnel, time plan, and related conditions and matters requiring cooperation with different stakeholders.

Compliance inspection entails verifying compliance with the equipment installation location, model, nameplate parameters, pipeline direction, pipe material, pipe diameter specifications, and valve, sensor, actuator, and other accessories' specifications. Defect inspection includes function, maintenance, and repair, performance checks, etc. The purpose of construction defect inspection is to quickly detect existing problems in the construction process through onsite inspection and rectify them in time. In the process of engineering adjustment, common defects mainly include construction defects—e.g., missing valve installation, inadequate shock absorption measures, etc.—and functional defects—improper installation of pipelines, lack of maintenance space for equipment and primary components, and improper sensor installation.

For projects with staged construction and operation, it is advisable to formulate a staged systematic commission plan and clarify the commissioning goals of each stage according to the construction and operation time plan. DCS are generally larger in scale and have a longer construction period. Considering the connections with end-users, it is generally not possible to build entire DCS at one time. In this case, a targeted system-wide commissioning plan should be specified according to the project's construction period. The commissioning plan should not only clarify the overall goal of system commissioning, but also the commissioning goals of each stage. Among them, the focus in the first stage should not only be on ensuring the use requirements of the first stage commissioning, but also on verifying the entire system operations, e.g., equipment performance, transmission and distribution capabilities, control capabilities, etc.

5.2.4.3 Joint Commissioning

The DC system has a high degree of system complexity and must operate in varying operating conditions. It is difficult to ensure that the entire system can meet the requirements under all operating conditions. Therefore, joint commissioning is particularly important. The completion of this work ensures that the DC system will make a complete set of "products" that can meet the user's design requirements and usage requirements.

The joint commissioning should be implemented after the equipment performance adjustment is completed and the building's automatic control system is prechecked and meets the requirements. A joint operation special commissioning plan should be formulated according to the system form and functional characteristics. The commissioning plan should ensure that the overall performance of the system under different working conditions can be fully reflected, and the overall performance should at least include safety, functionality, and convenience of maintenance.

Automatic control function verification includes the actuator verification, sensor accuracy verification, function verification, and logic verification. Accuracy verification of actuators and sensors should meet design or owner requirements. The functional verification results of monitoring parameters, safety protection, start-stop control, and automatic control of standalone equipment should meet the requirements of relevant standards. The functional testing of the HVAC monitoring system must meet the following requirements:

1. The test content shall be determined according to the design requirements.
2. All monitoring parameters of cold and heat sources should be tested. Monitoring parameters of ACs and fresh air units should be sampled according to 20% of the total and should not be less than 5 sets, and all should be tested when less than 5 sets. Various types of sensors, including 10% of the detectors should be sampled, should not be less than 5, and all should be tested when less than 5.
3. If the sampling results all meet the design requirements, the system should be deemed qualified.

The verification of the DC system control logic should include the following:

1. Verification of the start-stop chain control function and alarm function of each piece of equipment
2. Verification of the number of chillers and the control function of loading and unloading
3. Verification of chilled water and cooling water temperature control loops
4. Verification of the joint operation control function of the chillers and CHW pump
5. Verification of the number of cooling towers and control function of loading and unloading
6. Verification of the switching function of different modes of the TES..

Verification of control logic for water systems should include the following:

1. In the primary pump system, the number of pumps, frequency conversion adjustment function, and bypass adjustment valve control function
2. In two-stage pump and multi-stage pump systems, the variable flow control function of each stage pump is on the load side.

The abovementioned system automatic control function verification is used to verify the function of the linkage between the building control system and the HVAC system. The system's comprehensive performance adjustment is based on the overall performance and parameter adjustment of the cooling and heating system, which is in turn based on the automatic control system, including the accuracy and stability of system parameter control, cold and heat source system performance, variable load condition adjustment, etc., to verify whether the actual comprehensive system performance under all working conditions can meet the requirements.

5.2.4.4 Seasonal Verification

Seasonal verification includes at least one entire cooling season. Transition seasons can be added according to system characteristics and users' functional requirements. Each working condition should be verified continuously for at least five days to ensure the adequacy and integrity of seasonal verification.

Seasonal verification should be carried out based on the monitoring and recording functions of the automation system, rectify the issues detected in the process, achieve the expected functioning of the control system. In addition, seasonal verification should check the actual energy consumption of the project, whether the total energy consumption of the system, total energy consumption of sub-items, changing trends, proportion, etc. are reasonable, and whether the operational mode can be optimised on this basis.

Performance verification: Detailed checklists should be made, and parameters should be measured for all equipment that is under the scope of the DC service provider. These should be compared with the design documents and verified for compliance.

Factory acceptance and site acceptance tests: For certain equipment like chillers, it is recommended that factory witness tests be done to ensure performance as per relevant standards and design/approved technical submissions. For certain other subsystems, site acceptance tests should be performed to ensure equipment performs as an integrated system. Any corrections required in operating parameters and set points should be documented, and it should be verified that the designer and owner have undertaken the necessary approval processes.

5.3 OPERATIONS AND MAINTENANCE

5.3.1 Monitoring Parameters to Ensure Smooth Operations

A DC system includes a DC plant, distribution network, and ETS at the location of end-users' buildings. The overall energy consumption of the three determines the overall energy efficiency level of the DC system. Therefore, the parameter collection needs to include all three parts, and some end-user stations can be monitored but not controlled.

The parameters and operating status collected by the cooling station mainly include various parameters related to the chiller plant in the DC system, TES, transport, measurement, and supporting equipment to determine the cooling capacity, along with the chilled water output of the cooling station. The operating parameters for DC system monitoring include:

5.3.1.1 District Cooling Plant

- The inlet and outlet temperature, pressure, and flow across chillers, pumps, TES, etc.
- The inlet and outlet temperature, pressure, and flow of the primary and secondary sides of the heat exchanger
- The temperature, pressure (or pressure difference), and flow of the supply and return water entering and leaving the DC plant room
- Valve positions of the motorised valves related to the system
- Frequency of variable speed pumps
- Instantaneous and cumulative values of system cooling capacity (generation) and user cooling capacity (consumption)
- Instantaneous and cumulative values of each equipment's energy consumption
- Cooling capacity of each chiller unit
- Water level in cooling towers
- Status parameters of water pumps, cooling tower fans, valves, and other equipment
- Outdoor air temperature and humidity
- Concentration of refrigerant or potential leakage in the equipment room
- Operating parameters of the chillers, chilled water pumps, & cooling tower fans

5.3.1.2 Distribution Network

- Differential pressures at various points in the distribution network
- Status of the pipe network leakage alarm system
- Operating pressures
- Cooling loss across pipe network
- Pressure difference at the worst pipeline point.

5.3.1.3 Energy Transfer Station

- Primary and secondary side supply side and return water temperature and pressure
- Instantaneous chilled water flow and energy of primary and secondary side
- Outdoor air temperature and humidity
- Instantaneous and cumulative power and water consumption of heat exchange station
- Water tank level
- Running status, control status, fault status, running frequency, and running current of the circulating water pump
- Running status, control status, fault status, running frequency, and running current of the makeup pump
- Running status, control status, fault status, running frequency, and running current of the distributed variable frequency pump
- Status of the electric control valves
- Mains power in the ETS, uninterruptible power supply (UPS) status, etc.

5.3.2 Instrumentation for Monitoring

The DC system should be equipped with an intelligent centralised monitoring system to realise the monitoring and communication between the cooling station (DC plant), heat exchange stations (ETS), and pipe network system through wired or wireless means.

The centralised monitoring system manages a central host with unified monitoring and management functions and powerful management software, which can reduce the O&M workload and improve the management level. The intelligent control system is one of the key factors that determine the DC system's energy efficiency. The control system needs to control and communicate with the three main parts of the cooling station, pipe network, and user's heat exchange station to keep track of the overall operating status and achieve a closed loop of 'monitoring-control-feedback-monitoring'.

In the cooling station and substations in each building, cooling metering devices and control and adjustment devices should be set up and centrally managed by a central monitoring and management system. The accuracy of the cooling metering devices should conform to national or international standards.

The basic operational functions that a central monitoring and management system should carry out include monitoring functions, display functions, operation functions, control functions, auxiliary functions for data management, and security management functions.

The central monitoring and management system should meet the following requirements:

- It should be able to achieve the same time interval and continuous recording of measurement accuracy as the onsite measurement instrument parameter collection and display the operating parameters and equipment status of each system; the storage medium and relational database should be able to store and record continuous operational parameters for more than one year.
- It should be able to calculate and regularly measure the system's energy consumption and continuous and cumulative running time of each piece of equipment.
- It should be able to change the set value of each parameter at the controller level and directly start, stop, and adjust the equipment set to the remote state.
- The system or equipment should be started and stopped automatically according to a predetermined schedule or the energy-savings control programme
- Operator authority control should be established.
- There should be parameter-out-of-limit alarm, accident alarm, alarm recording, and system or equipment fault diagnosis functionality.
- It is advisable to set up an integrated interface that can share data with other centralised control systems or platforms, e.g. smart city platforms.

Scheduled calibration of all sensors and meters should be strictly followed to ensure monitoring accuracy.

5.3.3 Automatic Control Systems

The control of DCS is complex. DCS, especially those composed of a variety of cold and heat sources (e.g. waste heat, thermal storage, etc.), involve plans to release the stored cold energy in advance. The control system should predict the hourly load of the next day based on historical data, the hourly load distribution of the day, the weather forecast, and the change in end-users' energy consumption. The control system should then convert it into the hourly flow as the control target curve, to formulate or adjust the operational strategy. During operations, optimal adjustment and control can be carried out based on load forecasting according to the actual situation.

The control system should have the following centralised monitoring and energy management functions:

- Data collection and status monitoring
- Automatic control and operational mode switching
- Load forecasting
- Scheduling optimisation
- Energy consumption statistics and analysis
- User site data collection and status monitoring
- Troubleshooting.

5.3.4 Maintenance Requirements

The following sections summarise the post-installation maintenance requirements in a DC system.

5.3.4.1 Hardware Components

Maintenance processes are specific to each part of a DC system. For the main devices such as chillers, motors, cooling towers, ETS, and circulating pumps, maintenance protocols are manufacturer-specific and must be followed precisely. For smaller components such as valves or filters, maintenance requirements depend on each specific network (e.g. filter maintenance occurs more often if water is dirty). The parts of the DC system that are constructed on site (e.g. distribution network, consumer connections, etc.) require a maintenance protocol, which is based on the construction method and types of components installed. Such maintenance protocols may vary over time as the system gets older.

There are three types of maintenance:

- Run-to-failure consists of minimum maintenance and is based on equipment replacement.
- Preventive maintenance ensures that resources are available for the proper operation of cooling systems, aiming at durability, reliability, energy efficiency, and safety.
- Condition-based maintenance relies on inspections (usually using non-disruptive techniques) and monitoring to assess the equipment's condition.

5.3.4.2 Water Treatment

Maintaining consistent water quality throughout the system is important for the health of the entire CDW and CHW systems. Water quality is the key determinant of evaporative cooling system performance. For evaporative cooling equipment like cooling towers, evaporative condensers, and fluid coolers, water quality is essential for proper heat transfer and the healthy service life of the equipment.

It has been proven that makeup water quality and the consistency of water treatment programmes have a direct impact on the performance of cooling towers. They affect efficiency, available uptime, maintenance needs, and, ultimately, equipment longevity.

Designing an effective water treatment programme begins with assessing both the quality and composition of the project's makeup water. The goal is to design a water treatment system capable of consistently maintaining the desired heat transfer efficiency while simultaneously maximising equipment service life.

These cooling systems reject heat primarily through the evaporation of pure water. As heat is rejected via evaporation, ions such as alkaline, calcium, chloride, sulphate, and silica, which are dissolved in the makeup water, become more concentrated in the recirculating water. If not consistently controlled, the concentration of these dissolved ions can increase corrosion potential or lead to the formation of deposits like calcium carbonate. The calcium carbonate scale deposits impede heat transfer, and they can cause under-deposit corrosion, which may decrease the service life of the equipment.

Three primary types of treatment systems are used for evaporative cooling systems:

- Chemical water treatment
- Nonchemical treatment
- Hybrid systems.

Water quality criteria for cooling systems (as defined by the Electrical and Mechanical Services Department (EMSD)[35])

- pH value: 8.0-10.0
- Turbidity (Formazin Turbidity Unit (FTU) scale): below 10
- TDS: below 1000 parts per million (ppm)

35 Code of Practice for Water-cooled Air Conditioning Systems, Part 1: Design, Installation and Commissioning of Cooling Towers, 2006 Edition, Electrical and Mechanical Services Department

- Conductivity: below 1500 microsiemens (μS) per centimetre (cm)
- Total hardness (as calcium carbonate ($CaCO_3$)): below 50 ppm
- Total iron increment: below 1.0 ppm
- Total copper increment: below 0.2 ppm
- Nitrate: 250-600 ppm
- Total bacterial count: below 10,000 nonparametric maximum likelihood (npml).

5.3.5 System Expansion and Upgrade

To facilitate the future development and expansion of DCS, it is recommended to take the following actions:

- Plan space for additional capacity within the plant utility to cover the future expansion of the network
- Design the building to allow for plant replacement and the later fitting of new technologies
- Size the pipe work to allow future network expansion

Ideally, these factors should be considered an integral part of the master planning process in new building developments.

Another approach is to build a nodal network that involves the development of smaller, localised district DCS sized to meet the needs of the immediate area. Ultimately, these smaller systems would be linked together as market penetration allows and system interconnection merits. This gradual approach is in line with energy strategies adopted by a growing number of cities for the long-term development of extensive DC networks. Meanwhile, developments need to be designed to be ready to connect to the larger network when they can do so. Planning policy, informed by energy maps, is central to supporting this process and ensuring future customer connections. In this case, normally the future expansion can be coordinated and controlled by the municipalities or urban development authorities.

Wide adoption of DCS is only possible by making it a profitable business case for the DC service providers (DC project owners) and investors, while at the same time ensuring fair tariffs for end-users (building owners), making it affordable and viable. Business models play an instrumental role in the success of DC system implementation. This chapter provides guidance related to the tariff structure, enabling policy mechanisms, asset ownership, business models, and common challenges in the implementation and operational phase of DCS. This chapter should be of key interest to end-users, i.e. building owners, investors, DC service providers, and any stakeholder who wishes to know more about the economics of DCS.

Additionally, a suitable budget should be provisioned for mid-lifecycle equipment replacement costs. For instance, the service life of chillers may be 25-30 years, while the DC agreement may be longer than that. Hence the chillers or other DC systems and equipment, depending upon their service life, may require replacement or refurbishment to provide uninterrupted DC services for the contract duration.

6 ECONOMICS OF DCS

6.1 ENABLING MECHANISMS FOR DISTRICT COOLING IMPLEMENTATION

6.1.1 District Cooling Tariff Structure

The DC provider normally has a tariff structure largely analogous to an electric or PNG utility [36]. The two key stakeholders in any DC project are **the end-users**, who access cooling via the DCS against the notified tariffs, and the **DC service providers**, who are responsible for ensuring high-quality services at competitive tariffs. The final tariff to be notified and paid by the end-users for the services provided through the DCS comprises the following major charges:

- **Consumption charge**: This charge represents the actual cooling used by the end-users at the building level over the billing period and thus depends on several factors, such as weather conditions, season, occupancy, building envelope, etc. The consumption charge is normally measured in INR per kWh, INR per BTU, or INR per tonne-h[37].
- **Demand/fixed charge:** This charge represents the chiller plant capacity and distribution system capacity that the DC service provider allocates to meet the contracted cooling demand requested by the end-users on the basis of the building cooling demand estimation. The demand/fixed charges are usually fixed as per the contracted cooling demand and are directly proportional to the cooling load, i.e. the higher the cooling load, the higher will be the demand/fixed charge. Thus, the end-user should be cautious when estimating the cooling load and ensure that an optimum cooling demand is contracted. In addition, the end-user should focus on reducing the cooling load. The demand charge is calculated in INR per kW, INR per BTU/h, or INR per TR.
- **Connection charge**: A connection charge is a one-time charge taken by the DC service provider to help offset the costs of connections serving the building, meters, and any other equipment it installs at the customer site. This is usually an initial cost but could be amortised over a certain period to offset the high initial connection cost.
- **Compliance bonus**: Since DCS is a new technology in India, there are currently no benefits that can be exploited to reduce end-users' cooling consumption. However, in the future, reducing the cooling consumption of one end-user could potentially enable the provision of cooling to a new end-user or reduction of the overall cooling demand. Thus, to further emphasise the importance of

36 Tredinnick, Phetteplace, and Kirk, *Owner's Guide for Buildings Served by District Cooling.*

37 A tonne of refrigeration is a customary unit of refrigeration capacity dating back from when blocks of ice were used for refrigeration. It represents the amount of refrigeration capacity required to make a tonne of ice from unfrozen water (at 0°C [32°F]) in 24 hours; it is equivalent to 3.517 kW (12,000 BTU/h). The unit tonne-h is a unit of refrigeration energy supplied/used.

connecting with DCS, some DC service providers may use tariff structures that incentivise end-users with a credit or rebate of some percentage of each bill for a specific period for complying with the contract load. Even the government can look at incentivisation for end-users when they connect with DCS, which can create a positive demand for DCS in India.

- **Penalty for low return water temperatures**: Maintenance of design (high) temperature difference (delta T) is extremely important for the operational energy performance and in turn even the economic viability of DCS. The user may be penalized for not providing agreed chilled water return temperatures at the ETS.

These are the typical charges of the most DC service providers' tariff structures. There may also be other terms agreed to contractually between the end-users (building owner) and DC service provider, such as provisions for anticipated load growth or reduction, which are detailed in the next section.

6.1.2 Contracting Between Customers and DC Service Provider

When it comes to contracting between the end-user and DC service provider, there might be unique provisions in the contract, including:

- Provisions for conditions and terms under which the contracted capacity can be adjusted either up or down.
- Provisions that allow the building owner to make energy conservation efforts without penalties from the DC service provider in case of cooling demand reduction up to a certain threshold.
- Clearly defining the end-users' responsibility for maintaining the design temperature difference (delta T) between supply and return water temperature at the building side of the ETS.
- Provisions for passing on incentives to the end-users in the case of rebates and subsidies from the government via reduction of water and/or electricity prices.

There may also be surcharges/rebates that are based on current source energy and/or water prices, for example. Interruptible rates that would allow the DC service provider to curtail or limit the supply of chilled water might be an alternative where the building use allows for it. Furthermore, if a DC service provider becomes capacity constrained for some reason or wants to reduce demand during peak periods, they might offer the building owner an incentive to reduce their load, e.g. through building energy efficiency retrofits.

When the building owner receives a contract from a DC service provider, it is recommended to conduct a best-value analysis in lieu of only looking at costs, i.e. looking at all the benefits, whether quantifiable or not. Best-value analyses account for both technical and financial advantages and disadvantages of DC compared to onsite building cooling systems and certain nonquantifiable parameters that may have more value or worth than others.

6.1.3 Organisational Format and Governance Structure

The organisational format when developing a DC business is a critical success factor. Successful development, construction, and operation of a DC project is made possible by the following organisational elements:

a. Clear responsibilities and mandates on what is expected of each function within the organisation.
b. The right skills with the necessary resources in each development stage, with a focus on creating an effective organisation. Initially, a small, dedicated organisation with expertise in business development, marketing/sales, technology, and finance is recommended. As the plans and projects develop, the organisation should gradually expand.
c. Quick decision-making process by establishing and implementing routines for decisions and control. A top management steering committee can be one way to achieve this.
d. Defining clear start and end points.

The key activities in DC system installation and operations are the following:

- The DC company (DCC) identifies a potential business area (greenfield or brownfield) and engages in discussions with the existing cooling load clients.
- The DCC seeks in-principle approval to install and operate a DC system in the specified area for a long-term period of 15-25 years.
- The in-principle approval is generally given by a local city authority or the group of cooling load clients (if it is a purely private sector action) to the DCC.

- The DCC prepares the DPR, including scenarios for part-load operations, modular expansion to cater to future loads, etc.
- The DCC applies to the city authority or private cooling clients for supply terms and conditions, tariffs, and other related matters.
- On approval, the DCC arranges for financing, designs and constructs the plant, and commissions the project.
- To streamline the commissioning process, the respective timelines for providing 'Electrical Power Connection' to DCS and 'Cooling Load' on ETS by the customers are fixed and responsibility is assigned.
- After getting the relevant statutory approvals for safety and other such issues, the DC system is ready for commercial operations.

6.2 BUSINESS MODELS FOR DCS

Several key issues need to be discussed and decided upon before identifying the business model to adopt in the implementation of DCS.

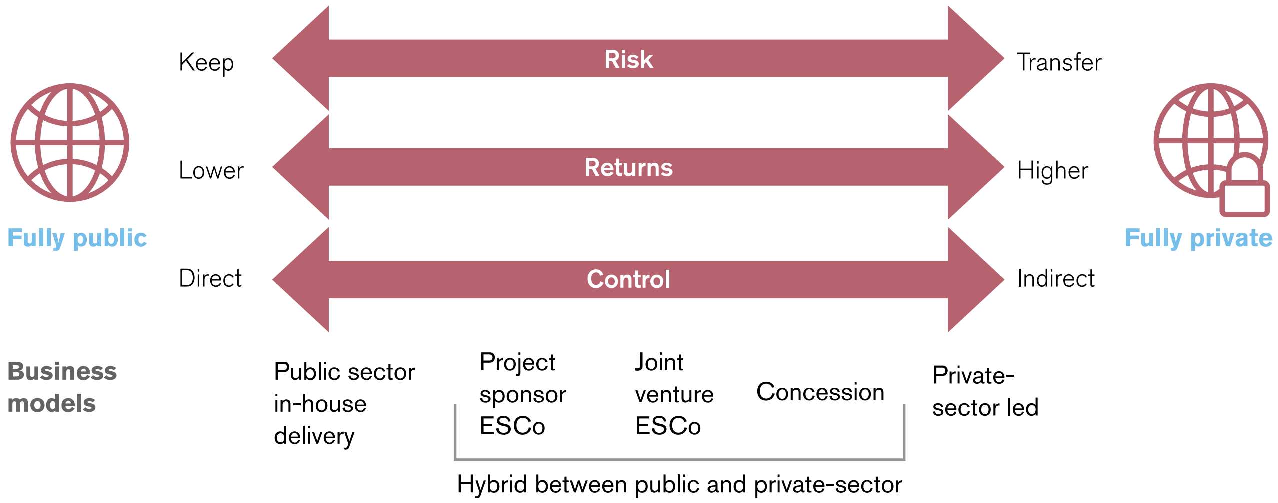
- **The role of a national agency in DCS**: regulation, technical and performance codes, quality of service, dispute resolution; any of the existing regulatory agencies (e.g. BEE or Central Electricity Authority (CEA)) may subsume these roles.
- **State-level**: mandating DCS to be adopted under certain conditions as a utility in the city master plans and state DCRs (prepared by Municipal corporations/Town and Country Planning Department for the respective state/ULBs). Based on the mandate from the state, cities can start to integrate DCS as an infrastructure need for certain areas/land-uses as per feasibility in Physical Infrastructure chapter/sub-chapter of respective planning document. There is a need for a decision-making structure within the ULB to streamline the process for making a decision on DCS.

These models can be broadly categorised as fully public, hybrid public/private, and fully private, as depicted in Figure 19. The selected models can be tailored by borrowing concepts from other models to meet the project aims and objectives and align the project with key stakeholder needs.

The majority of business models for DCS involve the public sector to some degree. In various cases around the world, the public sector has partial or full project ownership. The degree to which the public sector is involved is determined by how much it wants to steer a DC project towards local objectives.

The **fully public** business model has been widely adopted globally. As the local authority or public utility, the public sector has full ownership of the system. As a result, it has complete control of the project, making it possible to achieve broader social objectives, such as better environmental outcomes through tariff control.

Figure 17: District Cooling Business Models



(Source: European Bank)

Hybrid public and private business models have a rate of return that can attract the private sector, but the public sector is still willing to invest in the project and retain some control. These business models include:

- **A public and private joint venture** where investment is provided by both parties that are creating the DCC or where the public and private sector finance different assets in the DC system (e.g. production of heat/cooling vs. transmission and distribution).
- **A concession contract** where the public sector is involved in the design of a project, which is then developed, financed, and operated by the private sector, and the city usually has the option to buy back the project in the future.
- **A community-owned not-for-profit or cooperative** business model where a municipality can establish a DC system as a mutual, community-owned not-for-profit or cooperative. In this model, the local authority takes on a lot of risk initially in development and, in some cases, underwrites any finance to the project.

Private business models entail the private sector fully developing, owning, and managing the project, including financing; such models have limited public sector support in terms of getting concessions and approvals, among other things. The projects are developed as fully privately owned special purpose vehicles (SPVs) but may benefit from guaranteed demand from the public sector, a subsidy, or local incentives.

6.2.1 Business Models for The Indian Context

India has been exploring a range of business models over the last thirty years in various sectors such as roads, ports, airports, PNG distribution, etc. In most of these sectors, the investments are of the order of thousands of crores of rupees. The private sector has played a key role in raising resources and carrying out all technical activities, whereas the government has played the role of regulator, approver, and other such functions. In almost all the sectors, while the government takes an approach to ensure that reasonable financial returns are made by the private company for the investments made, it does retain the power to issue directions if certain special disadvantaged categories of the people are negatively impacted.

The business model for a DC system is very project-specific. It needs to ensure that all of the players involved – including investors, owners, operators, utilities/suppliers, end-users, and municipalities – can achieve financial returns, in addition to any wider economic benefits that DC projects bring.

The degree of public sector control over a project can vary greatly, ranging from full development, ownership, and operation to a role focused mainly on project coordination, local planning, and policy.

The public sector is extremely important in project development because of:

- its ability to guarantee demand through longer-term concessions
- its ability to be a large, stable consumer itself and provide offtake agreements
- its longer-term planning focus, greater interest in meeting social and environmental objectives, and ability to coordinate with the multiple stakeholders involved in DC projects.

The fully public model- The project is owned and implemented by public authorities, such as ULBs, with full investment from the ULB resources. Private contractor(s) are engaged for design, construction, commissioning, and operations (in some cases). The contractor may be given permission to operate the system for a fixed number of years and is paid the O&M costs, with all revenue retained by the ULB or the SPV created for this purpose. Examples of this are the ULB water and sewerage boards, as well as the health facilities at the city level, DISCOMs (Kanpur, Lucknow, Bangalore), smaller city airports, and intra and inter-city transport.

In this model, the customers sign long-term utility contracts, with little or no option to stop using the service. In most such cases, the financing for these projects is provided through resources raised through taxes and other levies. The primary reason for the government to take up full ownership is to keep the costs low and hence ensure that the disadvantaged sections of the society do not have to pay high tariffs.

In many cases, the municipal corporation is itself the regulator, acting as the decision-maker in the case of problems or issues related to tariffs or quality of supply. While this is not the ideal case, this does seem to be the ground reality in most large cities in India.

The fully private sector model- In this model, the private sector fully invests in and operates the systems, as well as taking on the responsibility to meet future demand (e.g. the Delhi Land & Finance (DLF) case study, Gurugram, India). In almost all such cases, the government is the concession provider or regulator, looking into pricing, supply terms and conditions, and quality issues. This model is prevalent in the roads sector, large airports, solar projects, transmission projects, and some private DISCOMs. In this model, there is no option for the customer to withdraw from the services offered, and the customers have little say in the terms and conditions, pricing, and quality of supply issues. While in some sectors such as electricity, the government has established Public Private Partnerships (e.g. BSES, Tata Power etc.), and this has not happened in many other sectors. This is the real challenge in this model, i.e. customers getting quality services at an affordable price.

The hybrid model- Both the public and private sectors have a role in this model and could even have a financial stake. This model is common in sectors such as DISCOMs (e.g. in Delhi), city PNG distribution, district industry centres, special economic zones, etc.

The government generally does not invest cash in these projects, but rather monetises the value of the land as its contribution to the project. The land ownership in most cases rests with the government, and the land can therefore not be sold, leased, or transferred without the government's permission.

The roles of public and private entities in DC governance and revenue sharing are summarised in Table 13.

In the Indian context, studies have been undertaken in collaboration with international agencies to identify ways to implement DCS at the city level. The studies have identified an initial set of cities where potential exists, and a letter of intent (LOI) was signed for one city with a private entity. Unfortunately, this project has gotten stuck in bureaucratic processes and has been halted until further decisions are taken.

Since DCCs operate at a city level, the city authorities play a crucial role in the project design and structuring. The regulations governing the project could be a part of the national regulations but be effected by notification at the state and city levels[38]. The national regulations could provide the framework for ensuring an enabling environment and identifying the roles of state and local bodies. It is essential for the national entity to give directions on technical performance and assessment for different technologies, including fuel used, to enable the equipment suppliers to increase efficiency.

There is a need for the technical regulator to be different from the one who fixes tariffs. While the technical regulator could be at a national level, the tariff fixing must be done either at the state or city level. DCS are implemented at the city level, and permissions and concessions are also granted at the city level. Hence, it is imperative that tariff fixing be done at the city level. The regulator's task is challenging, as tariffs have to be affordable for consumers while also allowing investors to earn a sufficient return on their investments to enable them to invest in future expansion and equipment replacement.

India has substantial experience in price regulation in the electricity sector, where it is done at the state level for different DISCOMs. Hence, DC price-fixing could potentially be done at the state level. Based on past experiences in other sectors, DCS in India will most probably adopt a 'cooling as a service' approach for revenue purposes and fix a tariff for the chilled water or space cooled.

6.2.2 Challenges for Business Models in India

DCS are still in their infancy in the Indian context, with perhaps GIFT City, Gujarat, and DLF Cyber City, Gurugram being the only examples. While the GIFT City is a project fully supported by the state government, with the private sector developing the financial city, the DC system has been installed as a part of the GIFT City, with total investment and ownership coming from GIFT City. In contrast, the DLF Cyber City project is a fully private sector-owned enterprise, with the project developer getting into an agreement with the buildings in Cyber City.

Table 13: Types of DC Governance Models

Model	Financing		Design	Construction	Commissioning	Operations	Revenue
	Public	Private					
Fully public	X		X	X	X	X	X
Fully private*		X	X	X	X	X	X
Hybrid*	X	X	X	X	X	X	X

* Concession is given to the private sector for a limited area of supply for a fixed number of years.

38 This could be along the lines of ECBC, which is notified by BEE but given effect by the state and city administrations.

Designation of appropriate zones: The biggest challenge is identifying a greenfield real estate project where a DC system can be implemented. This should be done by the local body at the city level. Alternatively, there could be guidelines on where DCS must be considered the default option for real estate projects that exceed certain area or cooling load requirements and must be considered in the master planning phase. Governments could mandate district cooling in defined areas where density levels render it appropriate. Government intervention should aim to be consistent and cover three main areas: the designation of appropriate zones, tariff regulation, and service standards and technical codes.

Cooling tariffs: India has some good examples of independent regulations in other utility domains such as PNG, electricity, and water that consider both the developer's and customer's perspective. For example, the electricity sector has had independent state-level regulators for fixing tariffs for DISCOM consumers. The city PNG distribution companies are another good example (e.g. in Mumbai and Delhi). It is important to have a consistent and transparent national framework that developers can adopt to calculate cooling tariffs.

Service standards and technical codes: Governments should define the basic levels of reliability and performance required of DC service providers. They should complement these requirements with technical codes to ensure high quality in the design and installation of assets. There is also a need for codes governing the operational interface between DC service providers and building owners.

In addition to the abovementioned technical challenges, as DCS is a new technology for India, there are not enough domestic business cases that can be used to estimate the required investment. However, as the technology has been proven elsewhere in the world, key financial figures can be estimated accordingly, as detailed in the following section.

DC projects are capital intensive, with costs ranging upwards of Rs. 100+ crores, depending on the project size. Furthermore, the DC projects have to supply a reliable continuous supply of cooling as a service to the customers in the buildings, which could be a combination of commercial and residential customers. The services are for a licence period that could be up to 25 years, with options to extend this with the necessary approvals.

The licence is given by the local municipal authority in the case of a project implemented under a public licence. This necessitates a transparent bidding process with inputs from all stakeholders to ensure the project's success.

India has vast experience in bidding procedures in different domains such as solar grid power, airports, ports, and transmission lines, among others. Across sectors, the key variables are similar: concession agreement time period, performance measurement, and ensuring a reasonable rate of return to the project developer.

7 BIDDING CHOICES FOR DC PROJECTS

7.1 BIDDING OBJECTIVES

The broad objectives of the bidding process are:

1. Promoting competitive procurement of cooling as a service from developers and protecting consumer interests.
2. Facilitate transparency and fairness in procurement processes.
3. Providing standardisation and uniformity in processes and a risk-sharing framework among the various stakeholders involved in the development of DC projects, thereby encouraging investment, enhanced project bankability, and profitability for the investors.

Bidding strengths

The bidding route is usually followed, due to its various advantages: i) flexibility; ii) potential for real price discovery; iii) ability to ensure greater certainty in price and quantity; and iv) capability to guarantee commitments and transparency.

Price discovery: Bidding is important from the standpoint of its effectiveness as a mechanism of price discovery. A well-designed bidding process brings out the real price of the product being auctioned in a structured, transparent, and, most important, competitive process. The bidding process addresses the fundamental problem of information asymmetry between the regulator (or any other entity responsible for determining purchase prices and support levels) and project developers.

Increased certainty regarding prices and quantities: Auctions allow policy makers to monitor both the price and quantity of the product by providing revenue guarantees for project developers, while at the same time ensuring that production and performance targets are met more precisely. Therefore, both investors and policy makers benefit from greater certainty on the future outcome of the policy.

7.2 CASE STUDIES OF BIDDING CONTRACTS

As mentioned above, there is a wealth of experience in India on bidding in various sectors. A summary of the Indian experience in bidding in selected sectors is provided below.

7.2.1 Solar Grid Power

Common elements in solar grid power bids include:

1. The total bid size is mentioned, and the bidders can choose to bid for any size, with a minimum bid size specified.
2. The successful bidder will take care of the project's O&M activities for a period of 10/15/25 years.
3. Bidders should have quoted, designed, operated projects equivalent to at least as specified percentage of of the bid being offered.
4. Turnover and profit requirements are specified; in some cases, a working capital requirement is also specified (and in some instances, bidders are also asked to provide an approval letter from a lending institution committing a line of credit for a minimum amount).
5. Proof of having land ownership or a lease signed for the period of the PPA is required.
6. Solar modules from vendors empanelled in the Approved List of Models and Manufacturers (ALMM), as announced by the Ministry of New and Renewable Energy, shall be used in the project.
7. Preferential bidders are specified. E.g. Class-I local suppliers will get preference in the bidding process. A Class-I local supplier is a supplier or service provider whose goods or services have local content equal to or greater than 50 percent.
8. Earnest money deposit and bid processing fees are also specified; in addition, the winning bidder has to also provide a bank guarantee for performance.
9. The first year capacity utilisation factor (CUF), CUF for subsequent blocks of five years, and penalty for the shortfall in availability of energy below CUF are specified; power in excess of CUF can be sold on the open market.
10. Compensation for change in law is specified.
11. Foreign companies must comply with foreign direct investment (FDI) rules.
12. For SPVs, the lead bidder should have more than 51% ownership in the SPV.

Two models have been followed in awarding solar grid-connected projects:

1. Open bidding, wherein bidders confirm that they meet all technical requirements and then offer a financial bid for the project; in this case, there is no upper or lower limit for the financial bids.
2. A ceiling tariff is specified, and bidders have to provide quotes below the ceiling price.

In the open bidding process, if there are only 2-3 bidders, there is a possibility of collusion or cartel between the bidders, which could be reflected in a higher price. In the bid through a ceiling tariff, there is a possibility that the prices are closer to the ceiling prices, thus preventing true price discovery.

The Ministry of Power has provided the following guidelines for bidding parameters:

1. For the procurement of electricity, the procurer may opt for either 'Tariff as Bidding Parameter' or 'Viability Gap Funding (VGF) as Bidding Parameter'.
2. Tariff as Bidding Parameter: In this case, the bidding parameter shall be the tariff quoted by the bidder. The Procurer may select either of the following for tariff-based bidding: (a) a fixed tariff in INR/kWh for 25 years or more; or (b) an escalating tariff in INR/kWh with a predefined quantity of annual escalations fixed in INR/kWh and number of years from which such fixed escalation will be provided.
3. The Procurer shall specify that the tariff quoted by the bidder cannot be more than the tariff for grid-connected solar photovoltaic (PV) power plants, notified by the appropriate commission, if any, for the financial year in which the bids are invited. The Procurer may disclose in the request for solution (RfS) the prevailing incentives like the generation based incentive (GBI) or other such incentives for solar power generators.
4. VGF as Bidding Parameter: This involves a mechanism wherein a predetermined tariff is offered to the solar power generator along with financial assistance to enable the solar power generator to supply power at the given tariff. For VGF-based bidding, the Procurer shall specify the following before issuance of the RfS: the predetermined tariff payable to the selected solar power generator for the duration of the PPA and the maximum amount of VGF for the solar power generator(s). The bidders have to submit their bids quoting the amount of VGF support they require. Bidders who do not want to avail of the VGF support may offer a discounted tariff below the predetermined tariff offered by the

Procurer in their bids. The Procurer is required to specify a suitable VGF safeguard mechanism in the RfS and project agreements, to provide a framework for the VGF disbursement agency for recovery of VGF amounts in case the project is not developed and/or operated in accordance with the project agreements, duly balancing market practice in terms of the lender's requirements.

7.2.2 Transmission Project Bidding

Ministry of Power and Central Electricity Regulatory Commission (CERC) have issued bidding guidelines for transmission projects and introduced tariff-based bidding, rather than cost-based bidding:

1. The bid evaluation is done based on the NPV of the tariff coming out of the capital cost and financial package submitted by the bidders. The tariff calculations are carried out broadly based on the terms and conditions of tariff notified by the commission, which is essentially a cost of service regulation.
2. Annual transmission charges must be quoted in Indian rupees only. No compensation for foreign exchange rate variation is allowed.
3. The bidders have to quote transmission charges in two components: one component is non-escapable, and the other is escapable, linked to the domestic inflation rate. The escapable component has to be quoted for the first year only.
4. The escapable component must not exceed 15% of the non-escapable component quoted by the bidders for the first year.
5. The non-escapable component has to be quoted by the bidders for each year of the licence period (25 years) minus the estimated construction period, e.g. 22 years. The maximum year-to-year variation allowed in the non-escapable component is 5 percent.
6. Availability of the transmission lines has to be 98 percent.
7. The power grid must specify the buyout price at the end of 25 years; bidders can quote any price above it.

7.3 BIDDING FOR DC PROJECTS

DC projects have now come to the forefront of the global infrastructure domain, having distinct advantages in terms of economies of scale and also offering the opportunity for projects with low GWP gases. Over the last few years, international agencies have taken the lead in introducing DC as an efficient and low GWP alternative to centralised cooling in large commercial complexes. Initial reports have identified select cities where DCS could be implemented. The city administrations have been made aware of the potential for DC in their cities. A number of foreign companies have entered India to exploit the potential for DCS in the growing cities.

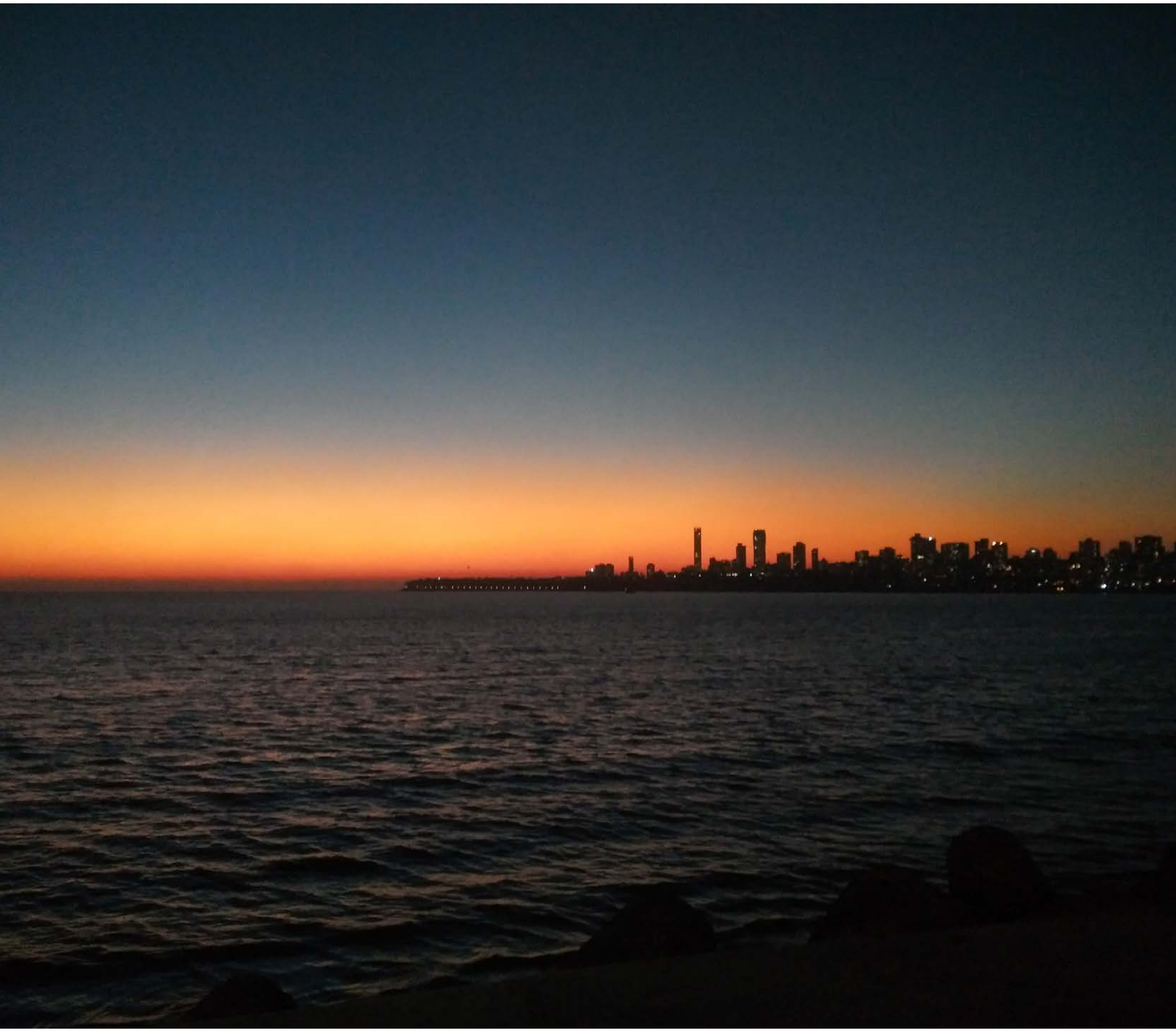
However, there are still many steps to be taken before DCS can become a reality:

1. First, national agencies such as BEE have to prepare the DC codes and design, implementation, and performance guidelines, get the states to adopt these guidelines, and then transfer these to the city level.
2. Stakeholders such as the ULBs, states, regional development authorities, NBCC, CPWD, and private real estate companies need to identify areas with high DC potential. The bidding process needs to be notified and consultations held to ensure that there is interest from companies who have experience in DC project implementation.
3. Generally, customers follow a two-stage process in the case of large projects such as DCS. The first stage is to get 'expression of interest', based on which agencies are selected based on past experience, including certain financial parameters such as capacity to invest, raise finance, etc. At this stage, a decision has to be taken on whether a consortium of companies can participate, since this could bring greater experience into the bidding pool. Potential DC service providers are asked to demonstrate their capabilities through presentations and submission of their technical approach to the project. Based on their technical submissions and presentation, a scoring process can be done. There can be a cutoff set by decision-makers, based on which they decide whether to take a project further.
4. This is followed by a detailed proposal stage, wherein financial proposals are invited, including total cost, tariffs, financing, and other key aspects. Evaluation criteria for bid ranking need to be specified based on quality cum cost-based selection (QCBS) parameters used globally to ensure a

balance between the quality and cost parameters of the selected bidder.

5. The entire two-stage process can take around 1-2 years depending on the number of applications, evaluations, discussions, approvals, etc. For both the stages, there is a tender expression of interest (EOI) and request for proposals (RFP) document, which itself takes more than one year to prepare and finalise after initial discussions to ensure that there is overall acceptance of the terms and conditions and that bidders are considering applying for the DC EOI and financial bids.
6. It should be noted that states and ULBs have given out work orders for large value contracts with values of INR 100+ crores, and there is a wealth of experience available. Furthermore, it is important to include the private sector throughout the bidding process, as there have been several instances where bids have to be called more than once because the proposals did not attract a sufficient number of bids.

Once the bidding strategy has been finalised, the procurement can be initiated by floating the terms of reference in the public domain, seeking active participation from DC service providers and ensuring selection of an appropriate bidder.



8 STATE LEVEL ACTIONS FOR PROMOTION OF DCS

Cities all across the world have turned to district cooling as a feasible option to meet the rising cooling demands. DCS are an important component of energy infrastructure, as they help alleviate the load on the electricity grid caused by air conditioning, which accounts for 50-70% of a city's peak electricity demand. Countries like Sweden, the United Arab Emirates, Singapore, China, Colombia, France, Malaysia, and Egypt have all started using DCS to meet their AC needs. DCS should be included in infrastructure operations like metro rail AC, government and private sector real estate, and buildings projects.

Aggregated cooling loads also promote innovative solutions like meeting water demand for DC plants through the concept of free cooling using lake or ocean water, greywater recovery, treated sewage effluent, and TES, all of which minimise AC costs and environmental impact. Furthermore, central plants avoid the sunk expenses of large, independent chiller plants, as well as the capital costs of chiller and cooling tower installation, freeing up valuable rooftop and building space.

8.1 ROLE OF MUNICIPALITY/ TOWN PLANNING DEPARTMENTS AT CITY/STATE LEVEL IN DCS

By investing in the use of district cooling, cities can become much more energy-efficient and drastically reduce GHG emissions (by 50% or more). A low carbon cities initiative in a city's vision plan can be an opportune vehicle for implementing viable DCS, thereby effectively reducing the increasing pressure on the city's electrical infrastructure. Municipalities/governing municipal bodies/development authorities play a crucial role in including DC technologies in their future plans.

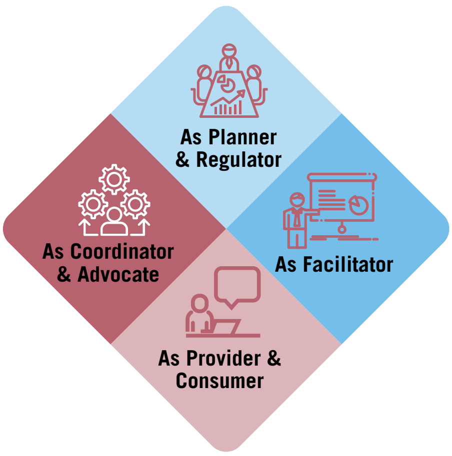
"Local governments are uniquely positioned to advance DC systems in their various capacities: as planners and regulators, as facilitators of finance, as role models and advocates, and as large consumers of energy and providers of infrastructure and services".[39]

39 Modernizing district energy systems could reduce heating and cooling primary energy consumption by up to 50% finds New report (no date) UN Environment. Available at: https://www.unep.org/news-and-stories/press-release/modernizing-district-energy-systems-could-reduce-heating-and-cooling

City authorities should thus have a clear-cut direction to increasingly plan for greenfield development, which includes DCS as an integral part of their design process, just like waste and water management, to reap the benefits in the long run. This should be supported by including the need for DC technologies in the city's policies and plans for smarter technology adoption in the future. Authorities have enormous capacity to implement schemes and local laws to accelerate the deployment of DCS. Cities' broad energy targets, including attaining energy efficiency and increasing their share of renewables, should also include DC-specific targets.

Local governments worldwide are using a wide range of policies and activities to promote district cooling, demonstrating the significant and diverse roles that cities can play in deploying such systems. The role of civic authorities in India in district cooling can be similarly designed and grouped into 4 major categories, as seen in Figure 18[40].

Figure 18: Roles of Municipalities in Adoption of DCS



Detailing the above categories, key pointers against each action point of the governing municipal bodies are summarised in Figure 19:

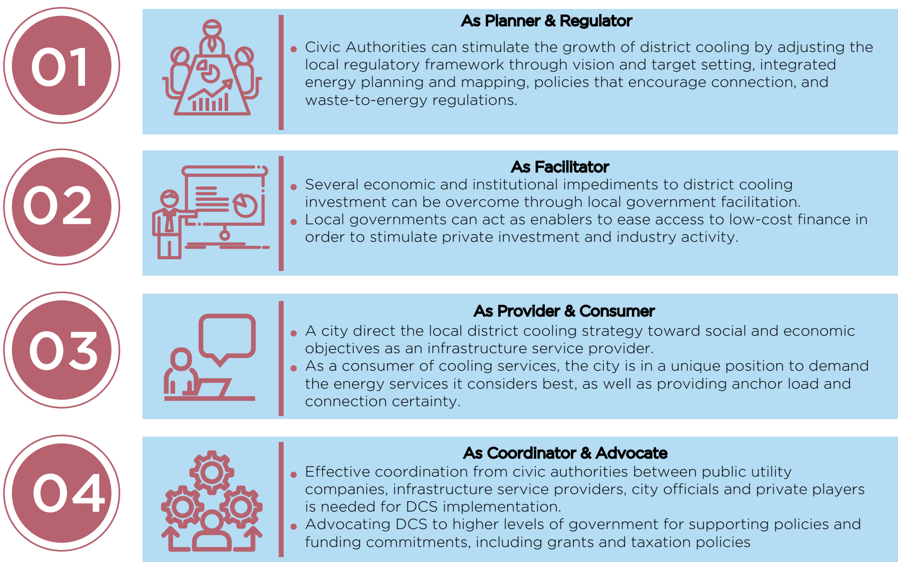
8.2 ACTION PLAN FOR PROMOTION OF DCS IN STATES AND CITIES

These actions can be further elaborated in short-, medium-, and long-term implementation periods, which can help civic authorities channelise efforts for DC system rollout by 2030.

Short-Term:

1. Explore the close placement of wastewater treatment plants (WWTPs) and DC plants to use recycled wastewater in cooling facilities, thereby working in a circular resource model.
2. Civic authorities can mandate DC system development through zoning policies that require DCS in new development areas over a certain size (e.g. Tokyo mandates DC systems in areas above 50,000 m^2). These zones can be selected based on a development planning exercise by the town planning departments.
3. Support the development of DCS in new greenfield expansion areas of cities by taking up pilot demonstration models and promoting them at all levels – citywide, as well as at higher governmental/ national levels to further leverage DCS.

Figure 19: Responsibilities of Municipality for Adoption of DCS in Cities



40 District Energy in Cities Initiative, UNEP-C2E2, E-Training Program District Cooling Development, Module 5. Policy Development: Integrating DCS Into Urban Planning, https://c2e2.unepccc.org/wp-content/uploads/sites/3/2022/03/module-5-policy-development-integrating-district-cooling-systems-into-urban-planning.pdf

4. Amendment of building bye-laws to include design standards of energy efficiency through DCS in commercial districts above 50,000 m^2.
5. Civic authorities can drive awareness and training of all stakeholders (public and private) on DC benefits and various working models tailored to the specific city.
6. Civic authorities can take a stake in a DISCOM and hire resources to undertake feasibility studies, through which they can incorporate energy supply or efficiency requirements into planning and land-use policies.

Medium-Term:

1. Mandate the DC guidelines through specific regulations for civic authorities for implementation with set targets by 2030.
    - Targets can be set as follows:
    - Use DCS in all new commercial district developments by 2030 (as done in Dubai).
    - Set ~20-30% target to meet cooling capacity through DCS in new city expansion areas (as done in Dubai).
    - Set city-specific DC system cooling capacity by 2030 (as done in Helsinki - 200 MW).
2. Expand use of DCS by 2030 for better refrigeration performance compared to using regular ACs.
3. Issue mandatory requirements for providing utilities like underground piping network and water/energy requirements for DC projects.
4. DCCs can be assigned to franchise zones, thus granting them exclusive rights to operate in that area.
5. Design high density greenfield development with piping and utility network for DCS.
6. In exchange for the operator licence, the local government can negotiate or regulate end-user pricing, guaranteeing that district cooling is the most cost-effective choice for providing cooling services.
7. Incentivise DC system adoption through special loans, operator licensing facilities, end-user pricing, and provisions for greater floor area ratio (FAR) in franchise zones.
8. Explore innovative funding mechanisms for DC system implementation like debt provision and bond financing, loan guarantees and underwriting, access to senior-level grants and loans, revolving funds, city-level subsidies, and development-based land-value capture strategies.

Long-Term:

1. Monitoring, evaluation, and reporting of DC projects implemented in cities.
2. Showcasing commercial viability nationwide.

Potential for DC system adoption is enormous in a rapidly urbanising economy like India. With over ~50% of the total population of the country forecasted to live in cities by 2030, it will be crucial to manage the cooling demand in cities through alternative sources and newer climate-efficient models. As a result, municipalities are expected to play a larger role in facilitating quick adoption of DCS in India.

9 CASE STUDIES OF OPERATIONAL DCS IN INDIA

9.1 DCS CASE STUDY 1: GIFT CITY, GANDHINAGAR

GIFT City is an emerging global financial and information technology (IT) services hub, the first of its kind in India, designed to be at or above par with globally benchmarked business districts. It is supported by state-of-the-art infrastructure encompassing all basic urban infrastructure elements. GIFT City is planned on approx. 4 million m^2 (886 acres) of land, with a total built-up area of approx. 6 million m^2, of which 0.3 million m^2 is already operational as of 2022. The planned development includes office spaces, residential apartments, schools, hospitals, hotels, clubs, retail, and various recreational facilities. The GIFT City DCS system has been set up with the vision to provide uninterrupted, energy-efficient, and sustainable air-conditioning to GIFT City occupants. The first phase of the GIFT City DC system has been operational since March 2015. The total planned DC capacity is 180,000 TR, out of which 10,000 TR is already operational. A TES system of 10,000 TR-h rated capacity is also installed for peak load shaving. An underground utility tunnel has been laid for the chilled water distribution network, along with other utilities.

GIFT City has mandated the use of DCS in buildings through the Development Control Regulations (DCR) of the region. GIFT Urban Development Authority constituted by the Government of Gujarat regulates the development in GIFT City. Gujarat International Finance Tec-City Company Limited (GIFTCL) provides the necessary technical support for preparing various design guidelines and evaluating the development proposals in GIFT City.

Figure 20: GIFT City DCS: View of DC Plant and TES Tank

Figure 21: GIFT City DCS: View of Ground Floor Chiller Bay

Figure 22: GIFT City DCS: View of Chiller Installation

Figure 23: GIFT City DCS: View of Transformer Yard

Figure 24: GIFT City DCS: View of Pump Installation

Figure 25: GIFT City DCS: View of DC System Piping Network in Utility Tunnel

9.1.1 Details of Case Study 1

S. No.	Parameter	DC System Details		
1	Location	Gandhinagar, Gujarat		
2	Operational Since	The first phase GIFT DC system has been operational since March 2015.		
3	Building Types	Mixed-use development covering all types of buildings, including office, residential, hotel, retail, institutional, etc.		
4	Total Master Plan Land Area	3,585,515 m^2 (886 acres)		
5	Total Built-Up Area	Current: (302,857 m^2); Planned: (5,759,994 m^2)		
6	Number of Buildings Connected to DC System	Current: (13); Planned: (130)		
7	Number of DC Customers	One connection per building for commercial buildings, submetering for residential buildings		
8	Is district heating supplied by the same plant/provider?	No		
9	Building-Wise Design Cooling Demand	Refer to list of operational buildings with an estimated design load		
10	System Details	Number of DC Plants		Current: (1)
		Chillers	Compression Technology	Electric Centrifugal Chillers
			Chiller Power Supply	11 kV
			Heat Rejection	Water-Cooled
			Capacity Control	Constant Speed Drive
			Refrigerant Type	R-134a
		Cooling Tower	Induced Draft	
			VFD on Fans	
			Located on Roof	
		Distribution Network	Length	Approx. 5 km
			Maximum Distribution Pipe Size	1100 mm
			Minimum Distribution Pipe Size	100 mm
			Pipe Material	Mild Steel Pipe
			Piping Location	Utility Tunnel
			Type and Amount of Insulation	Factory Pre-insulated (Spray Method)
			Leak Detection System Installed	Yes
		Thermal Energy Storage	Type	Stratified Above-Ground Sensible Heat Type MS TES Tank
			TES is designed for	Peak load shaving. Currently utilised for all types of load situations.
11	Estimated Life of Cooling System	25 years		

S. No.	Parameter	DC System Details		
12	Installed Cooling Capacity and Equipment Selection	DC Plant	Chillers (Number of Units and TR) (Working/Standby)	2 Units of 5000 TR (1W + 1S) * One set of 5000 TR made of 2 units of 2500 TR in series counter flow arrangement
			TES System (Number of Units and TR-h) (Working/Standby)	10,000 TR-h
			Reduction in Cooling Capacity due to TES System (TR)	10,000 TR-h rated capacity to deliver 2,500 TR peak load for 4 hours
			Cooling Towers (Number of Units, kW, TR) (Working/Standby)	4 Units; 110 kW each; 2500 TR each (2W + 2S)
			Condenser Water Pumps (Number of Units, Rated kW, and GPM) (Working/Standby)	3 Units; 450 kW each; 15000 GPM each (2W + 1S)
			Primary Chilled Water Pumps (Number of Units, Rated kW, and GPM) (Working/Standby)	3 Units; 110 kW each; 7500 GPM each (2W + 1S)
			TES Pumps (Number of Units, Rated kW, and GPM) (Working/Standby)	2 Units; 90 kW each; 3750 GPM each (1W + 1S)
		Distribution Network	Secondary Chilled Water Pumps (Number of Units, Rated kW, and GPM) (Working/Standby)	2 Units; 315 kW each; 3750 GPM each (1W + 1S) 2 Units; 550 kW each; 7500 GPM each (1W + 1S)
		ETS	PHEs (Number of Units and Size) (Working/Standby)	As per individual building loads *In the scope of building developers
			Chilled Water Pumps in the Building (Number of Units, Rated HP, and GPM) (Working/Standby)	As per individual building loads *In the scope of building developers
		Buildings	AHUs/TFAs/FCUs (Numbers and CFM)	As per individual building loads *In the scope of building developers
13	Chiller Piping Strategy	Series counter flow designed for 9°C delta T & 1.5 GPM/TR of water flow		
14	Chilled/Condenser Water Pumping Strategy	Constant Primary Variable Secondary System		
		VFD on Condenser Water Line		No
		VFD on TES pumps		Yes
15	Peak Cooling Load	3333 TR		
16	Peak Electrical Load-System	2500 kVA		
17	Solar PV System Capacity	250 kWp		

S. No.	Parameter	DC System Details		
18	DC System Design Specifications	Design Ambient Temperature and Relative Humidity (RH)		Comfort Application- 24±1°C, less than 60% RH
		Chilled Water Supply Temperature on Primary Side of PHE (Plant Side)		5°C (± 0.5°C)
		Chilled Water Return Temperature on Primary Side of PHE (Plant Side)		14°C (± 0.5°C)
		Chilled Water Supply Temperature on Secondary Side of PHE (Building Side)		6°C (± 0.5°C)
		Chilled Water Return Temperature on Secondary Side of PHE (Building Side)		15°C (± 0.5°C)
		Design Pressure of Chilled Water Distribution Network		90 m
		Pressure Loss in Chilled Water Distribution Network		Designed for 2.5-4 feet per 100 feet of run length
19	Operational Chilled Water Delta T	9 °C		
20	Full Load Design Efficiency at Duty Conditions	DC Plant	Chillers	0.63 kW/TR
			Cooling Towers	0.033 kW/TR
			Condenser Water Pumps	0.09 kW/TR
			Primary Chilled Water Pumps	0.022 kW/TR
		Distribution Network	Secondary Chilled Water Pumps	0.11 kW/TR
		ETS	Chilled Water Pumps in Building	As per individual building loads *In the scope of building developers
		Buildings	AHUs/TFAs/FCUs	As per individual building loads *In the scope of building developers
21	Annual Operational Cooling Demand	5,669,436 TR-h per year Plant generation in FY 2021-22		
22	Annual Operational Energy Consumption of DC Plant and Distribution Network	6,325,483 TR-h per year Energy consumption in FY 2021-22		
23	Annual Average Operating Efficiency of DC Plant and Distribution Network	1.08 kW/TR in FY 2021-22		
24	District Cooling Tariff	Billing Type		Refer to GIFT City: DCS Tariff Card
		Connection Charge (INR)		
		Demand/Fixed Charge (INR/TR)		
		Consumption Charge (INR/TR-h)		
		Compliance Bonus, if any (INR)		

S. No.	Parameter	DC System Details	
25	Consumer Interconnect	Ownership of Interconnection, i.e. ETS	ETS-PHE & tertiary pumps in building by developer
		Delta T or Demand Penalties in Consumer Rate Structure	Demand/delta T penalty is provisioned, but during development phase, the return water temperature adjustment charges are not enforced.
26	Distribution Network/ Makeup Water Rate	Open circuit-makeup water is 1.3 % of circulation water.	
27	Other Details	Installation and O&M Guidelines for Connected Customer Buildings	Comprehensive building permission process is established.
28	Water Treatment	Chilled/Condenser Water Treatment Methods	Corrosion inhibitor & biocide treatment and nitrite level in closed loop. Automated chemical dosing system installed in open loop. Bio dispersant, corrosion inhibitor, scale inhibitor, and acid control.
		Condenser Water Source	Treated Sewage Effluent

Note: The operational energy performance is subject to change over time as the system efficiency depends upon cooling load, ambient conditions, part load values, and other factors. The cooling load at GIFT City is expected to increase in the near future which will have a positive impact on the energy performance.

9.1.2 List of Operational Buildings with Estimated Design Load

S. No.	Building Name	Built-Up Area (m^2)	Building Type	Status	Design Cooling Load (TR) (Estimated)
1	MMR-C4	3,999	Commercial	Operational	154
2	GIFT-ONE	57,265	Commercial	Operational	2,201
3	GIFT-TWO	55,297	Commercial	Operational	2,126
4	Prestige Fintech	29,192	Commercial	Operational	1,122
5	Brigade Hotel	9,926	Commercial	Operational	436
6	BSE	28,813	Commercial	Operational	1,108
7	DC Plant	NA	Commercial	Operational	100
8	WTC	8,608	Commercial	Operational	331
9	WTC	8,608	Commercial	Operational	331
10	Tata Data Centre	6,098	Commercial	Operational	900
11	GIFT House	3,716	Commercial	Operational	143
12	Hiranandani Sig.	28,929	Commercial	Operational	1,112
13	Brigade Com	25,261	Commercial	Operational	971
14	Savvy (Pragya-I)	37,148	Commercial	Operational	1,428
Total		302,857			12,463

9.1.3 GIFT City: DCS Tariff Card
Applicable effective from 01-July-2022

1. **New DCS Connection Charges: (one-time charge)**
   (DCS connection charges shall be levied as per Appendix 1)

2. **Security Deposit (Interest-Free)**

S. No.	Category	Amount
1	Residential	1.5 months' collection charges, as applicable
2	Commercial	1.5 months' collection charges as applicable
3	Institutional	1.5 months' collection charges as applicable

3. **Monthly Billing Charges**

A. Consumption Charges (refer to Note 1 below)

S. No.	Category	Rate (INR)	Unit
1	Commercial	5.3	INR per TR-h
2	Institutional	5.3	INR per TR-h
3	Residential	4.3	INR per TR-h

B. Fuel Surcharges (refer to Note 2 below)

S. No.	Category	Rate (INR)	Unit
1	Commercial	2.6	INR per TR-h
2	Institutional	2.6	INR per TR-h
3	Residential	2.6	INR per TR-h

C. Demand Charges (refer to Note 1 below)

S. No.	Category	Rate (INR)	Unit
1	Commercial	420 (refer to Note 3 below)	INR per TR per Month
2	Institutional	420 (refer to Note 3 below)	INR per TR per Month
3	Residential	190	INR per Month

D. Charges for Demand Above Contract Demand (refer to Note 4 below)

S. No.	Category	Rate (INR)	Unit
1	Commercial	560 (refer to Note 3 below)	INR per TR per Month
2	Institutional	560 (refer to Note 3 below)	INR per TR per Month

E. Meter Charges

S. No.	Category	Rate (INR)	Unit
1	Residential	10,000	One time at the time of connection
2		190	INR per Month

F. Return Water Temperature Adjustment

S. No.	Category	Remark
1	Commercial	During the development phase of GIFT, the return water temperature adjustment charges are not enforced, but this will be evaluated on a case-by-case basis. The user may be penalised for not providing the chilled water return temperature as per DCS Ready reckoner for the loss incurred by the DC system due to the low return temperature.
2	Institutional	
3	Residential	

G. Payment Delay Charges

S. No.	Category	Amount
1	Commercial	18% interest per annum on the bill amount owed after due date
2	Institutional	18% interest per annum on the bill amount owed after due date
3	Residential	18% interest per annum on the bill amount owed after due date

Note:

- Any revision in the electricity tariff by GIFT Power Company Limited (GPCL) will have proportional revision in the DC system tariff in terms of consumption and demand charges, and this will be effective from the day of electricity tariff revision.
- The fuel surcharge will be as levied per GPCL with applicable duties/taxes. This is subject to change with any revision in the fuel surcharge amount by GPCL and will be effective from the day of revision by GPCL.
- Demand charges will be charged on 85% of the contract demand or actual peak demand, whichever is higher, at the applicable demand charge rate per unit per month.
- If the peak demand of any month exceeds the contract demand, the user will be charged as per the chargementioned in "D" for demand exceeding contract demand.
- The user may be penalised for not providing the chilled water return temperature as per DCS Ready reckoneron a case-to-case basis for the loss incurred by the DC system due to the low return temperature.
- The measurement unit of the energy meter in the commercial building meter is million BTUs (MBTU) and in the residential meter, it is kWh. These are also the units of energy consumption for the DC system and can be converted to TR-h by the following factors:
    1. 1 TR-h = 0.012 MBTU
    2. 1 TR-h = 3.5168 kWh.

9.1.4 Appendix 1

NEW DC SYSTEM CONNECTION CHARGES (ONE-TIME CHARGES)

The connection charges are one-time charges and represent the actual cost of work required to provide the DC services to the consumer. This cost is non-refundable.

1. **Commercial Tower: DCS Connection to Main Commercial Building**

   The connection charges shall include the cost of the following items, with 15% overhead and taxes as actual:

   i. Butterfly valves
   ii. BTU meter
   iii. Pressure independent balancing control valves (PIBCVs)
   iv. Differential pressure transmitter (DPT), resistance temperature detectors (RTDs), temperature and pressure gauges
   v. Strainer
   vi. ETS panel
   vii. Actual cost of total length of dedicated chilled water insulated pipe (both supply & return pipe included) of adequate size required to provide DC service, measured from the point of supply up to the branch pipe tapping connected to the main chilled water header. (Refer to Schematic 2 & 3)

The estimate for the connection charges shall be provided by GIFTCL as per the site requirement for providing a DC system connection to the building. The estimated cost shall be deposited by the developer in advance. Upon completing the DC system connection to the building, if the actual cost is higher than the estimated amount, any excess amount shall be deposited by consumer, and the cost shall be refunded to the consumer in case the deposited amount is more than the actual cost incurred.

2. Residential Scheme: DCS Connection to Main Residential Building

The connection charges shall include the cost of the following items, with 15% overhead and taxes as actual:

i. Butterfly valves

ii. BTU meter

iii. PIBCVs

iv. DPT, RTDs, temperature and pressure gauges

v. Strainer

vi. ETS panel

vii. Actual cost of total length of dedicated chilled water insulated pipe (both supply & return pipe included) of adequate size required to provide DC service, measured from the point of supply up to the branch pipe tapping connected to the main chilled water header. (Refer to Schematic 1 & 3.)

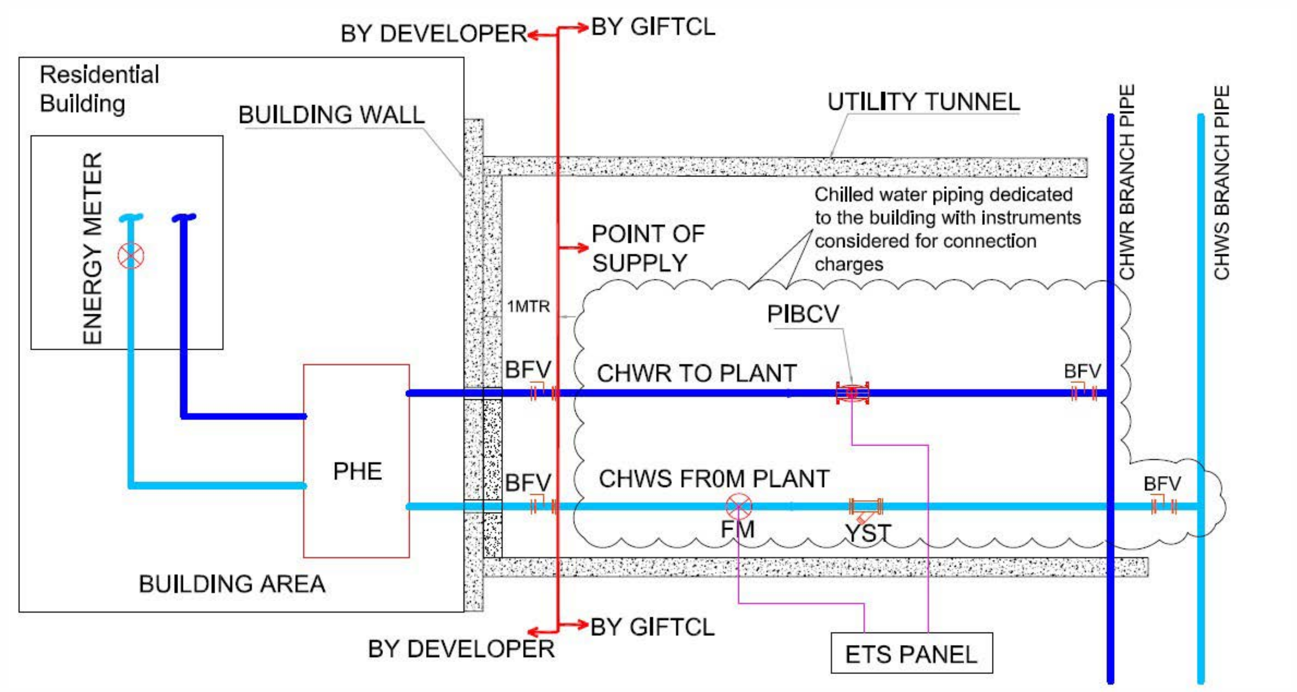
The estimate for the connection charges shall be provided by GIFTCL as per the site requirement for providing a DC system connection to the building. The estimated cost shall be deposited by the developer in advance. Upon completing the DC system connection to the building, if the actual cost is higher than the estimated amount, any excess amount shall be deposited by consumer, and the cost shall be refunded to the consumer in case the deposited amount is more than the actual cost incurred.

Connection Charges for Individual Residential Units

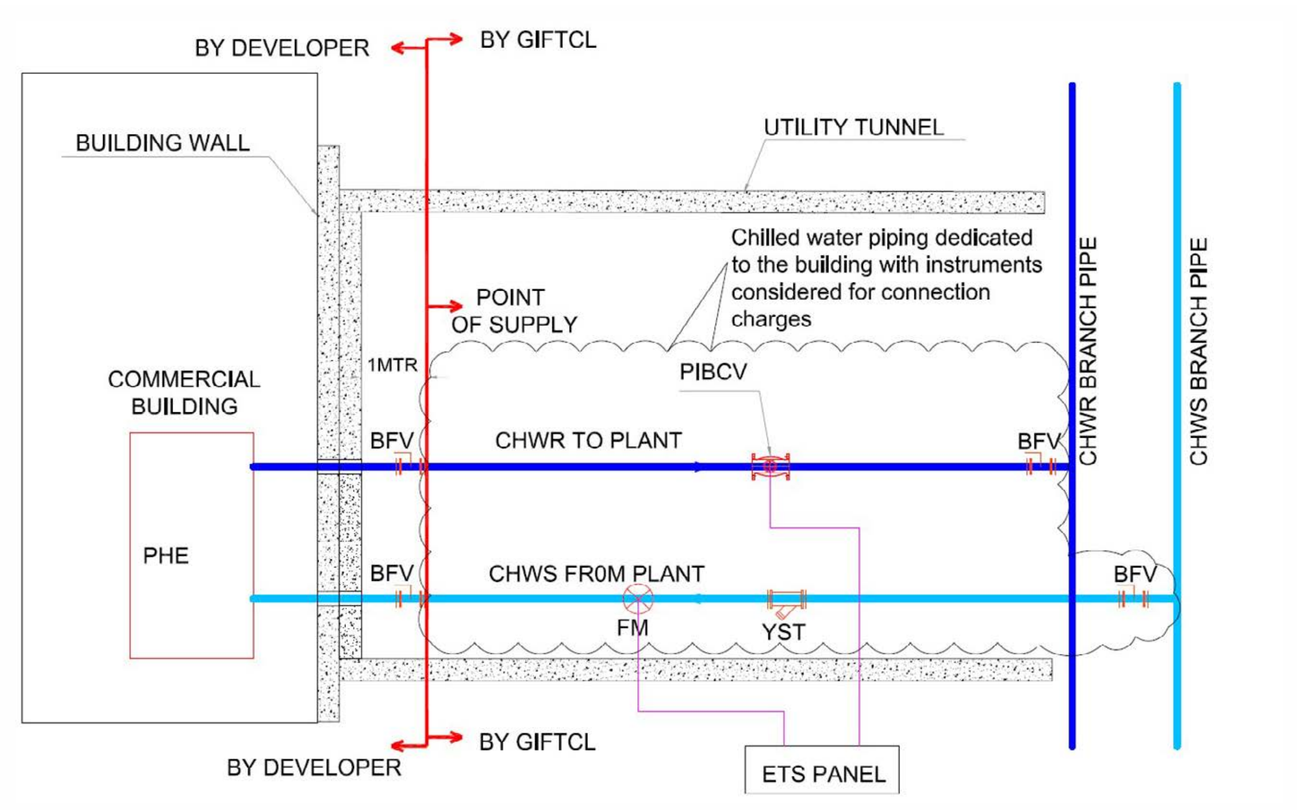
- One-time charges for consumer energy meters for each residential unit shall be as per Consumer Energy Metering Policy-Residential Building.
- One-time charges for consumer energy meters for each shop, office, and common facility unit up to an HVAC load of 5 TR shall be as per Consumer Energy Metering Policy-Residential Building.
- One-time charges for consumer energy meters for each shop, office, and common facility unit with an HVAC load above 5 TR: on actual basis and to be decided by GIFTCL.
- Recurring cost for BTU meter maintenance shall be as per Consumer Energy Metering Policy-Residential Building for the lifetime of the connection applicable to residential BTU meters. For meters of shops, offices, etc., meter maintenance charges shall be decided by GIFTCL. GIFTCL will address any issues related to submeter repair, maintenance, calibration, or replacement.

Battery limit line diagrams

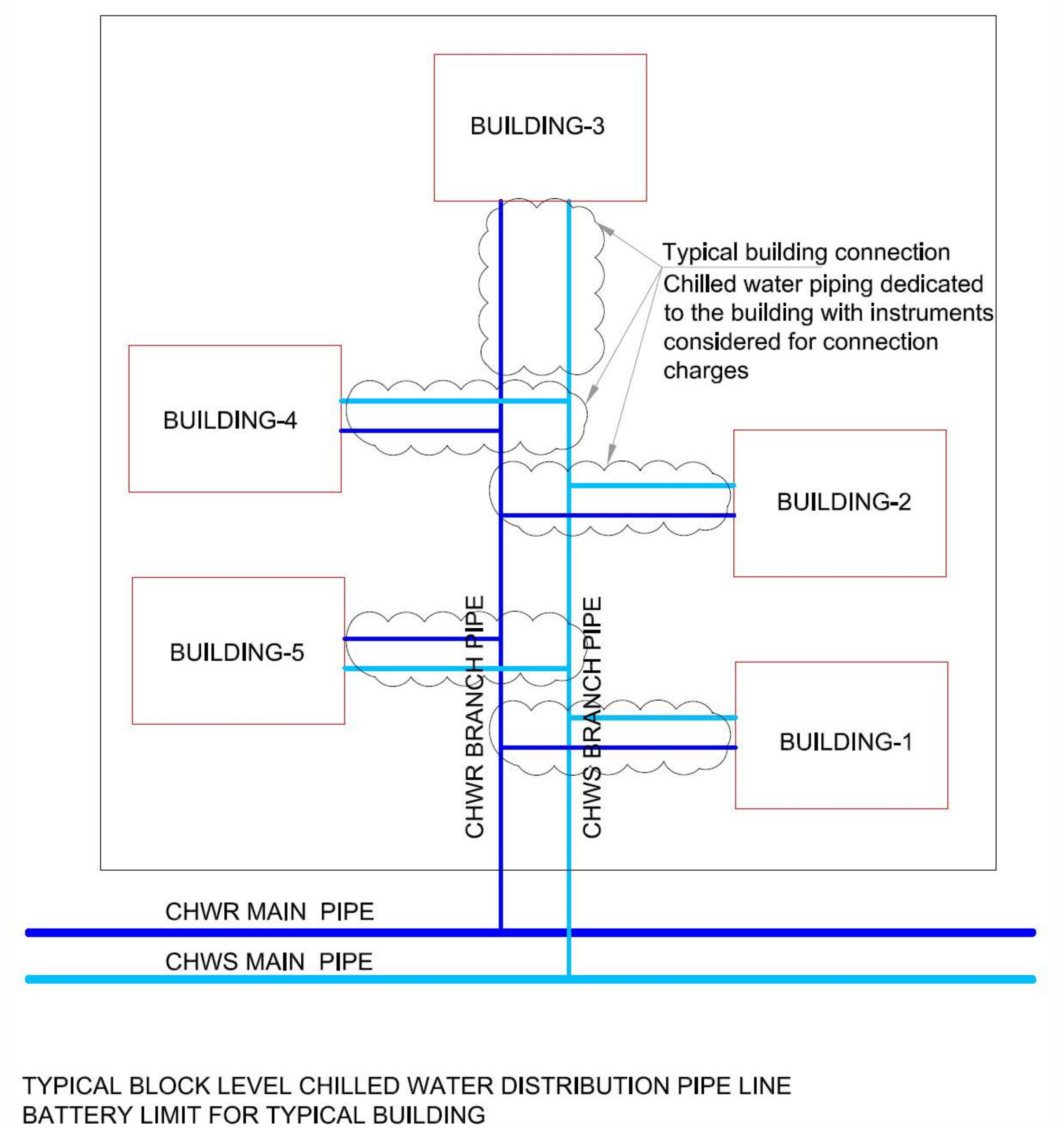
Schematic 1: Battery Limit in Residential Scheme for Residential Connection



Schematic 2: Battery Limit in Commercial Buildings



Schematic 3: DC System Battery Limit for Typical Block



9.2 DCS CASE STUDY 2: MY HOME ABHRA, HYDERABAD

My Home Abhra is a residential apartment complex in Madhapur, Hyderabad. The complex consists of 5 residential blocks, 18 floors each, with 5 apartments on each floor. The cooling requirements of the entire complex are met by a centralised air conditioning plant. The building is equipped with two water-cooled screw chillers of 450 TR each and one water-cooled screw brine chiller of 420 TR. Most of the time, one chiller is enough to meet the cooling requirements of the entire complex. Both chillers are used on a rotational basis based on a 15-day usage cycle. The brine chiller is used to charge a TES system of 3000 TR-h capacity that runs during low-demand days and power cuts. Each apartment has 7-10 indoor units (cassette/fan coil units) as per the size. Apart from homes, there are some common areas like the gym, shuttle court, multipurpose hall, etc. There are 9 CHW shafts to circulate chilled water from the plant to the indoor units of every apartment. For all apartments, chilled water tapping is taken from the respective shaft header through separate thermal energy (BTU) meters.

The building residents association owns, operates and maintains the DC System including the DCP and the distribution network. The indoor units belong to the respective apartment owners. There have been no tariff changes for cooling thermal energy consumption from the beginning i.e., 2015; however, the electricity tariffs have since then changed twice.

Figure 26: View of My Home Abhra, Hyderabad from Main Road

9.2.1 Details of Case Study 2

S. No.	Parameter	District Cooling System Details		
1	Location	My Home Abhra, Madhapur, Hi-tech City, Hyderabad, Telangana		
2	Operational Since	2015		
3	Building Types	Residential (5 towers, 18 residential floors with 390 homes and some common areas (gym, shuttle court, etc.) in the stilt floor)		
4	Total Site Area	20,234 m^2 (5 acres)		
5	Total Built-Up Area	84,200 m^2		
6	Total Air-Conditioned Area	54,730 m^2		
7	Number of Buildings Connected to DC System	5		
8	Number of DC System Customers	400 (390 homes + 10 common area)		
9	Is district heating supplied by the same plant/provider?	No		
10	Building-Wise Design Cooling Demand	Block A - 842 TR Block B - 841 TR Block C - 515 TR Block D - 840 TR Block E - 840 TR Total - 3,878 TR		
11	System Details	Number of DC Plants		1
		Chillers	Compression Technology	Electric Screw Chillers
			Chiller Power Supply	400 V
			Heat Rejection	Water-Cooled
			Capacity Control	Variable Speed Drive
			Refrigerant Type	R-134a
		Cooling Tower	Forced Draft	
			Fixed Speed Fans	
			Located Onsite (Not on Roof)	
		Distribution Network	Maximum Distribution Pipe Size	300 mm
			Minimum Distribution Pipe Size	150 mm
			Pipe Material	Mild Steel Pipe
			Piping Location	Runs along basement car parking ceiling
			Type and Amount of Insulation	Chilled water header pipe with 75 mm thick insulation with air-tight leak-proof vapour barrier, 22 gauge GI chicken wire mesh wrapping, and 26 gauge aluminium sheet cladding.
			Leak Detection System Installed	No
		TES	Type	Phase Change Material Based Thermal Storage Type (Setpoint -5°C)
			TES is designed for use	During power cuts and low-demand periods
12	Estimated Life of Cooling System	Equipment Wise (years)		Water Chillers - 25 Brine Chiller - 25 Cooling Tower - 20 Pump - 25 AHUs - 15 Storage Tank - 25 PHE - 12

S. No.	Parameter	District Cooling System Details		
13	Installed Cooling Capacity and Equipment Selection	DC Plant	Chillers (Number of Units and TR) (Working/Standby)	Water Chillers: 900 TR (2 Units of 450 TR each) (1W + 1S)
				Brine Chiller: 1 Unit of 420 TR (1 W)
			TES System (Number of Units and TR-h) (Working/Standby)	3000 TR-h (2 Units of 1500 TR-h capacity each) (2 W)
			Cooling Towers (Number of Units and TR) (Working/ Standby)	8 Units (3 Units of 150 TR; 3 Units of 125 TR; 2 Units of 220 TR) (8 W)
			Condenser Water Pumps (Number of Units, Rated HP, and GPM) (Working/Standby)	5 Units; 30 HP each, 900 USGPM each (4W + 1S)
			Primary Chilled Water Pumps (Number of Units, Rated HP, and GPM) (Working/Standby)	For Water Chillers: 3 Units; 30 HP each; 1200 USGPM each (2W + 1S)
				For Brine Chiller: 2 Units; 30 HP each; 1200 USGPM each (1W + 1S)
		Distribution Network	Secondary Chilled Water Pumps (Number of Units, Rated HP, and GPM) (Working/Standby)	For Water Chillers: 2 Units of 40 HP & 1200 USGPM each; 2 Units of 25 HP & 650 USGPM each (2W + 2S)
				For Brine Chiller: 2 Units of 30 HP & 1300 USGPM each; 2 Units of 20 HP & 650 USGPM each (2W + 2S)
		ETS	PHEs (Number of Units and Size) (Working/Standby)	2 Units of 450 TR each (2W)
			Chilled Water Pumps in Building (Number of Units, Rated HP, and GPM) (Working/Standby)	-
		Buildings	AHUs/FCUs/Cassette Units (Number of Units and CFM)	Apartments:- FCUs: 847 Units (mix of 1.5 TR, 2 TR, & 3 TR; 400 CFM/TR) Cassette Units: 1820 Units (mix of 1.5 TR, 2 TR, & 3 TR)
				Common Areas and Miscellaneous: AHUs: 8 Units (1 Unit of 4000 CFM; 2 Units of 3200 CFM, 4 Units of 3000 CFM; 1 Unit of 2400 CFM)
14	Chiller Piping Strategy	Parallel Scheme		
15	Chiller Pumping Strategy	Constant Primary Variable Secondary System		
		No VFD is on Condenser line		
16	Peak Cooling Load	354 TR		
17	Peak Electrical Load- System	489 kW		

S. No.	Parameter	District Cooling System Details	
18	Solar PV System Capacity	50 kWp	
19	Peak Electrical Load on Grid	829 kVA	
20	DC System Design Specifications	Design Ambient Temperature and RH (°C & %)	Summer: T = 41.1°C, RH=26% Monsoon: T = 29.4°C, RH=82% Winter: T = 12.7°C, RH=60%
		Chilled Water Supply Temperature at DC Plant (°C)	6°C
		Temperature Drop in Chilled Water Supply Distribution Network (°C)	0.5°C
		Chilled Water Supply Temperature at Consumer End (°C)	6.5°C
		Chilled Water Return Temperature at Consumer End (°C)	11°C
		Temperature Drop in Chilled Water Return Distribution Network (°C)	0.5°C
		Chilled Water Return Temperature at DC Plant (°C)	11.5°C
		Design Pressure of Chilled Water Distribution Network	400,000 Pa
		Pressure Loss in Chilled Water Distribution Network	50,000 Pa
21	Operational Chilled Water Delta T	Average Chilled Water Delta T Achieved	2°C
		Chillled Water Delta T Range	Summer: 2.0-3.5 °C Winter: 0.3-2.0 °C
22	Full Load Design Efficiency of Chillers at Duty Conditions	0.6 kW/TR	
23	Annual Operational Cooling Demand	565,451 TR-h per year	
24	Annual Operational Energy Consumption of DC Plant	1,138,306 kWh per year	
25	Annual Average Operating Efficiency	2.07 kW/TR	
26	Annual Energy Costs of DC Plant	INR 9,960,780 per year	
27	DC Tariff	Billing Type	Monthly
		Connection Charge (INR)	No
		Demand/Fixed Charge (INR/TR)	INR 1,200 per TR per year
		Consumption Charge (INR/TR-h)	Apartments: INR 14.91/TR-h
		Compliance Bonus, if Any (INR)	No
28	Water Treatment	Chilled/Condenser Water Source	Municipal Water
		Chilled/Condenser Water Treatment Methods	No treatment (only checking pH, TDS, and other tests by using required chemicals)
29	Contact Information	Synergy infra Consultants Pvt. Ltd.	

Notes:

1. My Home Abhra is not a typical example of a DC System where the overall cooling capacities are generally high with high cooling load diversities coming from a mix of different residential and commercial building typologies. However, since the apartments are billed for their cooling usage based on individual BTU metering, it has been considered a DC System.
2. A similar model where cooling is provided as a service is also designed for and followed in some commercial establishments in India such as retail malls where individual tenants are billed for their cooling usage based on individual BTU metering.

10 NORMATIVE REFERENCES

1. **Load Calculations**
    a. ANSI/ASHRAE Standard 55-2013 Thermal Environmental Conditions for Human Occupancy
    b. ANSI/ASHRAE Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality
    c. ISHRAE Indian Weather Data, Design Day and Hourly, 2022
    d. ANSI/ASHRAE Standard 169-2013 Climatic Data for Building Design Standards
    e. ASHRAE. 2014. Load calculation applications manual, 2nd edition
    f. 2019 ASHRAE Handbook—HVAC Applications
    g. ANSI/ASHRAE/ACCA Standard 183-2007 (RA 2017), Peak cooling and heating load calculations in buildings except low-rise residential buildings

2. **Sustainable Building Design and Air-conditioning Systems**
    a. National Building Code of India (NBC) 2016: Part 8 BUILDING SERVICES Section 3 Air Conditioning, Heating and Mechanical Ventilation; Part 11 APPROACH TO SUSTAINABILITY
    b. Energy Conservation Building Code (ECBC) 2017
    c. ANSI/ASHRAE/IES Standard 90.1-2019, Energy standard for buildings except low-rise residential buildings.
    d. ANSI/ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy
    e. ANSI/ASHRAE Standard 62.1-2022, Ventilation and Acceptable Indoor Air Quality
    f. ANSI/ASHRAE Standard 52.2-2017, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size

3. **HVAC Systems for District Cooling**
    a. 2020 ASHRAE Handbook- HVAC Systems and Equipment

4. **Chillers**
    a. IS 16590: 2017 Water Cooled Chilling Packages using the Vapour Compression Cycle
    b. AHRI 551/591 (SI): Performance Rating of Water-Chilling and Heat-Pump Water-Heating Packages Using the Vapor Compression Cycle; Air cooled Water Chilling Packages using Vapour Compression Cycle
    c. AHRI 560-2000 Absorption Water Chilling and Water Heating Packages
    d. EN 14511 Air conditioners, Liquid Chilling Packages and Heat Pumps for space heating and cooling and process chillers with electrically driven compressors
    e. EN 14825 Air conditioners, Liquid Chilling Packages and Heat Pumps with electrically driven compressors for space heating and cooling. Testing and rating at part load conditions and calculation of seasonal performances and process chiller

5. **Air Handling Units and Coils**
    a. AHRI 410 Forced Circulation Air Cooling & Air Heating Coils
    b. AHRI 1350 Mechanical performance of Rating of Central Station Air Handling Units

c. AHRI 410 Performance Rating of Central Station Air Handling Unit Supply Fans
d. EN 13053 Rating & Performance of AHU as a whole
e. EN 1886 Mechanical strength, leakage, thermal performance, filter bypass and acoustic insulation of Air Handling Units

6. Energy Recovery Ventilation

a. AHRI 1061 Performance Rating for Air to Air Heat Recovery Ventilation Equipment

7. Dedicated Outdoor Air Systems (DOAS)

a. AHRI Standard 921-2015 (SI) Performance Rating of DX-Dedicated Outdoor Air System Units

8. PHEs

a. ANSI/AHRI 400-2015 Performance Rating of Liquid-to-Liquid Heat Exchangers

9. Water Pumps

a. IS 6595-2: Horizontal Centrifugal Pumps for Clear, Cold Water, Part 2: General purposes other than agricultural and rural water supply
b. IS 5120: Technical requirements for rotodynamic special purpose pumps
c. ISO 2858:1975, End-suction centrifugal pumps (rating 16 bar) — Designation, nominal duty point and dimensions

10 Cooling Towers

Cooling Technology Institute (CTI) standards:

a. CTI ATC-105 (00) Acceptance Test Code for Water Cooling Towers
b. CTI ATC-105S (11) Acceptance Test Code for Closed-Circuit Cooling Towers
c. CTI ATC-106 (11) Acceptance Test Code for Mechanical Draft Evaporative Vapor Condensers

Water Quality and Safety during Cooling Tower O&M:

a. ANSI/ASHRAE Standard 188-2018, Legionellosis: Risk management for building water systems

11 Motors

a. IS 12615 Energy efficient induction motors – three phase squirrel cage

12 Fans

a. AMCA 205-1 Energy Efficiency Classification for Fans
b. ANSI AMCA 208-18 Calculation of Fan Energy Index

13 Pipes and Fittings:

k. EN 253: 2009 District heating / Cooling pipes – Standard Piping
b. EN 448: 2009 District heating / Cooling pipes – Fittings
c. EN 489: 2009 District heating / Cooling pipes – Jointing parts
d. EN 13 480: 2011 Metallic industrial piping
e. EN 13 941: 2009 Design and installation of pre-insulated pipes
f. ANSI/ASME B31.1 Power Piping code Rules for piping in electric power generating stations, industrial and institutional plants, geothermal heating systems and central and district heating and cooling systems
g. IS 1239-1 (2004): Steel Tubes, Tubulars and Other Wrought Steel Fittings, Part 1: Steel Tubes [MTD 19: Steel Tubes, Pipes and Fittings]
h. IS 816 (1969): Code of practice for use of metal arc welding for general construction in mild steel [MTD 12: Welding Applications]
i. IS 2379 (1990): Colour code for identification of pipe lines [MED 17: Chemical Engineering Plants and Related Equipment]
j. IS 3589 (2001): Steel Pipes for Water and Sewage (168.3 to 2 540 mm Outside Diameter) [MTD 19: Steel Tubes, Pipes and Fittings]
k. 2021 ASHRAE Handbook- Fundamentals

14 TES

a. ANSI/ASHRAE 152-2014 Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems
b. 2020 ASHRAE Handbook- HVAC Systems and Equipment
c. 2019 ASHRAE Handbook- HVAC Applications

15 Refrigerants

a. ASHRAE. 2013a. ANSI/ASHRAE Standard 34, Designation and safety classification of refrigerants
b. ASHRAE. 2013b. ANSI/ASHRAE Standard 15, Safety standard for refrigeration systems and designation and classification of refrigerants

c. ISO 5149-1:2014, Refrigerating systems and heat pumps — Safety and environmental requirements — Part 1: Definitions, classification and selection criteria

16 Thermal Energy Meters

a. ASHRAE. 1992. ANSI/ASHRAE Standard 125-1992 (RA 2011), Method of testing thermal energy meters for liquid streams in HVAC systems

b. OIML-R75; Part International Organisation of Legal Metrology – Heat Meters – Type approval tests and initial verification tests

c. European Standard EN 1434; Part 1) Thermal Energy Meters General Requirements

17 Commissioning

a. ISHRAE Standard 10003-2000, Commissioning Process Standard for HVAC Systems

b. ANSI/ASHRAE/IES Standard 202-2013, Commissioning Process for Buildings and Systems

18 System Energy & Efficiency

a. ISO/TC 205 & CEN/TC 228 Standards for calculation of system energy requirements and system efficiencies for cooling and heating system in buildings.

b. ISO/DIS 52032 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Space distribution systems (DHW, heating and cooling), Module M3-6, M4-6, M8-6

19 Energy Services & Management

a. ISO 50007:2017 Energy services — Guidelines for the assessment and improvement of the energy service to users.

b. ISO 37160:2020 Smart community infrastructure - Electric power infrastructure - Measurement methods for the quality of thermal power infrastructure and requirements for plant operations and management

c. ISO 50001:2018 Energy management systems - Requirements with guidance for use

20 Risk Management

a. ISO 31000:2018 Risk management — Guidelines

21 DC Guides and Other References

a. ASHRAE District Cooling Guide, Second Edition

b. IDEA. 2008. District cooling best practices guide. International District Energy Association

c. 2021 ASHRAE Handbook- Fundamentals

d. 2022 ASHRAE Handbook- Refrigeration

e. 2020 ASHRAE Handbook- HVAC Systems and Equipment

f. 2019 ASHRAE Handbook- HVAC Applications

11 KNOWLEDGE PRODUCTS BY UNEP FOR MORE DETAILS ON DCS

1. Rapid Assessment and Prefeasibility Studies in India
https://www.districtenergyinitiative.org/india
2. District Energy in Cities Initiative: National District Cooling Potential Study for India
https://www.districtenergyinitiative.org/sites/default/files/publications/final-reportnational-district-cooling-potential-study-india15032021clean-version-230320211216.pdf
3. District Energy Projects: MRV Framework Guidance MRV framework guidance
https://www.districtenergyinitiative.org/sites/default/files/publications/guidance-des-mrv-frameworkfinal-11092019539.pdf
4. District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy
https://www.districtenergyinitiative.org/sites/default/files/publications/districtenergyreportbook-07032017532.pdf
5. District Cooling Systems eTraining – India
https://c2e2.unepccc.org/collection/district-cooling-systems-etraining-india/

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