COOLING AND ENERGY EFFICIENCY IN BUILDINGS

INDIA

Jan VAN DEN AKKER

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Air-conditioning
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BAU	Business as usual
BEE	Bureau of Energy Efficiency
BEEP	Building Energy Efficiency Project
BEP	Building Energy Passport
CBO	Community-Based Organization
CII	Confederation of Indian Industries
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
CREDAI	Confederation of Real Estate Developers' Associations of India
CSO	Civil Society Organization
DCS	District Cooling System
DSM	Demand-Side Management
DX	Direct Expansion
ECBC	Energy Conservation Building Code
EE	Energy Efficiency
EER	Energy Efficiency Ratio
EESL	Energy Efficiency Services Limited
EMIS	Energy Management Information System
ENS	Eco-Niwas Samhita (ECBC-Residential)
ESCO	Energy Services Company
FICCI	Federation of Indian Chambers of Commerce & Industry
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GoI	Government of India
GSHS	Ground Surface Heat Pump
GWP	Global Warming Potential
HCF	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoro-olifins
HPMP	HCFC Phase-out Management Plan
HVAC	Heating, Ventilation and Air-Conditioning
ICAP	India Cooling Action Plan
IDEC	Indirect Evaporative Cooling
IMAC	Indian Model for Adaptive Thermal Comfort
IPLV	Integrated Part Load Value
ISEER	India Seasonal Energy Efficiency Ratio
IoT	Internet of Things
kW	Kilowatt
kWh	Kilowatt-hour
m^2	square meters
MEPS	Minimum Energy Performance Standard
MoEF&CC	Ministry of Environment, Forestry and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MoP	Ministry of Power
$MtCO_2$	Megaton of CO_2 (million tons)
NBC	National Building Code
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organisation
ODP	Ozone Depletion Potential

RAC	Room air-conditioner
S&L	Standards and Labelling
SDA	State-designated Agency
SDC	Swiss Development Corporation
SEER	Seasonal Energy Efficiency Ratio
SME	Small and Medium-sized Enterprises
TR	Tonnage of refrigeration (= 5.5168 kilowatt)
TWh	Terawatt-hour (10^{12} Watt-hours)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USAID	US Agency for International Development
USD	United States Dollar
UT	Union Territory
VRF	Variable Refrigerant Flow
WWF	World Wildlife Fund
WWR	Window-to-Wall Ratio

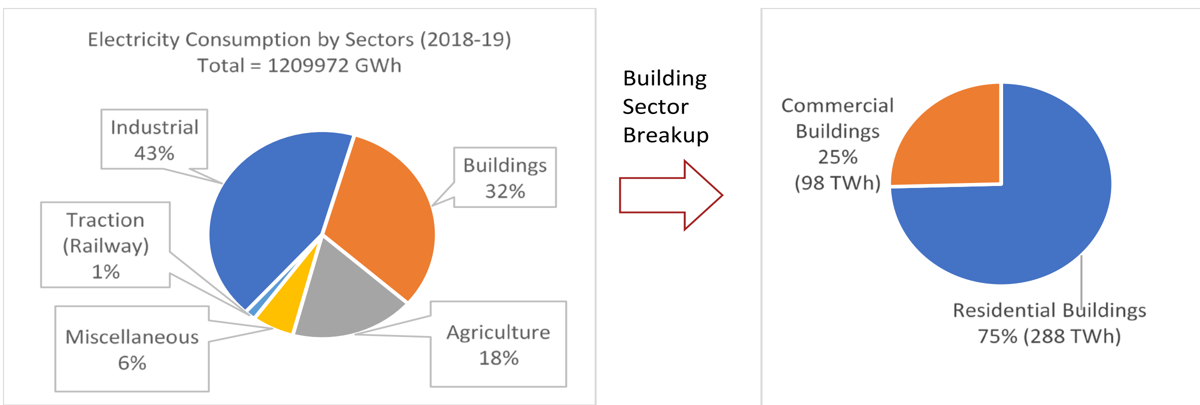
1. ENERGY EFFICIENCY IN BUILDINGS

1.1 Energy demand and greenhouse gas emissions

Electricity demand and buildings

India is a rapidly growing economy with a population of more than 1.34 billion in 2017 (up from 1.00 billion in 1997). GDP (inflation-adjusted) rose from USD 727 billion in 1997 to USD 2,660 billion in 2017 with an average annual growth of 7%. The rising per capita income (up from USD 727 in 1997 to USD 1,987 in 2017), rapid urbanization (about 26% in 1997 and 34% in 2017) and a largely tropical climate in India (see map, Annex A) will lead to a rapid increase in demand for energy-consuming appliances and equipment thereby resulting in a rise in energy demand in buildings, as indicated in Box 1.

Box 1 Electricity demand projections per sector in India



In India in 2018-19, the building sector had a share of 32% in total electricity consumption across sectors, of which 75% of the electricity is consumed by residential buildings and 25% by commercial buildings[1]. The buildings sector consumed 386 TWh in 2018-19, of which consumption related to heating, ventilation and air-conditioning (HVAC) and comfort systems was about 45%. Out of total electricity consumption of 173 TWh for HVAC, 118 TWh was in residential buildings and 55 TWh in commercial buildings.

GHG emissions

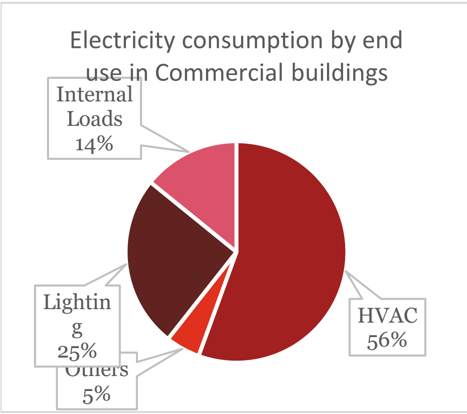
In 2018, India's total GHG emissions amounted to 2,308 $MtCO_2$ (million tons of CO_2), distributed amongst electricity and heat production (51%), road transport (13%), industry (25 %), residential (4%), commercial and public services (1%), agriculture (1%), other sources, 4%)[2] Despite the growth in the renewable energy sector in India, the country's economic growth is still significantly dependent on fossil fuels, with coal being the predominant source of energy[3]. The power sector and industry are the main consumers of primary energy from coal and natural gas, which results in relatively high GHG emissions.

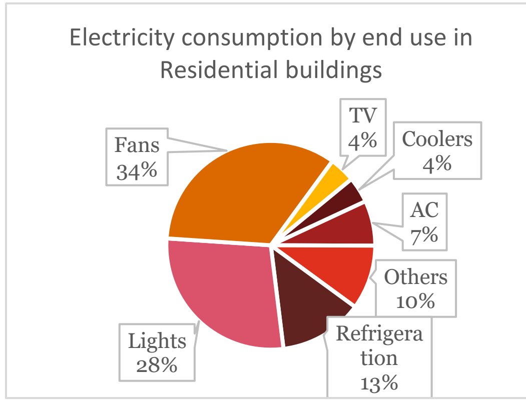
1 Growth of Electricity Sector in India from 1947-2020, CEA, Ministry of Power, Government of India, https://cea.nic.in/wp-content/uploads/pdm/2020/12/growth_2020.pdf

2 IEA Statistics, CO2 Emissions by Sector in India for the year 2018, www.iea.org

3 The total primary energy consumption from coal (452.2 Mtoe; 45.88%), crude oil (239.1 Mtoe; 29.55%), natural gas (49.9 Mtoe; 6.17%), nuclear energy (8.8 Mtoe; 1.09%), hydro electricity (31.6 Mtoe; 3.91%) and renewable power (27.5 Mtoe; 3.40%) is 809.2 Mtoe (excluding traditional biomass use) in the calendar year 2018, BP Statistical Review 2019

Box 2 Electricity consumption in residential and commercial buildings





Source: BEE, *ECBC Compliance in Indian Cities*

Future cooling energy demand and GHG emission growth

There is going to be an unprecedented expansion of India's building sector where residential building stock is projected to increase from 272 million households (over 15 billion m^2) in 2017-2018 to 386 million (over 28 billion m^2) by 2037-2038.[4] Similarly, the commercial building sector is projected to increase from 1.2 billion m^2 in 2017-2018 to 3.1 billion m^2 in 2037-38. Accordingly, the building sector cooling demand shows very significant growth as compared to the baseline situation. As a consequence, energy consumption for space cooling (comprised of refrigeration and air conditioning applications for residential and commercial buildings), is estimated to grow from 10% in 2017 to 45% by 2050[5].

The energy demand from Cooling Systems based on vapor compression (refrigerant-) technologies, such as room air-conditioners and chillers (other than fans and other non-refrigerant technologies) is estimated at 75 TWh (across residential and commercial buildings)[6]. In BEE projections, the energy consumption by cooling systems (both refrigerant and non-refrigerant based ones) is projected to grow by about 8.2% a year, to 284 TWh in 2027, and about 585 TWh in 2037[7]. While within space cooling, room air conditioners hold a dominant share of the sector's cooling energy consumption at about 42% in 2017-18, this is expected to grow to 52% by 2037-38[8].

A large part of the space cooling demand is currently catered through refrigerants-based cooling in air-conditioners and chillers (47%) as well as non-refrigerant cooling (through fans and air coolers) (41%)[8]. The aggregated nationwide cooling demand, in Tons of Refrigeration (TR), is projected to grow around 4 times by 2027 as compared to the 2017 baseline. Among the refrigerant-based systems, room air conditioner (RAC) is the dominant technology representing about 80% of the installed capacity, with an increasing share that reaches around 87% in 2037-38[9]. Room air conditioners find predominant application in the residential sector, and currently have fairly low penetration in India at around 7-9%, but will grow rapidly in the coming decades, according to projections made by BEE and presented in the India Cooling Action Plan

4 Low Carbon Cooling Solutions for Buildings in India, WWF, 2020

5 IEA 2018, Link: https://cstep.medium.com/cooling-india-38b84b6269e7

6 Demand Analysis for Cooling by Sector in India in 2027

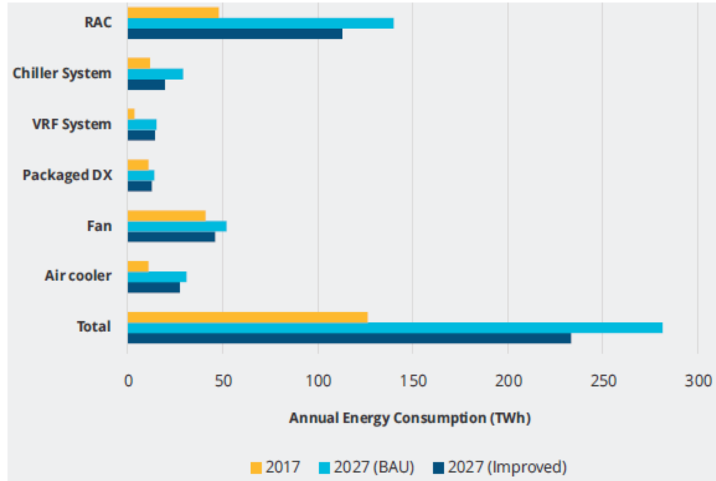
7 By about 8.2% a year to of 5-7.8% for residential buildings and 7.6-10.1% for commercial buildings through 2030. The consumption in the commercial sector, which comprises of chillers, VRF and packaged AC is currently at 27 TWh and is projected to grow by 433% (approx. 140 TWh) in business-as-usual scenario by 2037-38. *Low Carbon Cooling Solutions for Buildings in India*, WWF, 2020

8 *Mapping the Refrigerant Trends in India: An Assessment of Room AC Sector* - TERI Shakti 2019

9 In this respect it should be noted that RACs are also being applied in commercial buildings whereas central units or district cooling would be more appropriate technology for this market segment. The project will also emphasize this when piloting innovative cooling approaches for commercial buildings.

Box 3 Electricity consumption for cooling in buildings

	million units	million TR	2017 TWh	MtCO2
Buildings - total			**126**	**103.3**
Room air/conditioner	39	55	48	39.4
Chiller		5	11.8	9.7
VRF		2.3	3.6	3.0
Package DX		4.6	11	9.0
Fan	458		41	33.6
Air cooler	45		11	9.0



Source: data adapted from *Demand Analysis for Cooling by Sector in India in 2027* (BEE, 2018)
Notes:
VRF: variable refrigerant flow
TWh: terawatt-hour; $MtCO_2$: million tons of CO_2
DX: Direct expansion
TR: ton of refrigerator (unit to describe the heat-extraction capacity of refrigeration and air conditioning equipment, approximately 3.5 kW)

(ICAP, see Box 22). Worse, India's proliferating residential AC demand in a business-as-usual scenario is expected to be met by the most affordable and least energy-efficient room ACs available at the market. When considering an operational lifetime of over 10 years, these ACs may stretch the energy consumption pattern and GHG emissions footprint of such equipment.

Greenhouse gas emissions

In terms of energy demand, even though GHG emissions from residential and commercial buildings are currently comparatively low, the building sector presents an enormous opportunity in restricting emissions. If today's policy trends are followed, India's building energy demand will grow by almost 700%[10] by 2050 compared to 2005 levels and the associated CO_2 emissions are likely to increase tenfold to 1100 $MTCO_2$ from 119 $MtCO_2$ in 2018. If effective energy efficiency policy actions are taken, then the growth in CO_2 emissions in the building sector can be contained by means of measures aimed at reducing energy demand from growth to 440 $MtCO_2$ by 2050[11][12].

1.2 National policies and priorities

India is also a signatory to the Paris Agreement and has pledged to reduce the emission intensity of its GDP by 33-35% by 2030 in its Nationally Determined Contribution (see Section 3.2 on climate change mitigation commitments). The projections discussed in the previous section pertain to the fast growth of GHG emissions and increasing energy demand from the building sector related to India's rapidly developing economy. Thus, energy efficiency is seen as one of the cornerstones of India's mitigation policy, and especially significant. Over the last two decades, India has intensified energy efficiency initiatives starting from India's Energy Conservation Act (2001) and the establishment of the Bureau of Energy Efficiency (BEE) as the nodal agency to implement the provisions of the Act as well as other National Missions linked to climate

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10 Radhika Khosla & Kathryn B. Janda (2019) *India's building stock: towards energy and climate change solutions*, in: Building Research & Information, 47:1, 1-7, DOI: 10.1080/09613218.2019.1522482,

11 https://www.gbpn.org/activities/india

12 As the proposed project delineates the focuses between the GEF and Montreal Protocol, the reduced warming impact resulting from replacement of the conventional, high GWP refrigerant technologies with alternative cooling technologies with low or zero-ODP and low-GWP refrigerants is *treated as part of the baseline and are not included in the GEF core indicator total for the emission reduction of the Project.*

change[13]. In 2018, BEE formulated the *Strategic Plan for Energy Efficiency in India*, titled Unlocking National Energy Efficiency Potential. The plan estimated a total energy efficiency potential of 94 million tons of oil equivalent (Mtoe) by 2031, from different demand sectors (such as industry, buildings, domestic, municipal, transport, and agriculture.

The present buildings-related policies and policy interventions aim at enhancing the energy performance of buildings by focussing on a) optimization of building design to reduce heat gains/losses (driven by compliance with building energy codes for new buildings) with supportive programmes and incentives to increase their adoption, b) market mechanisms such as building labels to increase awareness and adoption of energy efficiency retrofits along with energy performance monitoring, and c) increasing the penetration and adoption of energy-efficient appliances and equipment used in buildings through standards & labelling. Box 4 gives a summary of various policy measures regarding energy efficiency in buildings.

Box 4 Overview of government programmes on energy efficiency in buildings

	Short description	Current status
Cross-sectoral		
National Building Code (NBC)	The National Building Code (NBC) is a document that provides guidelines for the construction of residential, mercantile, institutional, educational, commercial, assembly structures, storage spaces or even hazardous buildings.	NBC was first published in 1970 with subsequent amendments in 1983, 1987 and 1997, 2005 and 2016. The building by-laws of states and UTs in India comply with the mandatory provisions of the NBC. Guidance on Energy efficiency and thermal comfort aspects are part of the latest version of NBC 2016 (part 2).
HCFC Phase-out plan under Montreal Protocol[14]	The programme facilitated India's compliance with the Montreal Protocol control targets for consumption of (HCFCs) for a phase-out (see Box 9)	India has successfully implemented the ODS phase-out programmes that have enabled the industry to smoothly and systematically transition to ozone-friendly alternatives. India has banned imports of HCFC-141 b
Commercial buildings		
ECBC-Commercial Buildings	The purpose of the Energy Conservation Building Code is to provide minimum requirements for the energy-efficient design and construction of new buildings. ECBC focuses on building envelope, mechanical systems and equipment including heating, ventilating, and air conditioning (HVAC) system, interior and exterior lighting systems, electrical system and renewable energy, and also takes into account the five climate zones (Hot Dry, Warm Humid, Temperate, Composite and Cold) present in India (see Map, Annex A). The code prescribes the following three levels of energy efficiency (see Annex F for details): a) Energy Conservation Building Code Compliant (ECBC Building); b) Energy Conservation Building Code Plus (ECBC+ Building); and c) Super Energy Conservation Building Code (Super ECBC Building) The adoption of ECBC 2017 is estimated to save about 300 billion kWh of electricity and peak demand reduction of over 15 GW annually.	The ECBC was launched in 2017 and is applicable for new large commercial buildings with a connected load of 100 kW and above or 120 kVA and above So far, 18 states/UTs have notified the ECBC. Around 335 demonstration buildings have been supported with technical assistance for ECBC compliance in the States/UTs. Till 2018-19, 117 buildings were registered under ECBC of which, 23 buildings were completed as ECBC compliant by March 2019. ECBC compliant buildings are 20% efficient than conventional buildings and ECBC+ and Super ECBC buildings are 30-35% and 40-45% efficient than conventional buildings (see Annex F for more details)

[13] The *National Action Plan for Climate Change* (NAPCC) is a Government of India's programme launched in 2008 to mitigate and adapt to the adverse impact of climate change. The action plan was launched in 2008 with eight 'National Missions', including a National Mission on Enhanced Energy Efficiency and a National Mission on Sustainable Habitat. The EE Mission mentions that India has the potential to unlock market worth USD 10 billion, avoid capacity addition of 19 GW, fuel savings of 23 million tons and GHG emissions reductions of 98.55 million tons per year

[14] The HPMP project is in principle not an energy efficiency project but is listed here for its relation to energy efficiency due to the EE co-benefit of technology conversion of the appliances manufacturing industries

BEE – Star rating	BEE introduced the "Star rating" to supplement ECBC as a voluntary measure for measurement of the energy performance of buildings that are given labels based on their actual energy performance index (EPI, in kWh/m2/year)[15]. One-to-five stars rating is awarded based on the building's specific energy use with five stars as the most efficient. The rating applies to buildings with a connected load of 100 kW or greater, or contract demand of 120 kVA or greater.,.	BEE introduced a voluntary "Star" labelling programme for existing commercial buildings in 2009 and applies to offices, hospitals, shopping malls and business outsourcing offices (BPOs) and will be extended to hotels and data centres. By 2018-19, 261 existing commercial buildings across India had adopted BEE Star ratings
Residential buildings		
Eco-Niwas Samhita (ENS) (ECBC-R) [16]	ENS (Part 1) has been developed specifically for new residential buildings, to set minimum building envelope performance standards as well as for ensuring. It sets minimum building envelope performance standards to limit heat gains (for cooling dominated climates) and to limit heat loss (for heating-dominated climate zones) as well as for ensuring adequate natural ventilation and day-lighting. The code applies to all residential use building projects built on plot area ⩾ 500 m2 adequate natural ventilation and day lighting.	Eco-Niwas Samhita (ENS-Part I), launched in 2018, is the ECBC for residential buildings. Part 1 (Building Envelope) has been developed and Part 2 (Electro-Mechanical Systems) is under development. The code is being developed with special consideration for its adoption by the Urban Local Bodies (ULBs) into building by-laws, but ENS is yet to be implemented at the state level.
Appliances and equipment		
Standards and labelling of appliances	The BEE initiated the Standards and Labeling program for equipment and appliances in 2006 to provide the consumer with an informed choice about the energy savings and thereby the cost-saving potential of the relevant marketed product.	A total of 28 (10 mandatory and 18 voluntary) appliances or equipment are covered under S&L including chillers, room air conditioners, light commercial air conditioners, ceiling fans and other thermal comfort technologies. Energy savings in FY 18-19 for appliances sold during FY 2015-19 were 55.7 million kWh[17].

India Cooling Action Plan (ICAP)

The India Cooling Action Plan (ICAP) provides a 20-year perspective (from 2017/18 to 2037/38) and recommendations, to address the cooling requirements across sectors and ways and means to provide access to sustainable cooling. The government of India has developed ICAP as a transitional driver toward sustainable cooling solutions. This emphasizes a reduction in cooling energy demand by 25-40% and refrigerant demand by 25-30% cent by 2037-2038 from the baseline value in 2017-2018. The Plan provides a baseline projection (reference scenario) and an intervention scenario for cooling across the various demand sectors. The Intervention scenario projects that around 30% reduction in cooling energy can be achieved through improvements in cooling equipment efficiency, and better servicing and operation and maintenance (O&M) practices. Further significant energy savings could be accrued over and above the projected 30 % reduction by optimizing, and in effect, reducing the cooling load of built spaces. ICAP mentions a reduction potential of around 20% in cooling load could be achieved by 2037-38, through passively cooled building designs with climate-appropriate building

[15] Within this scheme, a standardized format for data collection of the actual energy consumption of the building exists to collect information on built-up area, type of building, conditioned and non-conditioned areas, hours of operation of building in a day, climatic zone, and other information related to facility

[16] Based on the code, "Energy Efficiency Label for Residential Buildings" was launched in 2019 with to make a transparent instrument over the energy performance of a home which will gradually lead to an effective model influencing decisions regarding home prices in future. It aims to provide a benchmark to compare one house over the other based on energy efficiency standards to create a consumer-driven market transformation solution for energy efficiency in the housing sector.

[17] *Third Biennial Update Report to UNFCCC* (2018), Ministry of Environment, Forest and Climate Change

Mandatory	1. Room air conditioners (RAC), 2. Frost-free refrigerators, 3. Tubular fluorescent lamp (TL), 4. Distribution transformer, 5. Colour TV, 6. Electric geysers, 7. Variable-capacity air conditioner, 8. LED lamp 9. IACs 10. Direct cool refrigerators
Voluntary	1. Induction motors, 2. Pump sets and diesel pumps, 3. Ceiling fans, 4. LPG stoves, 5. Washing machines, 6. Notebooks/laptops, 7. Office equipment (printer/copier/scanner), 8. Magnetic/electronic ballasts, 9. Solid-state inverter, 10. DG sets, 11. Chillers, 12. Microwave ovens, 13. Solar water heaters, 14. Deep freezers 15. Diesel Engine Driven Monoset Pumps for Agricultural Purposes 16. UHD Televisions 17. Air Compressors 18. Light commercial air conditioners

envelopes (driven by higher adoption of ECBC in new commercial buildings) and through the adoption of adaptive thermal comfort practices (pre-setting of lower set point temperature in air conditioning equipment).

1.3 Policy barriers and options

The transition to an economy with increased access to thermal comfort as with the use of high-efficiency, low-carbon cooling technologies, is faced by substantial challenges and barriers that are briefly described below.

Policy-regulatory barriers and gaps

(a) Fragmentation of mandates and lack of integrated and coordinated framework on building energy efficiency regulation and cooling action plan and (b) No mechanism in place to verify thermal comfort and energy efficiency in operated buildings. (c) Varying levels of building energy code implementation at national levels.

- *Suboptimal coordination on building energy efficiency policy actions*

Buildings' approvals cut across different mandates of different institutions and at national/subnational or local levels. Mandates are different for MoUHD and BEE at the national level, and SDA and ULBs at the sub-national level, thereby leading to ineffective coordinated efforts towards building energy efficiency.

Currently, there is a gap between emerging needs under the approved policies and programmes (NBC, ECBC, ICAP, Energy Star Labelling of buildings). The implementation on the ground is very slow and piecemeal; For example, policies transposition (notification) and implementation at state and municipal levels are slow and delayed.

ECBC (commercial buildings) has been notified in 18 States/UTs since 2007, but implementation at the municipal level is limited. Also, there is no mandate on implementation of 'Star Labelling' for new/existing buildings due to which the operational level energy efficiency of buildings remains unchecked and unreported. The 'Eco-Niwas Samhita' or ECBC-R for residential buildings is still in the early stages of its implementation and appropriate regulations to ensure its effective implementation in states are yet to be undertaken. This is putting at risk the achievement of policy targets at the national level. Code enforcement is the responsibility of local governments, where institutional capacity and resources are limited. The States and the Municipalities do not have sector-wide coordinated mandates or guidelines for developing and implementing building energy-efficiency programmes in an integrated manner. The building design approval process is under the purview of ULBs (urban local bodies) and it is at the ULB level where harmonized efforts to implement building energy efficiency actions rest. The State Designated Agencies (SDAs) are strategic partners for the promotion of energy efficiency in the State, they have limited resources and lacks overall convergence and coordination at many levels.

The National Building Code of 2016 is an advisory document for the states and not a statutory one. The states of Telangana, West Bengal and Uttar Pradesh are yet to adopt the latest NBC 2016 code guidelines as part of their building bye-laws. Green Building Ratings are voluntary across all states in India. There is no mandate in states for the developers on meeting the requirements of green building ratings. The cost and process of going through the procedures of application is a barrier for developers. Few incentives are available for certified green buildings in the states. The Government of India offers fast track environmental clearance for green building projects which are Pre-certified/ Provisionally Certified under the LEED, IGBC certification and GRIHA certification. There is no such mandate at the central level yet to introduce an energy code for residential buildings. The relevant amendments to Energy Conservation Act shall be required for the roll-out of R-ECBC in states.

- *Non-harmonized policy actions hamper the creation of enabling environment for increasing uptake of low carbon cooling solutions for enhanced thermal comfort.*

ICAP was launched in 2019 by MoEF&CC. However, there has been no clarity on the implementation of recommendations outlined in ICAP in terms of state-level implementation and agencies involved in implementation. Building level space cooling recommendations of ICAP are interlinked closely with building energy efficiency and hence they require coordinated efforts along with ECBC (commercial and residential) and 'Star Labelling' implementation in states. The ECBC provides minimum requirements for the energy-efficient design and construction and air conditioners in commercial buildings. The Star labelling programme for buildings does not rate the buildings based on actual energy efficiency levels attained to achieve thermal comfort conditions in buildings. The existing draft data reporting structures established by BEE (such as EMIS, BEP for Star Labelling of Buildings) requires strengthening and lack reporting framework for data reporting on thermal comfort aspects in operational buildings. While ICAP has put forward thermal comfort principles and access to cooling for all across India, recommendations made as part of the recently launched ICAP have not been yet integrated with the existing building energy efficiency codes. Hence, a government-harmonized code/standard for different climate zones along with the necessary data reporting framework will be required in India to facilitate energy efficiency and thermal comfort in a climate-friendly manner for both existing and new buildings (residential and commercial).

It is important to note that although the Montreal Protocol, through its Multilateral Fund (MLF), do support countries to achieve their compliance goals in eliminating the use of the controlled substances at its production (of the substance) and consumption (manufacturing of HVAC-R equipment), until now, it has not supported countries to apply energy efficiency Policies, nor the Montreal Protocol is mandated to establish structures related to EE standards, labelling programmes or removal of barriers/incentives to increase/improve the deployment and/or market penetration of super-efficient cooling equipment (see Box 5)

Policy options

Various programmes address energy efficiency in buildings, such as NBC, ECBC, ICAP, Energy Star Labelling of buildings. The India Cooling Action Plan (ICAP) is among the first documents that address the demand for cooling using a holistic lens of energy efficiency both through technology development (such as low-GWP refrigerant-based technologies) and the adoption of buildings codes. BEE is already taking efforts for ECBC adoption in states for commercial and residential buildings. The BEE 'five-star' rating is applicable to office spaces, hospitals, business process outsourcing (BPO) buildings, and shopping malls and soon will be extended to data centres and hotels. The Building Energy Passport (BEP) has been developed by BEE to be used for compliance checking during building design, construction and operation stages. However, the development of BEP ended in 2018 and the BEP tool has remained non-functional with modules inactive for ECBC compliance specific to states.

There is need for *Energy conservation building codes (ECBC) harmonized with India Cooling Action Plan (ICAP), National Building Code (NBC), Model Building By-laws at pan-India and State level.* The implementation of harmonized guidelines should cater to objectives of ECBC, Eco Niwas Samhita (part 1)[18], Star labelling of buildings, NBC, and ICAP recommendations for different climate zones in India with the intent of integrated policy actions of ECBC and ICAP. The harmonized guidelines will thus tackle energy efficiency and cooling demand, cooling technologies and people's thermal comfort simultaneously in new and existing buildings. This will include considerations for new technologies (not-in-kind and passive space cooling technologies) and consideration of other feasible strategies recommended by ICAP for integration with future revisions of ECBC code (ECBC-Residential and ECBC) and Star labelling aimed at achieving thermal comfort.

These guidelines should also detail out the institutional framework along with a roadmap to achieve the policy objectives through a consultative process for joint action from BEE and MoEF&CC to calibrate activities of India Cooling Action Plan, ECBC and 'Star Labelling' for improved energy performance of AC equipment and to track energy performance and thermal comfort. The policy directions shall strengthen the institutional arrangements in terms of inter-ministerial coordination and collaboration with common mandates of implementing agencies at the national and sub-national levels towards achieving sustainable thermal comfort in new buildings. Municipalities and states need to be provided with modules and guidelines for developing and implementing the harmonised building energy-efficiency programs and policies in an integrated and coordinated manner with guidelines on institutional responsibilities aimed at setting seamless coordination to achieve the objectives.

[18] The Project will build on the framework developed under the Indo-German Energy Programme (including thermal comfort database) for residential buildings during implementation

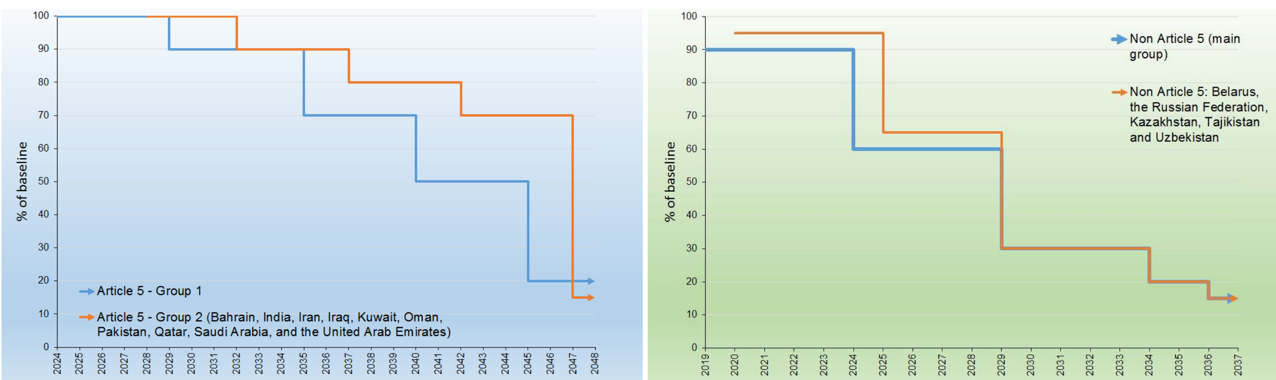
Box 5 Kigali Agreement

Many industrial products, including heat pumps that operate on a refrigerant and propellant aerosol, require non-flammable fluids capable of passing easily from gaseous state to liquid state and having significant latent heat. Historically, chlorofluorocarbons (CFCs) were used in these applications. In the 1970s the deleterious effect of these gases on the ozone layer was discovered, resulting in the Montreal Protocol (signed in 1987 and entered into force in 1989, decided to phase out CFCs. For each group of ODSs, the treaty provides a timetable on which the production of those substances must be shot out and eventually eliminated. This included a 10-year phase-in for developing countries identified in Article 5 of the treaty. The Protocol has successfully met its objectives Thanks to the collaborative effort of nations around the world, the ozone layer is well on its way to recovery.

The use of hydrofluorocarbons (HFCs) then developed as a replacement for a batch of ozone-depleting substances (ODS). While HFCs save the ozone layer, they are powerful greenhouse gases. Their lifespan in the atmosphere is quite short, but they filter infrared very strongly. HFCs are greenhouse gases which can have high or very high global warming potentials (GWPs), ranging from about 121 to 14,800 (as compared to GWP=1 for CO_2). For example, HFC-23 has a global warming potential (GWP) at 100 years of a 12400 Thus, eliminating emissions of these gases could therefore significantly limit global warming.

The Kigali Amendment to the Montreal Protocol is an international agreement (signed in 2016 and came into force in 2019) to gradually reduce the consumption and production of hydrofluorocarbons (HFCs). The Kigali Accord, on the other hand, divides states into 4 groups that have different phase-down schedules

1. Article 5 Parties "Group 1" (the main group of Article 5 Parties of the Protocol)
2. Article 5 Parties "Group 2" (5: Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates.
3. Non Article 5 Parties (main group)
4. Non Article 5 (Belarus, Russian Federation, Kazakhstan, Tajikistan)



Source: https://en.wikipedia.org/wiki/Kigali_Amendment; UNEP *Kigali Amendment – Factsheet*

India has already implemented and successfully achieved the targets under HCFC Phase-out management plan (HPMP) Stage I which implemented for a period of four years from 2012 to 2015 to achieve 10% phase-out targets of HCFCs by 2015. Stage I focused on the phase out of HCFC 141-b from foam manufacturing sector and initiated activities in RAC sector. Stage-I has successfully phased-out a total of 341.77 ODP tons of HCFCs including 310.53 OPD tons of HCFC 141b in foam manufacturing and 31.24 ODP tons of HCFC-22 in RAC servicing sector. Successful implementation of HPMP Stage II will result in 8190 MT or 769.49 ODP tons of HCFC consumption in 2023. In addition, it will also result in reduction of about 8,530,900 MT of CO2eq in direct GHG emissions from 2023 onwards.

As the proposed project delineates the focuses between the GEF and Montreal Protocol, the reduced warming impact resulting from replacement of the conventional, high GWP refrigerant technologies with alternative cooling technologies with low or zero-ODP and low-GWP refrigerants is *treated as part of the baseline and are not included in the GEF core indicator total for the emission reduction of the Project.*

2. ENERGY-EFFICIENT COOLING AND THERMAL COMFORT IN BUILDINGS

2.1 Overview of cooling and thermal comfort solutions

Thermal comfort can be defined as the expression of an individual's satisfaction with the thermal environment, and it affects humans psychologically. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) along with the University of California (Berkeley Center for the Built Environment) have indicated the following variables that predict a person's thermal comfort: air temperature, surface temperature, humidity, clothing level, activity level and air velocity.[19]
Thermal comfort can be achieved by three types of measures:

1. Construction of energy-efficient buildings incorporating passive design strategies to minimize heat gains/losses via the envelope and reduce cooling demand.
2. Adoption of adaptive thermal comfort standards[20] to specify pre-setting of temperatures of cooling equipment for built spaces
3. Incorporation of efficient cooling technologies (refrigerant-based, non-refrigerant based, not-in-kind technologies).

The project has a technology neutral approach and will therefore consider all three approaches during project implementation whereby a strong focus on passive building design will be applied in new building pilots and specific attention will be dedicated to innovative approaches that have not yet been widely applied, e.g. the not in-kind technologies such as trigeneration and district cooling based on non-vapor-compression systems.

1. Construction of energy-efficient buildings incorporating passive design strategies

Passive building design uses natural resources (e.g., sun, wind, microclimate or water) to provide thermal and visual comfort inside the building. Increasing the ability of the building envelope to provide thermal comfort can reduce or eliminate the requirement for active thermal comfort systems. These strategies can very well be analysed through building energy modelling and simulation for a given building configuration. Mechanical or 'active' comfort HVAC systems are responsible for more than 40% of a building's total energy consumption.[21] Passive building design offers significant potential to reduce peak cooling and heating load by up to 50%[22] of HVAC systems.

2. Adoption of adaptive thermal comfort standards

The National Building Code of India (2005) defines thermal comfort at temperature ranges of 23°C to 26°C (during summers), and 21°C to 23°C (for winters). This standard is derived from an international standard, created for an average group of people and typically for artificially ventilated spaces, thereby making it largely unsuitable for India. In fact, in the absence of an India-specific thermal comfort standard, most office spaces tend to operate at 22.5ºC (± 1°C) being well below the comfort range specified even by the National Building Codes. Worse, many consumers, go for the lowest temperature settings in AC, which is both unhealthy and consume much more electricity than running it at an optimum level. The Indian

[19] Re-defining and Delivering Thermal Comfort in Buildings May 2016

[20] The National Building Code 2016 (Volume 2) of India defines thermal comfort conditions for 3 types of buildings – 1) Naturally ventilated buildings based on indoor operative temperature, 2) Mixed-mode buildings (MM) based on indoor operative temperature and 3) Air-conditioned buildings based on Standard Effective temperature and Indoor Operative Air Temperature.

[21] https://www.coolingindia.in/energy-saving-in-the-hvac industry/#:~:text=HVAC%20systems%20comprise%2040%20percent,through%20system%20upgrades%20and%20optimisation

[22] https://journals.sagepub.com/doi/abs/10.1177/1744259117742989

Model for Adaptive Thermal Comfort (IMAC, 2014[23]) has been developed to recommend indoor temperature ranges to the ECBC for three types of commercial buildings cooling systems, namely: (a) air-conditioned; (b) naturally ventilate; and (c) mixed-mode buildings (both air-conditioned and naturally ventilated). The IMAC study predicts that 90% of the occupants will find the indoor environment acceptable within ±2°C of the neutral, that is between 22-27°C indoor. According to BEE, increasing the room temperature has an energy-saving impact of about 3-5% per centigrade. The Central Government in consultation with the Bureau of Energy Efficiency (BEE) has notified new energy performance standards for room air conditioners on 30 October 2019 that 24 °C default setting has been made mandatory starting January 2020 for all room air conditioners covered under the ambit of the BEE star-labelling programme.

3. Incorporation of efficient cooling technologies (refrigerant-based, non-refrigerant based, not-in-kind technologies)

In India, the refrigerant (coolant) HCFC-22, which have high Ozon Depletion Potential (ODP) and Global Warming Potential (GWP) values, is widely used. Also commonly used is HFC-410A which has zero ODP but a GWP even higher than HCFC-22. Fortunately, better refrigerant options (that are both more climate-friendly and market-proven) are available having significantly lower GWP that already has been effective in the AC market. One example is the HC-290 (Propane, a "natural" refrigerant), which has ultra-low GWP (although highly flammable, and which is being sold on the market following international safety standards)[24].

Low carbon cooling technologies have been present in the Indian market for at least a decade, offering significant energy and emissions savings, are scalable, attract adopters from multiple sectors and could significantly replace conventional cooling technologies. Such technologies are referenced in the India Cooling Action Plan (ICAP) and include vapour-compression based technologies (such as room air/conditioners, chiller systems, packaged direct expansion and variable refrigerant flow systems), non-refrigerant technologies (such as fans or air coolers) and include not in-kind cooling technologies (such as radiant and structure cooling, heat pumps, evaporative cooling and vapour absorption cooling). These are in various stages of market development. Alternate cooling strategies include a) the use of thermal energy storage; b) personalized cooling/conditioning systems; c) trigeneration (combined cooling, heating and power (CCHP) offers an optimal solution for air conditioning and/or refrigeration), and d) district cooling. These alternate technologies are only beginning to penetrate the space cooling segment.

2.2 Technologies for energy-efficient cooling

Space cooling technologies

Space cooling is an important segment of the cooling demand in the country. There are multiple technologies and a range of options available for addressing the space cooling demand. The space cooling technologies for providing thermal cooling in buildings fall within three broad categories: refrigerant-based, non-refrigerant-based, and not-in-kind technologies.

Among the **refrigerant-based systems**, *room air conditioner* (RAC) is the dominant technology representing about 80% of the installed capacity and the share will increase to around 87% in 2037-38. RACs come in various types, including mini- or single split (fixed-speed and inverter types) and window/through-the-wall (fixed speed type) configurations. RACs find predominant application in the residential sector. Current penetration in India is fairly low, at around 7-9%. But in future this will increase due to rapid urbanization, a construction boom, a growing middle class, decreasing room air conditioner prices, and rising average ambient temperatures (due to climate change). Air conditioning systems utilised in the commercial buildings, excluding room air conditioners, can be classified into three major types – chiller system, packaged direct expansion (DX), and variable refrigerant flow (VRF) system. *Chillers* (either air or water-cooled) are the preferred choice for large commercial buildings like hotels, hospitals, malls, office complexes and airports.

23 An Introduction to the India Model for Adaptive (Thermal) Comfort IMAC 2014, by Centre for Advanced Research in Building Science and Energy, CEPT University

24 R22: GWP 1700; R410: GWP 1725; R32: GWP 650 and R290: GWP 3.

Box 6 Current Star levels for cooling equipment

Star Rating Levels Valid Till 2022	
Fans with Sweep Size < 1200 mm	
Star Rating Service value	Service Value (m3/min/W)
1 Star	≥ 3.1 to < 3.6
2 Star	≥ 3.6 to < 4.1
3 Star	≥ 4.1 to < 4.6
4 Star	≥ 4.6 to < 5.1
5 Star	≥ 5.1
Fans with Sweep Size > 1200 mm	
Star Rating Service value	Service Value (m3/min/W)
1 Star	≥ 4.0 to < 4.5
2 Star	≥ 4.5 to < 5.0
3 Star	≥ 5.0 to < 5.5
4 Star	≥ 5.5 to < 6.0
5 Star	≥ 6.0

Star Rating Levels till December 2021					
Star Rating for Water Cooled Chillers					
kW of cooling	ISEER				
	1 Star	2 Star	3 Star	4 Star	5 Star
<260	4.8	5.2	5.6	6.1	6.6
>=260 & <530	5	5.6	6.2	6.8	7.4
>= 530 & < 1050	5.5	6.1	6.7	7.4	8.2
>= 1050 & <1580	5.8	6.5	7.2	7.9	8.7
>=1580	6	6.7	7.4	8.2	9
Star Rating for Air Cooled Chillers					
kW of cooling	ISEER				
	1 Star	2 Star	3 Star	4 Star	5 Star
<=260	3	3.3	3.6	4	4.4
>260	3.1	3.5	3.9	4.3	4.7

Valid Till December 2021 - Scheduled for an update after every 2 yrs.		
Indian Seasonal Energy Efficiency Ratio (kWh/kWh) for LCAC with cooling capacity >10.5 kW and <= 18 kW		
Star Rating Minimum Maximum	Min.	Max.
1 Star	2.7	3.09
2 Star	3.1	3.39
3 Star	3.4	3.69
4 Star	3.7	3.99
5 Star	>=4.00	

Valid Till December 2023 - Scheduled for an update after every 3 yrs.		
Indian Seasonal Energy Efficiency Ratio(kWh/kWh) for Unitary ACs		
Star Rating Minimum Maximum	Min.	Max.
1 Star	2.7	2.89
2 Star	2.9	3.09
3 Star	3.1	3.29
4 Star	3.3	3.49
5 Star	3.5	
Indian Seasonal Energy Efficiency Ratio(kWh/kWh) for Split AC		
Star Rating Minimum Maximum	Min.	Max.
1 Star	3.3	3.49
2 Star	3.5	3.79
3 Star	3.8	4.39
4 Star	4.4	4.99
5 Star	5	

Other than the chiller itself, which is the largest energy-guzzling component, the system comprises various auxiliaries including chilled water pumps, condenser water pumps, cooling tower fans, air handling units, and fan coil units. *VRF systems* are typically used in medium-sized commercial buildings and high-income group residential units. *Packages DX* covers ducted and packaged systems including rooftop and indoor packaged units in the commercial air conditioning segment.

Efficiency improvement options are a) more closely matching demand and power supply in RAC by applying multi-stage and variable speed drives/controls; b) advanced compressor technology; c) advanced heat exchanger designs, d) use of electronic expansion valves (EEV), instead of thermostatic valves, can match more closely the needs of variable-capacity A/C systems; e) use of high-efficiency fans, f) use of high-efficiency motors; g) advanced control systems and occupancy sensors. Some key developments in India with respect to refrigerant-based technologies in the last 3-4 years include:

- HFO-based chillers. The large chiller segment (screw and centrifugal types) has predominantly been R134a-based (see Box 9). Although HFCs such as R134a have provided a safe cooling option (compared to their HCFC predecessors) due to an ODP of zero, their GWP is quite high. HFOs have negligible GWP (0-1) and are an excellent substitute for the widely used R134a (GWP of 1,300). The system efficiency of HFO-based chillers is about 10-15% higher than HFC-based chillers, but their initial cost is also higher. Major chiller manufacturers in India have started promoting HFO-based chillers within the last two years and their market penetration within India is set to increase steadily if and when their initial cost becomes comparable with their HFC-based counterparts.
- HC-based RACs. The RAC market has transitioned from high-GWP, medium-ODP HCFC-based refrigerants such as R-22 to zero-ODP, medium-GWP HFCs such as R-32. The emerging refrigerants in this market are HC-based (such as R290a) and have an ODP of zero and very low GWP. These units are commercially available, despite some concerns over safety due to higher flammability than HFCs. However, from an emissions perspective, these are the best available option.

The **non-refrigerant** based cooling technologies like fans and air coolers are significantly pervasive in the residential sector, as well as in the small to medium commercial buildings, and commercial applications such as warehouses. Even among homes that utilize room air conditioning for thermal comfort, approximately 70% tend to use fans simultaneously. Air coolers are used in households and medium-sized commercial buildings in hot and dry and composite climates. Even with the growing penetration of room ACs, fans and coolers will maintain a substantial share in 2037-38 consuming nearly as much energy as the all-commercial AC systems combined (chillers, DX, VRF). Technology improvements include the use of high-efficiency fans and higher-quality cooling pads in air coolers.

The **not-in-kind technologies** have been applied at sizeable scales in commercial buildings in India and include 1) indirect-direct evaporative cooling systems (IDEC), 2) structure cooling systems; 3) radiant cooling systems, 4) vapour absorption cooling systems, and 5) ground surface heat pumps (GSHS). The not-in-kind options can be integrated with the conventional systems (to form 'hybrid systems') in order to achieve the benefits of both technologies. A recent study provides a comprehensive mapping of such technologies to assess their techno-economic feasibility in the Indian context, of which the results are summarized in Box 27.

Optimizing energy demand and use of passive building strategies

Using local climate conditions and 'passive' design features to provide comfort to the occupants and reduce the demand and utilization of HVAC systems. Key elements of passive design are building massing and orientation, window-wall ratio, airtightness and insulation, solar shading and natural ventilation.

1. *Mass and orientation*: Building mass and orientation play important roles in minimizing solar heat gains and reducing cooling demand. For a cooling-dominated region such as India, building designers can reduce conduction and radiation heat gains by minimizing surface-to-volume ratio and perimeter-to-area ratio; this can reduce solar heat gains by 20-40%. It is advisable to orient buildings with their longer axis parallel to, or within 0-30° of, a south-to-north axis; this can reduce cooling energy consumption by 15-25%.[a]
2. *Window-wall ratio*: The window to wall ratio (WWR) is the ratio of total window area to total wall area. A high WWR increases the amount of internal daylight and external views, at the risk of increased glare and cooling requirements. A low WWR provides savings on cooling energy use but reduces available daylight. Previous research has suggested an

optimum WWR of 20-40% across all orientations (US DOE 2014).[b] Energy savings of 15-20% are achievable through WWR optimization.[c]

3. *Airtightness:* A building's airtightness relates to heat transfer through the building envelope and is an important aspect of passive design. Unwanted and uncontrolled heat transfer reduces envelope efficiency and puts additional load on HVAC systems. Identification of thermal bridges and their treatment at the design stage helps reduce infiltration, as do continuous air barriers. For mechanically ventilated buildings, it is recommended to maintain an airtightness of less than $3m^3/h.m^2$. Proper airtightness can reduce HVAC energy consumption by 10%.[d]

Box 7 Overview of not-in-kind cooling technologies for buildings

Parameters	Radiant cooling	Structure cooling	GSHPs	Evaporative cooling (2-stage or higher)	Vapour absorption cooling
Description of the technology	Radiant cooling is a hydronic system that circulates chilled water through PEX pipes embedded in the floor or ceiling, or through copper pipes embedded in ceiling panels.	Structure cooling is an innovative low-energy variant based on the principles of radiant cooling. In this system, water cooled by a two-stage cooling tower to 20-26^{0}C is passed through pipes embedded in the concrete core.	The sub-ground conditions remain at stable temperatures year-round. The GSHPs this stable thermal environment as a heat source in the heating season and a heat sink in the cooling season.	Evaporative cooling is based on the principle that water evaporates by absorbing heat from the surroundings. An evaporative cooler draws in outdoor air and passes it through a cooling medium (e.g. soaked pads or a polymer surface).	Vapour absorption cooling is an alternative to vapour compression cycles. While the latter is electrically driven, VAMs use heat as an energy source to generate chilled water.
Feasible range of cooling	100-1,000TR	100-1,000TR	5-1,000TR	5-1,000TR	250-1,000TR
Capital investment per TR	₹120,000-150,000	₹40,000-50,000	For horizontal: ₹35,000-50,000 For vertical: ₹100,000-150,000	DEC: ₹5,000-10,000 Multi-stage: ₹25,000-40,000	₹250,000-400,000
Potential energy savings over conventional air conditioning	30-50%	>50%	35-40%	50-80%	40-60%
Product life	>30 years	>30 years	>30 years	15-30 years	15-30 years
Commercial availability & total installed capacity in India	Available, 18,000TR	Available, 4,600TR	Available, ~15,000TR	Available, 100,000TR	Available, 700,000TR
Controllability of thermal comfort (degree of control offered over thermal comfort conditions)	Offers good control over required temperature and RH	Requires shift in thermal and RH setpoints towards higher range	Offers good control over required temperature and RH	Requires shift in thermal and RH setpoints towards higher range	Offers good control over required temperature and RH
Suitability to different climatic conditions	Supplemental system needed year-round	Supplemental system needed year-round	Suitable across all conditions	Supplemental system needed for certain times of year	Suitable across all conditions
Dependence on refrigerants	At least 30-40% dependent on refrigerant	100% refrigerant-free	At least 30-40% dependent on refrigerant	100% refrigerant-free	100% refrigerant-free

Source: *Low Carbon Cooling Solutions for buildings in India* (by PwC), WWF-India (2020). https://wwfin.awsassets.panda.org/downloads/wwf_india_report_on_low_carbon_cooling_solutions_for_buildings_in_india_final_web_

4. *Insulation:* Thermal insulation reduces heat transfer through building elements, thus reducing heating and cooling requirements and enhancing thermal comfort. While all building materials offer some resistance to heat transfer, the conductivity of insulation materials ranges from 0.025-0.04 W/m.K, far lower than brick (1.3 W/m.K). Apart from reducing heat transfer, continuous insulation also helps increase envelope airtightness. A well-sealed and insulated building envelope can reduce heating and cooling energy requirements by 15% (on average across different climates) and 11% for overall energy use.[e]
5. *Glazing:* about 25% of heat transfer in a building occurs through windows via conduction and radiation. Thus, it is advisable to select glass material with lower thermal conductivity and SHGC. Double glazing also allows an increase in WWR to 40-60% over 30-40% for single glazing.[f] However, there are specialized glazing variants available that make use of smart technology and can tint electronicall, thus allowing building occupants to choose the best level of natural light for their comfort, year-round.
6. *Cool roofs:* Cool roofs use highly reflective paints, sheet coverings or highly reflective tiles to reflect up to 80 per cent of incident solar radiation, yielding a reduction of three to five degrees Celsius in air temperature for top floors. Cool roofs are also beneficial in reducing urban heat islands and improving microclimatic conditions [g].
7. *Shading:* Solar shading is an integral part of the passive design strategy. It cuts direct solar radiation, reducing the cooling load and improving thermal comfort. Solar shading can be designed in the form of overhangs, fins or a combination of both. Shading design in the form of light shelves also improves the internal distribution of daylight. Shading can reduce cooling requirements by 10-20%, with a maximum benefit in hot and dry climates. [h]
8. *Natural ventilation:* Natural ventilation uses outdoor air to provide thermal comfort during various seasons, depending on the climatic zone; methods include single-sided and cross ventilation, stack ventilation, night purge cooling and a combination of these strategies. Depending on the building type and climatic zone, natural ventilation can reduce cooling requirements by 10-30%.[i]

Notes:

[a] Alghamy and Azmi, *Buildings' orientation and its impact on the electricity consumption*, 2017

[b] https://www.ashrae.org/technical-resources/aedgs; Didwania et. al., *Optimization of window-wall ratio for different building types,* (2011)

[c] Chiesa et. al., *Parametric Optimization of Window-to-Wall Ratio for Passive Buildings Adopting a Scripting Methodology to Dynamic-Energy Simulation* (2019)

[d] https://www.planningportal.co.uk/info/200135/approved_documents/74/part_l_-_conservation_of_fuel_and_power/3; Klaus and Kubeckova, *Airtightness of Energy Efficient Buildings* (2013)

[e] https://beeindia.gov.in/sites/default/files/BEE_ECBC%202017.pdf; https://www.energystar.gov/campaign/seal_insulate/methodology

[f] Didwania et. al., *Optimization of window-wall ratio for different building types*, 2011. As an example, the smart glass offered by Saint Gobain, link: https://www.saint-gobain.com/en/sageglass-r

[g] https://shaktifoundation.in/wp-content/uploads/2017/06/cool-roofs-manual.pdf

[h] Farrar-Nagy et. al., *Impacts of Shading and Glazing Combinations on Residential Energy Use in a Hot Dry Climate*, 2000
Samanta et. al., Evaluation of Impact of Shading Devices on Energy Consumption of Buildings in Tropical Regions, 2014

[I] https://www.wbdg.org/resources/natural-ventilation; Gonzalez-Lezcano and Hormigos-Jimenez, Energy saving due to natural ventilation in housing blocks in Madrid, 2016

District cooling systems (DCS)

Centralizing the provision of cooling results in energy savings of over 40% and 20% compared to air-cooled and water-cooled systems, respectively. DCS could reduce cooling energy consumption by 30-70%, peak power demand and GHG emissions by 30-35%, lifecycle refrigerant savings in the range of 10-15%. Centralizing cooling reduces strain at utility by providing local generation, resilience, and balancing; high reliability of cooling; greater resilience to power and fossil fuel price volatility; ability to use large scale renewable cooling (e.g., solar thermal, free cooling, geothermal, geo-exchange).

Benefits of DCS include:

1. *Sustainable comfort:* Comfort is the ultimate purpose of air conditioning. DCSs can keep people more comfortable because industrial-grade equipment is used to provide a consistent and high-quality source of cooling. In addition, expert operating teams can be focused on optimal operation and maintenance of cooling systems, thus increasing the reliability significantly. Buildings are quieter because there is no heavy equipment generating vibration and noise. Local urban heat island effects can be reduced significantly by centrally producing chilled water, using renewables that reduce dumping of heat in the local atmosphere (e.g., free cooling with water bodies), and producing more chilled water at night with thermal storage.
2. *Increased energy efficiency:* District cooling benefits from load diversity and flexibility in capacity design and installation. This means this system utilizes at least 15% less capacity for the same cooling load compared to a combined cooling system distributed at individual buildings. District cooling caters to diverse cooling demands such as offices, commercial establishments, hotels, residences, which peak at different times. DCS aggregate peak demand of these diverse loads in contrast to individual systems which are designed to meet individual peak demands. The flexibility of capacity installation means capacity can be added as load increases. This ensures that DCS are not disproportionately oversized.
3. *Energy savings:* Aggregated cooling demand can be as low as 25% than the sum of individual loads, which translates to reduced energy consumption in the range of 40-50%. Energy savings are also realized due to the use of efficient chilled water systems and heat rejection systems. Economies of scale can be achieved as larger systems are considerably more energy-efficient compared to individual building systems. Integration of thermal storage can reduce strain on utility systems in peak hours and smoothen out power requirements during the day.
4. *Improved building space utilization:* Centralizing cooling at the district level can reduce the plant room requirements at the individual building level. In general, 75% space reduction for plant room can be achieved. Reduced plant room can increase the total usable space which can be used to generate additional profit. This makes DCS effective for retail, business and industrial zones.
5. *Reduced building management expenditure:* Since DCS centralizes plant room management, individual buildings benefit by simplifying their building management plan. The requirement for periodic maintenance and replacement of cooling system elements is also eliminated, resulting in cost savings.
6. *Improved reliability:* DCS are generally designed with multiple loops to ensure the provision of regular and reliable cooling. Some systems also integrate backup systems to provide additional reliability in distribution. Additionally, trigeneration based-DCS could help avoid expenditure on fossil fuel, generate local tax revenue, generate jobs, and defer investment in power generation expenditure.

Digital interventions to complement low-carbon cooling

Technology is increasingly creating value for its customers and information-based applications have the potential to add value for customers. Specifically, the Internet of Things (IoT) is already having a significant impact on the buildings' sector with a focus on cost reduction and other aspects beyond them. IoT and other digitalization of buildings measures have the potential to substantially increase efficiency in building operations, provide vital statistics to enhance tenant relationships and foresee new revenue generation opportunities. Such innovation via digitalization provides immense value to a building and a few of them are listed below for reference:

1. Enhanced building performance
2. Better asset management via portfolio analytics
3. Focus on employee health and productivity
4. Enable buildings to be future-ready (e.g., grid-interactive buildings)

2.3 ECBC and BEE Star Rating for commercial buildings

The Energy Conservation Building Code (ECBC) provides minimum requirements for the energy-efficient design and construction of buildings and applies to new building complexes that have a connected load of 100 kW or greater or a contract demand of 120 kVA or greater and are intended to be used for commercial purposes. ECBC requirements reflect cost-effectiveness and practical efficiency measures across five different climate zones in India (see map, Annex A). The code prescribes the following three levels of energy efficiency:

- Energy Conservation Building Code Compliant Building (ECBC Building)
- Energy Conservation Building Code Plus Building (ECBC+ Building)
- Super Energy Conservation Building Code Building (SuperECBC Building)

To comply with Code, buildings need to meet the following two requirements.
1) Comply with the mandatory requirements as per §4.2, §5.2, §6.2 and §7.2
2) Determine the Energy Performance Index Ratio (EPI ratio) as defined in §3.1.2.

EPI = (annual energy consumption [kWh] / (total built-up area, excluding unconditioned basements)

EPI ratio = (EPI of the proposed building) / (EPI of the standard building)

Lower EPI denotes a lower energy use and hence better performance. A "standard building" is a standardized building that has the same building floor area, gross wall area and gross roof area as the Proposed Building, complies with the mandatory requirements §4.2, §5.2, §6.2, and §7.2 of the ECBC, and minimally comply with prescriptive requirements of §4.3, §5.3, and §6.3 for ECBC Buildings. To comply with the Code, all buildings shall have an EPI ratio less than or equal to 1. ECBC+ Buildings and SuperECBC Buildings are required to have EPI Ratio equal to the EPI Ratios that vary between 0.66 and 0.91 depending on the applicable building type and climate zone. The building types mentioned are hotel, resort, hospital, outpatient, assembly, office (normal use), office (24 hours), school and university, open gallery mall, shopping mall, supermarket and strip retail. Climate zones are composite, hot & dry, temperate, warm & humid, cold (see Map).

The provisions of the ECBC apply to:

- Building envelope (§4.2, mandatory requirements: fenestration, opaque construction, daylighting, building envelope sealing, and in §4.3, prescriptive requirements: roof, external wall, vertical fenestration, skylights, building envelope);
- Mechanical systems and equipment (§5.2: ventilation, air conditioning, controls, system balancing, piping and ducts, service hot water heating, and §5.3: chillers, pumps, cooling towers, boilers, economizers, variable flow hydronic systems, air-conditioners, plus additional requirements for ECBC+ and SuperECBC buildings);
- Interior and exterior lighting (§6.2: lighting control and exit signs, and §6.3: prescriptive requirements for interior lighting power according to building area or space function, and installed interior and exterior lighting power with additional requirements on lighting controls for ECBC+ and SuperECBC buildings;
- Electrical and renewable energy systems (§5.2, mandatory: transformers, motors, diesel generators, metering and monitoring, power factor correction, power distribution, uninterruptible power supply, renewable energy systems)

The EPI can be determined in two ways. In the above-described '*prescriptive method*' the prescribed values for each of the elements need to be met. However, the design of the building may require more flexibility to be able to comply. For example, in the *building envelope trade-off method*, improvement in one component can compensate for the lack of it in another component within the building envelope group of requirements. Similarly, the air-conditioning systems also demand more flexibility in design, especially in the case of a chilled water plant in large buildings (*system efficiency method);* the ECBC offers flexibility to comply with efficiency at the overall plant level rather than comply with requirements of individual components.

The '*Whole Building Performance Method (WBP)*' offers complete flexibility in demonstrating compliance. In this approach, the individual elements are not assessed for compliance. Instead, the entire building as a system is assessed for its performance. The mandatory requirements (§4.2, §5.2, §6.2 and §7.2) must be met. But, even if the building may not comply with the specific provisions of the prescriptive requirements, the building is still compliant when the estimated annual energy use of the Proposed Design is less than that of the Standard Design.

The performance parameters as per ECBC 2017 for ECBC, ECBC+ and SuperECBC are indicated in the Box below for a) unitary, split, packaged air-conditioners, b) air/water-cooled chillers; and c) VRF.

Additionally, the Standards & Labelling (S&L) programme launched by BEE in 2007, defines star rating levels for ceiling fans, chillers, light commercial air-conditioners, and room air-conditioners (RAC). The 'Star Rating' levels defined by BEE for thermal comfort systems are periodically updated with an update after every 2 to 3 years (see Box 27). Currently, there is no standard term for super-efficient technology in thermal comfort systems. However, EESL specifies air-conditioners with ISEER 5.4 as super-efficient as they are estimated to be 8 to 10 % more efficient than a standard existing 5-star room air

conditioner as per the S&L programme in India. BEE has periodically revised the RAC efficiency norms resulting in an overall efficiency improvement of about 36%[25] compared to the baseline efficiency value in 2007. Given this, the star rating levels of air conditioning equipment are expected to be updated to drive the air conditioning market towards higher energy efficiency.

2.4 Barriers to efficient cooling and thermal comfort solutions

The transition to an economy with increased access to thermal comfort as with the use of high-efficiency, low-carbon cooling technologies, is faced by substantial challenges and barriers that are briefly described below.

Market development/ acceleration barriers

Slow penetration of EE technologies and low private sector investments due to lack of enabling environment, access to new technologies, pricing, supply chain, and of financing as well as limited business models at scale

- *Lack of local manufacturing and appropriate support system.*

The supply chain for technologies, applications and services are still at nascent stages. Many equipment and materials are imported with high-cost mark-ups and duties imposed. This leads to a situation of non-availability of energy-efficient equipment or raw materials in the local marketplace, while the uptake of inefficient (but less costly) cooling technologies continues. In India, for example, the compressor market is import-dominated. Specifically looking at room air-conditioners (RACs), the total RAC sales in India was about 6.7 million units in FY 2018-19 and around 6 million compressors were imported into India in the same year (at high costs given the duties imposed). There is a need to upscale national manufacturing of (energy-efficient) compressors in India.

- *High upfront cost.*

Consumer sensitivity to high upfront costs, risk averseness and lack of information can reinforce conventional buying behaviour and influence underinvestment in energy efficiency during the building design and construction process. Currently, the market adoption of low-carbon cooling technologies is low and can be attributed to high upfront costs. The development of innovative low-carbon energy-efficient cooling systems (including not-in-kind technologies, see Box 11**)** requires investment in new technologies and creating new manufacturing lines that need to be financed. There is a need to demonstrate business models/ financing mechanisms to increase uptake of super-efficient cooling technologies.

- *Limited demonstration*

Seeing is believing. There is a need to demonstrate pilots to increase uptake of low carbon cooling technologies which can be achieved through:

a) Pilots to demonstrate adoption of established innovative technologies to increase market uptake - There is a lack of pilots on technologies that are already established in the Indian market but face barriers to further market penetration. Having demonstration projects in place for such technologies will reduce the incremental cost of these technologies through demand aggregation;

[25] BEE Star labeled appliances

Box 8 ECBC electricity consumption guidelines for residential and commercial buildings

Minimum requirements for RAC/Packaged unit for ECBC		
Cooling Capacity (kW)	*Water Cooled*	*Air Cooled*
≤ 10.5	NA	BEE 3 Star
>10.5	3.3 EER	2.8 EER
Minimum requirements for RAC/Packaged unit for ECBC+		
Cooling Capacity (kW)	*Water Cooled*	*Air Cooled*
≤ 10.5	NA	BEE 4 Star
>10.5	3.7 EER	3.2 EER
Minimum requirements for RAC/Packaged unit for SuperECBC		
Cooling Capacity (kW)	*Water Cooled*	*Air Cooled*
≤ 10.5	NA	BEE 5 Star
>10.5	3.9 EER	3.4

Water Cooled Chillers						
Chiller Capacity	**ECBC**		**ECBC+**		**SuperECBC**	
(kW)	COP	IPLV	COP	IPLV	COP	IPLV
<260	4.7	5.8	5.2	6.9	5.8	7.1
≥260 & < 530	4.9	5.9	5.8	7.1	6	7.9
≥ 530 & < 1050	5.4	6.5	5.8	7.5	6.3	8.4
≥ 1050 & < 1580	5.8	6.8	6.2	8.1	6.5	8.8
≥ 1580	6.3	7	6.5	8.9	6.7	9.1
Air Cooled Chillers						
Chiller Capacity	**ECBC**		**ECBC+**		**SuperECBC**	
(kW)	COP	IPLV	COP	IPLV	COP	IPLV
< 260	2.8	3.5	3	4	NA	NA
≥ 260	3	3.7	3.2	5	NA	NA

Other types	*Size category*	*For heating or cooling or both*	
	(kWr)	EER	ISEER
VRF Air Conditioners, Air Cooled for ECBC buildings. *(These are not yet defined for ECBC + and SuperECBC. Also, S&L Star Rating levels have not been defined for VRF systems.)*	< 40	3.28	4.36
	> = 40 and < 70	3.26	4.34
	>= 70	3.02	4.07

COP: Coefficient of Performance = Output power (cooling capacity) [in Watt] divided by the input wattage [Watt]
EER: Energy efficiency ratio = Output cooling energy divided [in BTU] by input electric energy [in Watt.hour]
Using these physical units COP = 3.413 EER. EER can also be given in [Watt.hr divided by Watt.hr] in which case EER = COP
SEER: EER , reflecting the typical year's weather (temperature variations) at a given location
ISEER: seasonal EER rating for India
IPLV: Integrated Part Load Value = overall average efficiency of a chiller cooling system; the concept similar to SEER

b) Pilots to demonstrate benefits of innovative technologies - There have been no or limited pilots up to now on trying the feasibility of new low-carbon options, such as 'district cooling' for residential buildings based on zero-GWP refrigerants[26];

[26] There are other advanced technologies which are in various stages of development that require pilot demonstrations post which

c) Research pilots/studies to target future/next level of interventions - There have been no or very few demonstrated case studies on the use of IT-based digital platforms to set up a data management system to report thermal comfort and energy efficiency parameters on a continuous basis for buildings in India. The framework for this kind of data management and information systems at the national and sub-national levels is missing.

- *Lack of investment support and financing.*

Many of the business models rely on impetus through Governmental mandates programmes or regulations or concessional financing (to lower financing cost). There is generally a lack of innovative financing approaches and schemes tailored to promote EE in buildings. The need for evidence-based approaches to scale up is lacking as most of the energy efficiency measures are implemented in isolation. These are further influenced by factors such as challenges in obtaining approvals and/or new permits for new buildings or retrofit measures in existing buildings.

- *Local Manufacturing Vs. Imports of Cooling Equipment*

The local manufacturers of HVAC equipment are bound to comply with the Montreal Protocol targets in eliminating the use of ozone depleting (ODS) and high-GWP hydrofluorocarbons (HFCs) refrigerants. Manufacturers that are locally-owned, for example, can receive financial assistance from the MLF to convert their manufacturing lines and apply the use of lower GWP refrigerants. However, a substantial part of HVAC equipment is supplied by multinational suppliers (either manufacturing in India or importing finished cooling equipment). This can still lead to a supply of low cost, less efficient, and higher-GWP based refrigerant equipment. This situation can be addressed by minimum quality and energy performance standards and building energy policies. Therefore, streamlined EE Policy that can align the Montreal Protocol interventions to other EE Policies are needed.

Systemic Capacity, knowledge and information barriers

Lack of knowledge about benefits arising from energy efficiency in buildings among stakeholders and policy makers

- *Limited knowledge and low awareness.*

Alternative technologies such as thermal energy storage, trigeneration and district cooling are available but are not widely adopted in India. One of the challenges of adopting not-in-kind and alternative technologies is that these solutions need to be catered to a specific set of end-users considering building and other design parameters. These are often based on specific building needs and are comparatively more expensive. This forms a barrier in the price-sensitive Indian market.

These technologies also demand a skillset of multiple stakeholders which includes technology providers, HVAC consultants and other designers. Unlike conventional cooling solutions, not-in-kind and alternative technologies are not readily available off-the-shelf. The low uptake of non-conventional cooling technologies and thermal comfort concepts can be linked to a general lack of awareness among designers and consultants regarding ongoing technological improvements. Major challenges reported in the cities' context included insufficient awareness of the importance of energy efficiency and a lack of knowledge and technical expertise in building science. For many cities, this knowledge gap, which applies to both code enforcement officials and building industry stakeholders, impedes the building energy code enforcement system.

- *Temperature setting for thermal comfort.*

Most office spaces operate at 22.5ºC (± 1°C) being well below the comfort range specified even by the 2016 National Building Code, which recommends India-specific thermal comfort guidelines with higher temperatures. Public awareness of appropriate room temperature setting is low. Often occupants put the air con at low temperatures (e.g., 18^{o}C) under the wrong assumption that doing so will cool down a room faster. However, it will take the same amount of time for the room to reach 26 ^{o}C (which is still significantly cooler than the average summer outdoor temperature of 40 ^{o}C in Delhi) whether you set the temperature at 18 ^{o}C or 26^{o}C. Of course, 18^{o}C costs more energy to cool. Although some may feel comfortable

commercialization of such technologies can happen. Some of these technologies are but not limited to: 'Magnetic Refrigeration', 'Cryptocoolers', 'Solar thermal collector integrated cooling', "Smart Muscle" cooling.

at such a low temperature, modelling studies (e.g., IMAC, 2014 and international studies) show that occupants feel 'neutral' at around (24-25°C) and this does not seem to vary much with the outdoor temperature (if ranging between 16-38°C).

• *Limited technical capacity on super-EE technology and thermal comfort.*

Lack of capacity in using refrigerant alternatives integrated with energy-efficient buildings and equipment in an integrated manner among different stakeholders. There are few technical experts and consultants providing building energy efficiency related services and hiring international consultants is cost-prohibitive. Successful case studies need to be disseminated widely. Awareness creating needs to be supplemented with adequate training and access to markets.

Addressing market acceleration and development barriers

Energy Efficiency Services Limited (EESL) is an energy service company (ESCO) of the Government of India and is the world's largest public ESCO. EESL was formed under India's Ministry of Power to facilitate energy efficiency projects[27]. Apart from the efficient lighting programmes, EESL has implemented the following:

- *EESL's Super-Efficient AC Program (ESEAP).* Intending to integrate energy efficiency into India's cooling sector, EESL has initiated the Super-Efficient Air Conditioning programme. Consumers can buy super-efficient air conditioners distributed by EESL at prices that are comparable to most energy-efficient ACs in the market. These super-efficient ACs provide the normal 1.5 TR (tonnes) cooling capacity at high ambient temperature while reducing the cost of cooling by 50%. As to date, around 2,000 super-efficient air-conditioners have been sold;
- *Building Energy Efficiency Programme (BEEP),* established in August 2017 with aim of retrofitting 20,000 large public and private buildings. To date, EESL has completed building energy efficiency projects in 10,344 buildings including Railway stations. Energy audits show an energy-saving potential to the tune of up to 30-50% in these buildings. The major interventions in these buildings are in the area of lighting and air-conditioning systems.

District cooling systems (DCS) can be a gamechanger in a country like India, which has large neighbourhoods with a substantial population in most of its towns and cities. The system can be powered by local power generation plants using a combination of energy-efficient technologies such as trigeneration or industrial-grade electric chillers. Such a system provides cooling through a network of pipes that serves multiple buildings around the neighbourhood. The '*District Energy Initiative*' by the UNEP highlights the potential offered by these systems to make a cost-effective transition to sustainable refrigerants and energy-efficient cooling, as well as reducing primary energy consumption.[28]

The Kigali Amendment (KA) to the Montreal Protocol has established extended commitments which will, until the year 2045, impose limits on the use and availability of current refrigerants in the market. The KA obligations will require companies to transition to new alternatives, while the MLF provides financial support (grants) only to Indian-owned companies to adopt ODS-free/HFC-free technologies. The requirements of granting from the Montreal Protocol´s MLF leave aside a whole spectrum of non-eligible companies (multinational companies, companies founded after a cut-off-date and importers of finished products). Most important, the Montreal Protocol does not fund or promote energy efficiency improvement at cooling equipment manufacturing level. Thus, not all sector stakeholders will be given the appropriate investment models in a conducive enabling environment before such mandates are imposed on companies operating in India market. This is an investment-intensive activity, which could pose a major challenge for the manufacturers or importers and could push them towards adoption lower efficient cooling equipment, undermining India´s ICAP goals.

Enhanced investments and deployment of super-energy-efficient HVAC technologies and thermal comfort interventions in building

There is scope for the implementation of enhanced energy efficiency in buildings and cooling through promoting/piloting/deploying technologies and measures that are viable but not widely adopted in India by completing the

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27 It is 100% government-owned, a joint venture of state-owned NTPC Limited, Power Finance Corporation, REC Limited and POWERGRID

28 Details available at http://www.districtenergyinitiative.org/power-districtenergy, last accessed on 25 May 2021

interventions that are not supported/funded by the Montreal Protocol. The implementation thereof should be facilitated by suitable business and financing models, implementing procedures and bankable projects at participating states and municipalities:

- *Innovative business model*

  Market sentiments must be understood in order to come up with innovative business models to encourage investments in the energy efficiency sector; this applies to manufacturers as well as consumers. Business models need to be innovative such as EESL's model (see Box 7) which doesn't follow the traditional model of offering subsidies but works on the principle of Pay-As-You-Save (PAYS). This model addresses high upfront capital investment costs and EESL's approach to aggregate demand makes the market attractive for the industry. EESL's model has been quite successful in India because its initiatives are mostly market-led, rather than following an approach with dependency on fiscal incentives and subsidies. However, each business model has to be unique as there cannot be a 'one-solution-fits-all' approach especially since technologies and the target consumer groups are different for each one of them.

- *Demonstration of innovative approaches and efficient cooling technologies via pilots*

  Low carbon cooling technologies have been present in the Indian market for at least a decade, offering significant energy and emissions savings, are scalable, attract adopters from multiple sectors. These could significantly replace conventional cooling technologies. Such technologies are also referenced in the ICAP but not all are being applied in the market on a wide scale. Many such innovative and futuristic technologies can be explored and their demonstration can pave the way for greater acceptance of these approaches (e.g. passive building design) and technologies (e.g. tri-generation and non-refrigerant district cooling) in terms of efficiency and proven technical expertise.

The current rate of investments in energy efficiency is limited by barriers at the global, regional and national levels. There is no specific business model or financial mechanism which will fit into the Indian context at large, as the success factors need to be established which are based on the local market and cultural context. As described in the financial mechanisms' narrative, there are certain financial mechanisms/ business models which cater only to a specific set of people and also vary significantly in terms of their applicability with technical characteristics and building typology. Different financial mechanisms are suited to markets at different levels of maturity, both in terms of energy efficiency policies, and regulations, as well as the maturity of local financial systems and overall governance. Financial models are most successful when they are consumer-focused. Energy efficiency benefits should be communicated well to the consumers which can trigger behavioural change and eventually help unlock investment models.

Address barriers related to knowledge management and capacity strengthening

India has already implemented and successfully achieved the targets under the HCFC Phase-out management plan (HPMP), Stage I, implemented for a period of four years from 2012 to 2015 that achieved 10% phase-out targets of HCFCs by 2015 (see Box 5), and is currently implementing the Stage II of the HPMP, aiming to further reduce its HCFC consumption by 25% by 2023 by directly working with locally owned companies that manufacture Air Conditioning equipment and Polyurethane Foam (PU Foams) panels used in construction of buildings and cold storage. Furthermore, India plans to launch the HPMP´s Stage III that will likely promote the early phase-out of HCFCs consumption by the year 2030, while has recently ratified the Kigali Amendment to the Montreal Protocol, that will start to be implemented in the year 2028, expanding the work to also tackle the consumption of high-GWP HFCs. However, the Montreal Protocol programme does not take into account the energy efficiency spectrum and is mainly focused on creating capacity on refrigerants application at manufacturing level and their handling during this transitioning period (as technologies pose one or more safety-related issues due to sensitive parameters like high toxicity and high flammability, especially for end-users) and good servicing practices as critical actions to support these chemicals phase-out activities.

In terms of knowledge management on energy efficiency in buildings, the BEE 'five-star' rating is applicable to office spaces, hospitals, business process outsourcing (BPO) buildings, and shopping malls and acknowledges a wide range of energy efficient thermal cooling technologies. However, awareness of innovative thermal comfort technologies such as passive building design, tri-generation and district cooling remains limited as well as knowledge on application and technical requirements among manufacturers, vendors, importers, new entrepreneurs, architects and building owners.

Enhanced capacity at national, sub-national and within the private sector for identifying, designing, planning, financing and implementing efficiency improvement and thermal comfort systems in buildings

A consumer-focused campaign is needed to be organized to spread awareness on energy-efficient buildings, efficient and climate-friendly cooling approaches and technologies; and the need for transitioning towards ECBC compliances. However, mere awareness programmes have limited impacts and need to be supplemented with adequate training and handholding to showcase performance. There is a need to increase capacity, awareness, and knowledge of stakeholders, including assimilating existing knowledge of energy-efficient technologies and thermal comfort. This is required across the spectrum of stakeholders including policymakers, industry players, financiers, architects, technicians and consumers. This will be done by various mediums like workshops, training, focused group discussions etc. and using the latest and innovative mediums like social media, print and digital media, roadshows etc. Tailored technical support will be provided to manufacturers, vendors, importers, new entrepreneurs, building owners, to upgrade the design, testing and technical characteristics of EE equipment and products, and to local entrepreneurs to replicate and produce EE technologies locally and reduce the costs of production.

A knowledge platform that can act as an information repository for alternative technologies can be developed for India. This knowledge platform will also act as a podium for assessing the financial/ funding opportunities between the government and private sector and streamline information and funding opportunities at the national and sub-national levels. The portal can also bridge the gaps in accessing the tools and knowledge exchanges and experience sharing for further harmonisation during the pilot implementation at the sub-national levels. The portal may assist in finding the people with the required skills and improve awareness among designers and consultants regarding ongoing technological improvements.

Addressing financial barriers and gaps

Financing mechanisms, business models and incentives for energy efficiency are key for mobilizing investment but should be complemented by other efforts in an integrated approach, such as market transformation policies, regulations, awareness-raising activities and behaviour change initiatives. These efforts work alongside each other in a complementary manner. These programs include bulk procurement and AC Replacement Scheme by power distribution companies under DSM programmes to name a few. The above programs are only applicable to unitary cooling technologies and do not focus on innovative cooling technologies such as district cooling, thermal energy storage, etc.

Some of the established financing mechanisms and business models around the globe for both residential and commercial building typologies are referenced below along with their benefits and challenges[29]:

a. Loans & green credit lines
   Applicability: Residential & Commercial sectors

Households & the commercial sector can finance energy efficiency improvements through direct loans from local financial institutions (LFI) which can include banking or non-banking financial institutions. This loan is then paid with interest to LFI, which is typically available to consumers at low-interest rates with the help of support from bilateral funding agencies.
Benefits: Loans can be useful to the consumers in ensuring that they are not burdened with high upfront costs and have proven to be useful especially at scaling up energy efficiency in the residential sector.
Challenges in Residential Sector: Economically Weaker Sections (EWS) and Lower Income Groups (LIG) may not have access to banking accounts which is usually a pre-requisite to applying for a loan and only caters to clients having active accounts with financial institutions.
Challenges in Commercial Sector: Credit lines have high-interest rates, are only available with short-term tenors, or have high collateral requirements[30] making access for SMEs difficult.

[29] Basel Agency for Sustainable Energy (BASE) 2019

[30] UN Environment Developing Minimum Energy Performance Standards for Lighting Products Guidance: Note for Policymakers. (2015).

b. Dealer financing:
Applicability: Residential & Commercial sectors

It is a credit-based model wherein customers can procure energy-efficient products with little or no initial cost from the dealers, and then pay later in monthly instalments or a schedule as agreed upon with the provider.
Benefits: This type of model can be useful in developing countries where credit access is limited.
Challenges: The success of this model depends on the availability of credit lines with the dealer, which in most developing countries, is limited.

c. Microfinance:
Applicability: Residential sector

It is a provision of financial service via small transactions (i.e. microcredits, micro-savings, micro-insurance, micro transfers, micro equity) to EWS and LIG household groups.
Benefits: This is mostly carried out by NGOs, banks and non-banking financial institutions wherein LFI's considers unbankable due to higher transaction costs, perceived risks, low margins and lack of traditional security collateral.
Challenges: Due to strict eligibility criteria and high-interest rates[31], the customers are disinterested. Also, the reach of MFIs have limited geographical coverage and they also lack the technical capacity[32] to assess sound technology providers and cost-effective technologies, leading to missed opportunities for cost-effective primary energy savings and CO2 emission.

d. Savings Group:
Applicability: Residential sector

The savings group model is a market-based savings-led financing mechanism where self-selected individuals combine their savings and take small loans from those savings, with interest, and share the profits among themselves. They are owned, managed, operated and self-policed by members. Savings groups provide members with the opportunity to save frequently in small amounts, access to credit on flexible terms, and some basic forms of insurance.
Benefits: Savings groups are more structured, transparent and democratic than informal financial services found in villages. Also, this model can reach out to people who have no access to other means of financial mechanisms. There is substantial evidence to claim that this model is successful and has a positive impact on member savings and access to credit.
Challenges: The biggest challenges for savings groups on an organizational level are to keep accurate records of individual loan balances (i.e., memorization, passbooks, central ledgers or forms), and to keep the members' money safe. Another challenge of the model is its reliance on subsidies to pay the field officers of the facilitating agencies during the initial phases of savings groups' development[33].

e. On bill financial models/ Pay As You Save (PAYS):
Applicability: Residential sector

This model encourages consumers to buy energy-efficient equipment like ACs and to pay for the equipment over time through the savings in monthly utility bills.
Benefits: Usually, on-bill financing programs are designed to deliver immediate overall cost savings without the consumer having to invest.
Challenges: The main risks and challenges to establishing an on-bill financing mechanism are:[34]

- Engaging the utility to support the transition towards energy efficiency and/ or to serve as a financier.
- Evaluating credit risk of customers through their historical payments.
- Changing the utilities data and information management system to allow for on-bill repayment.
- Customer risk of power shut-off. This can be mitigated by enabling customers to obtain assistance with complaints, raise legitimate issues related to the loan and the project and access a dispute-resolution process.
- Repayment allocation (i.e., utility or lender being paid first can be an issue when customers partially pay their bills.

f. Bulk Procurement:

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31 Choice, M. Chapter 1 — An Overview of Marketing. 1–44 (2012). doi:10.1016/j. ejor.2008.02.014

32 Climate Investment Fund. The market matures for microfinance: Tajikistan. (2018).

33 Gash, M. Understanding the impact of savings groups. Learning Brief: A Typology of Relationships between Savings Groups and Financial Service Providers (2017).

34 University of North Carolina. *Consumer Considerations for On-Bill Finance Program*s.

Applicability: Residential & Commercial sectors

Market transformation tools like bulk procurement help bring energy-efficient products to market at an accelerated pace.[35] Bulk procurement provides economies of scale enabling manufacturers to bring down their prices through successive rounds of efficient and transparent bidding to create a large and sustainable market for energy-efficient products.

Benefits: One of the key benefits is that it improves domestic manufacturing capacity and fosters competition. It encourages manufacturers to invest more in the processes and lower their cost of production. More importantly, this model encourages energy-efficient products to create a market while passing on the savings to end-users.

Challenges: The potential for product cost reduction through bulk procurement depends on the volume of tenders and the number of suppliers in an energy-efficient product market. If both are small, the potential will be limited.

g. District service models: "servitisation" / Subscribe for Cooling:
   Applicability: Residential & Commercial sectors

This model ensures that the consumers only pay for the service that they are using, rather than a physical product or infrastructure that is needed to install the product. The technology provider installs the product and charges the customer based on a pre-determined rate, unlike the ESCO model.

Benefits: No upfront costs, while lower energy and maintenance costs make this model attractive for residential and commercial consumers.

Challenges: The initial cost associated with the installation of the physical product is often very high which might not always be feasible for technology providers. These models often require a broad portfolio of clients to compensate for demand uncertainty. Moreover, it is necessary to coordinate with building developers to ensure that district service systems are in line with building design.[36] Technology providers face the risk of payment default, which can be reduced by evaluation of the credit risk of customers, with mechanisms such as payment guarantees.

h. Energy Efficiency Mortgage (EEM)/ Mortgage financing:
   Applicability: Residential sector

Through this business model, a consumer purchases or renovates a home that is already energy-efficient or that will become energy efficient after upgrades. There is an involvement of an Energy Auditor who reports the home's existing energy consumption and recommends cost-effective upgrades which would improve energy efficiency. The lender provides financing only if the potential energy savings is greater than the cost of the loan to implement upgrades.

Benefit: This model unlocks the potential of finance provision from the private sector, in addition to subsidies provided by the government. Among other benefits, EEM is an affordable way to implement energy efficiency home upgrades that may be otherwise too costly for households and save money over the long run.[37]

Challenges: The auditors can sometimes overestimate the energy savings potential which in turn impacts the overall savings due to upgrades. The borrowing households also see EEM as unattractive due to a general lack of awareness of the EEM model, and information about the relationship between energy efficiency and risks.[38] They also perceive the home energy assessment process as gruelling and are more aware of the availability of other financing options on the market.[39]

i. On-tax financing model:
   Applicability: Residential sector

On-tax financing mechanism allows for an energy efficiency (EE) upgrade and distributed renewable energy (RE) installation. Homeowners get access to EE and RE upgrades from third-party investors, while the repayment is via property taxes.

Benefits: This model is beneficial to EWS and LIG groups since interest rates offered are lower than conventional bank rates. Long term financing is possible as it is associated with a property, and hence ownership can be transferred to a new owner.

Challenges: The model requires working with local municipalities and assessing a tax collection structure's compatibility on-tax financing.

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[35] Geller, H. *Energy Revolution: Policies for a Sustainable Future*. Isl. Press. Washingt. 1, 82 – 86 (2012).

[36] Lo, I. A., Lau, I. B. & Cheng, V. *Challenges of District Cooling Systems (DCS), implementation in Hong Kong*. Sustain. Build. (2013).

[37] *Energy Efficient Mortages Initiative. Energy efficient Mortgages Action Pla*n (EeMAP) Initiative. [14-Jan-19], Retrieved from www.energyefficientmortgages.eu/ (2018).

[38] Kaza, N., Quercia, R. G. & Tian, C. Y. Home Energy Efficiency and Mortgage Risks. Cityscape A J. Policy Dev. Res. 16, 279 – 298 (2014).

[39] Kolstad, L. Designing a Mortgage Process for Energy Efficiency. 163 – 174 (2014).

j. Remittance based payment models:
Applicability: Residential sector

Remittances are a significant and growing source of financial inflows for developing countries.[40] This model developed by BASE allows migrant workers living abroad to direct part of their income towards small-scale sustainable energy solutions for families back home.
Benefits: This model encourages migrant workers to invest in sustainable development in their home countries as upfront cost barrier is avoided via this model.
Challenges: The key challenge lies in working with local money transfer organizations (MTOs) to set up a business model to achieve the goal of sustainable energy solutions. While remittances undoubtedly contribute to higher living standards for some receivers, in many cases, remittances are not used for longer-term productive purposes.[41][42]

k. Financial incentives (e.g. rebate or subsidy program)
Applicability: Residential & Commercial sectors

This model provides financial aid to lower upfront costs of energy-efficient technologies and ensure that a consumer makes a choice that is energy efficient. This could be in the form of rebates, tax credit & VAT waiver.
Benefits: Incentives are proven, highly effective tools for increasing market adoption of energy-efficient technologies.[43] They ensure that consumers are lured towards the technologies and this creates a demand for a potential scale-up of energy-efficient technologies.
Challenges: The biggest challenge is ensuring financial incentives enable self-sustaining market changes that continue after the incentive program ends. [44] For government programs, another challenge is ensuring public money for incentives is used in an efficient, socially and responsible manner.

l. Leasing
Applicability: Commercial sector

This is an arrangement wherein an asset is provided on lease to the consumer for a specified period in exchange for regular periodic payments.
Benefits: There are no upfront capital costs associated with this model, can get access to state of the art technology without the risk of obsolescence, service can be discontinued at any time and comes with a transparent and predictable pricing structure.

Box 9 Energy service companies (ESCOs)

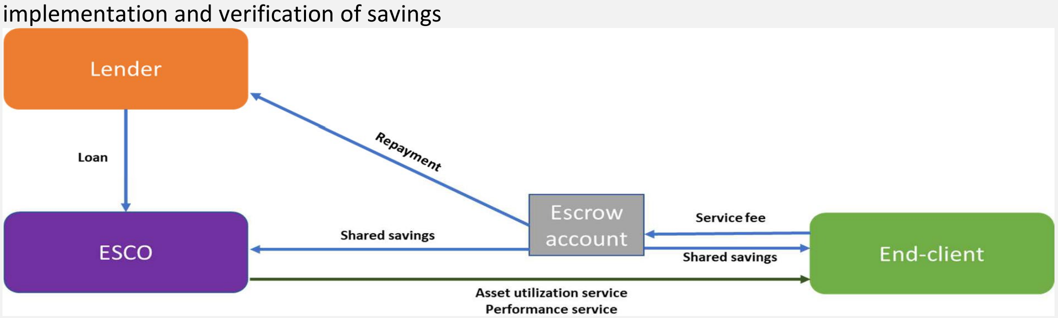
A 'Energy Service Company (ESCO) s a special service provider that combines procurement of goods, project installation capability and a post-installation service. ESCOs work on 'energy performance contracting (EPC)' basis, which provides energy savings measured in comparison with a previous energy cost baseline and in which the ESCO's remuneration depends on the respective outputs of the services provided. In principle, customers can have off-balance financing that will pay for the project through energy savings. A major advantage is that customers can fund the project over time and can do so with very little or no discretionary budgets and at relatively low risk. The models do require a proven ESCO presence in the energy efficiency market.

In the guaranteed savings (or performance guarantee) modality, the client makes the investment (from his own funds or the banks, or leasing) but the ESCO provides a guarantee for the energy savings realised. Based on *end-user or third-party financing*, this model has the advantage that interest rates are usually much lower and therefore more energy efficiency investment is possible. At the same time, the risk for the end-client is reduced by transferring to the ESCO the responsibility that the project will perform correctly. Penalties are applied to the ESCO should the performance of the project not meet the contractually agreed terms. A graphical summary of this model is indicated below.

40 World Bank. MIGRATION Recent Developments and Outlook. (2018). doi:1 0.1080/17441730.2013.785721
41 Asian Development Bank. Global Crisis, Remittances, and Poverty in Asia. (2012).
42 Samuwai, J. & Hills, J. M. Assessing climate finance readiness in the Asia-Pacific region. Sustain. 10, 1 – 18 (2018).
43 UNDP. Promoting of Appliance of Energy Efficiency and Transformation of the Refrigerating Appliances Market in Ghana - Project Document. Retrieved from http://www.gh.undp.org/ [Jan-15-19] (2014).
44 UN Environment. Climate-Friendly and Energy-Efficient Refrigerators. Retrieved from http://www.united4efficiency.org/[15-Jan-19] (2017).

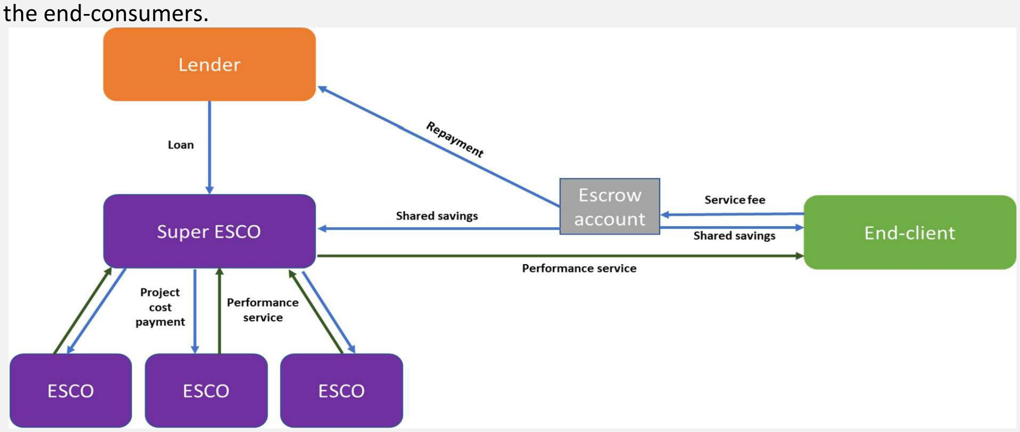
Box Energy service companies (cont'd)

In the shared savings modality, the ESCO guarantees the performance of the installation and invests or provides financing, and recoups this through the contracting fee, i.e. the cost savings (due to reduced energy consumption and maintenance) are shared by the ESCO and the client at a pre-determined percentage for a fixed number of years. Thus, the ESCO guarantees a certain level of cost savings to the customer, assuming both the performance and the credit risk. Maintenance of the facilities is also typically included in the scope of the ESCO. This model has several advantages. It substantially reduces the risk for the end-client and does not require any upfront capital. It also shifts the credit assessment to the ESCO, instead of the end-client and allows the reduction of transaction costs by packaging multiple projects from one ESCO into a single loan. The main disadvantage of this model is that it increases the complexity of the program management, as payments to be made to the ESCO depend on the monitoring and verification (M&V) of the savings. In less-developed markets, ESCOs may not offer this model due to the inherent risk for them and inexperience with actual project implementation and verification of savings



A variation of this model introduces the role of a Super-ESCO, which acts as an additional agent between the ESCO, the lender and the end-client. The Super-ESCO manages most aspects of the project, including the detailed technical design, sourcing funds, providing performance guarantees to the client, selecting smaller ESCOs for project implementation, aggregating projects and overall management and coordination of the implementation and performance guarantee phases. This option greatly simplifies the program for the end-client, reduces transaction costs for the lender, and supports the development of internal competencies amongst local or more inexperienced ESCOs. It also achieves economies of scale thanks to mass procurement of energy efficiency equipment. The main disadvantage is that a Super-ESCO may grow to dominate the ESCO market, creating a monopolistic situation.

In India, the Super-ESCO model has been successfully applied and showcased in LED public lighting projects. Energy Efficiency Services Limited (EESL) is a super ESCO set up by the Ministry of Power. EESL typically operates with a government guarantee scheme as risk mitigation in the case of performing ESCO services. EESL replaced about 92,000 HPS and TL street lights with LED lighting, resulting in 50% energy savings and improved road illumination levels in the city of Vizag, and is working witht he Indian Bureau of Efficiency in other municipalities . EESL has performed a mass LED rollout program known as UJALA that as of November 2018 has distributed over 330 million LED lamps. This program heavily relies on electricity distribution companies in India (DISCOMs) to distribute the lamps to the end-consumers.



Energy Efficiency Services Limited (EESL) is an energy service company (ESCO) of the Government of India and is the world's largest public ESCO. It is 100% government-owned, a joint venture of state-owned NTPC Limited, Power Finance Corporation, REC Limited and POWERGRID. EESL was formed under India's Ministry of Power to facilitate energy efficiency projects.

Challenges: The key risks associated with this model are a) Legal and tax environment can be less attractive as compared to loans; b) Risk of technology getting outdated due to rapidly evolving technological advancements, and c) high capital expenditure for the service provider

m. Energy Performance Contracts (EPC) – ESCO model (see Box 31)
   Applicability: Commercial sector

Energy Performance Contracts (EPCs) enable funding of energy efficiency upgrades from energy cost reductions. Under an EPC arrangement, an external organization, typically called an Energy Service Company (ESCO) implements an energy efficiency project, and uses the stream of income from the cost savings to repay the project costs.

Benefits: Consumers can reduce/ eliminate the performance risk and need for technical expertise. Higher savings can be achieved as the ESCO's strive to achieve maximum energy efficiency, which proves beneficial to both parties in the case of a shared savings model.

Challenges: Customers can default the payment after installation. An unexpected increase in monitoring cost coupled with the uncertainty of baseline measurement can be a huge challenge. Savings measured post-installation of upgrades could be higher than expected which could be translated into higher payments to the ESCO. [45]

n. Guarantees
   Applicability: Residential Sector

Guarantees (e.g. partial-risk loan guarantees, payment guarantees) are instruments that can help expand loan financing for commercially viable energy efficiency investments in the residential sector. Financial institutions (e.g. commercial banks, leasing companies) that are unfamiliar with energy efficiency projects and their risk mitigation options tend to perceive repayment risks as high.

Benefits: Guarantees are designed to reduce financial institutions' perceived risks in the short run and improve their technical and financial confidence in specific energy efficiency projects or project developer models in the long-run, by covering part of the loan repayment risk.[46]

Challenges: In some cases, loan guarantee programs are not appropriate because the main barriers for commercially viable energy efficiency lending are not perceived as high repayment risks, but rather other structural issues such as a lack of efficient processes to meet technical assessment requirements or the level of market maturity.[47]

2.5 Waste recycling and refrigerant recovery

Recovery and recycling of refrigerants[48]

Recovery, recycling, and reuse of refrigerants are the key processes for refrigerant conservation. Recovery means the removal and temporary storage of refrigerant that has been removed from a system undergoing service or disposal. Recycling means the passing of recovered refrigerant through filters in order to make the refrigerant suitable for reuse. Recycling is not intended for used refrigerants that will be repackaged and placed back into the refrigerant market.

Such refrigerant conservation efforts should be placed on refrigerant recovery at the point of installation and continue throughout service and ultimate equipment end-of-life. Refrigerant conservation could be achieved through efforts of equipment and chemical manufacturers, as well as equipment owners/operators by developing life cycle approaches aimed at reducing refrigerant emissions. It would also include the required training of service personnel.

45 Shang, T. et al. *What to allocate and how to allocate? Benefit allocation in Shared Savings Energy Performance Contracting Projects*. Energy 91, 60 – 71 (2015).
46 The World Bank. *World Bank Guarantee Program*. Retrieved from http//siteresources.worldbank.org [22-Jan-19] (2012).
47 The World Bank Group. *Energy Efficiency Finance*. Retrieved from https//www.ifc.org/ [23-Jan-19] (2010).
48 Source: India Cooling Action Plan

Recovery/recycling/reclamation processes have been implemented in developed and developing countries since the inception of the implementation of phase-out of ozone-depleting substances under the Montreal Protocol. The results of recovery and recycling efforts were not encouraging during the CFC phase-out regime of the Montreal Protocol except in the Mobile Air Conditioning (MAC) sector which was mostly handled by the organized sector, moreover, the quantity of refrigerant in MAC is significantly more in comparison to domestic and commercial refrigeration equipment.

India, through the Multilateral Fund for the implementation of the Montreal Protocol funded projects, has trained on good servicing practices more than 30,000 technicians, mostly in the unorganized refrigeration and air conditioning (RAC) servicing sector so far. Recovery, Recycling and Reclamation were important elements of training. The use of refrigerant recovery and recycling equipment is the most essential means of conserving refrigerant during the service, maintenance, repair, or disposal of refrigeration and air-conditioning equipment. Some of the servicing technicians were also provided recovery, recycling equipment. The recovery and recycling equipment is expensive and the affordability of RAC servicing technicians is limited.

India also established 18 mini Reclamation centres, 11 in Institutional Users (Army, Airforce, Navy and Indian Railways) and 7 in the private sector in various Stated/Union Territories (Chandigarh, Gujrat, Maharashtra, Rajasthan, Uttar Pradesh and West Bengal). These mini reclamation units are capable of reclaiming a number of refrigerants like CFCs, HCFCs and HFCs including some of the blends of HFCs. Each unit can reclaim up to 26 kg of refrigerant depending on the availability of recovered refrigerants.

E-waste

In addition, equipment such as refrigerators and air conditioners are subject to in India, E-Waste (Management and Handling) Rules 2016 and E-Waste Management Amendment Rules 2018 (notified by the Ministry of Environment, Forests and Climate Change Government of India). The legislation concerns the recycling of valuable materials, such as metal and plastic, as well as electronics components[49].

For example, the 'super-ESCO' EESL has a programme on recycling of air-conditioners, called "Addressing E-waste under the Super-Efficient AC Programme of EESL (SEAC)". Under the Programme, any Air Conditioner (any part or spare or whole) is considered as 'old' (Buy-Back /End of Life) when no longer intended for any use. coming from any process whether manufacturing or repair or supply or storage or buy-back or other may be considered as an e-Waste for the Program.

49 The materials/metals contents under the e-wastes, if recovered properly, can be a useful resource and may have some useful economic value to the user. Such materials may include plastics, iron, glass, aluminium, copper and precious metals (such as silver, gold, platinum, and palladium), and lead, cadmium, mercury etc.

Annex A. ICAP AND GREENHOUSE GAS EMISSION REDUCTION

A.1 Estimations of direct and consequential GHG emission reduction

Emission reduction calculation

The report *Demand Analysis for Cooling by Sector in India in 2027* (BEE, 2018) presents a first-of-its-kind comprehensive overview of the nationwide cooling demand in India. On the scenarios in this report, MoEF's *India Cooling Action Plan* (ICAP, 2019) builds with presenting two scenarios for the periods 2017-2027 and 2028-2037, a reference (business-as-usual, BaU) and an intervention (alternative, Alt) scenario.

The BEE (2018) analysis looks at the following cooling technologies used in buildings, a) room air conditioners (A/C), chiller systems, VRF systems, fans, and air coolers. About 95% of the ACs used in India for room cooling are single split (fixed-speed and inverter types) and window/through-the-wall (fixed speed type) configurations. Apart from A/Cs, air-conditioning systems utilised in commercial buildings are chiller systems, packaged direct expansion (DX), and variable refrigerant flow (VRF) systems. Chiller systems which are also called central (air-conditioning systems are the preferred choice for large commercial buildings like hotels, hospitals, malls and office complexes. VRFs are used in high-rise commercial buildings. DX systems are often installed in small to medium buildings. All these cooling systems use refrigerants. Non-refrigerant cooling systems include fans and air coolers.

A summary of the analysis is given in Box 11. The calculation of energy savings is based on:

- Estimated cooling demand in TR in a building given the average cooled surface area (from estimates by the PPG Project design team based on literature analysis and discussions with building sector stakeholders
- Energy consumption in baseline on assumptions on the current average value of ISEER (3.2) and IPLV (3.8) of air-conditioners and chillers respectively
- Reduction in energy consumption as compared to baseline, due to:
    - Use of super-efficient technology with better ISEER (5.9) and IPLV (9.0) values
    - ECBC compliance and passive building design improvements (new buildings only), lower cooling demand (in TR) by 40%.
    - Room temperature is set at a higher value by occupants according to thermal comfort considerations. Increasing the room temperature is assumed to have an energy-saving impact of about 4% per centigrade and is assumed to be raised by 4°C (from the operational temperature usually designed at 21°C to 25°C)

According to the BEE (2018) report, significant savings in cooling energy consumption in buildings are possible, about 17% in 2027 in the alternative scenario in comparison with the BaU scenario. Box 12and Box 11 give an overview of the energy savings potential and greenhouse gas (GHG) emission reduction based on certain assumptions per type of cooling technology. These assumptions form the basis for both the direct and indirect emission reduction estimates. The table shows that in 2027 a reduction can be achieved of 48 TWh in India (which is 17% of BaU energy consumption of 284 TWh). In the GHG reduction calculation, it is assumed that room temperature in 75% of the buildings is set from 22 at 25°C (thus giving savings add to the employment of super-EE cooling technologies of about 21 TWh). Total energy savings by 2027 are 69 TWh (24% of BaU energy consumption for cooling in 2027). At a grid emission factor of 0.872 $MtCO_2$ per TWh and a lifetime of 25 years, this means an emission reduction of 1,505 $MtCO_2$.

Box 10 Terminology in cooling technology and assumptions used in ICAP scenarios

Terminology used in cooling technology

Tons of Refrigeration (TR)

TR is often used as a general term to indicate the capacity or size of the cooling or refrigeration unit, i.e., the amount of heat removed per unit of time. One (1) TR has a cooling capacity of 3.516.85 Watt (W) at the prescribed temperature.

EER (energy efficiency ratio)

The EER = output wattage (cooling capacity) divided by the input wattage.

SEER (seasonal energy efficiency ratio)

As there is seasonal variation of temperatures, there is variation in the amount of cooling required. Amount of energy (or electricity) required by an air conditioner to cool a room to 25 degrees (or any other standard temperature) is different when outside temperature is 30 degrees in comparison to when the temperature is 40 degrees. Also, the usage (in hours per day) would vary as per the seasons. Thus, instead of being evaluated at a single operating condition, it represents the expected overall performance for a typical year's weather in a given location. The SEER is thus calculated with the same indoor temperature, but over a range of outside temperatures from 18 °C to 40 °C), with a certain specified percentage of time. The SEER follows from the EER by using the formula SEER = a (EER@25% load) + b (EER@50% load) + c (EER@75% load) + d (EER@100% load), where a,b,c,d are the load profile weighting factors relevant to the proposed application.

ISEER (Indian seasonal energy efficiency ratio)

SEER standards have to be different for different countries as every country has a different climate profile. Thus, BEE has defined an Indian SEER, based on the annual temperature profile of 54 cities in India in different climate zones The ISEER is the Ratio of the total annual amount of heat that the equipment can remove from the indoor air when operated for cooling in active mode to the total annual amount of energy consumed by the equipment during the same period. The assumption in the ICAP scenario is that the A/C is operated during 1600 hours a year.

IPLV (Integrated part load value)

IPLV is a standard way of measuring the overall average efficiency of a chiller cooling system. It is a concept similar to SEER, where part-load performance is measured and rated so that customers can have a way to do a comparison of real-world operating efficiency between various brands and models. Part load performance is the most important metric because a properly sized cooling system is larger than it needs to be 99% of the time. That’s because a properly sized air conditioner is specified to perform a proper level of cooling for a particular building on the hottest possible day of the year. The IPLV follows from the EER or the chiller according to IPLV = a (EER@25% load) + b (EER@50% load) + c (EER@75% load) + d (EER@100% load), where a,b,c,d are the load profile weighting factors relevant to the proposed application.

Air-conditioners

A weighted average of 1.4 TR is used, based on A/C surveys done. BEE publishes A/C production (or sales) data per star rating (1 to 5 stars). The ISEER mentioned in BOX CCC are the weighted efficiency level of 1.4-1.5 TR split RACs, adjusted by the consumer preference in RAC star rating. Annual runtime is 1600 hours. In the BaU scenario it is assumed that ISEER increases at 3% a year and 6% per year in the Alt scenario. Regarding refrigerants, the Alt scenario assumes a more aggressive HCFC phase-out schedule in the Alt scenario with lower-GWP HFC and R290.

Chillers

The relative market share of screw, scroll and centrifugal is based on BEE-commissioned market studies and projections. Operating efficiencies are based on minimum standards prescribed by ECBC (2017, ECBC+ (2027, BaU) and SuperECBC (2017, Alt) requirements. The BaU scenario incorporates HCFC phase-out and HFC phase-down but with a more aggressive HFC phase-down and higher penetration of low-GWP refrigerants. It is assumed in the BEE scenarios that chillers are operating 2568 hours a year.

VRF

A 10% improvement in 2027 is considered over the 2017 baseline level in the improved (Alt) scenario. It is further assumed that the VRF market grows 15 p.a. in 2017-2027. VRFs are operating 1920 hours a year in commercial buildings. Regarding refrigerants, penetration of R32 is considered likely.

DX

Similar to chillers, compliance is assumed with ECBC (2017), ECBC+ (2017; BaU) and SuperECBC (2027, Alt). Annual operating hours are 1920. The increased use of alternate refrigerants is assumed.

Box 11 Calculation of GHG emission reduction (due to the avoided use of fossil-fuel-generated electricity)

ICAP business-as-usual (BaU) and alternative (Alt) scenarios

Note: data based on estimates given in ICAP (2019) and BEE (2018)

		ICAP scenario (2027)			
	2017	BaU	Alternat.	Savings	
Air conditioners					
- million units	39	170			
- tonnage (million TR)	55	238			
- energy consumption (TW	49	142	116	19%	aa
Chillers					
- tonnage (million TR)	5	14			
- energy consumption (TW	11.8	29.2	19.7	33%	ll
VRF					
- capacity (million TR)	2.3	9.7	9.7		
- energy consumption (TW	3.6	15.1	13.6		
DX					
- tonnage (million TR)	4.6	6.7	6.7		
- energy consumption (TW	11.0	14.0	13.2	6%	
Fan					
- million units	458	646			mm
- energy consumption (TW	41	52	46	12%	bb
Air cooler					
- million units	55	155			
- energy consumption (TW	11	31	27.5	11%	
Total, superefficient EE					
- energy consumption (TW	127	284	236		a
- energy savings (TWh)			48	17%	e
Thermal comfort savings (TWh)			21		b=a*c*d
- Increase with 3°C (from 22 to 25°C)				12%	c
- Number of buildings that apply				75%	d
Total					
- Energy savings by 2027 (TWh)			69	24%	f=e+b
- Annual GHG reduction ($MtCO_2$/yr)			60.2		h=g*f
- Lifetime (yrs)			25.0		i
- Lifetime GHG reduction ($MtCO_2$)			1505		j=i*h

Base data

Exchange rate, USD =		73	INR			
Grid emission		0.872	tCO_2/MWh			g
1 TR		12000	BTU/hr			
		3.5168	kW			k
TR A/C		1.4	TR per A/C			
		4.92	kW per unit			

Note: TR A/C: BEE (2018). Grid factor: MoP (2018)

			BaU	Alt		
		2017	2027	2027		
Air conditioners						
	Load	98.0	427.0	427.0	million kW	l
	Run-time	1600	1600	1600	hrs/yr	m
	ISEER	3.2	4.8	5.9	kWh/kWh	n
	Energy	49.0	142.3	115.8	TWh	aa=l*m/n/1000
Chillers	Screw	3.8	8.2			
	Scroll	0.4	1.2			
	Centr	0.8	4.7			
	Total	5.0	14.1		million TR	o
	Load	17.6	49.6	49.6	million kW	p=o*k
	Runtime	2568	2568	2568	hrs/yr	q
	IPLV	3.8	4.4	6.5	kWh/kWh	
	Energy	11.8	29.2	19.7	TWh	ll=p*q/r/1000
VRF	Efficiency	0.81	0.81	0.73	kW/TR	
	Runtime	1920	1920	1920	hrs/yr	
DX	Efficiency	1.25	1.09	1.03	kW/TR	
	Runtime	1920	1920	1920	hrs/yr	
Fan	input	56	50	44.5	Watt	s=bb*10^6/mm/t
	runtime	1600	1600	1600		t

Thermal comfort - assumptions

Assumption: increasing room temperature with 1°C saves 4%

Temperature increased from 21 to 25°C

Source: BEE website, based on TERI data; https://images.livemint.com why-you-should-keep-the-ac-at-24c-4711541.html

Source: own elaboration

ASCENDIS

Box 12 Calculation of GHG emission reduction (due to the avoided use of refrigerants)

Base data

Refrigerant	GWP	ODP
R22	1700	0.055
R32	650	0
R410A	1725	0.037
R290	3	0
R134A	1300	0
R123	93	0,02
R407C	1526	0
R513A	631	0
R514A	2	0
R1233zd	1	0

Source: Data from BEE (2018); GWP and ODS are from: http://www.koudecentraal.nl/documents/handboekkoudetechniek/D%20TEWI%20-%20Totaal%20Equivalent%20Broeikaseffect%20van%20koelinstallaties.pdf, based on IPCC data

Room air-conditioners

Refrigerant	2017	BaU 2027	Alt 2027
R22	77%	20%	15%
R32	14%	50%	70%
R410A	9%	20%	
R290		10%	15%

Charge rate	0.21	t/MW
Aircon load	427040	MW
Leakage rate	5%	per year
Lifetime	25.0	years
Recovery 2017	0%	
Recovery 2027	15%	
Leaked amount	89678	ton of refrigerant
A/C units	170	million
GHG impact	56469	$ktCO_{2\text{-equivalent}}$

Chillers

Refrigerant	2017	BaU 2027	Alt 2027
R134A	91.0%	61%	50%
R410A	7.6%	9%	
R407C	0.4%		
R123	1.0%		
R513A		21%	38%
R514a		3%	5%
R1233zd		7%	8%

Charge rate	0.28	t/MW
Aircon load	49587	MW
Leakage rate	2%	per year
Lifetime	25.0	years
Recovery 2017	50%	
Recovery 2027	90%	
Leaked amount	13884	ton of refrigerant
GHG impact	2704	$ktCO_{2\text{-equivalent}}$

VRF

Refrigerant	2017	BaU 2027	Alt 2027
R32			20%
R410A	100%	100%	80%

Charge rate	0.28	t/MW
Aircon load	34113	MW
Leakage rate	2%	per year
Lifetime	25.0	years
Recovery 2017	0%	
Recovery 2027	0%	
Leaked amount	9552	ton of refrigerant
Climate impact	3080	$ktCO_{2\text{-equivalent}}$

DX

Refrigerant	2017	BaU 2027	Alt 2027
R32	15%	15%	30%
R410A	85%	85%	70%

Charge rate	0.26	t/MW
Aircon load	23563	MW
Leakage rate	5%	per year
Lifetime	25.0	years
Recovery 2017	0%	
Recovery 2027	0%	
Leaked amount	6126	ton of refrigerant
Climate impact	2223	$ktCO_{2\text{-equivalent}}$

GHG impact of refrigerants

Reduction of IACP Alt scenario vs. BaU	64476	$ktCO_{2\text{-equivalent}}$

Source: own elaboration

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