COOLING FOR TOMORROW: SUSTAINABLE SOLUTIONS FOR INDIA'S COOLING DEMANDS

INTRODUCTION

India's diverse climatic conditions, exacerbated by climate change, pose significant challenges to maintaining comfortable living and working environments. As temperatures rise and extreme weather events become more frequent, the demand for cooling solutions has surged nationwide to maintain thermal comfort. This narrative explores the multifaceted dimensions of cooling in India, focusing on the socio-economic, technological, and environmental aspects while promoting sustainable and inclusive approaches to address the growing need for cooling.

The upward trajectory of temperatures across India has propelled the demand for cooling technologies to unprecedented levels. From residential air conditioning units to industrial refrigeration systems, cooling solutions have become indispensable for maintaining comfortable living and working environments. Space cooling technologies are experiencing significant evolution and are broadly categorized into refrigerant-based, non-refrigerant-based, and not-in-kind technologies. Despite their prevalence in residential settings, room air conditioners have relatively low penetration rates in India, currently at about 8%-9%. Room air conditioners dominate the refrigerant-based category, representing approximately 80% of installed capacity, and are projected to rise to 87% by 2037-38 (MoEF&CC, 2019). Commercial air conditioning systems, excluding room units, include chiller systems, packaged direct expansion (DX), and variable refrigerant flow (VRF) systems. Non-refrigerant-based cooling technologies like fans and air coolers are extensively used in residential and small to medium commercial spaces and warehouses. Fans and coolers are expected to maintain a significant share in upcoming years, resembling all commercial AC systems combined. Not-in-kind technologies, such as thermal energy storage, radiant cooling, district cooling, etc., are gradually making inroads into the space cooling segment, further diversifying air conditioning options.

The energy consumption associated with cooling has also skyrocketed, posing challenges to sustainability and exacerbating environmental degradation. Energy utilization within buildings stems from various appliances

that cater to human needs and comfort. Residential and commercial buildings collectively contribute 30% to India's total electricity consumption, with 45% attributed to space cooling and HVAC applications in residential buildings (Gupta et al., 2023). Notably, most energy expenditure is directed towards maintaining thermal comfort conditions in residential buildings. Consequently, there has been a notable surge in greenhouse gas (GHG) emissions associated with the building sector. Considering the projected growth in the space cooling sector, adhering to the existing Business-As-Usual (BAU) policies for buildings could result in a staggering 700% increase in building energy consumption and GHG emissions by 2050 compared to 2005 levels as per the Global Buildings Performance Network (GBPN). The exponential growth will also give rise to the heat island effect, which will highly impact the most vulnerable sector, i.e., the economically weaker section of society. This escalation poses a looming threat of heat-related health repercussions in the future. These consequences are deteriorating public health conditions, diminished workforce efficiency, and compromised air quality. In recent years, this alarming projection has sparked researchers' interest in achieving net-zero energy or emission buildings.

Efforts are underway to mitigate the escalating energy demand in buildings and the consequent emissions by adopting proactive measures. These measures include embracing passive cooling technologies, integrating green building principles, deploying energy-efficient equipment, adopting building energy efficiency codes, and maximizing renewable energy utilization.

Annual per capita electrical energy consumption has risen from 631.4 kWh in 2006 to 1010 kWh in 2015. It is projected to reach 2750 kWh by 2050, which could be anticipated to be curtailed to 1170 kWh per household by implementing stringent policies and various energy conservation strategies (Rawal & Shukla, 2014). Building space per capita is expected to increase from 1.8 m2 to 35 m2 for residential and from 0.7 m2 to 5.9 m2 for commercial buildings by 2047. Industrial sector growth will further drive commercial building space expansion, expected to reach 1932 million m2 with 66% yet to be constructed.

Addressing the diverse cooling needs of India's population requires a holistic approach that integrates technological innovation, policy interventions, and community engagement. The climatic diversity necessitates adaptable and region-specific cooling solutions to ensure comfort and well-being. Sustainable cooling solutions must prioritize energy efficiency, affordability, and inclusivity, catering to the needs of both urban and rural populations. Embracing indigenous knowledge and passive cooling techniques alongside advanced technologies can optimize comfort while minimizing environmental impact.

KEY PRIORITY SECTORS

Addressing the diverse needs of India's population requires a holistic approach to cooling that accounts for varied climatic conditions, cultural preferences, and socio-economic disparities. Sustainable cooling solutions must prioritize energy efficiency and embrace inclusivity and affordability. In urban and rural settings, initiatives to enhance cooling comfort must be tailored to local contexts, leveraging indigenous knowledge and innovative technologies. The India Cooling Action Plan (ICAP) has delineated sector-wide priorities and intervention pathways. Therefore, concerted action is necessary to embrace an integrated approach to foster energy-efficient and environmentally friendly cooling systems. The Indian cooling sector is witnessing a paradigm shift towards sustainable and economically viable technologies. From passive cooling techniques, such as natural ventilation and shading, to cutting-edge refrigeration systems powered by renewable energy sources, a spectrum of options exists to meet diverse cooling needs. Embracing technologies with low environmental impact, such as hydrocarbon refrigerants and evaporative cooling systems, holds promise for reducing carbon emissions and enhancing energy efficiency.

Achieving sustainability in the cooling sector requires a multifaceted approach that addresses both demand-side and supply-side challenges. This entails reducing the cooling load through sustainable architectural designs, improving the efficiency of cooling appliances through stringent energy performance standards, and transitioning towards low or zero GWP refrigerants to mitigate environmental impact. Policy interventions, industry collaborations, and consumer awareness initiatives are essential to drive systemic change and foster a transition toward a decarbonized cooling sector.

ADAPTIVE THERMAL COMFORT STANDARD

Adaptive thermal comfort strategies allow for higher temperature set points, with research showing that occupants express comfort at temperatures higher than those mandated by Indian codes. For instance, residential apartments exhibit comfort ranges between 26 °C and 32°C, while naturally ventilated and air-conditioned office buildings range between 28°C and 26°C. This finding challenges conventional norms and underscores the significance of behavioral adaptation in achieving thermal comfort.

Adaptive comfort models offer a pathway to reduce energy consumption by operating buildings at more moderate temperatures. Energy consumption can be significantly reduced by rigorously avoiding the need to maintain specific comfort conditions through mechanical systems. Increasing indoor temperatures during summer months decreases reliance on cooling systems and reduces overall cooling demand. Implementing higher set point temperatures in summer presents promising energy conservation opportunities, aligning with sustainable building design and operation principles. Thus, embracing adaptive thermal comfort strategies enhances occupant well-being and contributes to the broader goal of energy efficiency in cooling systems across India.

PASSIVE BUILDING DESIGN STRATEGIES

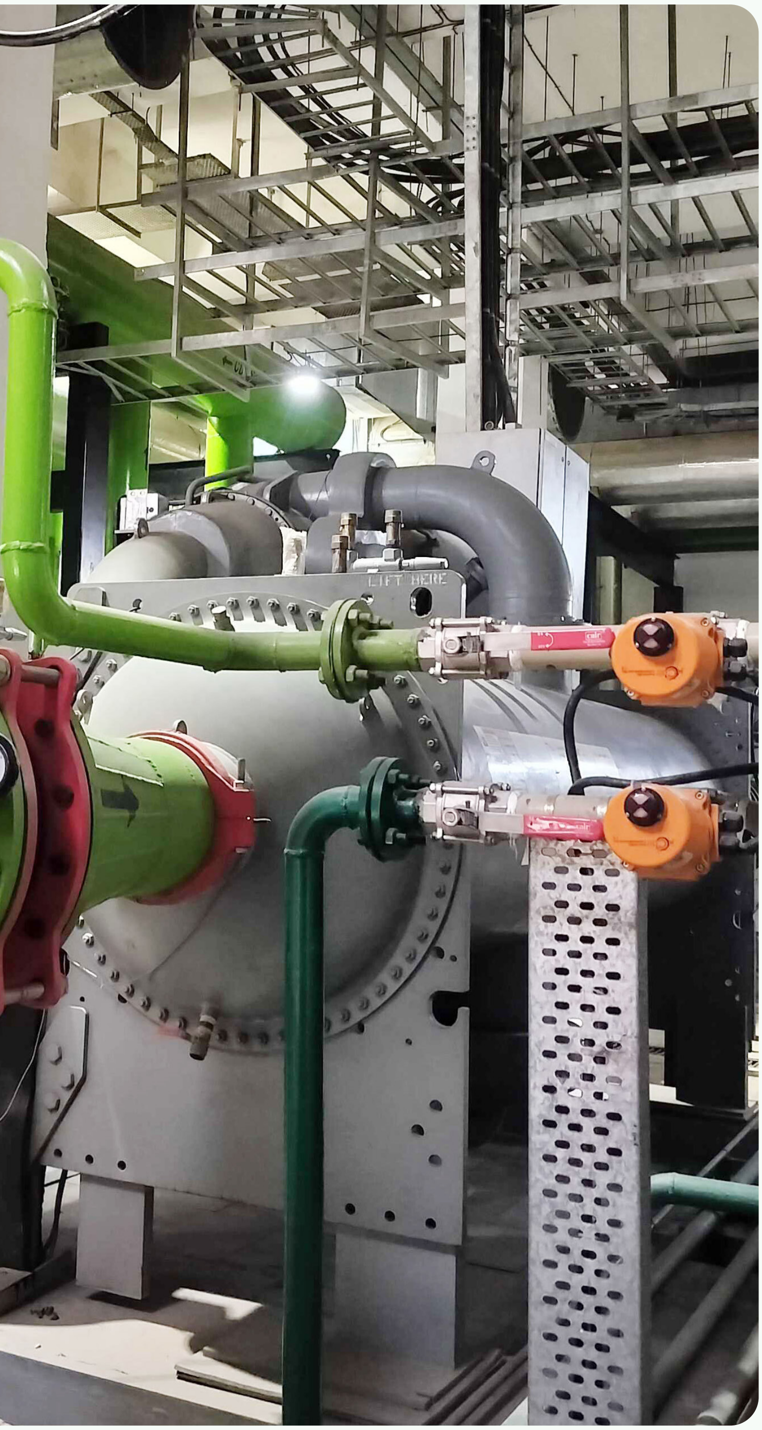
Passive design strategies, i.e., those that do not depend on any mechanical and/or energy-based system, emerge as a versatile solution to curtail energy demands for achieving thermal comfort within buildings, particularly in regions like India, known for their diverse climatic landscapes. Representing a sustainable alternative to conventional cooling systems, it champions energy efficiency in building operations (Panchabikesan et al., 2017). A recent report by MoEF&CC (2022), titled "Passive and Low-Energy Cooling Strategies for Achieving Thermal Comfort in India's Upcoming Affordable Housing," casts a spotlight on a myriad of passive cooling technologies tailored to India's varied climatic conditions (MoEF&CC, 2022). Delving deeper, the report meticulously prioritizes passive strategies, offering a comprehensive assessment of nine fundamental techniques, including building orientation, wall-to-window ratio (WWR), window shading, glazing, cross ventilation and night flush, ventilation, wall materials, envelope insulation, roof material/techniques. These strategies are then methodically categorized into three groups based on their relevance and urgency, which factor in cooling load and cost considerations. Recommendations are meticulously prioritized, reflecting their potential to strengthen building energy efficiency within specific climatic contexts.

Moreover, the report delves into envelope materials, emphasizing the most fitting options. Autoclaved aerated concrete (AAC) and hollow blocks are considered suitable for all climates, whereas materials such as clay bricks, cellular concrete, and fly ash are suggested for most climates. These prioritized groupings and rankings aim to guide stakeholders in fostering building sustainability initiatives.

SUSTAINABLE BUILDING CODES

The Indian government has taken significant strides in advancing green building initiatives by formulating and revising policies to integrate green building principles. It is imperative to enact policies mandating existing and new buildings to adhere to green building standards while establishing relevant laws and regulations to ensure effective implementation. Key initiatives like the India Cooling Action Plan (ICAP), along with the National Building Code (NBC) of India and the Energy Conservation Building Codes (ECBC), aim to promote the construction and utilization of sustainable, energy-efficient buildings. The Energy Conservation Building Code (ECBC), launched by the Bureau of Energy Efficiency (BEE) under the Ministry of Power, Government of India, sets forth minimum requirements for energy-efficient building design and construction. State governments and urban local bodies oversee its adoption, implementation, and enforcement. Approximately 23 states in India are in various stages of mandating ECBC, reflecting the widespread construction activities nationwide. Establishing green building cells at the urban local bodies level and high-level green building committees further reinforces promoting and adopting energy-efficient and green buildings across cities. City assessments based on these measures result in progressive star ratings, reflecting their commitment to green building initiatives. Through adopting green building codes and voluntary green building rating systems, efforts are underway to make buildings and the built environment more environmentally friendly and sustainable.

The code offers prescriptive and performance-based compliance paths, mandating minimum requirements for building envelopes and energy systems, including lighting, HVAC, and electrical components. Additionally, the Eco Niwas Samhita (ENS) Code, developed by the BEE, extends energy-efficient standards to residential buildings on plots of 500 m2 or more. Split into two parts, Part 1 focuses on setting minimum standards for building envelope performance to control heat gains and losses, ensuring adequate natural ventilation and daylighting. Part 2, launched in 2021, extends these standards to electro-mechanical equipment for building operations, renewable energy generation, building services, indoor electrical end-use, and parameters related to building envelope materials and structural systems. These codes collectively aim to promote energy efficiency in building construction across India. Further, a draft of the Energy Conservation and Sustainable Building Code (ECSBC) is under review to enhance the efforts to make the building more energy efficient.



ENERGY EFFICIENT EQUIPMENT

Energy performance labeling is a highly effective policy tool for enhancing energy efficiency and reducing energy costs for consumers. This encompasses defined test protocols and target limits on energy performance. Labels provide consumers with essential information to make informed purchases, with two main types: comparative labels allow consumers to compare energy consumption among similar products. In contrast, endorsement labels certify highly energy-efficient products. These labels can stand alone or complement energy standards, serving as a benchmark for energy efficiency. The success of energy labels relies on effective presentation and support through information campaigns and financial incentives. In India, the Standards and Labeling (S&L) program assigns star ratings ranging from 1 to 5 based on energy efficiency, with an endorsement label available for select products. Technical committees of experts and stakeholders oversee the program's implementation, ensuring representation from various sectors. Launched in May 2006 by the Bureau of Energy Efficiency (BEE), the program covers 28 appliances and aims to reduce energy consumption without compromising consumer needs. Products like room air conditioners, refrigerators, lamps, lights, televisions, etc., are currently part of this initiative.

Designing an HVAC system requires selecting equipment to meet comfort requirements at the lowest lifecycle cost. It is crucial as it determines energy efficiency and changes post-installation can be costly. A well-designed system integrates components for maximum efficiency. Right-sizing equipment based on heat load calculations and considering building design, use, location, and climate is essential. Compliance with the Energy Conservation Building Code ensures equipment efficiency. Emphasizing energy-efficient HVAC technology is critical in system selection.

ALTERNATIVE COOLING TECHNOLOGIES

Today, recent advancements in HVAC technology, such as Variable Refrigerant Flow (VRF) systems, provide precise control over heating and cooling in different building zones, enhancing energy efficiency and personalized comfort. Smart thermostats and building automation systems utilize sensors and AI algorithms to optimize energy usage and indoor air quality. In contrast, energy recovery ventilation (ERV) systems recover heat and humidity from exhaust air to improve energy efficiency. Active cooling systems, like ACs, significantly contribute to energy consumption and greenhouse gas emissions due to their widespread use. However, the higher costs associated with purchasing and operating ACs pose affordability challenges for many households.

The India Cooling Action Plan (ICAP) projects that a significant percentage of households will still be unable to afford ACs in the coming decades. In response to these challenges, there is a growing need to identify and implement low-energy alternative cooling systems that are both affordable and environmentally friendly. These technologies utilize various methods, such as heat sinks and energy-consuming components like fans or pumps, to achieve cooling and thermal comfort. They are selected based on their minimal energy use, lesser emission of greenhouse gases, and suitability for climatic conditions. Among the numerous available strategies, they can be prioritized based on their applicability, affordability, scalability, and market potential.

One such strategy is using energy-efficient fans, particularly those powered by brushless direct current (BLDC) technology. These fans offer significant energy savings compared to conventional models, making them an attractive option for residential use. Another promising approach is using evaporative air coolers, which harness the cooling power of water evaporation. Evaporative coolers come in various types, including direct, indirect, and two-stage models, each offering unique advantages and suitability for different climatic conditions and building types.

Additionally, ground temperatures remain relatively constant a few feet below the earth's surface, typically between 20-27°C in India. Geothermal heat pumps utilize this stable temperature by exchanging heat with the ground through a buried system of pipes called a ground heat exchanger. In winter, the pump extracts heat from the ground and transfers it indoors. The process is reversed in summer, with indoor heat transferred to the ground. This system also provides free hot water. Geothermal heat pumps are highly efficient, saving energy, reducing costs, and minimizing air pollution, making them suitable for many regions in India.

By promoting the adoption of these low-energy cooling strategies, India can mitigate the environmental impact of traditional ACs while ensuring thermal comfort for its citizens, especially the most vulnerable. These aim to create a more sustainable and resilient built environment for future generations.

ADOPTING ALTERNATIVE REFRIGERANTS

Vapor compression refrigeration (VCR) systems have long dominated the air conditioning sector due to their versatility, maturity, and ease of use. As per the ICAP, the consumption of refrigerants required for space cooling is projected to increase from ~70 million tonnes of refrigeration (TR) in 2017-18 to ~245 million TR in 2027-28, out of which 85% of the demand is expected to be from RACs. These systems typically employ halocarbons like HCFCs and HFCs as refrigerants. HCFCs are ozone-depleting substances (ODS) with high global warming potential (GWP). HFCs do not contribute to ozone depletion but can have significant GWP, contributing to direct atmospheric emissions. India, a signatory to the Montreal Protocol, has phased out CFCs and is now tackling HCFCs through a phased approach. The latest, HCFC phaseout management plan-III (HPMP-III), aims to eliminate all HCFC production and consumption by 2030, including the widely used R22 refrigerant. Additionally, India ratified the Kigali Amendment to phase down the use of HFCs, committing to reducing HFC production and consumption in four steps, starting from 2032, to achieve an 85% reduction by 2047 compared to 2024 levels. Amendments to existing regulations are underway to align with the Kigali Amendment, ensuring India's compliance and facilitating the transition to more sustainable refrigerants.

Low-GWP natural refrigerants are promising for climate-friendly cooling but remain underutilized. There are alternative refrigerants with lower or near-zero Global Warming Potential (GWP), including hydrocarbons like propane (R-290) and isobutane (R-600a), ammonia (R-717), carbon dioxide (R-744), and new hydrofluoro-olefin (HFO) refrigerants such as R-1234yf and R-1234ze(E) and their blends. Initiatives like the ICAP and safety standards from the Bureau of Indian Standards (BIS) support their adoption. However, challenges persist, such as low consumer awareness, high initial costs, retrofitting difficulties, and safety concerns. Economic incentives, technology support, education, and policy action are needed to promote their uptake. Despite ongoing refrigerant transitions, HFCs still dominate the market, driven by cost considerations. Overcoming these barriers requires concerted efforts from industry, policymakers, and consumers alike.

CONCLUSION

As India grapples with the challenges posed by climate change and escalating temperatures, the imperative to develop sustainable and inclusive cooling solutions has never been more pressing. By harnessing technological innovation, policy interventions, and community engagement, India can pave the way toward a decarbonized cooling sector that prioritizes environmental stewardship, social equity, and economic prosperity.

REFERENCES:

Panchabikesan, K., Vellaisamy, K., & Ramalingam, V. (2017). Passive cooling potential in buildings under various climatic conditions in India. Renewable and Sustainable Energy Reviews, 78, 1236-1252.

Rawal R, Shukla Y. (2014). Residential buildings in India: Energy use projections and savings potentials. A report by Centre for Environmental Planning and Technology (CEPT) University and Global Buildings Performance Network (GBPN).

Gupta, S. K., Chanda, P. R., & Biswas, A. (2023). A 2E, energy and environment performance of an optimized vernacular house for passive cooling-Case of North-East India. Building and Environment, 229, 109909.

MoEF&CC, (2022). Passive and low energy cooling strategies for achieving thermal comfort in India's upcoming affordable housing. Ozone Cell, Ministry of Environment, Forest & Climate Change Government of India. https://ozonecell.nic.in/wp-content/uploads/2022/09/3-Passive-and-low-energy-cooling-strategies.pdf

ECBC (2017). Energy Conservation Building Code, 2017. Bureau of Energy Efficiency, Ministry of Power (MoP), Government of India. https://beeindia.gov.in/en/energy-conservation-building-code-ecbc#:~:text=The%20Energy%20Conservation%20Building%20Code%20(ECBC)%20sets%20minimum%20energy%20standards,design%20strategies%20%26%20day%20light%20Integration.

MoEF&CC, (2019). India Cooling Action Plan. Ozone Cell, Ministry of Environment, Forest & Climate Change Government of India. https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf

ABOUT INDIA COOLING COALITION

Knowledge Sharing

Endorse

Act

India Cooling Coalition (ICC) is a growing multi-stakeholder group of organizations led by representation from non-profits, academic and research institutions, and industry associations engaged extensively in sustainable cooling research and application. The Coalition aims to fast-track the implementation of the India Cooling Action Plan (ICAP) to ensure thermal comfort, health, and food security for all through knowledge exchange and policy interventions. It serves as a national platform for dialogue with diverse stakeholders, recommending policy initiatives to ensure the success of government programs while advocating for affordable and sustainable cooling for all, aligned with national and international commitments such as the Kigali Amendment, the Paris Agreement, and the Sustainable Development Goals. 23 organizations are members of this coalition at present.

INDIA COOLING COALITION

www.indiacoolingcoalition.org

011 4123 5600

info@indiacoolingcoalition.org