THERMAL COMFORT FOR ALL

Sustainable and Smart Space Cooling

SHAKTI SUSTAINABLE ENERGY FOUNDATION

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clasp

Prayas (Energy Group)

SMART JOULES

Alliance for an Energy Efficient Economy

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Table of Content

List of Figures

List of Tables

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GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST &
CLIMATE CHANGE

FOREWORD

In 2015, India framed Nationally Determined Contributions (NDCs) based on Honourable Prime Minister Shri Narendra Modi's vision for a sustainable lifestyle and climate justice to protect the poor and vulnerable from adverse impacts of climate change. The NDCs are centred around India's various policies and programmes including promotion of clean energy, enhancement of energy efficiency, development of less carbon intensive and resilient urban centres and others.

GHG emissions from the building sector have more than doubled since 1970 to reach 9.18 GtCO2eq in 2010. In 2010, the building sector accounted for approximately 32 per cent of global final energy consumption and 19 per cent of energy-related GHG emissions (including electricity-related). Many of the modern buildings are highly energy intensive. Producing one tonne of cement releases roughly one tonne of CO2 to the atmosphere.

Global CO2 emissions from electricity and heat generation sector allocated to residential end-use contributed to 11 per cent of the total emissions in 2012. It is estimated that in developed countries, for most people, the highest emissions are from energy used to heat or cool homes.

India has a history of low carbon footprint and lifestyle which needs to be encouraged.

Decarbonisation can be effected by making sustainable changes to lifestyle by modifying consumption behaviour, using green and low GWP refrigerants and becoming energy efficient.

The Thermal Comfort for All – Sustainable and Smart Space Cooling Report prepared by the Sustainable and Smart Space Cooling Coalition of 12 organizations is timely and provides a holistic view for sustainable space cooling. The report advocates adoption of Lean Mean Green approach to energy efficient space cooling and providing affordable thermal comfort to all. The report also substantively covers green refrigerants under the Green construct is directly aligned with India's stated commitments to work with companies and technology providers to identify natural refrigerants that can address India's growing active cooling requirement. The space cooling strategies have significant potential reduce cooling demand and also reduce electricity demand by at least 50% by 2030 with just peak load savings potential of 50 GW or ₹3,25,000 crores. The reduced power demand and greenhouse gas emissions contribute to NDC goals under the Paris Climate Agreement and other high level international agreements like SE4LL, Mission Innovation and others.

The key message the report conveys is the necessity to make paradigm shift from 'adaptive thermal comfort' to 'thermal comfort for all'. This is a direct response to India's focus on sustainable development and behavioural changes as it addresses climate change mitigation efforts. The Ministry of Environment, Forest and Climate Change endorses the 'Thermal Comfort for All' as a guide for policy makers and practitioners alike.

(Anil Kumar Jain)

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Preface

Alliance for an Energy Efficient Economy (AEEE), with support from Shakti Sustainable Energy Foundation (SSEF), has taken the initiative in bringing together research and academic institutions, industry associations, and non-profit organisations, to form the Sustainable and Smart Space Cooling Coalition. The Coalition's mission is to lead India's transition to a sustainably cooled built environment with the objective of providing thermal comfort for all by supporting advanced research, analysis, joint policy recommendations and facilitating market transformation.

The Coalition strives to provide a national platform for dialogue with various stakeholders and jointly recommend policy initiatives to ensure the success of government programmes on smart cities, smart grid, housing, buildings and universal access to power while ensuring affordable and sustainable thermal comfort to all. With an underlying theme of thermal comfort for all, the Coalition works to comprehensively address aspects of space cooling through: energy efficient building design and construction; energy conserving and thermal comfort enhancing technologies and market transformation strategies; and low-energy and green air-conditioning technologies.

The Coalition comprises the following twelve members. The members' domain expertise in space cooling enables the Coalition to engage with multiple stakeholders including leading businesses and policy makers.

- Shakti Sustainable Energy Foundation (SSEF)
- Council on Energy, Environment and Water (CEEW)
- CEPT University
- Collaborative Labelling and Appliance Standard Program (CLASP)
- Fairconditioning
- ICLEI - Local Governments for Sustainability, South Asia (ICLEI)
- Indian Society of Heating, Refrigerating and Air-conditioning Engineers (ISHRAE)
- Malaviya National Institute of Technology (MNIT)
- Natural Resources Defense Council (NRDC)
- Prayas (Energy Group)
- Smart Joules
- Alliance for an Energy Efficient Economy (AEEE)

Shakti as one of the founding members, is providing financial support and strategic inputs for the functioning of the Coalition. AEEE, as the other founding member, acts as the nodal organiszation coordinating all activities and facilitating interaction amongst Ccoalition members.

As one of the initial tasks in the drive for Thermal Comfort for All, the Coalition members have jointly prepared this report with a twofold intent: (1) to bring together dispersed sustainable and smart space cooling strategies, as well as the independent initiatives from the government and the private sector; and (2) to propose a set of recommendations designed to promote the vision of thermal-comfort- for-all through the use of energy efficient and environmentally sustainable cooling strategies and technologies.

Satish Kumar
Executive Director (Interim), AEEE

About the Coalition Members

Shakti Sustainable Energy Foundation (SSEF)

Shakti works to strengthen the energy security of India by aiding the design and implementation of policies that support renewable energy, energy efficiency and sustainable transport solutions. The Foundation's buildings sector goal is that by 2030, enabling policy mechanisms to exist and drive energy efficiency actions. To achieve these goals, the Foundation is supporting design and implementation of regulatory and market mechanisms to foster efficiency opportunities in building design, comfort conditioning and end use appliances.

India's building sector is forecasted to grow three to fivefold during 2005-30, and this is likely to translate into similar growth trends in energy consumption. Better comfort expectations and rising average temperature all over the country are driving the demand for Indoor Space Cooling, and this, in turn, is causing the burgeoning energy demand.

Recognising this need to address indoor space cooling demand sustainably, the Foundation has developed a space cooling strategy that brings together interrelated components from the buildings and appliances efficiency areas. This strategy recognizes the need to form a civil society coalition that will consolidate varied technical work, support holistic action, and more meaningfully engage with key policy making bodies i.e. the Bureau of Energy Efficiency, National Institution for Transforming India Aayog, Ministry of Urban Development, Housing and Urban Poverty Alleviation, State Energy Departments, State Urban Development Departments, State Nodal Agencies for Energy Efficiency, State Electricity Regulatory Commissions (SERCs), Urban Local Bodies, etc.. To achieve this objective, the Foundation has supported the creation of the Sustainable and Smart Cooling Coalition that brings together think tanks, research organizations and universities. The Alliance for Energy Efficient Economy acts as the Secretariat of the Coalition.

Council on Energy, Environment and Water (CEEW)

CEEW is one of South Asia's leading policy research institutions. CEEW addresses pressing global challenges through an integrated and internationally focused approach. In 2017, CEEW has once again been featured extensively across nine categories in the '2016 Global Go To Think Tank Index Report', including being ranked as South Asia's top think tank (14th globally) with an annual operating budget of less than US$5 Million for the fourth year running. In 2016, CEEW was also ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings. CEEW has been working on issues related to transition away from high GWP refrigerants since 2012 and has been advising the Government of India on this issue. Among its other work, CEEW has modelled India's long-term hydrofluorocarbon emissions across sectors as well the potential cost of transitioning away from these. Currently CEEW is working on understanding the challenges of the refrigerant servicing sector as well as institutionalising research and development for alternatives to high GWP HFCs.

CEPT University

CEPT University is one of the premier academic institutions in the field of Human Habitat in India and is recognized as a Scientific and Industrial Research Organization (SIRO) by the Department of Scientific and Industrial Research (DSIR), Government of India. Centre for Advanced Research in Building Science and Energy (CARBSE) at CEPT, is one of the six research centres at CEPT University with approx. 22 Full-time Research staff and has the best infrastructure in India for R&D in building energy efficiency.

Research focusses on energy efficient building design, energy efficient building construction processes, thermal comfort, low energy cooling technology, environment friendly construction materials and resource audit and management. CARBSE is a USAID ECO-III ‘Regional Energy Efficiency Centre on Building Energy Efficiency’, a ‘Centre of Excellence’ of the Indian Ministry of New and Renewable Energy, and a Centre for Excellence in Green Energy and Efficiency for the Government of Gujarat.

CARBSE has led, or been a partner in, more than twenty-five successful international collaborative R&D projects including a recent project with Loughborough University, Oak Ridge National Lab, Oxford Brooks Uni and UC Berkeley. Most notably, CARBSE is the India lead for the prestigious US-India Joint Centre for Building Energy Research and Development (CBERD) partnership with Lawrence Berkeley National Lab. This is the largest R&D project the Government of India (GOI) has ever supported in the field of building energy-efficiency research over five years (2012-2017).

Collaborative Labelling and Appliance Standard Program (CLASP)

CLASP improves the environmental and energy performance of the appliances and related systems we use every day, lessening their impacts on people and the world around us. CLASP develops and shares transformative policy and market solutions in collaboration with global experts and local stakeholders.

Founded in 1999, CLASP has worked in over 50 economies on 6 continents, and is the leading international resource for improving energy efficiency in commonly used appliances, lighting, and equipment. CLASP partners with policymakers, manufacturers, utilities, and other stakeholders on all aspects of appliance energy efficiency program and policies.

For over fifteen years, CLASP has been supporting Bureau of Energy Efficiency (BEE) in the design and implementation of standards and labelling program. CLASP’s support to BEE includes strategic advice on all aspects of standards and labelling program including technical, institutional capacity building for administration and implementation of the program.

CLASP carried out comprehensive market and technical analysis for various categories of room and commercial air conditioners to provide policy recommendations to BEE for formulation of labelling program, notably Inverter ACs. CLASP also carried out a study on the incremental cost of efficiency improvements for air conditioners and led the design of an Air Conditioner Challenge program in India. CLASP is currently supporting BEE for formulating a program for Chillers and Variable refrigerant flow (VRF) ACs.

Fairconditioning

The ‘Fairconditioning’ Programme is a demand side management research, analysis, outreach and pilot implementation programme related to behavioural transformation and reduction of heat loads (cooling demands) and reduction of energy and GHG intensity to satisfy the remaining demand as efficiently as possible. The program is organized into four sub-projects that focus on transforming architecture and engineering college curricula (Academic Curricula Integration Project, ACIP), capacity building to default sustainably-cooled building design in architecture and HVAC engineering firms (Building Energy Modelling Project, BEMAP), corporate technology adoption (Technology Adoption Project, TAP), and corporate behaviour change (Corporate Thermal Comfort Policies Campaign Project, UpBy2) with the legacy of establishing a sustainable cooling ecosystem and driving evidence-based policy-change. It is funded by the Shakti Sustainable Energy and OAK Foundations.

ICLEI - Local Governments for Sustainability, South Asia (ICLEI)

ICLEI South Asia has initiated a project on 'Renewable Energy and Energy Efficiency in Buildings & Cities: Assessing Potential for District Energy Systems (DES) in Indian Cities' with United Nations Environment Programme (UNEP) under their District Energy in Cities Initiative.

The initiative was launched to provide technical assistance and undertake capacity building activities for local governments and stakeholders in India to develop a replicable modern district energy approach, particularly for district cooling that can be scaled up in the country. The objective of the project is to assist Indian cities to accelerate their transition to low-carbon and climate resilient societies through modern district energy system.

Indian Society of Heating, Refrigerating and Air-conditioning Engineers (ISHRAE)

ISHRAE was founded in 1981 at New Delhi by a group of eminent HVAC&R professionals. ISHRAE today has more than 12,000 HVAC&R professionals as members and additionally there are 7,500 Student-members. ISHRAE operates from 41 Chapters and sub Chapters spread all over India. ISHRAE promotes research in the field of HVAC&R technology. It offers financial support to students, to carry out innovative work on R&D in Technology, Systems and Processes.

Malaviya National Institute of Technology (MNIT)

MNIT is one of 31 Institutes of National Importance set up by the Act of Parliament of India. It was founded in the year 1963. Centre for Energy and Environment at MNIT Jaipur is actively engaged with research related to low energy cooling and thermal comfort studies. The group has been actively working on performance improvement of radiant cooling systems, passive cooling systems, and adaptive thermal comfort studies with respect to Indian conditions. It is also involved with development of Codes and Standards in India.

Natural Resources Defense Council (NRDC)

NRDC is an international non-profit organization, combining 2.4 million members and online activists with the expertise of 500 scientists and other professionals. NRDC is dedicated to research and advocacy activities on global initiatives addressing issues such as climate change, energy, oceans, water, air and health.

Launched in 2009, NRDC's India Initiative partners with local organizations to advocate and implement policy for bridging energy access through renewables and energy efficiency and to strengthen resilience to climate impacts. NRDC has been leading the adoption and implementation of building energy codes and cool roofs with major cities in India. The organization has been effectively working with the air-conditioning industry in developing India's position and strategy on phasedown of HFCs and continues to engage with stakeholders to accelerate the adoption of more efficient and sustainable cooling.

Prayas (Energy Group)

Prayas (Energy Group) works on theoretical, conceptual, regulatory and policy issues in the energy and electricity sectors. Our activities cover research and intervention in policy and regulatory areas, as well as training, awareness, and support to civil society groups. We have contributed to the energy sector policy development as part of several official committees constituted by Ministries and Planning Commission. We are also authorized consumer representatives for the Central Electricity Regulatory Commission (CERC) and several state ERCs. Prayas' work on energy efficiency is focused on promoting rapid implementation of effective energy efficiency policies and programmes in India and building a knowledge base to facilitate the same. Our recent research includes review of regulations and activities on Demand Side Management at state level, compilation of the literature and data on India's residential electricity consumption, and developing a framework for evaluating energy efficiency policies and programmes in India. We also contribute to BEE's technical committee for setting standards and labels for ceiling fans and lighting. We are also on Maharashtra ERC's DSM consultative committee which meets regularly to discuss the progress of current DSM programmes and approve new programmes.

Smart Joules

Smart Joules is an energy efficiency company with innovative technology and service offerings for the commercial buildings segment, and pro-bono programs to catalyse market transformation for sustainable cooling in the residential real estate segment. Smart Joules' Smart HVAC controls technology platform – DeJoule – targets continuous optimization of central air-conditioning systems using self-designed embedded systems hardware, cloud-based software and an Artificial Intelligence platform. On the services side, Smart Joules invests in comprehensive efficiency retrofits and offers guaranteed energy savings to Hospitals and Hotels in return for a fixed percentage of energy savings delivered under their five-year pay as you save contract called JoulePAYS. The company won First Prize in the National Energy Conservation Awards from the Ministry of Power in the Hospitals segment for their first project at Sant Parmanand Hospital, where they are delivering 29% energy savings on a year-on-year & bill-to-bill comparison basis. Smart Joules is now replicating this model in other large hospitals under long-term contract. On the pro-bono side, Smart Joules engages closely with young and sustainably-minded residential real-estate developers to imagine, design and execute catalytic programmatic interventions for sustainable space cooling.

Alliance for an Energy Efficient Economy

AEEE is a policy advocacy and energy efficiency market enabler with a not-for-profit motive. It is the only organisation in India which works on creating awareness about energy efficiency as a resource. It advocates for data driven and evidence-based energy efficiency policies that will unleash innovation and entrepreneurship within the country to create an energy-efficient economy.

AEEE, through a host of collaborative measures, continues to put the spotlight on energy efficiency and support the creation of an energy-efficient India. AEEE works closely with the government, businesses and key national and international agencies across diverse sectors.

Executive Summary

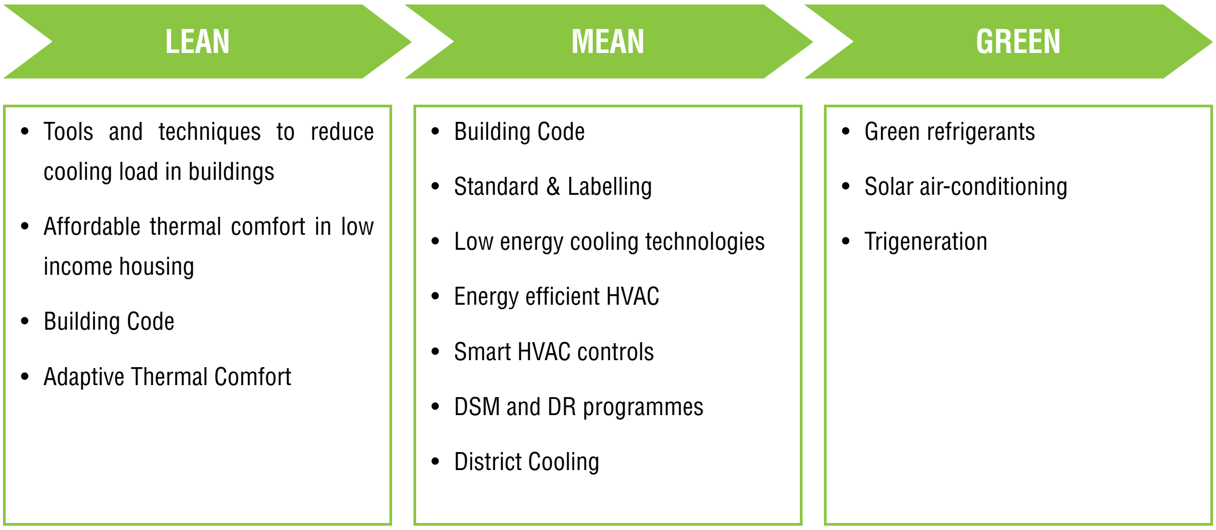
Introduction

India, with a population of 1.3 billion, air conditioner (AC) penetration of less than 10%, annual per capita electricity consumption of merely 1,000 kWh per year, and national average annual cooling degree days (CDD) of approximately 3100, is particularly vulnerable to the adverse impacts of rising temperature. The challenge for India is twofold: Firstly, with extreme heat, areas of high relative humidity, and a significant portion of the population with limited means for active space cooling, how does one provide thermal comfort to all in an affordable and sustainable fashion? Secondly, India is at the cusp of an exponential growth in the AC market (Davis and Gertler, 2015). Under a business as usual scenario, room AC (RAC) penetration is expected to add approximately 150 GW to the peak demand by 2030 (equivalent to 300 large power plants of 500 MW capacity each) (Kumar, 2016). This poses severe adverse impacts – strain on the electric grid, significant additional power generation capacity, peak load impact, and an enormous greenhouse gas (GHG) footprint, both directly through refrigerants and indirectly through electricity use. In addition, it creates indefensible social inequity emerging from the asymmetrically distributed impacts of summertime power outages which denies even the basic thermal comfort available through fans to those sections of society that contribute least to peak AC related demand.

While the building stock in India continues to increase at a rate faster than anywhere in the world (GBPN, 2013) and the AC market braces for a rapid increase in penetration, now is the critical window of opportunity to mitigate adverse societal and environmental impacts through timely policy interventions. In this context, the Sustainable and Smart Space Cooling Coalition was formed with a vision to advance thermal comfort for all.

Smart Space Cooling Strategies

Foundational to the Coalition's work is the lean-mean-green construct popularized by building scientist Bill Bordass (Figure A). A hierarchical approach, lean-mean-green as it applies to smart and sustainable cooling strategies advocates: (1) lean i.e. first,



LEAN	MEAN	GREEN
• Tools and techniques to reduce cooling load in buildings • Affordable thermal comfort in low income housing • Building Code • Adaptive Thermal Comfort	• Building Code • Standard & Labelling • Low energy cooling technologies • Energy efficient HVAC • Smart HVAC controls • DSM and DR programmes • District Cooling	• Green refrigerants • Solar air-conditioning • Trigeneration

Figure A: Lean-Mean-Green: a hierarchical construct for space cooling (Based on the Lean-Mean-Green concept by Bordass et al., 2001) reduce the cooling load through incorporating better building design, (2) mean i.e. next, optimise energy use through energy efficient and low energy measures and efficient performance standards for appliances and (3) green i.e. finally, reduce the carbon footprint to the extent possible through use of clean energy and low global warming potential (GWP) technologies. The impact on energy savings will be most from lean cooling strategies followed by mean methods; green cooling strategies are focussed on reducing the carbon footprint from active cooling.

Latest research has shown that a combination of lean-mean-green strategies for space cooling in India has the potential to reduce electricity demand by at least 50% by 2030 with just peak load savings potential of 50 GW or 3,25,000 crores ($50 billion) (Kumar, 2016). The uniqueness of the report lies in its approach. This report elaborates on the various cooling strategies organised under the lean-mean-green construct, discussing the current body of knowledge, potential challenges, and the wide-ranging benefits including indoor thermal comfort to a larger section of the Indian population, decreasing energy consumption and peak demands, reducing stress on the grid, improving energy security and cutting down on carbon emissions. In addition to the local, societal and environmental good, these benefits also uphold many of the Sustainable Development Goals (SDGs), and closely link with Sustainable Energy for All (SE4ALL) and other global initiatives focused on sustainability and climate change.

The Way Forward

To achieve these benefits, overcome potential barriers, and advance the vision of thermal comfort for all, the Coalition presents a set of recommendations that are directed at the central and state governments as the primary influencers. These recommendations, when implemented, will involve and impact a diverse range of stakeholders – the building industry, manufacturers, consumers, and researchers. These are:

- Establish thermal comfort for all as a government priority to align with GHG reduction goals and ongoing government initiatives and link it with India's ambition to provide a better quality of life to all its citizens. We envision two key ways in which government can support and expand adoption of sustainable and smart space cooling:
    A. Leverage ongoing government initiatives and require designers/architects of government- funded projects (residential or commercial) to design buildings incorporating the principles of lean-mean-green cooling strategies.
    B. Institute comprehensive legislation as a cornerstone to achieve a viable market for smart cooling
- Generate market momentum towards smart cooling through awareness campaigns, access to information and technical assistance.
- Drive adoption of energy efficient building materials into the mainstream through consistent testing and rating protocols, and market transformation strategies.
- Undertake bold actions to phase out hydrofluorocarbons (HFCs) and drive the industry towards green, low GWP refrigerants.

Call to Action

It is important to note that the Coalition's drive for sustainable and smart cooling is not proposed as just another standalone initiative. On the contrary, it is envisioned as, and would be most effective as, a component that is integrated within several of the ongoing government initiatives to maximize their potential benefits. For example, the energy efficient building design and construction strategies, energy conserving technologies, and clean energy alternatives proposed in this report would be very relevant to the following Government of India initiatives: (1) Mission Innovation under which India will see growth of 109 smart cities that provide improved core infrastructure, enhanced quality of life to its citizens, and a clean and sustainable environment,

(2) Housing for All that is poised to build 2 crore houses for the economically weaker sections in urban areas by 2022, (3) National Mission on Sustainable Habitat that envisages a framework to build urban resilience to climate change and (4) National Mission for Enhanced Energy Efficiency that aims to strengthen the market for energy efficiency by conducive regulatory and policy regime and innovative business models.

The Coalition strongly believes that timely and bold interventions to adopt smart cooling strategies into the mainstream will lead towards significant societal, national and environmental benefits. While the path to get there may be challenging, it is one that must be embraced with conviction. The Coalition has laid down the first steps – now is the time for the policy-making entities at the centre – such as Ministry of Power, Bureau of Energy Efficiency (BEE), Department of Science & Technology, Ministry of Environment, Forest & Climate Change, Ministry of Housing & Urban Poverty Alleviation, and Ministry of Urban Development – and relevant state level departments, to embrace the drive for thermal comfort for all and marshal their resources and policies to lead us towards this vision – and in this drive, all the Coalition member organisations stand committed to offer any support per their respective areas of expertise.

1

Introduction

Thermal comfort is defined as the expression of an individual's satisfaction with the thermal environment and is assessed by subjective evaluation. Thermal comfort is affected by environmental factors such as air temperature, mean radiant temperature, air flow and relative humidity and by personal factors such as clothing and activity level. Variations in these factors, such as high temperatures and/or humidity in summer, can affect the thermal equilibrium of the body leading to discomfort. In hot weather, humans achieve thermal comfort by wearing lighter clothing, reducing activity level, opening windows for enhanced natural ventilation and air flow when the outdoor temperature is conducive, and using space cooling equipment such as fans and ACs.

Indoor thermal comfort affects humans psychologically and physiologically. It positively impacts health and productivity and improves the sense of wellbeing (Shaikh et al., 2014). For these reasons, thermal comfort for all should become an important goal for all developing countries. It is closely linked with many SDGs, SE4All and other global initiatives.

When compared to developed countries, developing countries need to surmount larger barriers in attaining proper levels of indoor thermal comfort. Grappling with modest national resources, the disappearing use of traditional and indigenous housing and the pressing need to provide housing to hundreds of millions are some of these challenges. Just like basic heating of dwellings is considered a necessity and a basic human right in the western world, providing affordable thermal comfort should also be a basic human right in the developing and tropical world irrespective of people's social strata – this should not be misconstrued – active cooling is not the end but the means to the end i.e. indoor thermal comfort. Often, houses are not sustainably designed and built, especially in urban conglomerations wherein thermal comfort is neglected. It is also common in India for rural dwellers to move to cities for better economic opportunities invariably leading to dense and increasingly, unsustainable infrastructure. To overcome the urban heat island effect and growing thermal discomfort in typical modern dwellings, the relatively affluent sections of the society, with more disposable income and aspirations of better living, take up active air-conditioning.

Ceiling fans, air coolers and ACs are constantly used to combat uncomfortable ambient conditions for a large part of the year in most places in India. However, relying only on active cooling leads to increased peak demands and overall energy consumption. Figure 1 points towards the magnitude of the cooling problem in India vis-à-vis China and the US.

As reported by CEEW-IIASA, in the business as usual scenario, the use of prevalent cooling solutions will lead to increased electricity demand (Figure 2) – this will cause stresses in the power grid. Presently, demand for cooling is one of the

Climate change is causing increases in the frequency of floods, droughts, and heat waves. Average temperatures across India have risen by more than 0.5°C in 1960-2009, with statistically significant increases in heat waves. This corresponds to a 146% increase in the probability of heat-related mortality events of more than 100 people. A recent study indicates that even moderate increases in mean temperatures from climate warming may cause great increases in heat-related mortality. *(Mazdiyasni et al., 2017).*

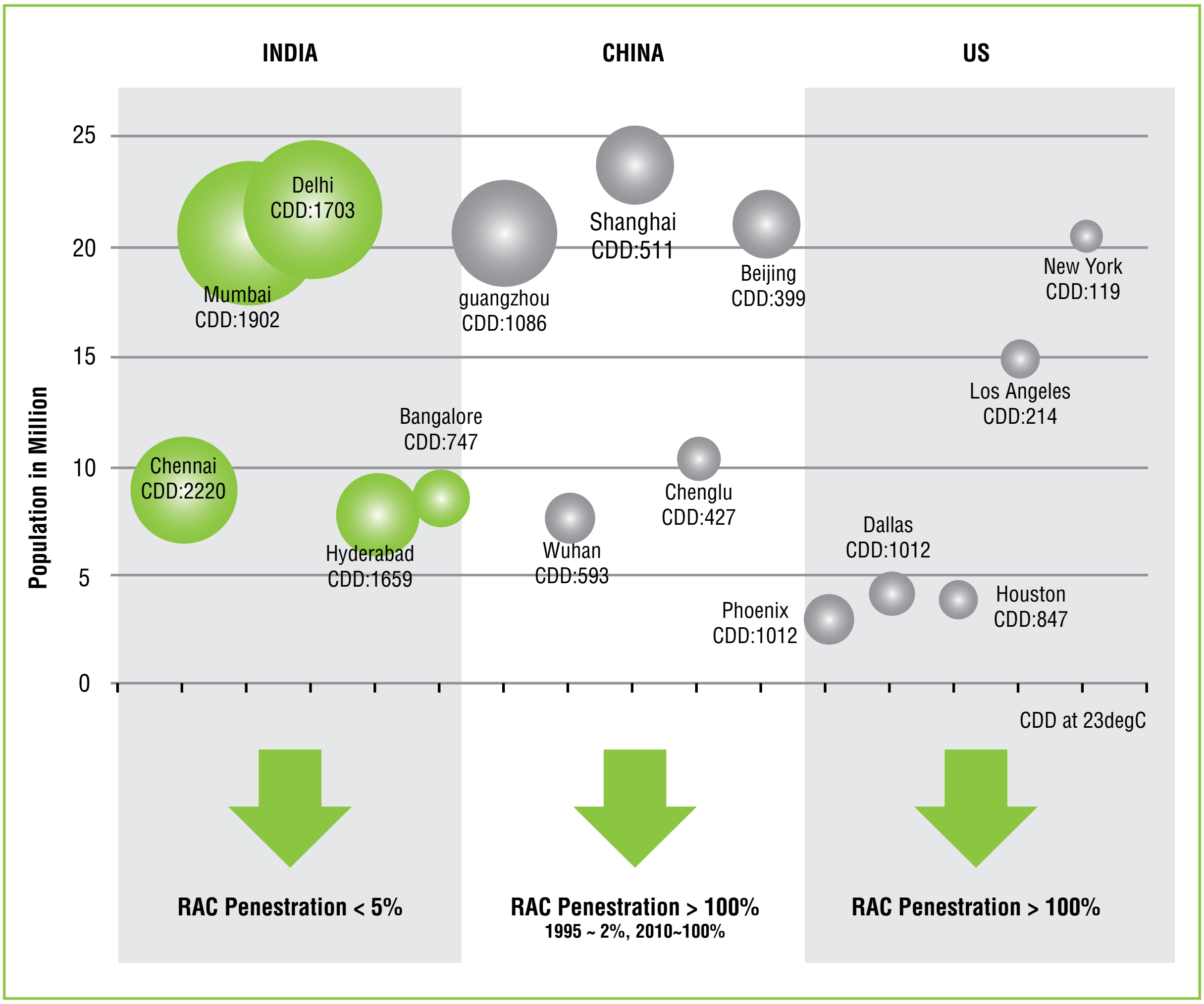


Figure 1: Cooling demand in India, China and the US (selected cities) – size of the sphere corresponds to number of cooling degree days, which is a metric commonly used to quantify cooling demand

largest drivers of power demand, as evidenced by the average daily load in Mumbai and New Delhi in summer versus winter (Figure 3). Considering their precarious financial situation and notwithstanding the positive impact of Government of India's Ujjwal DISCOM Assurance Yojana (UDAY) scheme, many Indian power utilities would find it challenging to deal with peak demand induced by active cooling. In commercial buildings, heating, ventilation and air-conditioning (HVAC) systems can account for 40-60% of the total energy use (LBNL, 2013), putting a heavy drain on enterprises by significantly increasing the operating cost of buildings.

In May 2017, Forbes covered an Lawrence Berkeley National Laboratory (LBNL) international energy specialist's estimate that air-conditioning is expected to double India's electricity demand in 15 years, requiring 200-300 new electric plants. Air-conditioning is part of the reason India is expected to be the world's largest contributor to new electricity demand between now and 2040. Most cities are very hot and very populous – India is home to four of the five most populous cities with the highest cooling, namely, Chennai, Mumbai, Kolkata and New Delhi – which means that going forward, as people get richer, the demand for room air-conditioning will increase. ACs are the first appliance people want to buy when they cross a certain income threshold and millions of Indians are expected to cross that threshold in the next 10 to 15 years (Forbes.com, 2017).

Active cooling of a fraction of India's built space is achieved at the cost of undermining thermal comfort for a vast number of less privileged persons who endure the escalated global effects from a warming planet, and local effects of intensified urban heat island effects stemming from heat rejection from air-conditioned buildings as designers rely more on air-conditioning technology than on the design to reduce or eliminate the need for active cooling. This effect hampers the ability of non air-conditioned spaces to naturally cool down during the night time among other undesirable impacts. In many cases, it also currently uses refrigerants with a high GWP.

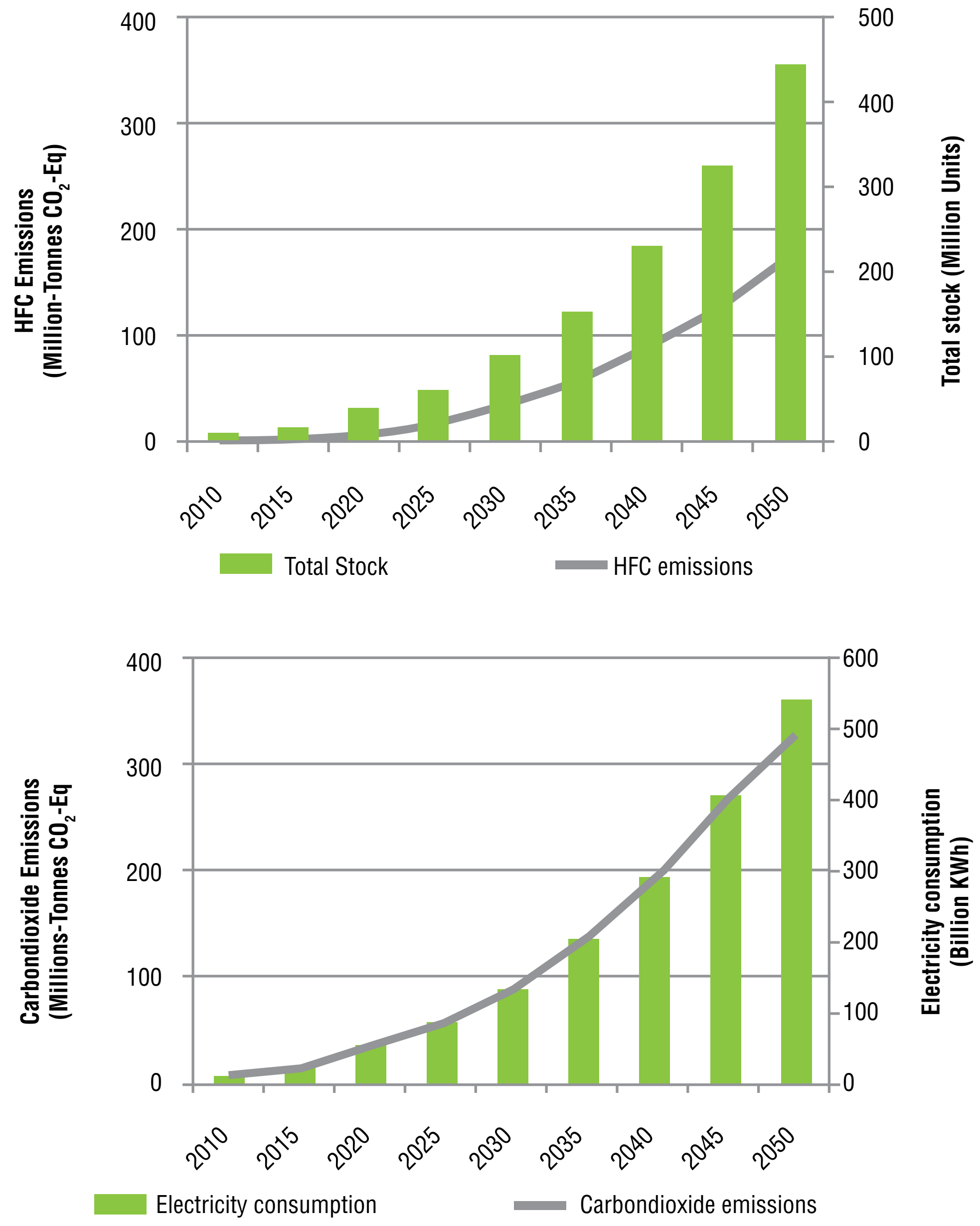


Figure 2: Residential AC stock, electricity consumption and emissions (all-India estimates) (CEEW-IIASA, 2015)

A sustainable and smart space cooling strategy which uses less energy and causes minimal environmental impact must be implemented in India to reap multiple benefits. A strategic dialogue with AC manufacturers is required to advance environmentally friendly and cost-effective cooling technologies. This can be a win-win situation, considering that India is poised to be the largest air-conditioning market in the world in the next 15 to 20 years, given its large population and rising lifestyle aspirations. In this regard, efforts made by Energy Efficiency Services Ltd. (EESL) to aggregate demand and perform bulk procurement of super-efficient room air-conditioners is an innovative idea that can bring best available technology to Indian consumers at affordable prices. To avoid the unintended consequence of indiscriminate use of active air-conditioning because of sharply lower RAC prices, it will be very important to require incorporation of

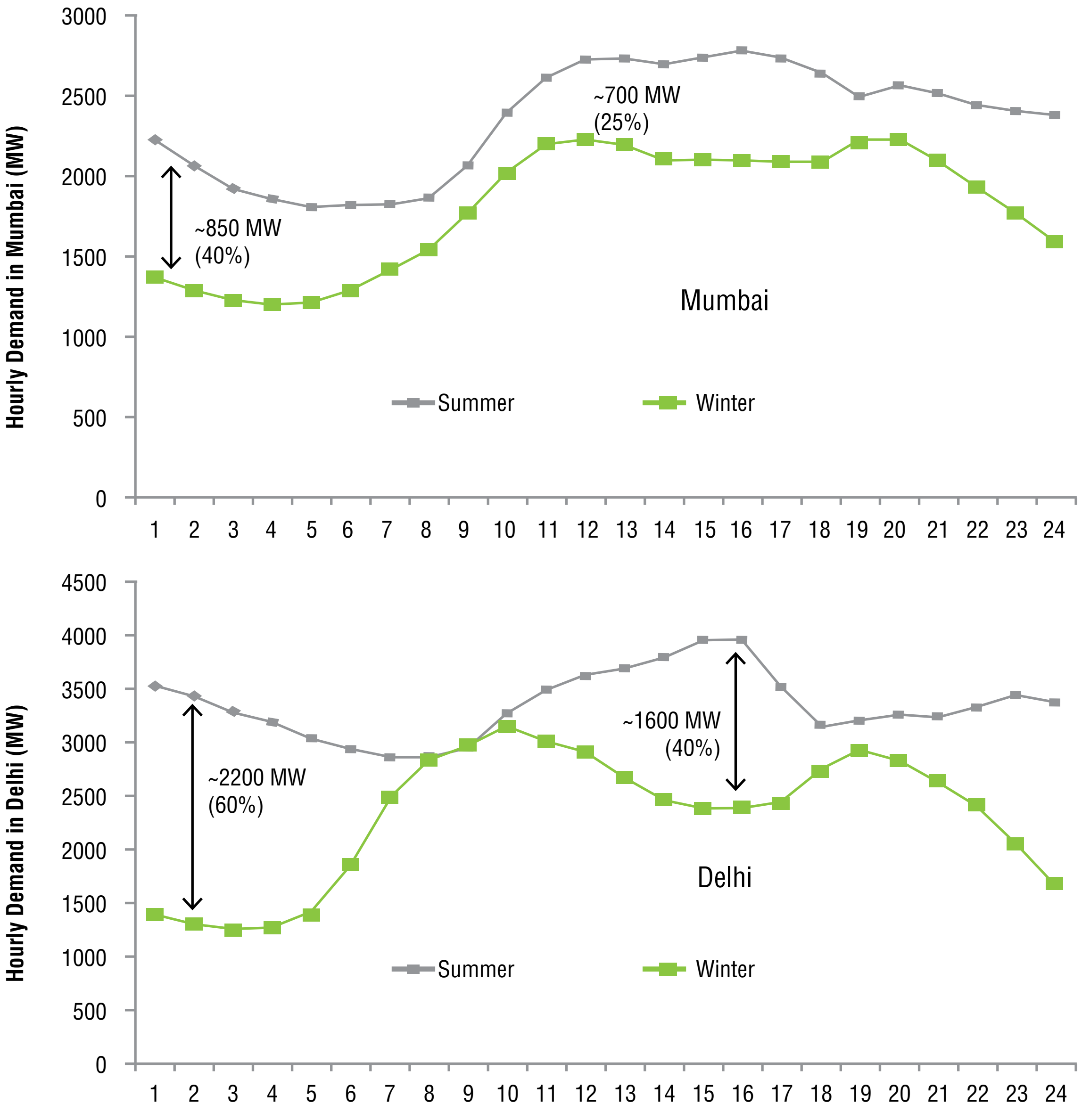


Figure 3: Average daily load curves in Mumbai and Delhi for summer v/s winter (LBNL, 2014)

lean cooling strategies to send a clear signal to the building design, engineering and construction community.

The Sustainable and Smart Space Cooling Coalition has synthesized the existing body of knowledge on sustainable space cooling. The objective of this report is to capture the enormity of the cooling challenge and address it through a holistic approach that includes passive and active cooling methods. This can lead to a cohesive and coherent discourse which will propel smart policy actions to address this pressing challenge which has social, design and construction, energy use and climate change dimensions.

These sustainable and smart space cooling strategies includes lean-mean-green approaches (Bordass et al., 2001). These strategies include several space cooling elements which could be used in combination and leveraged to meet cooling demand. Implementing this strategy has the potential to significantly reduce cooling demand. This would reduce power demand and greenhouse gas emissions and contribute to India's Nationally Determined Contributions (NDCs) goals under the Paris Climate Agreement of 2015. In the more recent Kigali Agreement of 2016, the Government of India moved up the HFC phase-out from 2030 to 2028. It would also be useful to assess the thermal comfort range for Indians – studies have indicated that close to 80% of building occupants in India are comfortable with indoor operating temperatures of 24-28°C (Manu et al., 2016). Designing and operating buildings in this thermal comfort range could enable the adoption of a range of low energy cooling solutions, providing an added benefit from an energy use reduction perspective.

2

Lean-Mean-Green Strategies for Space Cooling

Adoption of a combination of lean-mean-green cooling approach could reduce the electricity used for space cooling in India by as much as 50% by 2030 and up to 70% by 2050 (Kumar, 2016). This can be achieved by advocating and practising the integration of various space cooling elements that fall under the categories of lean-mean-green strategies.

2.1 Lean

Lean strategies can be effectively used to reduce the cooling load of a building. This reduced cooling load can then be met with mean and green cooling strategies.

2.1.1 Tools and Techniques to Reduce Cooling Load in Buildings

Buildings can be lean in energy consumption if they are well designed and adhere to building energy codes. Good building design can reduce heat gains, thereby reducing cooling demand. Experts believe indoor air temperature can be lowered by up to 7°C in summer months by following shading, ventilation and insulation techniques (Lall, 2016). Even in conditions with elevated indoor air temperatures above the classically defined comfort temperature range, establishing a low mean radiant temperature through methods that drain heat from the structure can satisfy thermal comfort requirements. This characteristic of a space enables human bodies to effortlessly achieve thermal equilibrium i.e. the body can spontaneously reject internal body heat from metabolic activity. Building envelope plays a more significant role in small floor plate buildings than in large floor plate ones. Heat gain in buildings is primarily due to conduction, convection and radiation through roofs, walls, windows and doors. Shading, ventilation and insulation are directly linked with these three modes of heat transfer and can form a key aspect of designing buildings from the first principles.

2.1.1.1 Shading and Glazing

Shading reduces internal heat gain through coincident radiation. There are various methods to shade windows – overhangs, awnings, louvres, vertical fins, light shelves and natural vegetation. These can reduce cooling energy consumption by 10-20% (NREL, 2000; Haghighi, Asadi and Babaizadeh, 2015). The shading mechanism can be fixed or movable (manually or automatically) for allowing varying levels of shading based on the sun's position and movement in the sky.

Shading, in combination with high-performance glass with low solar heat gain coefficient (SHGC), can reduce cooling energy consumption even further by cutting down on heat gain through radiation. Glazing is a part of the building envelope which consists of glass window panes. Heat gain through a window happens primarily through conduction and radiation, which can be controlled by properly specifying the U-value and SHGC respectively. A lower U-value and SHGC will lead to smaller heat gains through any fenestration in a building. The Energy Conservation Building Code (ECBC) of India prescribes a range of values for these technical parameters for different climate zones, and window to wall ratios (WWRs), as applicable.

A study on the effects of shading and glazing on residential energy use in a hot-dry climate (NREL, 2000) indicated that

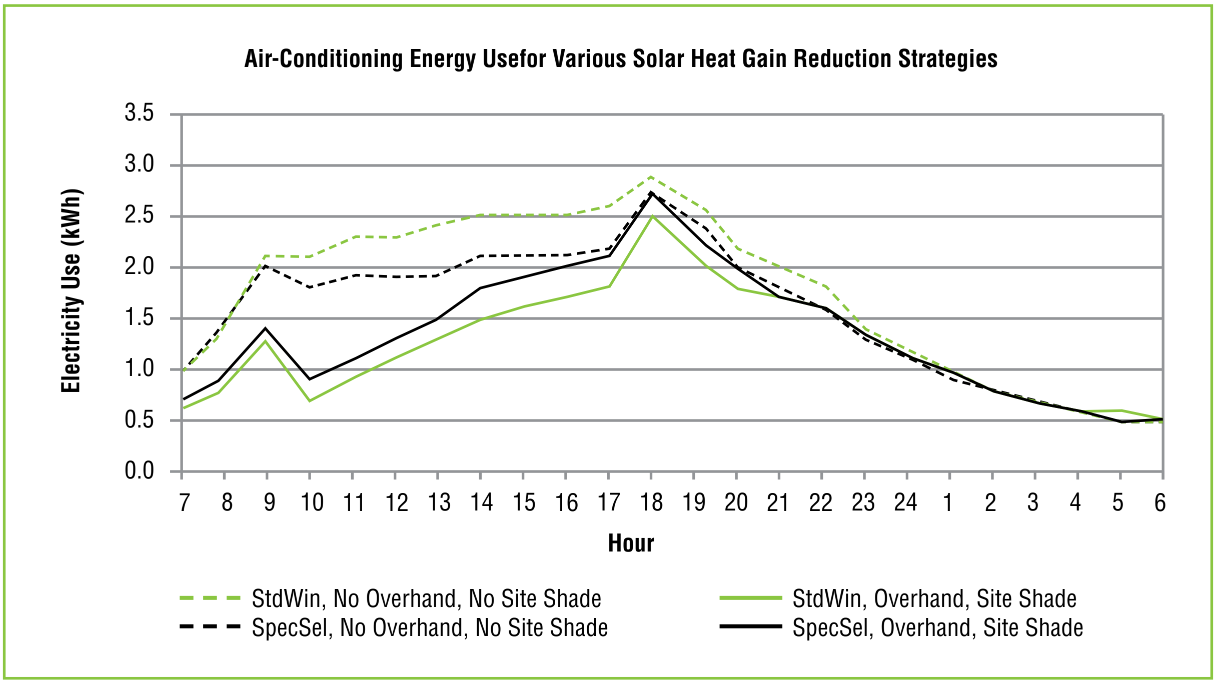


Figure 4: Air-conditioning energy use for various solar heat gain reduction strategies (NREL, 2000)

a combination of shading (overhangs and shading from trees or adjacent buildings) and high-performance glazing achieved a 30% reduction of the daily cooling energy consumption. Effectiveness of shading as a cooling load reduction strategy can be gauged from the fact that shading alone resulted in a 22% reduction in cooling energy consumption, whereas using high-performance glass without shading resulted in an 11% reduction. Figure 4 shows the daily energy use for cooling in a house in Arizona, US, using a combination of shading and high-performance glazing strategies, in the months of July and August when the average outdoor temperature is in the range of 24-37°C. The house used 2.5-tons of air-conditioning, while the thermostat was set to 24°C.

Wipro Infotech located in the temperate climate of Bengaluru uses double glazed windows (6-12-6 mm) at a WWR of 26.1%. The glazing has a U-value of 2.64 W/m^{2}K and SHGC of 0.20. This is responsible for a part of the total energy saving of 28% (High-performancebuildings.org, 2017).

2.1.1.2 Controlled Ventilation

Designing windows and vents to dissipate warm air and allow the ingress of cool air can reduce cooling energy consumption by 10-30% (Wbdg.org, 2017). Air velocities in the range 0.5-1 m/s result in a perceived drop in temperature of about 3°C at 50% relative humidity (Yourhome.gov.au, 2017). However, air velocity of 1 m/s in an office environment is considered too high, although it may be acceptable in a home situation, and especially if there is no recourse to active air-conditioning.

Natural ventilation takes advantage of the differences in air pressure between warm air and cool air, as well as convection currents, to remove warm air from an indoor space and allow fresh cooler air in. This also has the added advantage of cooling the walls and roofs of the buildings that hold significant thermal mass, further enhancing the thermal comfort of the occupants. Buildings can be designed with cross ventilation, stack ventilation and single-sided ventilation. Cooling with natural ventilation especially works best in dry climates when there is a breeze. However, even in the absence of a natural breeze, fans can be used to improve the flow of cool air within a building. Natural ventilation promotes the occupants' adaptation to external temperature, called adaptive thermal comfort. Even in hot-dry and warm-humid climate zones where some air-conditioning may be required during peak summer, buildings can be designed to operate in a mixed mode to enable night ventilation and natural ventilation during cooler seasons.

2.1.1.3 Insulation

In buildings, conduction of heat takes place through the roof, walls and windows. If this heat transfer is not controlled, dissipation of additional cooling load will be required to maintain thermal comfort within occupied spaces. An insulating material can resist heat transfer due to its low thermal conductivity. Insulating walls and the roof can reduce cooling energy loads by up to 8% (IGBC, 2008).

Analysis by the Indo-Swiss Building Energy Efficiency Project (BEEP) indicates a 70-90% (BEEP, 2016) reduction in heat flow through the roof and walls with low U-values as prescribed by ECBC (Figure 5).

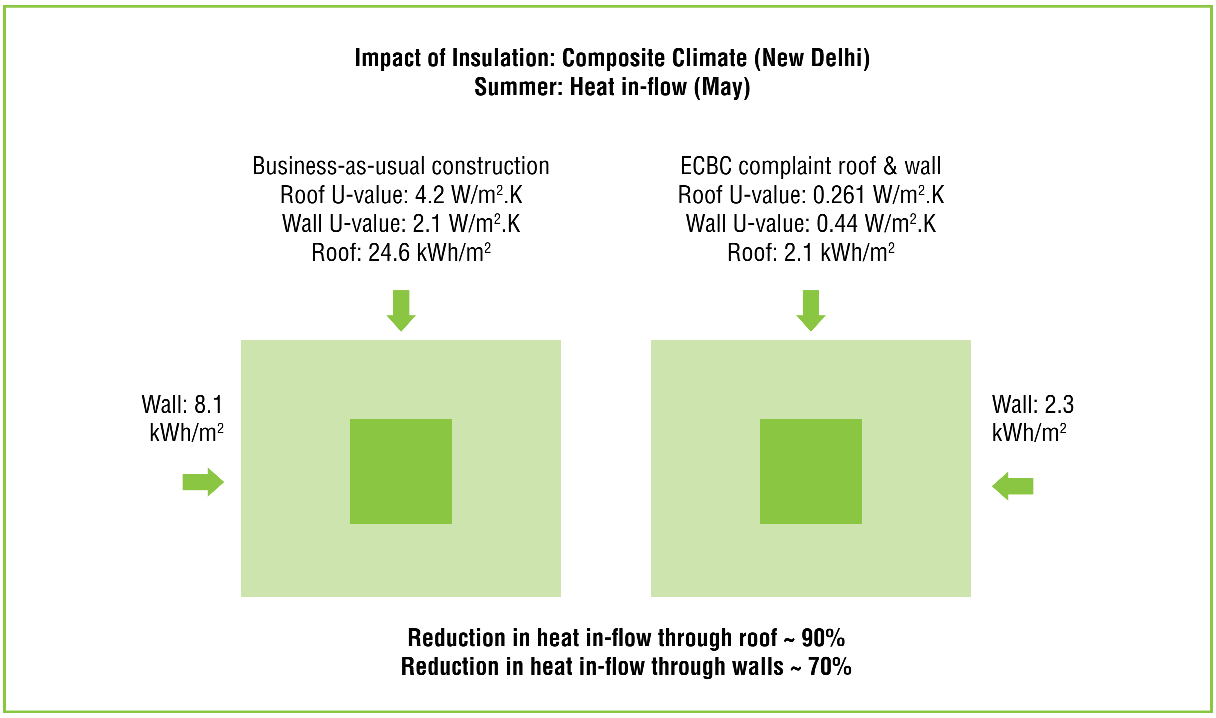


Figure 5: Impact of insulation in New Delhi (BEEP, 2016)

2.1.1.4 Cool Roofs

Cool roofs are one of the passive design options for reducing cooling loads in buildings. Cool roofs reflect most of the sunlight (about 80% on a clear day) (Figure 6), reduce solar heat gain and can decrease the use of air-conditioning by up to 20% in the top floors (LBNL, 2011). Cool roofs are beneficial at the city level also, as they diminish the urban heat island effect. They also help in mitigating climate change by reflecting solar radiation back into space which would otherwise be converted into infrared radiation and thus getting trapped in the atmosphere leading to global warming. A typical cool roof surface temperature stays 25-35°C cooler than a normal roof in summers which brings down the inside air temperature by around 3-5°C that enhances the thermal comfort of occupants and increases the life of the roof (BEE and Shakti, 2011). Cool roofs increase the durability of the roof itself by reducing thermal expansion and contraction. Apart from helping enhance the thermal comfort in the top floor and helping reduce air-conditioning load, cool or white roof or pavements also offer significant reduction in urban heat island effect (Rosenfeld et al., 1998). Practical application of this age-old traditional design technique can be seen in cities of Jodhpur and Jaipur in the extremely hot state of Rajasthan, where most of the city dwellings are painted with light blue and light pink colours and in Jaisalmer where buildings are either built from golden yellow sandstone or painted with the same colour.

During the winter season, cool roofs may cause a marginal increase in heating energy consumption. For India, potential heating penalties are a small fraction of cooling energy saving due to (mostly) long and intense summers and short and mild winters. Regions having predominantly colder climate in India should weigh the pros and cons before adopting cool roofs.

When sunlight is incident on a dark roof	When sunlight is incident on a cool roof
38% heats the atmosphere	10% heats the environment
52% heats the city air	8% heats the city air
5% is reflected	80% is reflected
	1.5% heats the building

(Global Cool Cities Alliance, 2017)

The roofs can be painted with cool roof paints. The other types of cool roofs materials are broken china mosaic coating, built up roofing, modified bitumen (asphalt or tar modified with plastic and layered with reinforcing materials), slate or tile, metal and shingles.

Global Experience

Cool roofs are a part of building codes in different parts of the world. In the US and in Europe, cool roofs rating councils have been established for testing and rating cool roof materials based on their solar reflectance and thermal emittance. In the US, many cities and states have a cool roof policy and a few utilities also offer rebates for cool roofs. New York, Tucson, Pittsburgh and California are some of the places that have a cool roof policy in place.

The City of Seoul in South Korea launched a programme in 2015, the Cool Roof Project, to paint roofs with a thermal barrier paint for free to mitigate heat from urban heat island and save energy. The city provided loans to construction

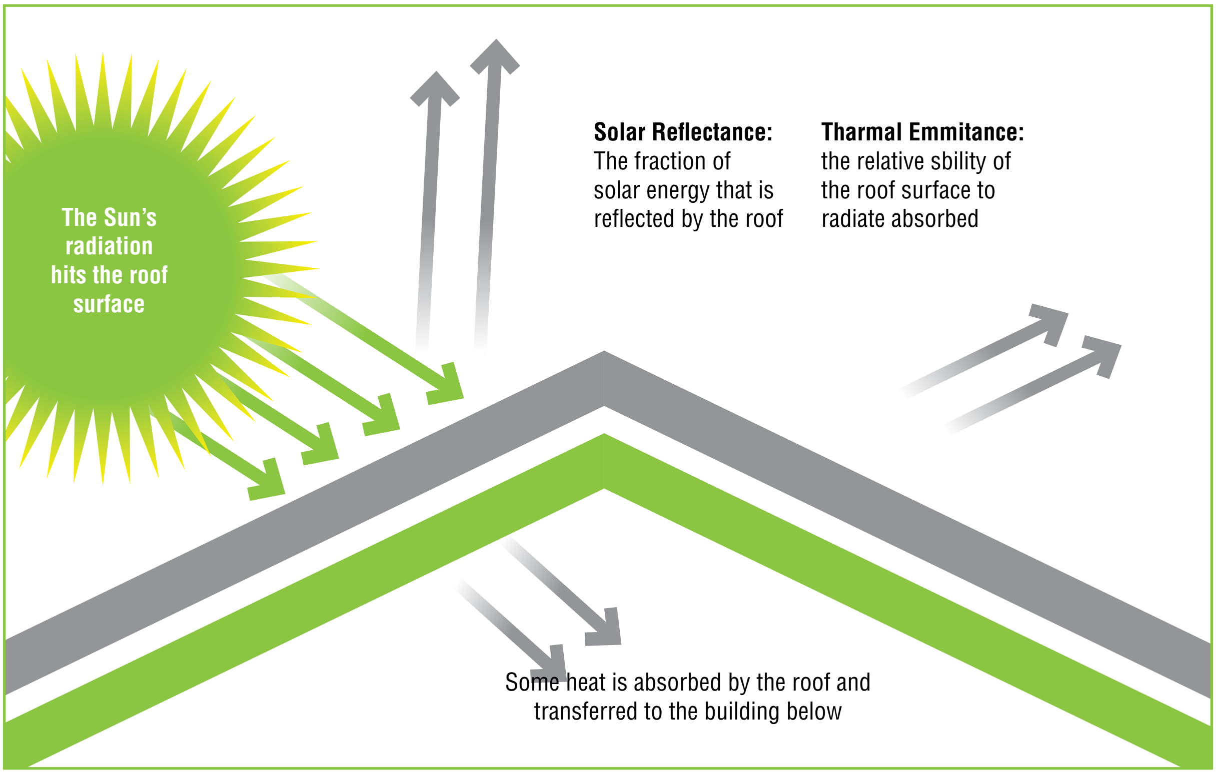


Figure 6: Principle of cool roofs (Coolroofs.org, 2017)

companies for painting cool roofs. The city has allocated \$13.6 million in loan support at just 1.75% interest for constructing energy efficient buildings (Koreatimes, 2017).

Studies and Potential Impact in India

India offers great promises as its population density, growth in buildings and tropical climate zone make it a high potential region for cool roofs. It has been estimated that this cool roof technology can be applicable to 90% of the Indian region (Garg, 2012). This can reduce air-conditioning consumption by 20% in single storey buildings in hot and sunny climates and 7% in three storey buildings (Akbari, Levinson and Rainer, 2005). Use of cool paints is projected to have savings ranging from approximately 170 kWh/year for mild climates to over 700 kWh/year for very hot climates (Akbari and Matthews, 2012). Figure 7 shows the total rooftop space in India, total potential RAC requirement (TWh/year) and the potential reduction in RAC consumption from 2015-2050 due to cool roofs.

A hospital in Ahmedabad installed white china mosaic in place of tar roof to reduce internal hospital temperatures, as a part of the Ahmedabad City Resilience Programme to combat extreme heat. This cooled indoor temperature and reduced heat-related illnesses, particularly among new-born infants

Radiant barriers can reduce summer heat gains and reduce cooling costs. The barriers consist of a highly reflective material that reflects radiant heat rather than absorbing it. This principle can be used by covering the roof with a highly reflective cover during the day and withdrawing it at night, thus exposing the roof for cooling by radiation to the sky. The highly reflective shade prevents heating of the roof during the day and once removed after sunset promotes cooling by sky radiation at night. The combined effect leads to a slab bottom temperature consistently below 30O.

For an industrial shed in Pune (GI metal roof, 0.5 mm thick, 8200 sq. ft.), simulations on ISHRAE's Smart Energy software showed a 38.8% reduction in the roof load (from 25.8 TR to 15.8 TR), when a radiant barrier material (4 mm XLPE + 0.2 mm aluminium foil) was used for underdeck insulation.

In a recent publication in Science, the free and natural phenomenon of radiative cooling to cool buildings was explored further. Although radiative cooling systems suitable for night-time use have been heavily investigated earlier, this research focuses on radiative cooling using a film of a polymer hybrid metamaterial which is apparently suitable for round-the-clock application. This film is a 50 μm thick hybrid metamaterial consisting of a visibly transparent polymer encapsulating randomly distributed silicon dioxide (SiO_2) microspheres. The film is backed with a 200-nm-thick silver coating. It generates a cooling effect combining radiative cooling with the cool roof effect. The silver film diffusively reflects most of the incident solar irradiance while the hybrid material absorbs all incident infrared irradiance and is highly infrared emissive across the entire atmospheric transmission window (8-13 μm).

An average noon-time (11am – 2pm) radiative cooling power of 93 W/m^2, under normal-incidence solar irradiance greater than 900 W/m^2, during a three-day field test was recorded. An average cooling power > 110 W/m^2 over the continuous 72-hour day and night test was recorded. It might be worthwhile to carry out more detailed experiments to assess its suitability for residential houses and as a top floor(s).

since the neonatal ward was on the top floor. Ahmedabad decided to apply this heat mitigation technique to all hospitals (NRDC, n.d.) and now extended it to low-income communities.

To provide affordable cooling to the urban poor, NRDC and its partners, the Indian Institute of Public Health – Gandhinagar (IIPH-G) and ASCI, are collaborating with the city and state government in Hyderabad to pilot cool roofs in low-income housing communities in the city. The cool roof pilot project aims to demonstrate cost-effective solutions to increase thermal comfort and provide health benefits. Also, as part of the 2017 Ahmedabad Heat Action Plan, a city-wide initiative on cool roofs was launched to provide access to Ahmedabad's slum residents and the urban poor. The Ahmedabad Heat Action Plan was developed and launched in collaboration with the Indian Meteorological Department (IMD), (IIPHG) and NRDC (NRDC, 2017).

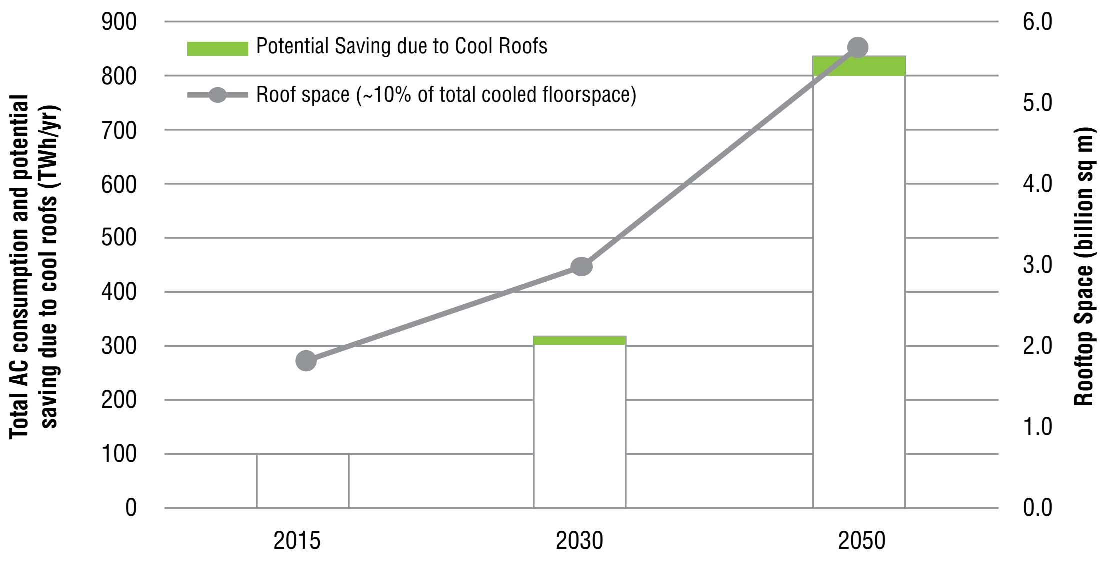


Figure 7: Total AC consumption and potential savings due to cool roofs (LBNL, 2011)

Raman et al. (2014) experimentally demonstrated radiative cooling to nearly 5⁰C below the ambient air temperature under direct sunlight. Using a thermal photonic approach, an integrated photonic solar reflector and thermal emitter consisting of seven layers of HfO_2 and SiO_2 were introduced, that reflects 97% of incident sunlight while emitting strongly and selectively in the atmospheric transparency window. When exposed to direct sunlight exceeding 850 W/m^2 on a rooftop, the photonic radiative cooler cools to 4.9⁰C below ambient air temperature, and has a cooling power of 40.1 W/m^2 at ambient air temperature. These results demonstrate that a tailored, photonic approach can fundamentally enable new technological possibilities for energy efficiency. The research was published in Nature.

2.1.1.5 Green Roofs

A green roof is a roof of a building that is partially or completely covered with vegetation. Green roofs serve several purposes for a building such as absorbing rainwater, providing insulation, and helping lower urban air temperatures and mitigating the urban heat island effect. Reduction in energy use is an important feature of green roofing.

Green roofing allows buildings to better retain their heat during the cooler winter months while reflecting and absorbing solar radiation during the hotter summer months, allowing buildings to remain cooler. A study conducted by Environment Canada recorded a 26% reduction in summer cooling needs and a 26% reduction in winter heat losses, when green roofs were used (Green Roofs for Healthy Cities, 2017).

Table 1 lists out some of the most important case studies in India wherein Energy Performance Index (EPI) reductions are estimated to be achieved by implementing lean strategies (along with some other strategies).

Table 1: Case studies from India and associated energy savings (BEEP, 2017; NRDC, 2017; MNIT, n.d.; UNDP in India, 2017)

Case Study	EE Measures Adopted	'Before' EPI (kWh/m^2/year)	'After' EPI (kWh/m^2/year)	Energy Saving (%)
		Lean cooling strategies contributed to a part these reductions.		
Centre for Environmental Science and Engineering, IIT Kanpur	• Use of cavity walls with insulation • Insulated and shaded roof • Shading and double glazing of windows	240	208	13
Aranya Bhawan, Jaipur	• WWR - 21% • Insulated roof - 40 mm of PUF • Sandwich brick walls with 50 mm of extruded polystyrene insulation • Double glazing • Centralized water-cooled chiller system with COP of 5.8	77	43	44
Jupiter Hospital, Pune	• Roof insulation • AAC blocks instead of brick • HVAC system sizing based on simulation • Air-conditioning design ~ 514 sq. ft./TR instead of ~ 430 sq. ft./TR • Heat recovery: 75% (sensible + latent) • Using condenser water for reheating in AHUs with a backup from hot water system	154	130	16

Case Study	EE Measures Adopted	'Before' EPI (kWh/m²/year)	'After' EPI (kWh/m²/year)	Energy Saving (%)
World Trade Centre, GIFT City, Gandhinagar	• Building massing revision • Shading and daylight integration • Heat recovery and free cooling • Ceiling fans for the offices	76	62	18
IIIDEM, New Delhi	• Building massing revision • Shading and daylight integration • Fixed shading (using 'jaali') • Free cooling • Heat recovery wheel • Use of high performance water cooled chillers with better part load performance • Automated control on the chiller water temperature	182	128	30
Prabha Bhavan, MNIT Jaipur	• Building massing revision • WWR 27% • Self-shading feature • Glazing with U-value of 1.9 W/m²°C, SHGC 0.28, VLT 0.39 • U-value of wall – 0.72 W/m² °C • VRF system with 3.75 COP • Heat recovery wheel of 1200 CFM enthalpy wheel	182	128	30

2.1.2 Building Energy Code (for Building Envelope)

ECBC is BEE's flagship measure to introduce minimum energy performance in (mainly) commercial buildings. It is a definitive pathway to energy savings in buildings using energy efficient building design and construction practices. It succinctly encapsulates lean strategies alluded to in the aforementioned subsections, to reduce the cooling load of buildings. It specifies building design parameters and material properties to reduce the ingress of external heat through conduction, convection and radiation. ECBC prescribes maximum U-values for the overall assembly of opaque walls and roofs for different climatic zones; it prescribes maximum U-values and SHGC and minimum visible light transmittance (VLT) for glazing for different climatic zones at typical WWRs; it also prescribes the minimum reflectance for cool roofs.

Aranya Bhawan located in the hot and dry type climate of Jaipur complies with the ECBC implicitly. A combination of lean measures, including roof and wall insulation, reduced glazing area and double-glazed windows with high performance glass, has cut down the cooling system size (TR) by 28% (BEEP, 2016).

The new version of the ECBC, launched in June 2017, provides present as well as futuristic advancements in building technology to cut down building energy consumption and promote low-carbon growth. The new code considers market changes, and the energy demand scenario of the country. To be ECBC-compliant, new buildings should be able to demonstrate minimum energy savings of 25%. Energy savings of 35% and 50% will enable the buildings to achieve higher grades like ECBC Plus or Super ECBC status respectively. The adoption of ECBC 2017 is expected to achieve a 50% reduction in energy use by 2030 which will translate into energy savings of about 300 Billion Units by 2030. It will result in expenditure savings of Rs. 35,000 crore and reduction of 250 million tonnes of CO_2. *(BEE, 2017).*

2.1.3 Affordable Thermal Comfort in Low Income Housing

According to the World Health Organization, "adequate housing" or "sustainable housing" in the modern era is far from being "healthy" and tends to be informed by technological rather than health rationales. Internationally, building codes and housing regulations provide either too little or very vague information on the minimum standards that must be met to characterise houses from a health perspective. It is well-known that indoor thermal comfort is important for the occupants' physiological and psychological well-being. The need to maintain indoor thermal comfort has become even more pronounced in the milieu of climate change – per a recent study in Science by Mazdiyasni et al. (2017) even moderate increases in mean temperatures from climate warming may cause great increases in heat-related mortality. It is now more imperative than ever before to view indoor thermal comfort as a basic human right – just as 'fuel poverty' is recognised as a condition to not keep one's home adequately heated in cold western countries (especially UK), 'coolth poverty' should be recognised as a condition to not keep one's home adequately cool in tropical countries such as ours. It is important to be mindful that a very large section of the Indian people do not have access to active air-conditioning and/or cannot afford inflated energy bills from space cooling. Amid this discussion, now is the critical window to explore, implement and mainstream passive space cooling strategies to make space cooling both sustainable and affordable in the upcoming housing stock.

Global Experience

Philadelphia Housing Authority (PHA) undertook a campaign 'Conserve Energy - Preserve Public Housing' in 2006. The purpose of the campaign was to reduce the energy costs incurred by the housing authority that completely or partially subsidized energy consumption of approximately 80,000 residents. This programme saved more than $500 per unit annually. The PHA received the 2007 ENERGY STAR for Excellence in Affordable Housing. The houses met the

South Africa joined the United States Department of Energy's Global Superior Energy Programme (GSEP) Cool Roofs and Pavements Working Group in 2013. Since then, it has been focused on bringing thermal comfort into the informal and formal structures of low-income communities and reducing the heat island effect over human settlements, while simultaneously collecting data about the performance of these interventions.

Through its Cool Surfaces Project, SANEDI has done several demonstration projects in the Northern Cape and Gauteng, with more to follow over the rest of the country. In the Kheis municipality in Groblershoop in the Northern Cape, dramatic cooling of between 7°C and 10°C was measured, but in a more moderate climate zone, the cooling potential is closer to between 2°C and 4°C. *(Building & Decor, 2017).*

federal ENERGY STAR rating. The federal ENERGY STAR standard considers insulation, ventilation, high performance windows, tight construction, and efficient heating and cooling equipment. Testing confirmed that these homes met the federal ENERGY STAR standard by checking that these homes were at least 15% more energy efficient than homes built to the 2004 International Residential Code (IRC) (Pha. phila.gov, 2017).

Affordable Housing in India

India's urban population is growing at an average of 2.1% since 2015 and is likely to reach 60 crores by 2031 (as compared to roughly 38 crores today). However, the growth in new housing to shelter the newly urbanised people has not been commensurate with the growth in the urban population – the housing shortage in India is about 1.9 crore units, 96% of it comprised by the economically weaker sections of the society and the low-income group. In the wake of this housing crisis, the Government of India has announced its ambitious plan to provided 'Housing for All by 2020'.

In May 2017, The Economic Times reported that according to CLSA India Pvt., rising incomes and the best affordability in two decades will unleash a $1.3 trillion wave of investment in housing over the next seven years leading to 60 million new homes to be built between 2018 and 2024. The volume of social and affordable housing will rise almost 70% to 10.5 million annually by 2024. *(The Economic Times, 2017).*

Lean cooling strategies like shading, free cooling through ventilation, insulation and cool roofing should be integrated in this Government initiative. In a study conducted at MIT, it was shown that comfortable indoors were possible for 72% of the year in affordable housing in Bhuj, Gujarat using passive strategies, namely, adaptive thermal ventilation, sun-shading for windows, evaporative cooling, high thermal mass, night flush cooling and solar heat gain. It is important to fully understand the climatic conditions of a region to maximise the passive cooling potential of new buildings. In other words, region-specific and climate-responsive vernacular architecture would become necessary. This can be readily explained using the assortment of endemic building practices in houses in Tamil houses – the art of thatching using mud, coconut and palm fibre platted with bamboo attests to the practical use of organic material to provide cool insulation; similarly, the use of Cuddapah stone in the courtyard and terracotta tiles in the interiors for flooring helps keep cooler indoor temperatures.

Under the Mission Innovation (MI) programme, a global initiative of 22 countries and the European Union, the Government of India will build 100 smart cities that will use energy efficient technologies. Following the launch of MI, the Department of Science and Technology (DST) announced a new Initiative to Promote Habitat Energy Efficiency (I-PHEE). I-PHEE is focused on promoting R&D activities to improve energy performance of buildings and cities and support the enhancement of knowledge and practice to save energy in design, construction, and operation of human habitats. Some focus areas for research are building materials and/or construction technology for walls, roofs, windows which will help reduce operational energy, increase thermal comfort, or reduce embodied energy of a building (Mission-innovation. net, 2017). A primary goal, in this regard, should be 'rightsizing' the energy consumption in the built environment through the integration of lean cooling methods in all new constructions.

2.1.4 Adaptive Thermal Comfort

People's perception of thermal comfort depends on their historical exposure to their immediate thermal environment (controlled or uncontrolled) over a long period of time. An extension to this premise is that an average person's perception of thermal comfort will be affected by the average outdoor weather conditions that prevail in and around his/her geographical location. This could have a tremendous impact on comfort conditions in buildings and on energy consumption.

Studies and Potential Impact in India

People in warm, tropical countries need a different range of thermal comfort conditions compared to those in temperate climates. Two independent studies in India (Manu et al., 2016) and Japan (Indragati, Ooka and Rijal, 2014) indicated that close to 80% of occupants are comfortable with indoor operating temperatures of 24-28°C in these countries. This thermal band becomes wider in the presence of air motion and low mean radiant temperature of walls, floors and ceilings around occupants. This is much higher than the thermal comfort range defined for air-conditioned buildings by American Society for Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) 55 – 2010 which is widely followed in North America and in many countries around the globe.

The India Model for Adaptive Comfort (IMAC) developed by CEPT University indicates that Indians' thermal comfort range is even wider for Naturally Ventilated (NV) and Mixed Mode (MM) buildings. The IMAC study found that the thermal comfort range for people in NV buildings is 19.6-28.5°C, and for those in MM buildings it is 21.5-28.7°C. Even for those already accustomed to fully air-conditioned buildings, the acceptable thermal comfort range is 23.5-25.5°C, which is warmer than the 22.5 ± 1°C 'Class A' specification (ASHRAE 55, 2010) that a typical commercial air-conditioned building in India operates at all year round. The IMAC research findings have been incorporated in the National Building Code (NBC) Sustainability Chapter (BIS, 2015).

A study on thermal adaptation in air-conditioned buildings in the composite climate zone, using the Standard Effective Temperature (SET) approach, indicated that 80% of occupants were comfortable in the range 23.42-26.56°C. The SET approach considers air temperature, mean radiant temperature, relative humidity, air speed, clothing and activity (Dhaka and Mathur, 2017).

A study on occupants in NV buildings in the composite climate zone indicates a thermal comfort range of 25.6-29.4°C, depending on the season, i.e. winter, moderate and summer. The acceptable humidity and air velocity were found to be 36% and 0.44 m/s, respectively, across all seasons (Dhaka et al., 2015).

Buildings can be designed and operated to exploit natural ventilation and mixed mode operations to meet occupants' thermal comfort and other IEQ requirements. Even when air-conditioning is used, the thermostat can be set to 24-25°C, and possibly higher when fans are deployed to provide assisted air motion. Doing so would bring down the average energy consumption per unit area due to HVAC operation, since HVAC energy use can be up to 40-60% of the total energy consumed in such buildings. The estimated reduction in EPI (kWh/m^2/year) for HVAC per degree increase in thermostat setting is 5-6% (Manu et al, 2015).

Fairconditioning has been running a campaign on Corporate Thermal Comfort Policy, to encourage corporate offices to establish thermostat settings and dress codes to enable occupants to work at 24°C without any negative impact on comfort and productivity. They are piloting an intervention at the ICICI bank call centre in Maharashtra – a centrally air-conditioned four storey commercial building consisting of 75,000 sq. ft. built-up space with an average occupancy of 1,500 employees. Fairconditioning is currently assessing the potential energy savings that could be achieved by prescribing the most suitable clothing options for the desired comfort conditions. ICICI already has a regulation to set all ACs at 24°C. It has been estimated that raising the set point temperature to 26°C (as compared to 24°C) could lead to 13% reduction of annual energy consumption of the building.

Cool Biz in Japan

- 1.56 mtCO$_2$ reduction in 2011
- Launched in 2005 & extended to "Super Cool Biz" in 2011
- Business & government office thermostat upped to 28°C
- Light, summer dress code

(Env.go.jp, 2017).

ISHRAE released an IEQ Standard in 2016, which specifies an adaptive comfort based temperature range for buildings in India. These values are based upon synthesis of various adaptive comfort studies conducted in different parts of the country by different research groups.

2.1.5 Challenges and Opportunities in Lean Cooling Strategies

Several proven tools and practices exist to reduce the cooling load in buildings. Their adoption is typically the easiest and most effective when incorporated right into the building design and construction stage. However higher rate of adoption continues to remain a challenge due to either lack of consumer awareness or market confusion about available options. We see a couple of key areas of opportunity to advance the integration of lean cooling strategies into mainstream:

- Utilise market transformation strategies to drive the adoption of energy efficient building materials
- Leverage ECBC to move the industry towards more efficient building design.

With India adding new building stock at a rate faster than anywhere else in the world, several development initiatives by the government focused around clean energy, sustainable communities and affordable housing for all, afford another important opportunity to incorporate and benefit from lean space cooling strategies. Integration into ongoing government initiatives will also aid in consumer awareness about the value proposition of embracing lean strategies, as well as position the government to lead by example as a steward of sustainable practices.

2.2 Mean

Cooling technologies and equipment with high efficiency and hence low energy consumption can be used to meet the cooling demand of buildings. Standards & Labelling (S&L) programme are ratcheting up the standards of RACs, ceiling fans and other cooling equipment. At the same time, there are various low energy cooling technology options, many that make no or significantly less use of refrigerants that are emerging which can also supplement cooling needs.

2.2.1 Building Energy Code (for HVAC)

HVAC system in a commercial building accounts for a significant portion of energy consumption. Systems efficiency can be directly related to the energy consumed by HVAC, wherein an inefficient system can have a big negative impact on the building’s energy demand. The efficient and sustainable cooling technologies which include natural ventilation, efficient artificial cooling technologies or apposite combination of both can significantly reduce the energy loads by bringing down the HVAC load requirement. Underperforming and poorly sized HVAC systems not only results in higher energy consumption, but also affect the occupants’ health, comfort and productivity. Other issues linked to HVAC system design and maintenance are improper ventilation, poor indoor quality and user discomfort. ECBC lists mandatory and prescriptive requirements for some of the frequently used HVAC systems.

ECBC provides mandatory requirements which are to be fulfilled with the prescriptive approach as well as the whole building approach. The mandatory compliance must be demonstrated for natural ventilation, equipment efficiencies, controls, piping and ductwork, system balancing and condensers. ECBC refers to NBC ventilation guidelines for naturally ventilated buildings but it does not define a temperature for thermal comfort inside buildings based on climatic conditions. There can be 5-6% savings in EPI for increasing the thermostat temperature by 1°C (Manu et al, 2015). This can yield significant savings for large commercial buildings with large cooling and heating loads. The minimum system efficiencies are listed for unitary air-conditioning equipment, chillers, heat pumps, furnaces and boilers. The prescriptive requirements also cover key HVAC controls strategy such as the use of economizers and variable flow hydronic systems.

2.2.2 Standards & Labelling (S&L)

S&L helps consumers make informed decisions regarding energy consumption of appliances and helps promote the penetration of energy efficient appliances and equipment in the market. The S&L programme was launched by BEE in 2006. Currently, RACs are the only space cooling appliance under the mandatory labelling scheme. Ceiling fans and variable speed ACs are under the voluntary labelling scheme. Super-efficient fans have been developed under the Super-Efficient Equipment Programme (SEEP) to leapfrog to an efficiency level which will be about 50% more efficient than the market average. Further, EESL is working with IIT Chennai to develop another category of super-efficient ceiling fans for their national programme. The chiller standard has been developed by BIS with support from RAMA, ISHRAE, CLASP and other important stakeholders.

2.2.2.1 Room Air Conditioners (RACs)

In 2015, BEE announced a new star rating methodology called the Indian Seasonal Energy Efficiency Ratio (ISEER) for variable capacity (inverter type) ACs. This metric will be used instead of Energy Efficiency Ratio (EER) and is based on the ISO-16358 standard with adjustments made to account for higher outdoor temperature ranges found in India. ISEER considers the range of temperatures across the year in Indian climate zones and provides a more realistic approximation of the cooling efficiency for the entire year. Currently, variable capacity (inverter type) split ACs are rated 1-star for an ISEER of 3.1 and 5-star for an ISEER of 4.5 ISEER standards for inverter ACs will be made mandatory from 2018. The standard for fixed and inverter ACs will be merged in 2018 incorporating the ISEER methodology. In the six years since introducing mandatory S&L for RACs, the Minimum Energy Performance Standard (MEPS) has improved from an EER (W/W) of 2.30 in January 2010 to 3.10 in June 2015 (BEE 2010; BEE 2015) (Table 2).

Table 2: BEE star rating levels for inverter ACs effective from June 2015 through December 2019 (BEE, 2015)

Star Rating	Min. ISEER	Max. ISEER
1-star	3.10	3.29
2-star	3.30	3.49
3-star	3.50	3.99
4-star	4.00	4.49
5-star	4.50	-

International Trends in RAC S&L

Many countries are raising RACs' energy efficiency standards aggressively with the objective of having only high efficiency equipment using the best available technology in the market.

Japan and South Korea are the best examples of RACs with high energy efficiency standards. Japan with its Top Runner Programme has been able to double RACs' efficiency in 10 years. In a span of 10 years (1995-2005), EER of RACs in Japan improved by 7.2% per year and this increased the Coefficient of Performance (COP)/EER from 2.55 to 5.10 (LBNL, 2017). Interestingly inflation-adjusted RAC prices continued to drop even as the efficiency of RACs doubled. The programme was applicable to 21 products in Japan and RACs was one of them (Figure 8).

In 2011, South Korea launched the Energy Frontier Programme that set efficiency goals at 30-50% more than the most efficient product. This programme applied to RACs and 3 other appliances. The efficiency of RACs has significantly increased, and the price of RACs has come down (LBNL, 2017).

In September 2014, Singapore introduced more stringent RAC standards. The MEPS for both inverter and non-inverter splits increased from a COP of 2.9 to 3.78, equivalent to a 2-tick rating in Singapore's 5-tick rating scheme. A consumer would be able to save S$100 on the annual energy cost by buying a 2-tick rated product (Nea.gov.sg, 2014).

In February 2016, Australia and New Zealand issued a Regulatory Impact Statement for consultation for revising ACs and chillers standards (Commonwealth of Australia

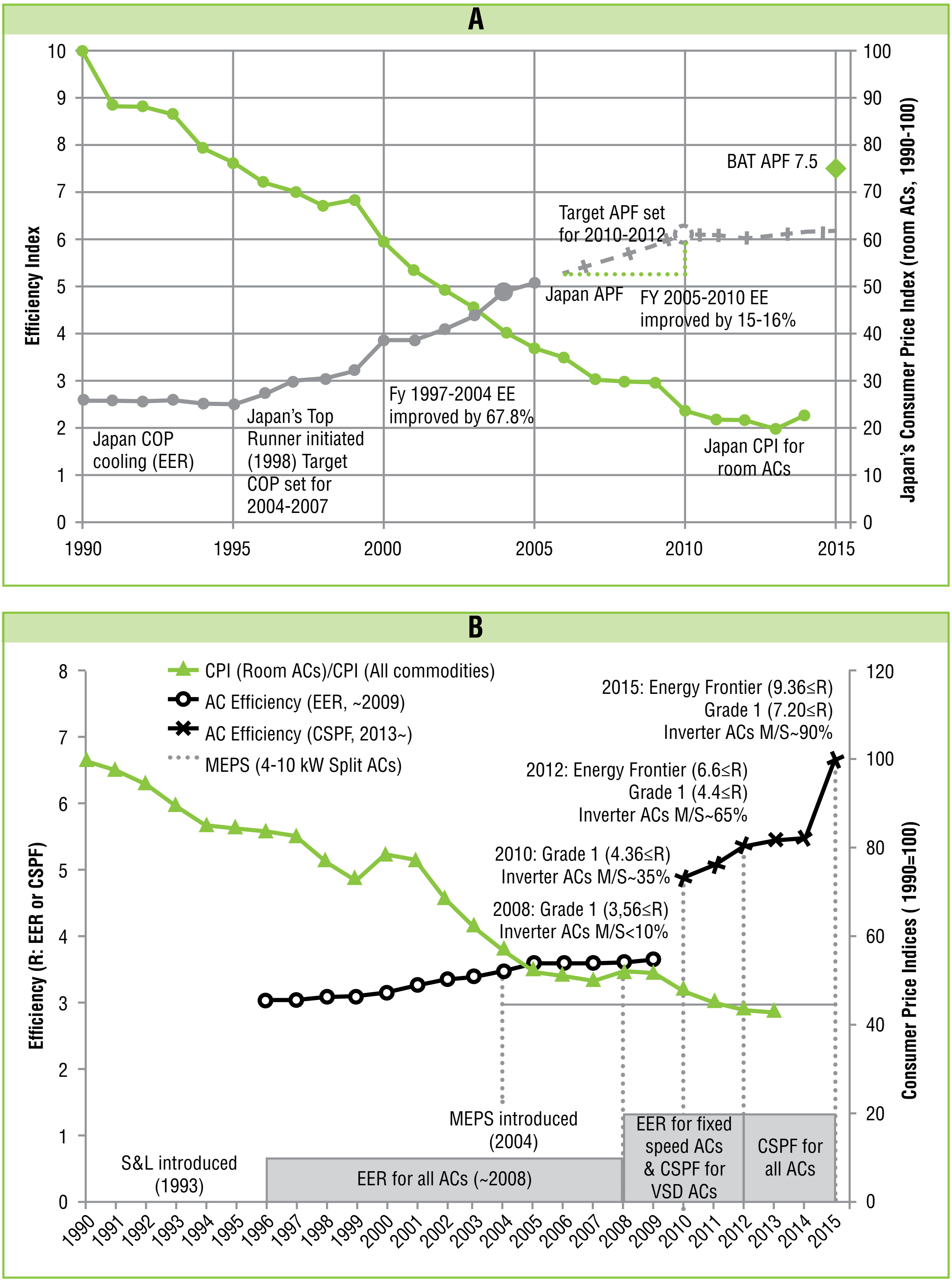


Figure 8: AC standard and prices in (A) Japan and (B) South Korea (LBNL, 2017)

- Department of Industry, Innovation and Science, 2016). The objective of the consultation was to address regulatory failures and one of the measures suggested was Zoned Energy Rating Label instead of the energy rating label that would provide energy efficiency information for three distinct climate zones across Australia and New Zealand for ACs with capacity up to 30 kW. The notification also mentioned that air enthalpy tests would be accepted for ducted, three-phase and certain 'commercial use' products and multi-split systems had to comply with Seasonal Energy Efficiency Ratio (SEER) standards. The rating information would be on the website and the product need not carry a physical label. The usefulness and relevance of this decision need to be evaluated in the Indian context.

Standards Stringency's Potential Impact in India

Household RAC penetration was 5% in 2011. RAC growth projections in the business as usual (BAU) scenario is estimated to result in additional peak demand of 140 GW by 2030 and 300-500 GW by 2050. However, significantly improving the MEPS of RACs to an ISEER of 5.7 by 2026 and up to 7.1 by 2030 could shave nearly 40 GW off peak demand and reduce energy consumption by 64 TWh/year by 2030 (LBNL, 2017). The inflation-adjusted price of more energy efficient RACs has been coming down over the last decade, as evident in Figure 9.

2.2.2.2 Ceiling Fans

Ceiling fans accounted for 6% of the energy consumed by residential buildings in 2000 and are estimated to consume 9% by 2020 due to the expected increase in the number of installed ceiling fans (Shah et al., 2014). Ceiling fan energy performance is typically defined in terms of the volume of air delivered per minute per unit of power (m^3/minute/W), and is termed as fan efficacy rather than efficiency. BIS and BEE both rate fan performance. The BIS standard specifies minimum efficacy for various fan sizes, whereas BEE assigns star ratings for only 1 size of fan with 1200 mm sweep, based on minimum efficacy requirements specified by BIS (BEE, 2017).

Under the BEE star rating voluntary labelling programme, the 5-star ceiling fan is marginally efficient, consuming 45-50 W and has an air delivery of 210-220 mm^3, compared to typical models that consume 75-80 W and are noisy (Bijlibachao.com, 2017).

BEE designed the Super-Efficient Fan Programme in 2012 for India under the Super Efficient Fan programme. The aim was to improve fan performance using brushless DC (BLDC) technology motor, efficient blade design and electronic components for easy control. Super-efficient fans consume only 30-35 W of power compared to 75 W or so for similar sized, less efficient models, deliver about 230 mm^3 of air and

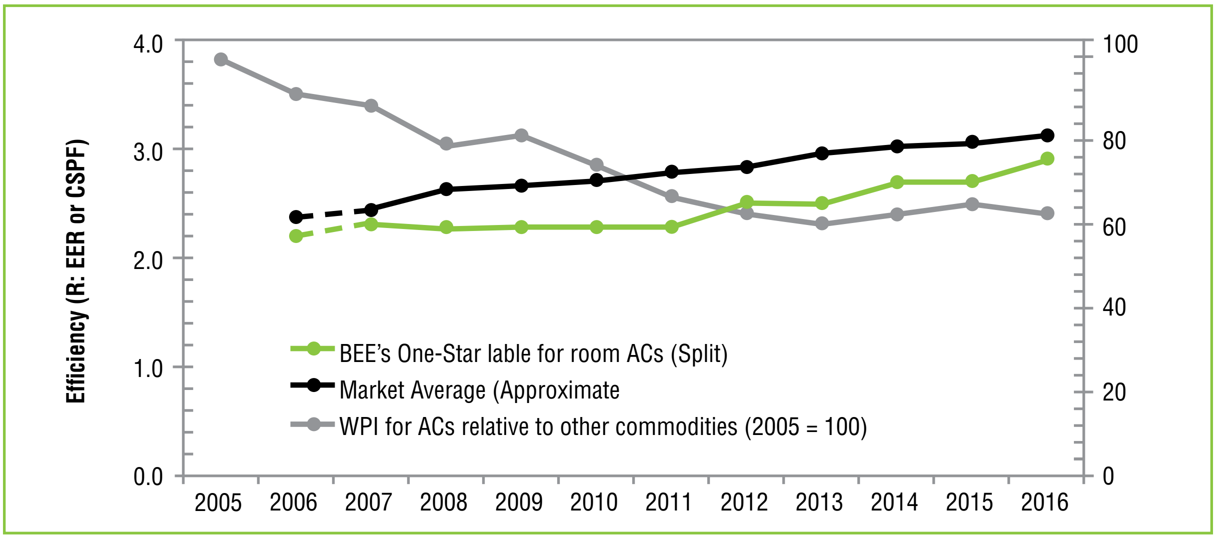


Figure 9: Trends in improvement of AC efficiency and fall in AC prices in India (2005 to present) (LBNL, 2017)

are less noisy (Prayas, 2012). They are already available in the market and the payback period is about 3 years.

In April 2016, EESL launched the National Energy Efficient Fan Programme to distribute 5-star rated ceiling fans at lower than market price. With a power consumption of 50 W, 5-star rated fans are 30% more efficient than typical models in the market (Pib.nic.in, 2016), but are not as efficient as BLDC fans which consume 30-35 W.

2.2.2.3 Chillers

ECBC (version 2) specifies minimum chiller performance efficiency based on Air-conditioning, Heating and Refrigeration Institute (AHRI) standards that specify test conditions that are more representative of climate found in the US and Europe. Realising the importance of the chiller standard, the ISHRAE has taken up the task of developing test conditions for chillers. The standard was jointly developed by ISHRAE and the RAMA which defines a new set of rating and performance testing conditions (temperature, part load weightages and fouling conditions) for air cooled as well as water cooled chillers. After the development of this standard, the same was presented to BIS and it has now been released as the national standard. ISHRAE has also developed a standard for rating and performance testing of variable refrigerant flow (VRF) systems; the same is currently under wide circulation. Attempts are also being made to develop standards for air handling unit (AHU), cooling towers and other HVAC components.

2.2.3 Low Energy Cooling Technologies

These are unconventional cooling technologies that do not use a lot of energy. These can be used as either standalone cooling systems or in conjunction with the conventional air-conditioning. The most important low energy cooling technologies have been outlined below with associated case studies from India.

2.2.3.1 Radiant Cooling System

Radiant cooling uses actively cooled surfaces to provide thermal comfort primarily through radiative heat transfer between human body and the cooled surface. Radiant based HVAC systems provide direct sensible cooling by absorbing heat from the space that is taken away by the chilled water flowing in the pipes embedded in floors, walls or ceilings, or through externally mounted wall and ceiling panels (Figure 10). The system takes advantage of the considerably higher thermal capacity of water over air.

Figure 10: Radiant floor cooling system layout (Rehau.com, 2017)

These thermally conditioned surfaces are maintained at a temperature slightly above the local dew point temperature to provide maximum thermal comfort as defined by ASHRAE Standard 55 while avoiding the possibility of condensation. Radiant cooling is highly efficient compared to regular air-conditioning due to the higher chilled water temperature used in the radiant systems and the minimal use of air that is typically used to provide minimum outdoor air needed to maintain optimum indoor air quality (IAQ).

A radiant cooling system should be appended with a dedicated outdoor air system (DOAS) to avoid condensation in highly humid conditions – this might increase the initial cost of the system. Also, to avoid condensation, the temperature of the radiation surface must be maintained at a temperature higher than the indoor air dew point temperature, which limits the cooling capacity of the system. To minimise condensation, radiant panels should be part of the ceiling – this gives better control of the chilled water temperature than wall embedded radiant systems.

Studies and Potential Impact in India

Infosys conducted a study (Sastry, n.d.) in two identical buildings at its Hyderabad campus (35,000 m2 area), with conventional air-conditioning complying with ASHRAE standards in one and with the radiant cooling system in the other. The conventional air-conditioning EPI was recorded as 38.7 kWh/m2 and the radiant cooling EPI was recorded as 25.7 kWh/m2. This showed that the radiant cooling system was 33% lower in energy consumption compared to the conventional air-conditioning system, which was extremely efficient to begin with, for the year 2011-12. A cost comparison suggests that while conventional air-conditioning would cost Rs.322/sq.ft., radiant cooling would cost Rs.319/ sq. ft.– it is clear that the two do not differ in cost.

In another case (Khan et al., 2015), Tech-Mahindra, Hyderabad installed a radiant cooling system of 356 m2 area, and it was found that the radiant cooling system was 18% more efficient than the conventional cooling system.

Research on radiant panels to increase the efficiency of radiant cooling systems is being carried out at MNIT, Jaipur. A test lab has been setup with different configurations of radiant systems and the team is conducting experiments to increase the performance of radiant cooling systems with different strategies such as integration of thermal storage and cooling tower.

Oorja Energy Engineering has implemented radiant floor cooling at multiple sites where customers can get a 25-50% energy saving. Oorja is presently working on a radiant cooling project that would cool the 2,00,000 sq. ft. library building of K. L. University, Vijayawada (Oorja.in, 2017).

2.2.3.2 Evaporative Cooling

The evaporative cooling technology is based on heat and mass transfer between air and cooling water. Direct evaporative cooling is based on mechanical and thermal contact between air and water, while indirect evaporative cooling is based on heat and mass transfer between two streams of air, separated by a heat transfer surface with a dry side where only air is cooling and a wet side where both air and water are cooling (Porumb et al., 2016). As the capacity of air to absorb vapour is directly related to its humidity, evaporative coolers are most suitable for regions where high temperature coincides with low air humidity. It can cool air using much lesser energy than vapour compression techniques (Figure 11).

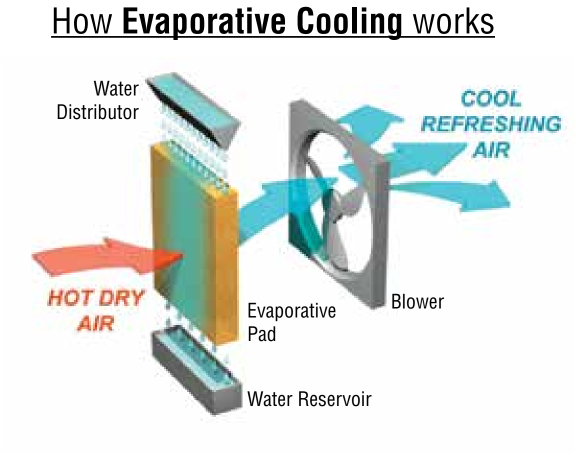


Figure 11: Evaporative cooling system
(Müeller Design Lab, 2017)

Conventional evaporative cooling is not very effective in humid climate. However, it can be used in humid conditions after the inlet air is dehumidified by suitable mechanisms such as a liquid desiccant system or a desiccant wheel.

Studies and Potential Impact in India

Studies conducted by IIT Delhi (Kant and Mullick, 2003) for summer conditions in Delhi showed that an evaporative cooler could provide indoor thermal comfort in April and May in Delhi. However, in more humid months, discomfort can be partly mitigated by using a cooler of 20-40% by-pass factor and adequate flow rate up to 40 air changes per hour to maintain comfort level.

In another study, a financial analysis of a hybrid system consisting of an AC unit and an evaporative cooler was done for four different cities in India. It was found that the hybrid system appears to be more attractive for buildings with higher cooling loads such as high-density offices, movie theatres, waiting halls and similar applications in hot and dry climate.

A study is being conducted at MNIT, Jaipur on redefining the comfort zone for India for the use of evaporative cooling to provide indoor thermal comfort.

Evaporative cooling units by Waves Aircon are currently in use in a variety of evaporative cooling applications such as generator rooms, gas turbine intakes, industrial cooling of hot spots and hot zones, comfort cooling and commercial agriculture. These are widely available in Tamil Nadu, West Bengal, Maharashtra and many states of northern India.

Ambiator Technology from Toro Group is a two-stage evaporative cooler. Indirect-Direct (ID) evaporative cooling is a process in which the hot ambient air is pre-cooled indirectly, without adding moisture to the outdoor air (by using one side wet air to air polymer plate heat exchanger) at the first stage. In the second stage, the pre-cooled air passes through a wet pad having large surface area or water spray bank. The pre-cooled air picks up moisture from this process and gets further cooled. Since the outdoor air is sensibly pre-cooled in the first stage, without adding any moisture hence less moisture is transferred in the direct stage to reach the lower supply air temperatures. The result is cooler air with minimum water use, compared to a traditional evaporative cooler which adds almost double the quantity of moisture in the conditioned air.

TORO's Ambiator technology is the cost effective and climate appropriate. It can provide space temperatures below 27 ºC and humidity 55 ±5% even if the ambient temperatures exceed 45ºC during hot Indian summer climate. The seasonal cooling EER during dry summer remains within 18-20 W/W. TORO is in the process of licensing the Ambiator Technology to Indian manufacturers or local production and marketing. Locally produced Ambiator as an appliance can be made available in 3.5, 7 and 10 kWt capacities in window/split configurations.

2.2.3.3 Desiccant Cooling System

A desiccant is a substance, either liquid or solid, which absorbs water molecules from the air and dehumidifies it. There are two types of desiccant cooling systems: solid desiccant system where silica gel is used for a rotating bed of the wheel within the system and liquid desiccant system which consists of a contact surface, either a cooling coil or tower, wetted with liquid desiccant. The desiccant system also improves indoor air quality. Integration with conventional HVAC systems to remove latent heat can reduce energy consumption by up to 30% for cooling and 5% for heating (Sahlot and Riffat, 2016). Experiments performed in Saudi Arabia and the Persian Gulf Region have given remarkable results in energy saving and effectiveness in controlling temperature and humidity. Desiccants can fail to reduce the air moisture content to the desired level in very humid climates and maintenance of desiccant cooling systems to deliver peak performance over long periods of time has proven to be challenging as well.

2.2.3.4 Personalised Conditioning System (PCS)

A personalised air-conditioning system creates a microclimatic zone around a single occupant in the workplace, so that energy is deployed only where it is needed. This technology helps to improve thermal comfort for the occupant and saves energy consumption because of effective localised energy use.

Engineers at Stanford University devised a new clothing fabric using nanotechnology that can help moisture and infrared radiation leave the human body faster. The body should feel 2.7 and 2.1 cooler than cotton and commercially available synthetics, respectively. The research was published in the leading journal Science. Although outside experts are sceptical as this new fabric has not been tested or worn by humans, it is a step in the direction of task cooling. *(Hsu et al., 2016)*.

A PCS works when it is situated close to the occupant – areas away from these turn into a hot/cold spot. Also, the installation of a PCS requires extensive plumbing and mechanical work which increases the cost and the complexity of the distribution system. However, PCS can be used more efficiently by integrating it with various technologies such as thermal storage, phase change materials and radiant cooling technologies.

In a study conducted in San Francisco by UC Berkeley (Bauman et al., 1997) in collaboration with the Bank of America and Johnson Controls on Personal Environment Module (PEM) at 42 workstations, it was found that PEM units increased overall occupant satisfaction and air quality.

2.2.3.5 Earth Coupling

Just a few meters below the surface, the Earth maintains a nearly constant temperature which is less than the outdoor temperature in summer and higher in winter due to high thermal inertia of soil. The geothermal technologies such Earth Air Tunnel Heat Exchanger (EATHE) and Ground Source Heat Pump (GSHP) harnesses this temperature stabilising feature of earth to provide central heating or cooling to a building by pumping or exchanging heat with the earth.

Earth Air Tunnel Heat Exchanger (EATHE)

When ambient air is passed through ducts or pipes buried in the earth, the air is cooled or heated because of the temperature difference between the ambient air and the soil. This system can significantly reduce the requirement or sometimes even eliminate the need for active air-conditioning during summers, which results in a major reduction in electricity consumption of the building. The main advantage of such systems is their simplicity and high cooling potential.

The ground temperature fluctuates with time, depth and stabilizes after some time. Hence, the ducts should be buried as deep as possible (~4 m is ideal) to reduce the fluctuation of temperature. Also, the length and the diameter of the ducts should be sized for optimum heat transfer. It is important to note that moisture removal is another concern when condensation occurs in systems due to low airflow rates and high ambient dew point temperatures.

In a residential building in Gurgaon, the thermal performance of an earth-air-pipe system was studied (Thanu et al., 2001). The study shows high effectiveness of this system in summer months.

The thermal performance of a conventional 1.5 TR window type air-conditioner coupled with EATHE was experimentally studied for the composite climate of Ajmer, Rajasthan (Misra et al., 2012). Results showed that the power consumption of the AC reduced by 18.1% when cool air from EATHE was used completely for condenser cooling of the RAC.

Studies conducted by MNIT show that, in dry and rocky solid beds, thermal derating of earth air tunnels is an important phenomenon due to heat accumulation in the immediate surrounding area of the pipe. If neglected in design, it can result in reduction in the cooling effect with continuous operation of earth air tunnels.

Ground Source Heat Pump (GSHP)

GSHP employs a heat exchanger in contact with the ground or groundwater to extract or dissipate heat. The biggest benefit of GSHPs is that they use 25-50% less energy than conventional heating or cooling systems (Luo et al., 2016). According to the US Environmental Protection Agency (EPA), geothermal pumps can reduce energy consumption and corresponding emissions by up to 44% as compared to conventional pumps and by up to 72% compared with standard air-conditioning equipment (Energy.gov, 2017).

A GSHP has been installed at Central University of Rajasthan, Ajmer, India in the hostel building. Water from the boreholes is used to cool the air before introducing the same in the indoor spaces. The system uses 100% fresh air and is designed to reduce the temperature of the supply air by around 10°C. Design temperature for the hostel rooms is 29°C. Average outlet water temperature from the boreholes is recorded at 25°C. Outlet temperature in winter is around 19°C. EPI was measured to be approximately 78 kWh/m^2/year (NZEB, 2017).

2.2.3.6 Structure Cooling

Structure cooling aims to reduce the mean radiant temperature by extracting heat from the structure. This is achieved by circulating water at ambient temperature in pipes embedded over slabs to extract heat from the structure, thereby preventing it from getting too hot. The higher thermal mass of water delays the transfer of heat from the surroundings to the interiors of the structure. The circulated water drains heat from the structure and the heated water flows to the radiator where it gives away the heat gained and goes back to the tank for recirculation. It is a closed loop system so water requirement is one-time. There is no chilling of water or refrigerants required – only the pump takes up energy.

Studies and Potential Impact in India

Panasia Engineers have executed several projects that involve cooling through heat drain from structures. A detailed study at Veer Savarkar Rashtriya Smarak in Dadar, Mumbai reveals that after installing the system, a reduction in cooling load of 10.8 TR was observed. This led to a total energy savings of 7.69 kWh/sq. ft./year. Importantly, a 11.2%reduction in surface temperature was also observed.

2.2.4 Energy Efficient HVAC

HVAC systems are one of the largest consumers of energy in a building, consuming approximately 60% of the total energy consumption in commercial buildings. In most cases, HVAC systems designs follow from long-standing practice (rather than theory), conservative estimates and calculations based on large safety factors. The decision to opt for an HVAC system depends on a variety of factors including initial costs, building size (that determines the cooling load) and efficiency, among others.

Before choosing an efficient cooling technology for a building, the building design should be optimised to reduce the external heat gain as much as possible. Then, a thorough assessment of the cooling load of the building should be carried out. This cooling load should consider the following three major components – external heat gain through building envelope via conduction, convection and radiation, internal heat generated by building occupants, lighting and equipment. The cooling load should be met with an energy efficient cooling technology. Singapore's Green Mark rating system is a classic example wherein it is mandatory to design an HVAC plant below a certain minimum kW/ton to qualify for the rating. This is also verified during building operation to ensure that the building HVAC system is operating as designed.

2.2.4.1 High Performance RACs

The efficiency of an AC ensues from the efficiency of several individual components like the compressor, the indoor and outdoor heat exchangers, the indoor and outdoor fan motors, the expansion valve and the refrigerant. Improving the efficiency of one or a combination of these can result in higher overall energy efficiency of the AC. As cost is an important factor in consumers' choice of ACs, the components chosen for improvement should depend not only on their energy efficiency and environmental performance but their availability and costs as well.

EESL recently requested manufacturers to supply 50,000 units with an ISEER of 5.2. It is to be noted that the latest RAC standard that BEE has launched puts the ISEER of 4.5 for 5-star RACs. Three companies responded to this solicitation - the details of the prices along with the refrigerant that the RACs will use are indicated below:

- Panasonic with R-410a at Rs.35,000
- Godrej with R-290 at Rs.36,000
- Daikin with R-32 at Rs.41,000

The lowest price quoted by Panasonic is on an average 25-30% lower than the average price of the 5-star RACs available to Indian consumers through the retail channel. This significant development has the potential to transform the high-efficiency RAC market.

Table 3: Energy savings from energy efficient components (LBNL, BEE and CLASP, 2016)

Component		Energy Savings from Base Case (1.5 ton mini-split RAC of ISEER 2.8)
Compressor	3.0 EER compressor	5.5%
	3.2 EER compressor	10.5%
	3.4 EER compressor	15.0%
Variable speed drive	Alternating current compressor variable speed drive	21.0%
	Direct current compressor variable speed drive	23.0%
	Variable speed drives for fans and compressor	26.0%
Heat exchanger	UA value of both heat exchangers increased by 20%	7.5%
	UA value of both heat exchangers increased by 40%	13.5%
	UA value of both heat exchangers increased by 60%	17.5%
	UA value of both heat exchangers increased by 80%	21.0%
	UA value of both heat exchangers increased by 100%	24.0%
Expansion valve	Thermostatic expansion valve	3.5%
	Electronic expansion valve	6.5%

Table 4: Bill savings and payback period from energy efficiency improvements made to the base case model (LBNL, BEE and CLASP, 2016)

ISEER (W/W)	Increase in Retail Price (INR)	Annual bill savings for 1000-1600 hours of use per year (INR)	Simple payback period for 1000-1600 hours of use per year (Years)
2.8 (base case)			
3.5	4900, ~15%	2625 – 4200	1.9 – 1.2
4.0	9360, ~27%	3950 – 6300	2.4 – 1.5

LBNL, BEE and CLASP (2016) highlights the potential energy savings by upgrading certain components in a 1.5-ton mini-split RAC with an ISEER rating of 2.8 W/W (or the base case model), as indicated in Table 3. Table 4 gives an estimate of bill savings and payback periods for upgrading the base case model to an ISEER of 3.5 and 4.0.

2.2.5 Smart HVAC Controls

Controls – manual or automatic – enable equipment to operate effectively. Controls for HVAC systems in commercial buildings can have a range of benefits: Controls provide an indoor environment suitable for the building and help to enhance energy management and safety (McDowall et al, 2011); automatic controls eliminate the need for constant human monitoring, remove the element of human error, are more consistent and often provide better performance; they also reduce labour costs; very importantly, a properly functioning automatic HVAC controls ensure that the cooling system is operating at the lowest achievable kW/ton without compromising thermal comfort.

HVAC control systems can be designed to save energy – this requires knowledge of the building, its operating schedule and the equipment. Some commonly used HVAC control strategies are as follows: Optimum Start/Stop Control (OSSC) schedules the timings for switching cooling systems on and off such that indoor temperature falls within the limits of acceptability during the period of occupancy without spending excess energy; setting back the set-point allows cooling to drift from set-points to warmer temperatures during unoccupied times. However, this control strategy should be used alongside motion sensors (Canbay, 2003).

Complex HVAC systems can be interfaced with the Building Management System (BMS). Systems linked to a BMS typically comprise 40% of the building's energy usage (and up to 70% with lighting). Upon installation, smarter HVAC controls can increase energy efficiency by 20%.

To take full advantage of smarter HVAC controls, it is recommended that well trained facility staff should be deputed to run large central plants and BMS equipment and the inspection and calibration of different meters and sensors be done in a consistent and rigorous manner.

Godrej Bhavan, Mumbai has deployed several mean cooling strategies, among others, which led to a reduction of 12% in EPI from 271 kWh/m^2/year to 238 kWh/m^2/year. These included an energy metering system, HVAC system replacement and an auto blow down controller at the cooling tower.

Mahindra Towers, also in Mumbai, underwent a retrofit in lighting, HVAC and the electrical system. For the HVAC system, the AHU motors were replaced with high efficiency motors and the chiller pump efficiency was improved. In the first year after the retrofit, the average monthly saving was 45,259 kWh/month, a 14% reduction from pre-retrofit monthly electricity consumption. In the second year, the average monthly savings was 59,207 kWh/month, an 18% reduction from pre-retrofit monthly electricity consumption.

2.2.6 DSM & DR Programmes

Demand Side Management (DSM) and Demand Response (DR) are programmes used by utilities to incentivise or modify consumers' behaviour to reduce overall electricity consumption, as well as help manage peak demand requirements of the utilities.

Studies and Potential Impact in India

Distribution companies (DISCOMs) such as Reliance Infrastructure (RInfra) and Tata Power Company - Distribution (TPC-D) have been running DSM programmes addressing cooling needs of the consumers. RInfra had been implementing a pilot incentive programme for ACs from February 2014 to January 2016. The aim of the programme was providing incentives to consumers to purchase 5-star split ACs and replacing window ACs with them and bridging the price gap between 3-star and 5-star split ACs. RInfra reported energy savings from the programme to be about 10% and for commercial consumers. TPC-D in Mumbai and Delhi has also been undertaking various DSM programme under the campaign 'Be Green' in Mumbai and Delhi and has been running appliance exchange programmes including decorated ceiling fans, 1.5-ton ACs and refrigerators. It offers 40-60% discount to consumers, and in turn, the consumer can save 30-50% on energy costs. This programme is highly successful and has removed 20,000 power-guzzling appliances (EESL and PwC, 2015).

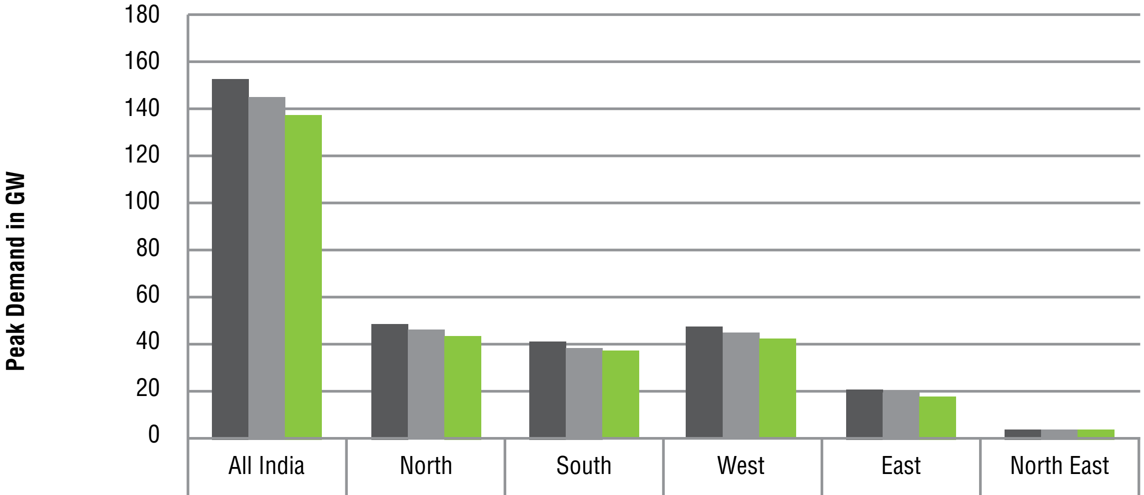
Peak demand creates indefensible social inequity emerging from the asymmetrically distributed impacts of summertime power outages which denies even the basic thermal comfort available through fans to those sections of society that contribute least to peak AC related demand. To manage peak demand, TPC-D also runs a manual DR programme (Khadilkar, n.d.) for voluntary load curtailment for commercial and industrial consumers with a connected load of 500 kVA or higher. The duration of the load curtailment is up to 2 hours each time and could happen up to 50 times in a year. TPC-D triggered the DR events based on peak power pricing and expected transmission constraints and paid each consumer 2.25 for every kW curtailed.

Tata Power Distribution Delhi (TPDDL) launched a pilot Auto Demand Response (AutoDR) programme in partnership with Honeywell and IBM in Delhi (Greentechmedia.com, 2017). 173 industrial and commercial consumers with a load greater than 100 kW and a consolidated connected load of over 400 MW are participating in the programme. Their aggregated peak demand is over 67 MW. 111 kW feeders fed from 40 substations are involved in this programme.

The northern, western, and southern India contribute to 90% of the country's peak demand. On the assumption that 50% of peak demand arises from the commercial and industrial sector and 50% from residential and rural sectors, it is estimated that DR market size in just the commercial and industrial sector would be 3.81 ~ 7.63 GW (Figure 12).

2.2.7 District Cooling

District cooling distributes thermal energy in the form of chilled water from a central source to residential, commercial, institutional and industrial consumers for use in space cooling and dehumidification. Thus, the cooling effect comes



	All India	North	South	West	East	North East
BAU	152.746	48.136	40.367	47.108	19.088	2.536
Achievable	145.1087	45.7292	38.34865	44.7526	18.1336	2.4092
Maximum	137.4714	43.3224	36.3303	42.7972	17.1792	2.2824

Figure 12: Peak demand for all regions in India (Honeywell, LBNL and TPDDL, 2015)

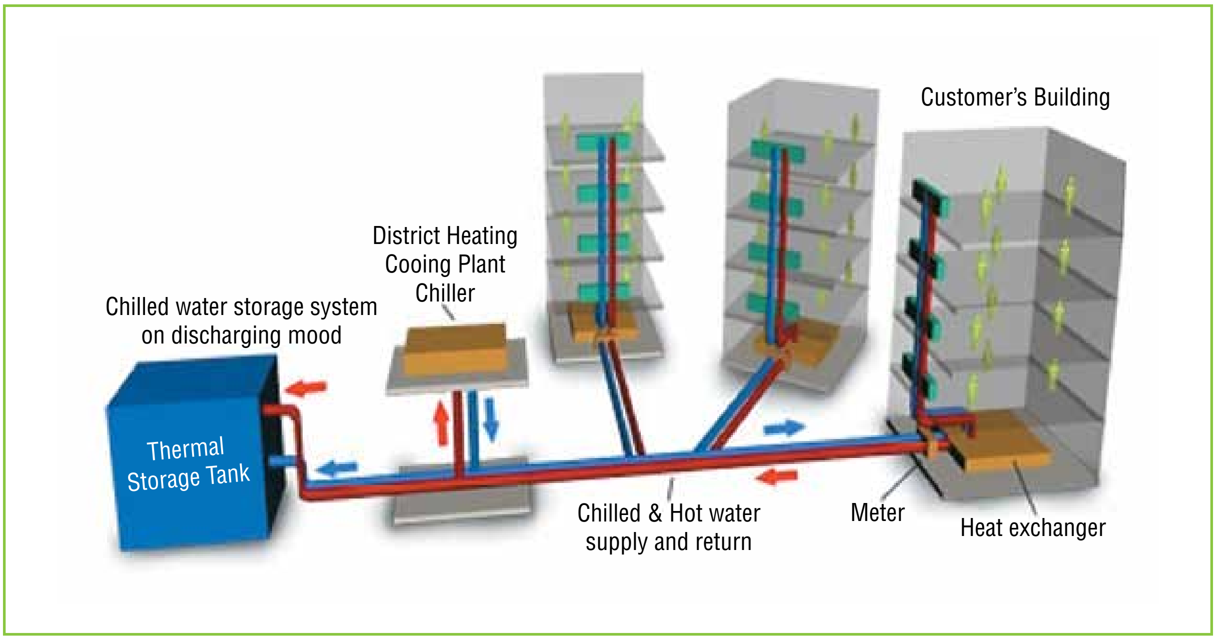


Figure 13: Representation of a district cooling system (Comfort futures, 2017)

from a distribution medium rather than being generated on site at each facility. It consists of a central chiller plant, the distribution/piping network and the consumer systems (Figure 13).

Generating chilled water in a large central plant is more efficient than generating it in each building. District cooling can take advantage of varying demands across all users in the system and may implement technologies such as thermal storage more effectively than individual cooling systems.

A district cooling system has been installed at St. Paul, Minnesota (District Energy, St. Paul, 2017). The plant has 2 chillers with a total capacity of 25,000 TR for an area of 1.8 million m^2. The distribution length was 11,500 m and the system connected with approximate 50 buildings of same type. A cogeneration system with biomass was used in this system.

Since constructing and running a district cooling plant is akin to operating a utility requiring significant capital investments, local or city government needs to create a conducive environment to attract organisations with both financial capabilities and technical expertise. There will be several issues related to the procurement of land, permissions to run ducts and pipes over long distances amidst crowded and expensive city blocks, ensuring signing of bullet-proof long-term contracts with anchor clients providing the requisite base load necessary to design and operate such plants that will need to be addressed and a public-private partnership model should be looked at for such initiatives to share the risks and have joint ownership to ensure its success.

Studies and Potential Impact in India

ICLEI, with help of UNEP (Riahi, 2016) is conducting a rapid assessment in five cities in India – Bhopal, Coimbatore, Pune, Rajkot and Thane. The organisation is working on creating awareness on the potential of district cooling and its role in achieving socio-economic and environmental benefits.

Gujarat International Finance Tec-City (GIFT City) is developing India's first district cooling network. The city opted to use district cooling due to its higher efficiency, lower operation and maintenance cost, and its ability to significantly cut carbon emissions. GIFT city installed a huge plant of 1,80,000 TR (GIFT Gujarat, 2017) cooling load capacity with several chillers and thermal storage systems. The chilled water distribution is underground through utility tunnels.

2.2.8 Challenges and Opportunities in Mean Cooling Strategies

While there are various low energy cooling technologies available for space cooling, these technologies are at different stages of development and use and some of them have not been adequately explored for Indian climatic conditions. Investments should be made in R&D and policies rolled out for providing incentives for mainstreaming low energy cooling technologies.

The other key aspect of mean cooling strategies - DSM programmes - have been very successful in parts of the world, but these haven't scaled up in India due to lack of awareness, necessary business focus, resources being made available to and expertise at the DISCOMs. Moreover, DISCOMs are yet to be convinced of the viability, payback and gain from the DSM programmes and the scale of revenues that can be generated, at the expense of reducing energy use at the Commercial and Industrial customers, their highest and most profitable customer segment, in the absence of strong regulatory push and availability of dedicated funds to compensate DISCOMs for revenue losses at the state level. All of this has led to few and sporadic pilots. We envision that given the success that EESL has enjoyed in demand aggregation and bulk procurement of LED lamps and the likelihood of repeating that success with energy efficient appliances, it can play an integral role in scaling DSM programmes by enabling AC manufacturers to fast-track energy efficient HVAC systems with DR features, in partnership with utilities and BEE. ACs equipped with smart controls for DR can automatically increase the set-point temperature to reduce power consumption during peak time. DISCOMS can also undertake customer education that can assist them to participate actively in DR programmes and contribute to demand savings directly affecting the bottom line of DISCOMs.

2.3 Green

Deploying green technologies, such as RACs with green refrigerants, solar air-conditioning and trigeneration, wherever possible will have a considerable impact on the energy security of India and contribute towards mitigating climate change.

2.3.1 Green Refrigerants

Globally, stationary AC systems account for nearly 700 million metric tons of direct and indirect CO_2-equivalent emissions (MMTCO_2e) annually. Indirect emissions from electricity generation account for approximately 74% of this total, while direct emissions of HFC and hydrochlorofluorocarbon (HCFC) refrigerants account for 7% and 19%, respectively. Direct

The strong advantages of natural refrigerants are that they have zero ODP, a negligible GWP, are part of the natural biogeochemical cycles and do not form persistent substances in the atmosphere, water or biosphere. They include carbon dioxide, ammonia and hydrocarbons such as propane, propene and isobutane. Natural refrigerants are widely used in some RAC applications, for example isobutane in domestic refrigerators and ammonia in large cooling processes.

A green refrigerant would have the benefits of natural refrigerants and also be energy efficient.

One of the foremost challenges with hydrocarbon based natural refrigerants is the safety concerns arising from the flammability - measures such as using appropriate materials, selection of safe components and technician training can offset these undesirable characteristics. CO_2, which is also a natural refrigerant, is energy inefficient. One needs to be mindful of these caveats while selecting a refrigerant. *(Green-cooling-initiative.org, 2017).*

emissions can occur from leakage during use and/or release at end-of-life due to poor deconstruction and recycling practices. Although electricity consumption is the largest driver of GHG emissions from AC systems (i.e. indirect impacts), emissions of HFC and HCFC refrigerants have a disproportionately large global warming impact relative to their mass. Addressing direct emissions, therefore, offers an important path to substantially reducing GHG emissions. Many available low-GWP alternative refrigerants having GWPs of 100 or less, can potentially reduce 75% or more of all direct emissions. Efficiency improvements can offset increases in up front purchase costs to consumers resulting from more expensive refrigerants and system redesigns, through lifecycle energy savings. The relative contribution of equipment, refrigerant, installation and operating costs to customer life cycle AC costs in an Indian RACs (1.5-ton, R-22) is as follows: non-refrigerant equipment cost (14%), refrigerant cost (1%), installation cost (2%), and lifecycle energy cost (83%) (US DoE, 2016). These numbers indicate that the cost of the refrigerant is disproportionately insignificant to its climate change impact and there may be possibilities to re-allocate some of these costs to fast-track the transition to green refrigerants. Policies ranging from DSM incentives to minimum standards and labelling programmes can help encourage development and deployment of energy efficient and climate friendly options that reduce lifecycle costs to consumers.

HFCs, also known as super greenhouse gases (since their GWP is almost 1000 times more than CO_2) are widely used for refrigeration and air-conditioning. They will be phased out according to the latest amendment to the Montreal Protocol made at Kigali in October 2016. Replacing HFCs with natural refrigerants will significantly reduce the risk of global warming.

Globally, some firms are leading the way in transitioning to green or natural refrigerants. NRDC and AHRI reached an agreement in February 2016 setting a joint deadline of 2025 for phasing out high GWP HFC such as R-134a, R-410A, and R-407C used in chillers. This agreement provides an opportunity to companies to phase out HFCs by identifying suitable climate-friendly refrigerants and manage transition costs at their own pace within the stipulated time frame.

The Consumers Goods Forum, a global industry association with 400 members comprising CEOs of retail companies, manufacturing companies and service providers in 70 countries, started phasing out HFCs, as of 2015. One of the members, PepsiCo has started using HFC-free equipment in 25 countries including India, China, Russia, Brazil and others. Another member, Nestle, committed that by the end of 2015, all their ice cream chest freezers will be HFC-free and by the end of 2014, 92% of their industrial refrigerants were replaced with natural refrigerants. In light of the Kigali Meeting of Parties, the Consumer Goods Forum has adopted a new resolution to use natural or ultra-low GWP refrigerants. In countries where barriers exist, they will work with all stakeholders to phase out HFCs as quickly as possible as and no later than 2025. They are committed to reducing environmental impacts of their refrigerants, improving energy efficiency and optimizing charge size of refrigerants and minimizing leaks. They also committed to setting and achieving individual targets and publishing their achievements.

Studies and Potential Impact in India

At Kigali, recognizing that its growing population is just beginning to afford air conditioners to combat extremely hot weather and that it will be required to provide an adequate timeframe to companies to make the transition to low GWP refrigerants, India negotiated for a later deadline and agreed to stop production and freeze HFCs by 2028. India will freeze HFCs by 2028 and by 2047 reduce 15% with respect to the 2025 levels. India also has the choice of fast-tracking this. India moved up its timeline – freeze years by three years from 2031 to 2028 and its baseline by four years from 2028-2030 to 2024-2026. India has also committed to immediately destroying HFC-23 (tri-fluoromethane), a by-product of HCFC-22 with a GWP of 14,800 through incineration. India issued instructions to the five companies manufacturing this chemical as a by-product to destroy it immediately using safe disposal methods and to avoid leakages.

It is understood that a good refrigerant should be non-flammable, non-toxic, and odourless, have very low GWP and zero ozone depletion potential. The list of refrigerants and their properties are given in Table 5. Indian AC manufacturers are ready to adopt new technologies and use green refrigerants. Major companies are also gearing up to manufacture green and alternate refrigerants for both, the local market and export. Likewise, large chiller manufacturers are using natural refrigerants. Moreover, research by WWF-India and CEEW (2014) points out that HC based room ACs are a bit on the expensive side because of new design and safety features, but these are also highly energy efficient so the life time cost could be cheaper. Most importantly, it has negligible GWP. Figure 14 depicts a schematic of the various factors which should be thought through before choosing any one refrigerant.

> Many next-generation refrigeration choices are non-flammable with ultra-low GWP that ideal for chiller applications with larger refrigerant charge sizes or they are non-flammable refrigerant blends with moderate GWP of less than 750. Standards and codes are continuing to change to balance environmental impacts, safety (flammability and toxicity) and product costs. The HVAC&R industry will perhaps need to adjust product refrigeration charge sizes in many direct refrigeration expansion applications to accommodate these developing standards. Non-flammable, low-GWP refrigerants in high performance products is the easiest way to quickly meet environmental goals. *(Kujak, 2017).*

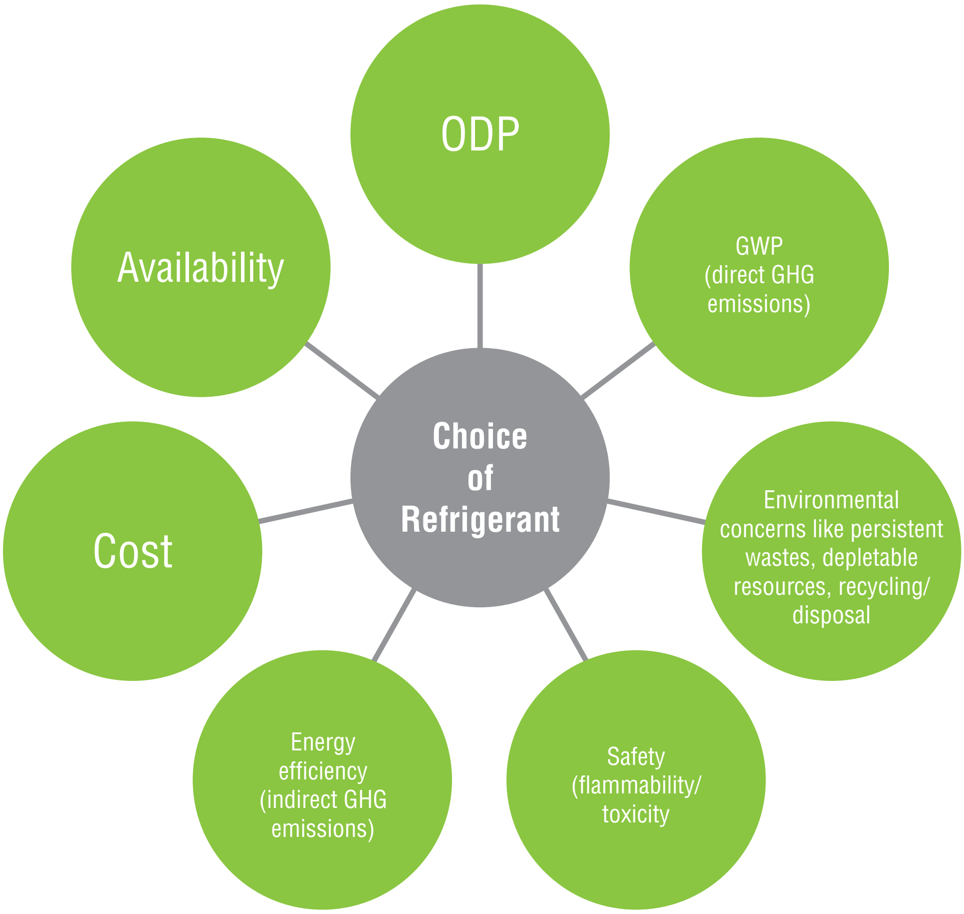


Figure 14: Factors informing the choice of refrigerant

Table 5: Types of refrigerants and their GWP (Assimilated from AEEE's secondary research)

Refrigerant	**GWP**	**Energy Efficiency**	**Companies**	**Market status**	**Cost**
HCFC-22	High (1800)	High	All phasing out	GHG, scheduled for phase out under Montreal protocol	High
HFC-410a	High (1923)	Low	LG, Samsung, GE, Carrier	GHG, ozone safe	High
HFC-32	Medium (675)	High	Daikin, Fujitsu, Hitachi, Mitsubishi, Panasonic, Toshiba	Ozone safe, mildly flammable	Medium
HC-290	Very low (<5)	High	Godrej	Low GWP, best available for ozone safe in small room AC, highly flammable	Low
HFC Blends (DR7, L41, L20)	Medium (300-450)	Medium	DuPont, Honeywell	Low GWP, low flammable	Medium
HFOs	Very low (<4)	Very High	In research phase	Environmental friendliness, cost-effectiveness	Low

R-290 is a wonder refrigerant but its chemical composition (hydrocarbon) leads to concerns about its flammability. Lower-flammability-limit related safety standards defined by ISO 5149:2007 address these concerns adequately and all room AC products based on R-290 comply with maximum allowable charge limits set by the relevant ISO or equivalent regional standard. Furthermore, the charge quantities of R-290 present in typical room ACs is in the range of 300-400 g. The threat level posed by this quantity of hydrocarbon must be calibrated in the context of the quantities of hydrocarbons (in the proximity of a source of ignition) stores in conventional homes and automobiles; most urban Indian homes possess 1-2 LPG cylinders each containing approximately 14 kg of flammable fuel and automobiles routinely contain upwards of 20 kg of flammable fuel.

2.3.2 Solar Air-conditioning

Solar air-conditioning refers to any air-conditioning system that uses solar power. This can be done through passive solar, solar thermal energy conversion and photovoltaic conversion. Thermally driven chillers use the vapour absorption/adsorption principle to produce cooling. Vapour pressure and temperature of the refrigerant is raised using desorption instead of using compressors. Thermally driven chillers also produce chilled water that is then used to cool the hot or warm spaces in a building (Figure 15).

Solar absorption chillers are very low in operating and maintenance costs and consume little or no electrical energy. The current market potential for solar air-conditioning is about 0.7 million TR and is increasing at the rate of around 17% per annum.

Pilot in India

A solar air-conditioning system of 100 kW cooling capacity has been integrated with a triple effect vapour absorption chiller (VAC) and solar parabolic concentrators for an office building at Solar Energy Centre, Gurgaon. The system is designed to meet cooling loads of 13 rooms at the centre. The integrated system is estimated to be 20% more efficient than a VAC with no solar components. Additionally, the system has a built-in phase thermal energy storage system using phase change material that allows it to supply cooling continuously (NZEB, 2017).

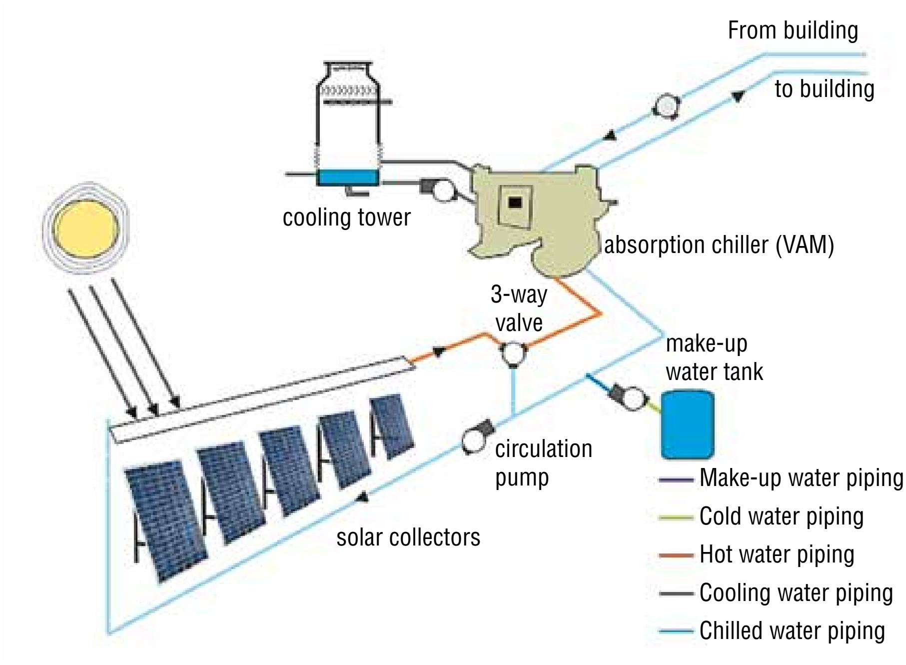


Figure 15: Schematic of a solar air-conditioning system (NZEB, 2017)

2.3.3 Trigeneration

Trigeneration technology, also known as combined cooling, heating and power (CCHP), produces three forms of energy, i.e. electricity, heating, and cooling which could be used to generate power, hot water and air-conditioning with suitable equipment (Figure 16). Heat captured through burning waste, production of electricity with generators or heat generated through solar panels could be used to generate chilled water with absorption chillers. Trigeneration systems at the end user sites can achieve excellent efficiency by using waste heat recovery system with no transmission losses. They could even supplement peak power demand and reduce damaging power cuts in India if they can sell to the grid. The most promising areas of trigeneration application include hospitals, hotels, department stores, data centres and industries where both electricity and heating or cooling demand is present.

Pilots in India

DLF Cyber City in Gurgaon has the CCHP installation with 11 million m^2 total area including more than 10 buildings. DLF has 40 MW of power generation through gas turbines with 17,500 TR of absorption chillers running on waste heat. There are 59 generators with 30-35% efficiency, and 33 chillers are installed with the capability of recovering 85-95% waste heat. After utilizing the waste heat, the total efficiency of the system is shown to increase to 83%.

A trigeneration system with 1000 TR conditioning load has been installed in Max Super Speciality Hospital, Vaishali. Components to meet loads include a gas gen-set (1.7MW), 600 TR capacity Vapour Absorption Machines with heat recovery, and electrical chillers of 400 TR capacity. The net annual saving achieved through the system was approximately Rs.3 crores. Additionally, the system provides uninterrupted power supply (NZEB, 2017).

A joint venture comprising Tata Industries and the Karnataka State Government has developed an integrated complex of multi-storied offices, residential and recreational facilities supporting over 130 companies with 20,000 employees. The concept of heat recovery and cooling was developed and all generator sets were equipped with waste heat recovery systems. The heat was recovered from a new 7.4 MW high-temperature water-cooling system and designed

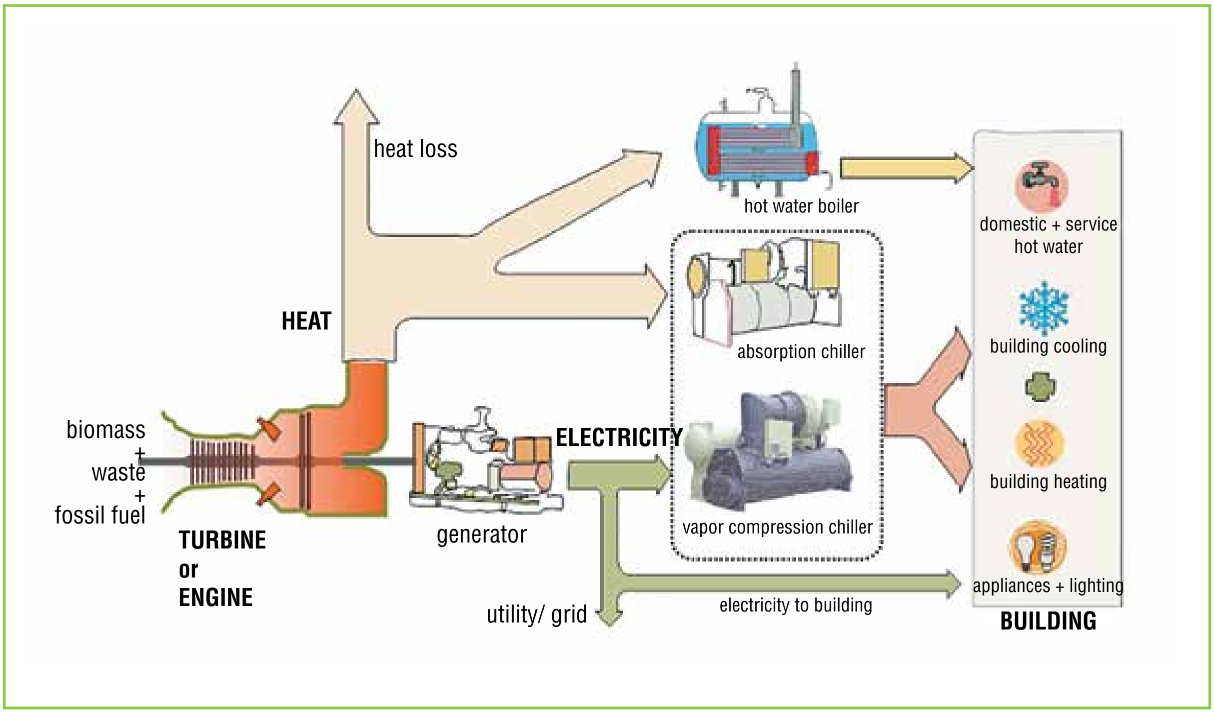


Figure 16: A schematic representation of trigeneration (NZEB, 2017)

to generate chilled water using VACs. The total peak power demand for the facilities is 54 MW, with a total system efficiency of 67% (UNEP, 2016).

A pilot project was carried out at the AIIMS Trauma Centre, Delhi by GIZ implemented by Development Environergy Services Limited (DESL). Components included – electricity 347 kW, 365 TR capacity vapour absorption chillers for cooling and 20 kW electrical chillers for kitchen and laundry. The payback period was 2 years and yielded annual savings of Rs.2 crores (IGEN, n.d.).

2.3.4 Challenges and Opportunities in Green Cooling Strategies

When we talk about green cooling strategies, there are two key areas that pose a challenge. First, both solar air-conditioning and trigeneration are emerging technologies that are relatively unexplored in India. The government should consider publishing technology alerts from recognised research bodies to increase awareness of these technologies. Simultaneously, R&D in solar air conditioning and trigeneration can be provided by means of policy directives. The MNRE and DST should consider incentivizing demonstration projects to promote these technologies and highlight their benefits.

Secondly, with the imminent growth in the AC market, the refrigerants, with their high GWP, pose a significant environmental challenge. Industry experts and research organisations, and agencies such as the MoEFCC should take immediate steps to address the lack of clarity on the best refrigerant for the future. This may involve developing an evaluation framework or composite rating system to fully acknowledge the climate and environmental impacts of refrigerants, safety considerations, cost, energy efficiency and availability. Additionally, the work of industry experts and organizations such as the UNFCCC can be leveraged to drive the industry towards green refrigerants.

3

The Way Forward

Importance of the drive for 'thermal comfort for all' cannot be overstated in India, which is experiencing a growing population with rising lifestyle aspirations against the backdrop of two recent international climate agreements, at Paris (2015) and at Kigali (2016). The ensuing societal, economic and environmental benefits of this drive are many - enhanced thermal comfort for a larger section of the Indian population, improved health and well-being, decrease in energy consumption and peak demands, reduced stress on the electric grid, improved national energy security, and reduction in carbon emissions.

In order to help achieve these benefits, this report serves two functions. First, it aims to be a repository of suitable cooling technologies, tools and techniques for fostering the ideal of sustainability and energy efficiency in the built environment, while gathering the independent approaches and existing efforts from the government and the private sector. Secondly and importantly, the report presents the Coalition's recommendations to promote smart cooling strategies, overcome potential challenges and advance the vision of thermal comfort for all. Directed at the central and state governments as the primary influencers, these recommendations when implemented will involve and impact a diverse range of stakeholders – building industry, manufacturers, consumers, and researchers.

The Coalition suggests four key recommendations that are presented below. For each of the recommendations, the Coalition also identifies supporting actions and tactics that will help facilitate transformative change. These actions are grouped per suggested timeframes - short-term: 1 to 3 years, medium-term: 3 to 8 years, and long-term: past 8 years.

1. **Establish 'thermal-comfort-for-all' as a government priority to align with GHG reduction goals and ongoing government initiatives, and link it with India's ambition to provide a better quality of life to all its citizens.**

Underpinning all the recommendations is one that calls for government backing including a supportive legislative framework to create and maintain viable market conditions for smart cooling strategies, and stronger governance of mandatory codes and energy performance thresholds. We envision two key ways in which government can support and expand adoption of sustainable and smart space cooling:

1A. Leverage ongoing government initiatives and require designers/architects of government- funded projects (residential or commercial) to design buildings incorporating the principles of lean-mean-green cooling strategies.

Supporting Actions: Short-term

- Government policies related to Housing for All and Smart Cities should advocate the inclusion of affordable thermal comfort concepts in the housing schemes. Leverage initiatives such as Housing for All to develop sustainably cooled 'Demonstration Projects' in a few sites, piloting low-energy as well as clean energy cooling solutions. For solutions that show significant energy saving potential, develop Government Technology Alerts in order to create awareness and establish credibility of these systems through an objective and yet technically rigorous manner.
- Facilitate R&D for low-energy as well as clean energy cooling technologies.
- Establish protocols for a National Home Energy Cost Benchmarking and Verification System for new developments. This could begin with a government-backed apartment-level energy cost calculation 'cell' (using 3-D Building Energy

Modelling software) for builders to estimate and communicate energy costs to potential home-buyers. The goal of this effort would be to demonstrate, through certified home life cycle energy cost values, the cost-effectiveness of energy efficient homes.

Supporting Actions: Medium-term

- Establish design guidelines based on Lean cooling strategies as a mandatory minimum standard for all new construction.
- Establish policy framework to enable DISCOMS to implement a Demand Response (DR) programme for room air conditioners. Subsidies for residential renewable energy capacity or bulk-procurement of super-efficient ACs for large developments could be linked with cooling load demand-side management performance (verified through submission of building energy modelling reports) of approved building designs.

1B. Institute comprehensive legislation as a cornerstone to achieve a viable market for smart cooling

Supporting Actions: Short-term

- **Greater emphasis on Standards and Labeling:** Develop mandatory standards and labeling programs for all ceiling fans, as well as for VRFs and chillers. Enforce stringency of energy performance thresholds.
- **Drive ECBC adoption:** Make ECBC implementation mandatory in all states. Provide governance to ensure strict compliance with all mandatory codes. Over time, develop variants of ECBC or simplified energy efficiency codes/ guidelines to cover smaller commercial buildings and all residential buildings.

Supporting Actions: Medium-term

- Encourage and enforce more stringent standards and labelling program for cooling equipment, drawing from Japan and Korea's successful experiences. A case in point is EESL's recent procurement of ISEER 5.2 RACs at prices lower than 5-star rated ISEER 4.5 RACs. This clearly indicates that there is a way to get cost-effective super-efficient RACs in India with innovative procurement and standards; and refutes the oft-cited cost-barrier argument against more stringent EE products put forward by RAC manufacturers.
- Establish policy to create state-level financial facilities for low-cost/preferential line of credit to real estate projects with a demonstrably high cooling efficiency.
- Introduce sustainable rating of architects/architecture firms based on a suitable building performance or energy efficiency quotient (e.g. the average EPI of operational project portfolio). Mandating minimum eligibility criteria for practicing architects in terms of these ratings will help ensure a constant push towards embodiment of energy efficiency and sustainability features in their projects.

Supporting Actions: Long-term

- Promote a voluntary framework to enable cooling efficiency benchmarks.
- MNRE should consider providing financial support and structuring performance based incentives for solar air-conditioning and trigeneration

2. **Generate market momentum towards smart cooling through awareness campaigns, access to information and technical assistance.**

Supporting Actions: Short-term

- Create consumer awareness through campaigns that focus on promoting and cultivating energy conserving behaviour in space cooling.
- Facilitate market transformation efforts for penetration of labelled products. Educate customers to make informed product choices based on operational savings, rather than the first cost alone.
- Support educational institutions to provide technical assistance, and undertake capacity building exercises including setting up a centre of excellence for smart cooling strategies. Facilitate upgradation of existing curricula across relevant streams/ branches/ fields of study to include sustainable cooling techniques and technologies.

3. **Drive adoption of energy efficient building materials and equipment into mainstream through consistent testing and rating protocols, and market transformation strategies.**

Supporting Actions: Short-term

- Create consumer awareness for energy conserving and efficient building materials, utilizing demonstration projects, infomercials, and stakeholders across the construction supply-chain to guide consumer choices.

Supporting Actions: Medium-term

- Develop protocols for EE ratings for building materials – wall/floor/roof construction blocks, insulation, paints/coatings/ finishes, glazing and whole window systems. Commission testing labs and enforce performance testing and certification of energy efficient building materials.
- Stimulate the market transformation for building materials through range of financing mechanisms such as upstream incentives for manufacturers and similar mechanisms for consumers.
- Create an open access platform which maps data of energy efficient and sustainably cooled buildings, to act as decision support design tool and enable evidence based policy-making.

4. **Undertake bold actions to phase out HFCs and drive the industry towards green refrigerants.**

Supporting Actions: Short-term

- Government of India should come out with an evaluation framework for rating refrigerants keeping in mind all the key criteria, to send a clear and strong signal to manufacturers and safeguarding the interest of its citizens and the environment.
- Encourage R&D on green refrigerants. Supporting development of natural refrigerant based ACs provided all safety and EE requirements are being met.

Supporting Actions: Medium-term

- Design upstream incentive schemes to phase out HFCs.

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