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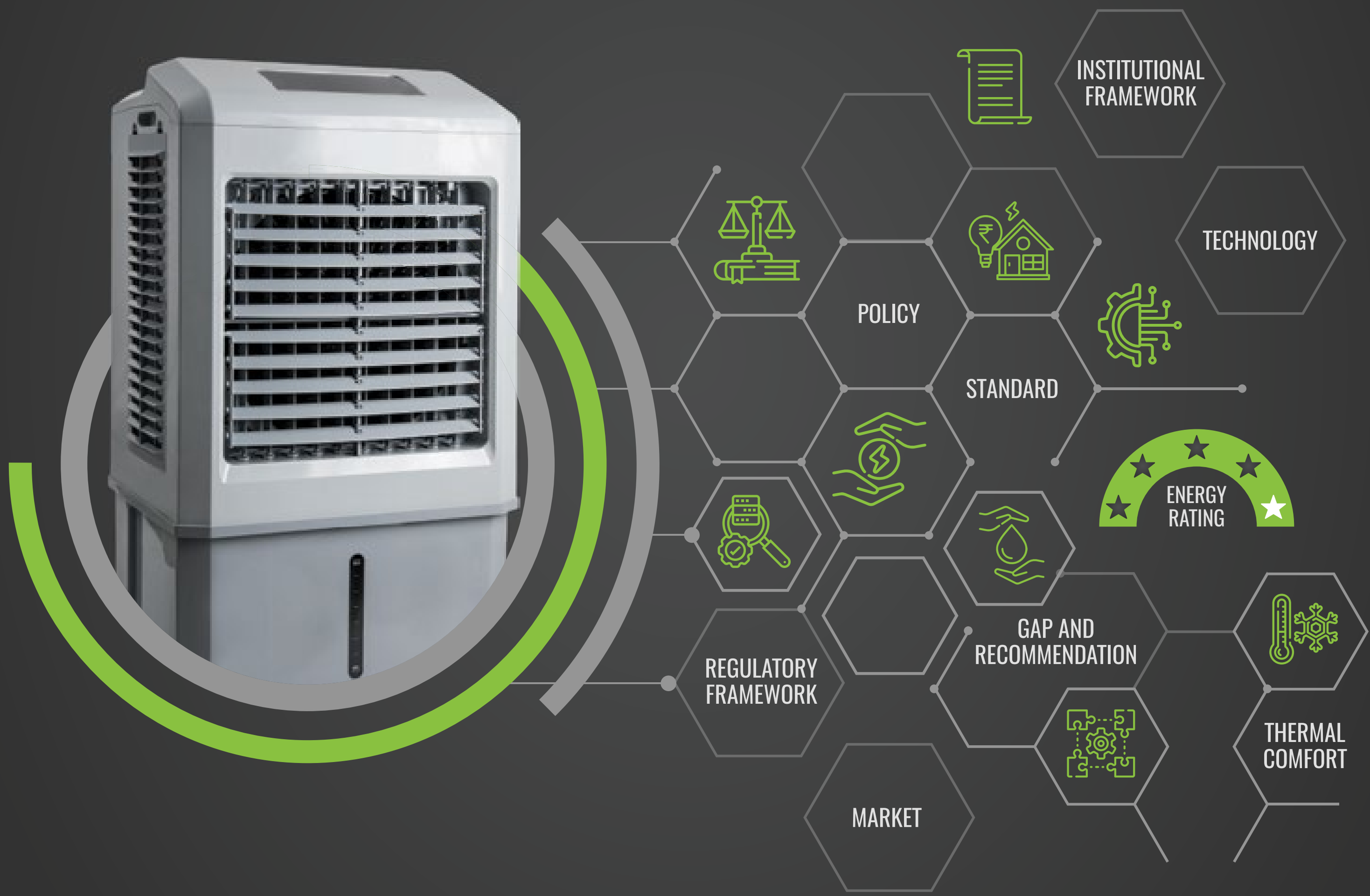
SHEETAL
Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort for All

Alliance for an Energy Efficient Economy

DECODING EVAPORATIVE AIR COOLERS



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Project: Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort (SHEETAL)

"The Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort (SHEETAL) is a consortium of Civil society organizations led by The Energy and Resource Institute (TERI) with the Alliance for an Energy Efficient Economy (AEEE), and the Council on Energy, Environment and Water (CEEW) as partners.

Supported by CIFF, SHEETAL facilitates the roll out of India's sustainable cooling agenda enshrined in the India Cooling Action Plan. Engaging with national and international stakeholders, the consortium partners discuss, identify and test integrated approaches best suited to improve the development, access and use of energy efficient cooling practices and technologies for R&D, space cooling, cold chain, transport air-conditioning, and the servicing sector. SHEETAL convene different line ministries and international and domestic cooling policy experts to collaborate and synergise actions to accelerate sustainable cooling in India".

Funded by: Children's Investment Fund Foundation (CIFF)

CIFF is a philanthropy organisation working towards the upliftment of children's quality of life, in developing countries. There areas of work are inclusive of maternal and child health, adolescent sexual health, nutrition, education, and deworming, tackling child slavery and exploitation, and supporting smart ways to slow down and stop climate change. Their prime focus towards quality data and evidence-based approach to measure the impact.

Prepared by: Alliance for an Energy Efficient Economy (AEEE)

AEEE is a policy advocacy and energy efficiency market enabler with a not-for-profit motive. AEEE advocates energy efficiency as a resource and collaborates with industry and government to transform the market for energy-efficient products and services, thereby contributing towards meeting India's goals on energy security, clean energy and climate change. AEEE collaborates with diverse stakeholders such as policymakers, government officials, business and industry, consumers, researchers, and civil society organisations. We believe that our work speaks for itself and we hold Respect, Integrity and Synergy as central to our efforts.

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FOREWORD

India is a signatory to the Paris Agreement and has declared to reduce the emission intensities by 33-35% by 2030 below the 2005 levels. Buildings account for almost 40% of the total global primary energy consumption and are responsible for approximately 17% of overall Greenhouse Gas (GHG) emissions. One of the major contributors to building energy consumption is cooling appliances. In addition, the COVID – 19 pandemic has forced most of the population to spend 90% of their time indoors and are increasingly dependent on mechanical cooling, heating, and artificial lighting systems. India witnesses extreme temperature variations and is categorized into majorly five climatic zones, of which four require cooling. While several initiatives have been taken globally to reduce the energy demand from buildings, energy efficiency has proven to be one of the key strategies for achieving energy demand and emission reductions.

Over the last four decade's Indian Society for Heating Refrigerating and Air Conditioning Engineers (ISHRAE) have been working to support various Government of India initiatives to promote energy-efficient cooling solutions with environmental responsibility to make buildings more and more energy-efficient. We work closely with government including BIS, BEE, DST, MOEFCC and various such bodies to collaborate and provide technical assistance to achieve common goals.

ISHRAE is also aggressively working with several technical groups consisting of subject matter experts to develop India specific standards relevant to building industry and shall shortly be rated as Standards Development Organization (SDO). Considering the huge potential of evaporative cooling system for Indian sub continent and understanding its importance, apart from writing the standard for the said domain, ISHRAE shall be releasing software tool to design and analyse evaporative cooling system for more then 40 Indian cities by providing annual heat map and expected outcome to improve the system design and industry standards.

The Alliance for an Energy Efficiency Economy (AEEE), established ten years ago, has worked with governmental institutions, industry organizations, research organizations, and civil society organizations and has laid the foundation for India's cooling journey by supporting the development of the India Cooling Action Plan (ICAP) which outlines the role of low energy cooling technologies.

Low energy cooling technologies such as evaporative air coolers, fans postulate a crucial role in realizing India's Thermal Comfort for All agenda, being affordable, sustainable, and scalable. If brought under the Minimum Energy Performance Standards (MEPS) or Star Labelling regulations for appliances such as evaporative air coolers, these technologies can prove to be a low-carbon transition pathway and significantly contribute towards a decrease in building energy consumption.

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AEEE's prudence in bringing out the "Decoding Evaporative Air Coolers" report acts as a foundation stone. It lays out in detail a bouquet of opportunities that can be tapped into for the implementation of MEPS for Evaporative air coolers. It provides a detailed overview of the institutional landscape in India and policy regimes adopted by countries internationally concerning the performance and testing of Evaporative Air Coolers. The report provides insights on the existing gaps and provides bridging mechanisms as recommendations. This report does not only encapsulate views from Indian stakeholders but also captures recommendations provided by international agencies such as United for Efficiency (U4E), Eurovent Certita Certifications (ECC), renowned for their work in transforming markets towards energy-efficient products and HVAC performance testing and certification respectively.

Information on Evaporative Air Coolers being sparse, this report put – forwards the much-needed information and shall act as an enabling document for the foundational work for the development of MEPS for evaporative air coolers in India.

I gratefully acknowledge AEEE's efforts and the support of all those associated with the development of this report and look forward to their continued efforts to bridge the gap for the development of MEPS for low energy cooling technologies in India.

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List of Abbreviations and Acronyms

°C: Degree Celsius

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

BEE: Bureau of Energy Efficiency

BIS: Bureau of Indian Standards

BLDC: Brushless Direct Current

BLY: Bachat Lamp Yojana

CAGR: Compound Annual Growth Rate

CEAMA: Consumer Electronics and Appliances Manufacturers Association

CFL: Compact Fluorescent Lamp

CFM: Cubic Feet Per Minute

CNRA: California Natural Resources Agency

CPRI: Central Power Research Institute

CSO: Civil Society Organisation

dBA: A-weighted decibels

DEC: Direct Evaporative Air Cooler

DG: Diesel Generator

DMITRE: Department of Manufacturing, Innovation, Trade, Resources and Energy

E3 Programme: Equipment Energy Efficiency Programme

EC Act: Energy Conservation Act

ECC: Eurovent Certita Certification

ECE: Evaporative Cooling Equipment

ECER: Evaporative Cooler Efficiency Ratio

EEFP: Energy Efficiency Financing Platform

EER: Energy Efficiency Ratio

EESL: Energy Efficiency Services Limited

FEEED: Framework for Energy Efficient Economic Development

GDP: Gross Domestic Product

GEMS: Greenhouse and Energy Minimum Standards

GHG: Greenhouse Gas

GWP: Global Warming Potential

HCFCs: Hydrochlorofluorocarbons

HE: Heat Exchanger

HPMP: Hydrochlorofluorocarbons Phase out Management Plan

HVAC: Heating, Ventilation, and Air Conditioning

Hz: Hertz

IAQ: Indoor Air Quality

IAME: Independent Agency for Monitoring and Evaluation

IBEF: India Brand Equity Foundation

ICAP: India Cooling Action Plan

IDEC: Indirect-Direct Evaporative Air Cooler

INR: Indian Rupee

IS: Indian Standard

ISEER: Indian Seasonal Energy Efficiency Ratio

ISHRAE: Indian Society of Heating, Refrigerating and Air Conditioning Engineers

ISIRI: Institute of Standards and Industrial Research of Iran

ISO: International Organisation for Standardisation

Kg: kilogramme

kWh: kilowatt-hour

L: litre

LED: Light Emitting Diode

LPG: Liquefied Petroleum Gas

m3: cubic metre

MeitY: Ministry of Electronics & Information Technology

MEPS: Minimum Energy Performance Standard

MFD: Multi-Function Device

mm: millimetre

MoCI: Ministry of Commerce & Industry

MoP: Ministry of Power

MoU: Memorandum of Understanding

MTEE: Market Transformation for Energy Efficiency

MW: Megawatt

NAPCC: National Action Plan on Climate Change

NDC: Nationally Determined Contribution

NIST: National Institute of Standards and Technology

NMEEE: National Mission for Enhanced Energy Efficiency

OEM: Original Equipment Manufacturer

Pa: Pascal

PAT: Perform, Achieve and Trade

PRGFEE: Partial Risk Guarantee Fund for Energy Efficiency

R&D: Research & Development

RH: Relative Humidity

S&L: Standards and Labelling

SATBA: Renewable Energy and Energy Efficiency Organisation

SDAs: State Designated Agencies

SEC: Specific Energy Consumption

SEEP: Super Efficient Equipment Programme

SEER: Seasonal Energy Efficiency Ratio

SERCs: State Electricity Regulatory Commission

SHEETAL: Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort for all

SoP: Standard Operating Procedure

SSI: Small Scale Industries

TSC: Total Salt Content

TDS: Total Dissolved Salts

UJALA: Unnat Jyoti by Affordable LEDs for All

VCFEE: Venture Capital Fund for Energy Efficiency

VRF: Variable Refrigerant Flow

W: Watt

WELS: Water Efficiency Labelling and Standards

Key Definitions

1. Psychrometry: The science of understanding air mixture, specifically the dry air, humidity and temperature. It explicitly deals with the properties of moist air. The psychometric chart is a visualisation tool extensively used in buildings system design and operations to understand the relation between the physical properties of moist air.[1,2,3&4]

2. Dry-Bulb Temperature: The temperature of the ambient air (sensible heat). It can be measured with an ordinary thermometer. The unit is degree Celsius.[5]

3. Wet-Bulb Temperature: The lowest temperature that can be achieved through evaporation at 100% saturation effectiveness. After reaching this temperature, air cannot be further cooled through direct evaporative air cooling. The wet-bulb temperature determines the amount of humidity present in the air. If the humidity is more, the difference between the wet-bulb temperature & dry-bulb temperature will be less; this denotes that not much evaporation is possible. Generally, the unit is degree Celsius (°C) or Kelvin.[6]

4. Enthalpy (kJ/kg): The sum of both sensible and latent heat and measures the total heat content in the air.[7]

5. Relative Humidity (%): The ratio of the actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.[8] It is measured as the percentage of moisture present in the air as compared to its full capacity/the maximum moisture it can hold at a given temperature. With a change in air temperature, the capacity to retain moisture increases or decreases, thus affecting relative humidity.

6. Specific Humidity: The mass of water vapour present in 1 kilogramme (kg) of dry air. It is also called specific humidity or humidity ratio. Generally, the unit is g/kg of dry air.[9]

[1] Dincer, I. & Rosen, M. A., 2007. Chapter 6 - Exergy Analysis of Psychrometric Processes. *EXERGY, Elsevier,* pp. 76-90.

[2] Govekar, N., Bhosale, A., & Yadav, A., 2015. Modern Evaporative Cooler. *International Journal Of Innovations In Engineering Research And Technology [IJIERT], 2(4).*

[3] Gatley, D. P., 2013. *Understanding Psychrometrics*, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

[4] Teitelbaum, E., Jayathissa, P., Mil, C., & Meggers, F., 2019. Design with Comfort: Expanding the psychrometric chart with radiation and convection dimensions. *Energy & Buildings, Elsevier.*

[5] Gatley, D. P., 2013. *Understanding Psychrometrics*, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

[6] Ibid.

[7] REHVA, 2012. *Definitions of terms and abbreviations commonly used in REHVA publications and in HVAC practice,* s.l.: REHVA.

[8] Govekar, N., Bhosale, A., & Yadav, A., 2015. Modern Evaporative Cooler. *International Journal Of Innovations In Engineering Research And Technology [IJIERT], 2(4).*

[9] Ibid.

Executive Summary

Achieving thermal comfort is essential to ensure overall wellbeing and increasing productivity. India is one of the countries with the lowest access to cooling globally but simultaneously has around 4 trillion person cooling degree days. Currently, only a small fraction of the total residential population has access to air conditioners, and a significant share of households will still not have access to air conditioners over the next 10-20 years, due to lack of purchasing power, for achieving thermal comfort.

Despite air conditioners' low penetration, they contribute significantly to emissions based on their energy use as they use high Global Warming Potential (GWP) refrigerants, peak demand in metropolitan cities and space cooling energy consumption which is predicted to rise significantly by 2037-38. Therefore, India is facing the challenge of providing access to affordable cooling for all, while simultaneously mitigating climate change.

With India's tropical climatic conditions and pressing climate need for cooling, there is a significant opportunity to increase the uptake of evaporative air coolers in India's appliance market. Evaporative air coolers could play a significant role in providing thermal comfort for all while also reducing the demand for refrigerants with GWP in India. They are a sustainable and affordable cooling technology alternative, when compared to air conditioners, as they work on the simple principle of evaporation, where water is used as a natural refrigerant, and they function well in India's hot-dry and composite climatic zones. In comparison to air conditioners, evaporative air coolers are more affordable, consume less energy, have low operational and maintenance costs, and are a Non-GWP refrigerant based space cooling solution.

Evaporative air coolers could play a significant role in providing thermal comfort for all while also reducing the demand for refrigerants with GWP in India.

In order to facilitate evaporative air cooler market growth, there is a critical need to promote and facilitate the penetration of standardised and energy-efficient evaporative air coolers by developing their Minimum Energy Performance Standards (MEPS). Henceforth, this study focused on the national and international policy, regulatory, and institutional frameworks related to evaporative air cooler performance through an extensive literature review. The study also highlighted the gaps and recommendations for India, based on the learnings from international evaporative air cooler testing standards, regulations, and MEPS frameworks.

The study provided detailed information on the different types of evaporative air coolers—direct evaporative air coolers (DECs), indirect evaporative air coolers (IECs), and indirect-direct evaporative air cooler (IDECs)—based on their structure, technology description, working principle, and applications. In DECs, cooling pads are used as the cooling medium, and the cooled air has increased humidity. DECs are more efficient than IECs. In this technology, the dry-bulb temperature decreases, whereas the wet-bulb temperature remains constant, and there is no change in enthalpy. This type of evaporative air cooler is best suited to the residential sector and hot-dry climatic zones.

The IECs, in contrast, use heat exchangers as their cooling medium. In this technology, no humidity is added to the supply air, and there is a reduction in enthalpy and the dry- and wet-bulb temperatures. This technology is best suited to both the residential and commercial sectors and is adaptable in composite/hot-dry climatic zones.

An IDEC combines an IEC, in the first stage, and a DEC, in the second stage. It is the most efficient technology in comparison to the other two types. Humidity is added to the supply air, but the increase in humidity is lower than in DECs. In this technology, there is a reduction in enthalpy and the dry-bulb temperature. The wet-bulb temperature initially decreases in the first stage and then remains constant in the second stage.

This technology is best suited to both the commercial and industrial sectors and is adaptable in composite/hot-dry climatic zones.

The study also provided a brief overview of the Indian evaporative air cooler market and institutional framework. Currently, India's unorganised evaporative air cooler market has a larger market share than the organised market. The unorganised sector uses offline market distribution channels and retail shops, whereas the organised sector employs both offline and online market distribution channels. The evaporative air cooler market is segmented into residential and commercial, according to the cooler application. Preliminary stakeholder consultations indicated that DECs are majorly in demand in the residential sector, and the demand for IDECs is expected to grow multifold in the commercial and industrial sector in the near future due to potential IDEC applications and lower energy consumption in comparison to air conditioners.

India's unorganised evaporative air cooler market has a larger market share than the organised market.

The institutional framework for appliances in India is governed by various ministries, regulatory bodies, state agencies and associations, including the Ministry of Power (MoP), Ministry of Commerce & Industry (MoCI), Ministry of Environment, Forest & Climate Change (MoEF&CC), Ministry of Electronics & Information Technology (MeitY), Ministry of Consumer Affairs, Food, and Public Distribution, Bureau of Energy Efficiency (BEE), Bureau of Indian Standards (BIS), India Brand Equity Foundation (IBEF), Central Power Research Institute (CPRI), State Electricity Regulatory Commissions (SERCs), State Designated Agencies (SDAs), Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE)and Consumer Electronics and Appliances Manufacturers Association (CEAMA). These organisations could potentially play a role in the implementation of MEPS for evaporative air coolers.

Moreover, the study also examined the Indian Standard (IS) for evaporative air coolers and energy efficiency programmes focused on increasing appliance efficiency in India. As per the latest IS standard for evaporative air coolers, the airflow, outer structure material, noise levels, cooling pads, and fan motor and water pump efficiency are the most critical parameters for evaluating a cooler's overall performance. Water consumption is not included as a parameter in this standard. The study also looked at the national programmes aiming to enhance appliance efficiency—the BEE Standards and Labelling (S&L) programme and National Mission for Enhanced Energy Efficiency (NMEEE).

The literature review on India's policy, regulatory, and institutional framework revealed significant scope for improvement. Hence, there was a need to look at international best practices in improving evaporative air cooler energy efficiency, in order to extract learnings and develop a more robust policy, regulatory, and institutional framework for evaporative air coolers in India.

Only Iran has established MEPS for evaporative air coolers.

For the international review, Iran, USA (California), and Australia were selected, and their policies, regulations, testing standards, and MEPS for evaporative air coolers were analysed. In addition to this, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) testing standards for both DECs and IECs were also examined, along with Eurovent Certita Certification (ECC) initiatives for increasing the performance. All the international standards/regulations cover power consumption, airflow, and cooling/saturation effectiveness. However, only ASHRAE and ECC have touched upon parameters related to water efficiency, and only Iran has established MEPS for evaporative air coolers.

Based on the comprehensive review of national and international institutional, policy, and regulatory frameworks in regards to improving the performance of evaporative air cooler, the study identified gaps at the national level in terms of 'policy and regulatory' and 'research and design' which are followed by recommendations to address them in the near future.

1

Introduction

This chapter provides the context for this study by highlighting the challenge faced by India to provide access to sustainable thermal comfort for all and the need for promoting the use of an alternative sustainable cooling technology.

1.1 | Background

Access to cooling for attaining thermal comfort is no longer a luxury, but, rather, a necessity for enhancing overall quality of life, productivity, and well-being. Thermal comfort can be defined as a state where an individual is satisfied with the thermal environment, which is determined and affected by various factors, such as the microclimatic conditions—temperature, relative humidity, airflow, air temperature, dew-point temperature, and wind speed— and an individual's clothing insulation & metabolic rate[10&11]. Achieving and experiencing thermal comfort is essential for an individual's psychological and physiological well-being.

A country's cooling demand depends on multiple variables, the most vital being the country's per capita Gross Domestic Product (GDP), population, and cooling degree days. India is one of the largest and fastest-growing economies in the world, with over 3,000 cooling degree days per year[12]. Despite the growing economy and pressing climatic need for cooling, according to the India Cooling Action Plan (ICAP) 2019, India has one of the lowest levels of access to cooling, with per capita space cooling energy consumption at 69 kilowatt-hours (kWh), compared to the world average of 272 kWh.

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[10] ASHRAE, 2017. STANDARD 55 – *Thermal Environmental Conditions for Human Occupancy.* [Online] Available at: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy

[11] Sustainable and Smart Space Cooling Coalition, 2017. *Thermal Comfort for All - Sustainable and Smart Space Cooling*, New Delhi: Alliance for an Energy Efficient Economy.

[12] Lalit, R. & Kalanki, A., 2019. *How India is solving its cooling challenge.* [Online] Available at: https://www.weforum.org/agenda/2019/05/india-heat-cooling-challenge-temperature-air-conditioning/[Accessed 2020].

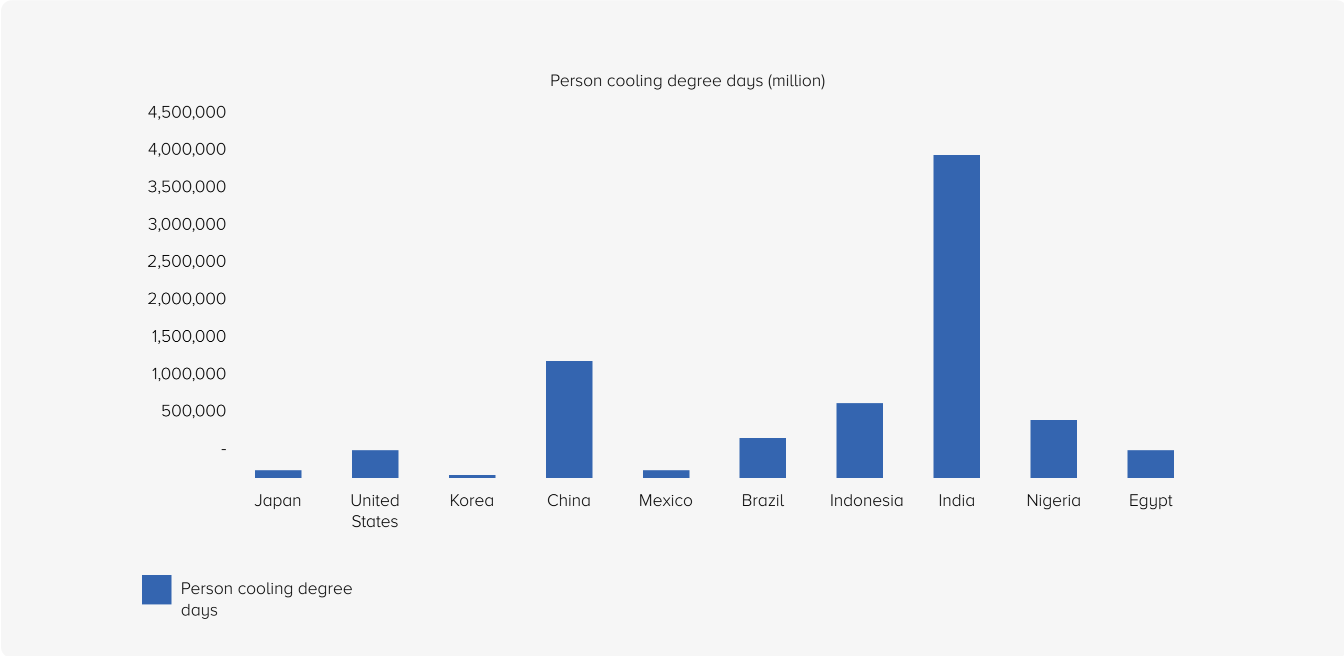


Figure 1: Global Comparison of Person Cooling Degree Days [13]

As per a recent study by Rocky Mountain Institute (RMI)[14], India has around 4 trillion 'person cooling degree days'[15], which is significantly higher than that of other countries, as shown in Figure 1. However, only 7-9% of the Indian households currently own room air conditioners, and it is estimated that even in the coming decade, a significant share of households will still not have sufficient purchasing power to buy room air conditioners, for attaining thermal comfort[16]. Despite the fact that room air conditioners have low penetration in Indian households, they use refrigerants, which have high[17] global warming potential (GWP) accounting for a significant share of emissions based on their energy use[18].

Furthermore, room air conditioners still account for a dominant share of Indian space cooling energy consumption—around 42% in 2017-18, which is expected to steadily grow to ~52% in 2037-38—and are currently contributing around 50% of the peak load, specifically in major metropolitan areas of India[19&20]. At the same time, India has ratified the Kigali Amendment on the use of refrigerants with high GWP, which calls for the pursuit of enhanced energy efficiency amidst the refrigerant transition. Therefore, India is currently facing the challenge of providing access to affordable cooling for all without exacerbating environmental issues.

In India, interventions such as the Hydrochlorofluorocarbons (HCFCs) Phase Out Management Plan (HPMP) Phase 1 has been successfully completed for some sub-sectors, namely, Variable Refrigerant Flow (VRF) Products, Rail Coach Air-Conditioning (AC), Bus AC, and Transport Refrigeration under room air conditioner manufacturing industry[21]. However, it will take significant time to phase out the existing products with HCFCs from the Indian room air conditioner market and built environment, which is now being aggressively carried out under HPMP Phase 2 (2017-2023).

India has five climatic zones consisting of hot-dry, warm & humid, temperate, composite, and cold[22]. Considering India's tropical climatic conditions and the impact of room air conditioners on power consumption, along with the associated greenhouse gas (GHG) emissions, there exists a significant opportunity to promote evaporative air coolers.

[13] Adapted from Lalit, R. & Kalanki, A., 2019. *Cooling Demand Versus Current AC Ownership in Different Parts of The World.* [image] Available at: https://www.weforum.org/agenda/2019/05/india-heat-cooling-challenge-temperature-air-conditioning[Accessed 17 January 2020].

[14] Lalit, R. & Kalanki, A., 2019. *How India is solving its cooling challenge.* [Online] Available at: https://www.weforum.org/agenda/2019/05/india-heat-cooling-challenge-temperature-air-conditioning/[Accessed 2020].

[15] A cooling degree day is a measurement to estimate the demand for energy needed to cool a building. Person cooling degree days represent a country's average annual cooling degree days multiplied by the total population.

[16] Ministry of Environment, Forest & Climate Change, 2019. *India Cooling Action Plan*, New Delhi: Ministry of Environment, Forest & Climate Change.

[17] 'High' here refers to refrigerants that have a GWP above 750. As per ISHRAE's 2015 data, the most commonly used refrigerant in India is HFC 134a, which has the GWP of 1340.

[18] Ministry of Environment, Forest & Climate Change, 2019. *India Cooling Action Plan*, New Delhi: Ministry of Environment, Forest & Climate Change.

[19] Ibid.

[20] Pandita, S., Kishore Kumar, P., Walia, A., & Ashwin, T., 2020. *Policy measures and impact on the market for the Room Air.* [Online]. Available at: https://clasp.ngo/publications/policy-measures-and-impact-on-the-market-for-room-air-conditioners-in-india

[21] Ministry of Environment, Forest & Climate Change, 2017. *HCFC Phase-Out Management Plan Stage II*, New Delhi: Ministry of Environment, Forest & Climate Change.

[22] Bureau of Indian Standards, 2016. *National Building Code of India 2016 Volume 2,* New Delhi: Bureau of Indian Standards.

Evaporative air coolers can prove to be an effective alternative technology because it uses a sustainable and affordable Non-GWP refrigerant based cooling mechanism to ensure thermal comfort and works reasonably well in Indian climatic conditions, with its only limitation being extremely humid conditions. Evaporative air coolers would not only reduce the user's dependency on room air conditioners with high GWP, but would also help India meet its nationally determined contribution (NDC), i.e. the 2030 targets for emission reduction, along with its commitments made in the Kigali agreement. This would also align with goals set in the ICAP.

Evaporative air coolers are also known as swamp or desert coolers and have applications in both residential and commercial settings. They work on the simple principle of evaporation of water, where water also acts as a refrigerant. Several studies and literatures have indicated that evaporative air coolers can effectively provide thermal comfort in India's two major climatic zones, hot-dry and composite, covering the majority of the country, as shown in Figure 2[23,24&25].

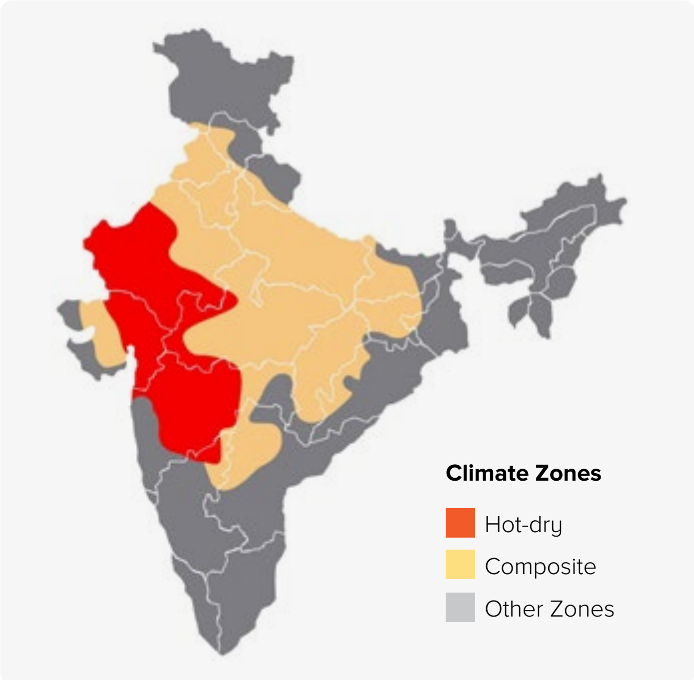
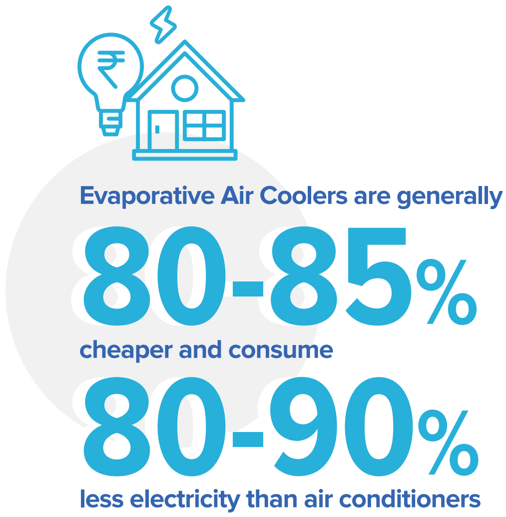


Figure 2: Climate Zones in India Where Evaporative Air Coolers Work Effectively [26]



In addition to being a Non-GWP refrigerant based space cooling solution and adaptable to India's tropical climatic conditions, evaporative air coolers are an affordable and sustainable cooling technology alternative. They are generally 80-85% cheaper and consume 80-90% less electricity than air conditioners[27&28]. Furthermore, new age evaporative air coolers with energy-efficient fans and pumps have an energy saving potential of an additional 10-20% in the coming decade, when compared to business as usual case[29]. Evaporative air coolers could facilitate provision of thermal comfort for all, while simultaneously reducing the demand for refrigerants with GWP in India.

India's evaporative air cooler market is projected to grow at a Compound Annual Growth Rate (CAGR) of 14.2% in 2019-25[30]. With their growing demand and evaporative air coolers' approximate lifespan of 12 years or more, there is a critical need to develop their Minimum Energy Performance Standards (MEPS) in order to lock in energy savings in the coming years, thus creating a level playing field and encouraging the adoption of energy-efficient evaporative air coolers.

[23] Jain, J. & Hindoliya, D., 2013. Energy saving potential of indirect evaporative cooler under Indian climates. *International Journal of Low-Carbon Technologies 2016*, p. 193–198.

[24] Sarkar, J., 2020. *Evaporative Cooling Technologies for Buildings*, Varanasi: Cooling India.

[25] Govekar, N., Bhosale, A., & Yadav, A., 2015. Modern Evaporative Cooler. *International Journal Of Innovations In Engineering Research And Technology [IJIERT]*, 2(4).

[26] Adapted from Bureau of Indian Standards, 2016. *National Building Code of India 2016 Volume 2*, New Delhi: Bureau of Indian Standards.

[27] Grand View Research, 2019. *Air Coolers Market Size, Share & Trends Analysis Report By Type (Tower, Dessert), By Application (Residential, Commercial), By Region (North America, Europe, APAC, CSA, MEA), And Segment Forecasts, 2019 - 2025*, California: Grand View Research.

[28] Jain, A., 2020. *Bijli Bachao*. [Online] Available at: https://www.bijlibachao.com/air-conditioners/best-air-cooler-india-brand.html [Accessed 2020].

[29] Ministry of Environment, Forest & Climate Change, 2019. *India Cooling Action Plan*, New Delhi: Ministry of Environment, Forest & Climate Change.

[30] 6Wresearch, 2019. *India Air Cooler Market (2019-2025)*. [Online] Available at: https://www.6wresearch.com/industry-report/india-air-cooler-market-2019-2025#:~:text=According%20to%206Wresearch%2C%20India%20Air,with%20the%20demonetization%20in%202016.

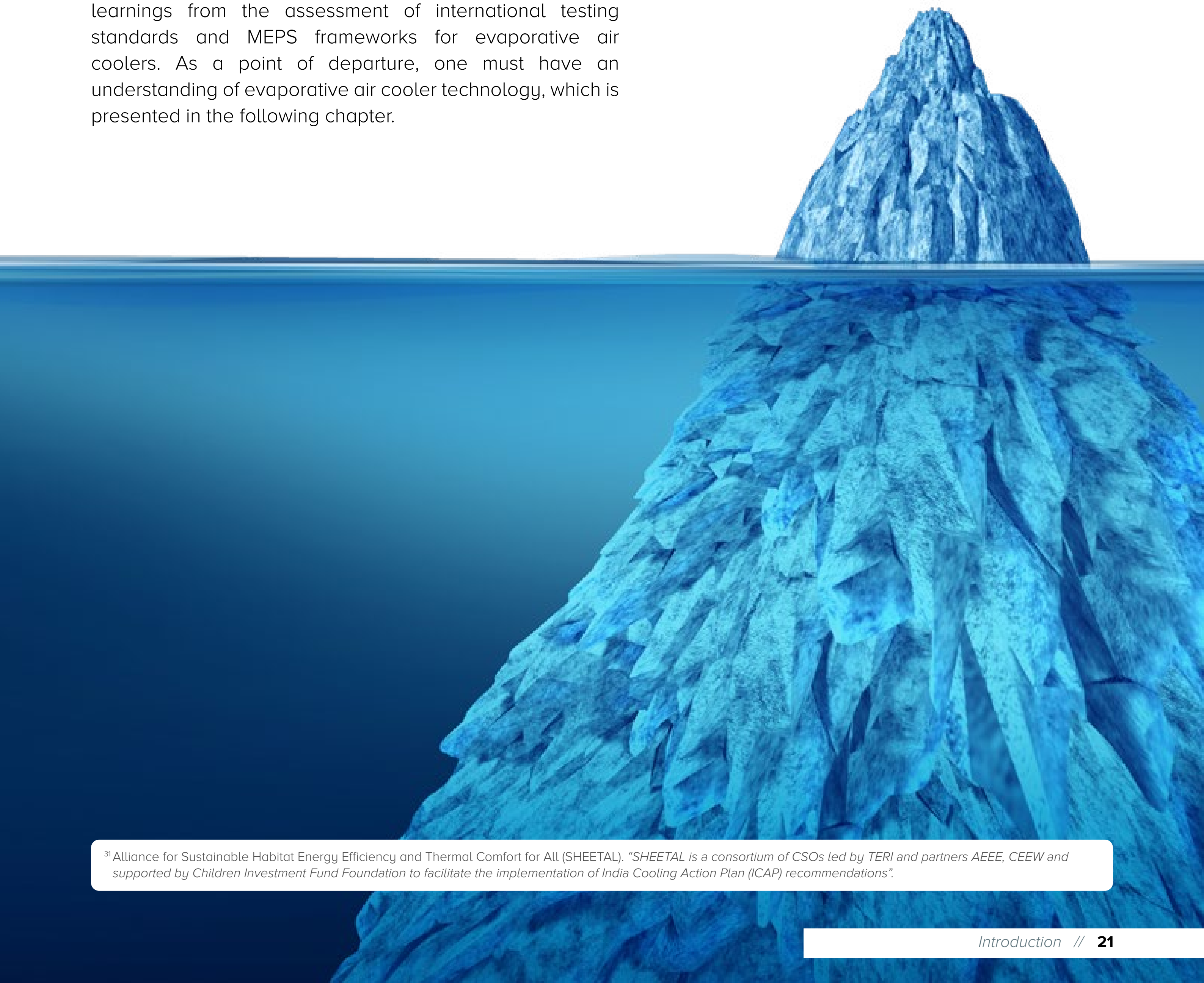
1.2 | Objective

This study is envisioned to act as a catalyst for influencing policymakers to facilitate improvements in evaporative air cooler performance and standardise the existing market through the development of the MEPS framework for evaporative air coolers in India. This study is the part of AEEE's on-going effort 'SHEETAL[31]', which is focused towards facilitating the ICAP implementation. In the long term, the study will facilitate increased access to efficient and sustainable space cooling technologies to achieve thermal comfort by promoting the use of standardised evaporative air coolers. It will also contribute to the wider market adoption and mainstreaming of Non-GWP refrigerant based space cooling technologies in India.

This study aims to map and provide an in-depth understanding of national and international policy, regulatory, and institutional frameworks focused on increasing the energy performance of evaporative air coolers. Through an extensive literature review, the study identifies prevailing gaps in the existing national framework and provides recommendations for India based on the learnings from the assessment of international testing standards and MEPS frameworks for evaporative air coolers. As a point of departure, one must have an understanding of evaporative air cooler technology, which is presented in the following chapter.

India's evaporative air cooler market is projected to grow at a Compound Annual Growth Rate (CAGR) of

14.2% in 2019-25



[31] Alliance for Sustainable Habitat Energy Efficiency and Thermal Comfort for All (SHEETAL). *"SHEETAL is a consortium of CSOs led by TERI and partners AEEE, CEEW and supported by Children Investment Fund Foundation to facilitate the implementation of India Cooling Action Plan (ICAP) recommendations".*


BLOGGER

2

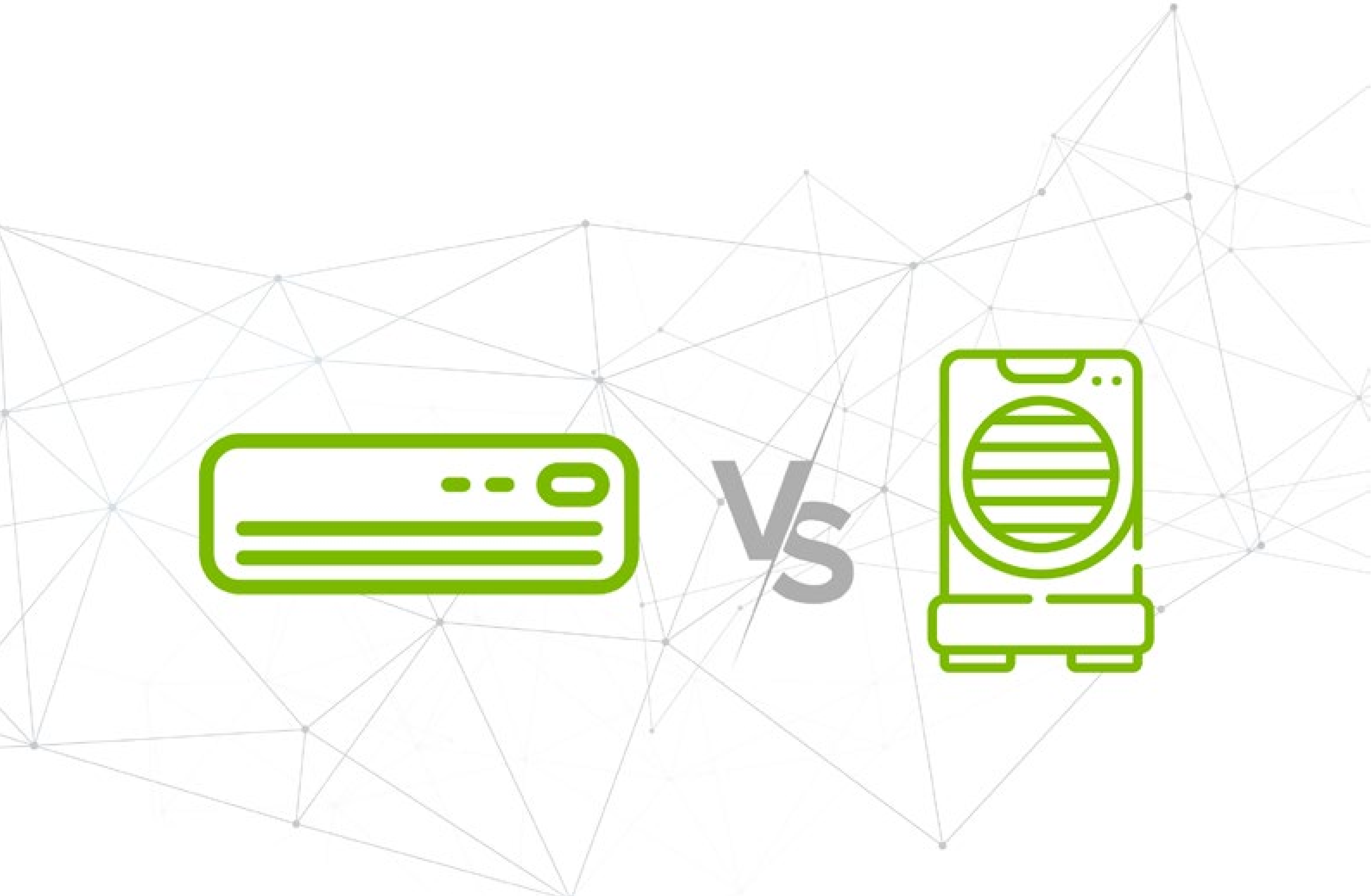
Understanding Evaporative Air Coolers: Technology & Market Assessment

This chapter begins with a comparison of the benefits of evaporative air coolers versus conventional air conditioners in terms of providing thermal comfort. It then takes a deep dive into the types of evaporative air coolers based on their structure, technology, working principle, and applications. This chapter concludes with a brief overview of the market outlook for evaporative air coolers in India.

2.1 | Evaporative Air Coolers vs Conventional Air Conditioners

Evaporative air coolers can effectively provide thermal comfort in hot-dry and composite climatic zones, as they work on the principle of evaporation, leading to an exchange of heat and mass during this process. The air that is drawn into the evaporative air cooler passes through the 'cooling pads', and, simultaneously, the pump circulates the water, which acts as a refrigerant, over the cooling pads. The water absorbs the heat from the warm air, resulting in evaporation of water, and then the fan releases fresh cooled air into a space. If an evaporative air cooler is drawing air from ambient surroundings, it brings in 100% outdoor air into an indoor setting which helps maintain the indoor air quality (IAQ)[32&33].

In contrast, conventional air conditioners cool down the recirculated air, which increases the chances of breathing in contaminated air. Nevertheless, conventional air conditioners are somewhat more effective cooling appliances than evaporative air coolers, as, in addition to cooling the air, they also dehumidify the supply air and thus create a more comfortable indoor environment for the user by cooling and dehumidification. However, conventional air conditioners come with high installation, operational, and maintenance costs. Moreover, as mentioned in Chapter 1, the refrigerants used in these air conditioners have high GWP, meaning they are harmful for the environment. In comparison, evaporative air coolers are more affordable, have low operation and maintenance costs, consume less energy, and are a Non-GWP refrigerant based space cooling technology. Thus, evaporative air coolers have higher market growth potential in terms of their application for achieving thermal comfort without impacting the environment. The next section examines evaporative air cooler technology.



[32] Jain, A., 2020. *Bijli Bachao.* [Online] Available at: https://www.bijlibachao.com/air-conditioners/best-air-cooler-india-brand.html [Accessed 2020].

[33] Paschold, H., Li, W.-W., Morales, H., & Walton, J., 2003. Laboratory study of the impact of evaporative coolers on indoor PM concentrations. *Atmospheric Environment, Elsevier*, p. 1075–1086.

2.2 | Evaporative Air Coolers

Evaporative air coolers are also known as swamp or desert coolers and have applications in both residential and commercial settings. They use water (R718), which is a natural refrigerant[34]. Evaporative air coolers are used to cool the air through the fundamental principle of evaporation of water. They provide cooled air with added specific humidity. Evaporative air coolers can effectively and efficiently operate and provide thermal comfort in hot-dry and composite climates. However, they cannot operate effectively in areas with higher humidity, as the evaporation process slows down due to the presence of high relative humidity in the air or air being highly saturated. Furthermore, in arid areas, they may exacerbate water scarcity, since they require water to operate. However, this is still preferable to conventional air conditioners, as air conditioners are quite energy-intensive and require energy from thermal power plants, which, in turn, require a lot of water to operate. Moreover, not all such plants have good water recovery.

Evaporative Air Coolers use
water (R718)
which is a natural refrigerant

Evaporative air coolers work effectively in adequately or naturally ventilated spaces, but cannot work in closed spaces, as they need to maintain the flow of fresh air to sustain the continuous process of evaporation. There are three types of evaporative air coolers, as shown below in Figure 3[35].

Direct Evaporative air Cooler (DEC)

Indirect Evaporative air Cooler (IEC)

Indirect - Direct Evaporative air Cooler (IDEC)

Figure 3: Types of Evaportive Air Coolers

[34] Water is environmentally friendly, thermodynamically attractive, safe i.e. non-toxic, non-flammable and a natural refrigerant.

[35] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. A Review of Evaporative Cooling Technologies. *International Journal of Environmental Science and Development*, Volume V6.571.

2.2.1 | Direct Evaporative Air Coolers

Structure - Components and Their Functions:

A direct evaporative air cooler (DEC) consists of cooling pads, blower fan, water reservoir tank, water distributor, pipe, pump, and float valve, as shown in Figure 4.

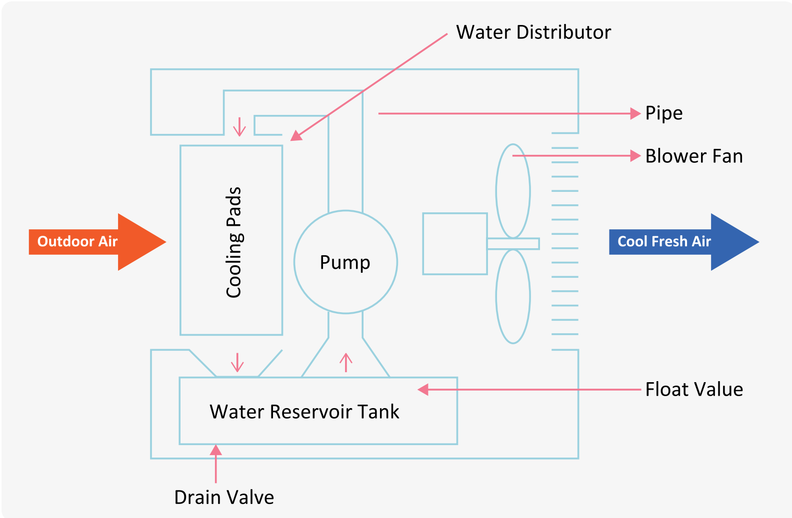


Figure 4: Basic Structure of a DEC[36]

The above-mentioned components of an evaporative air cooler have the following functions:

Pump: The pump helps circulate water from the water tank to the cooling pads. When the appliance is switched on, the pump immediately starts operating, followed by the blower fan.

Blower Fan: The blower fan circulates and maintains the airflow within the room. The blower fan creates airflow at low pressure; however, it is efficacious to be used in large room settings. The blower fan draws in air from the outside and supplies cooled air to the room.

Cooling pad: The cooling pads hold water and are fitted on the sides of the cooler, ensuring that outside air passes through these pads and is cooled. The cooling pad can be cross-fluted or have a honeycomb structure.

Water reservoir tank: The water reservoir tank is used to store the water supplied to the cooling pads. It is filled either manually or automatically, depending on the type of the evaporative air cooler.

Water distributor and pipe: The pipe is used to circulate water, with the help of the pump, from the water reservoir to the water distributor, which ensures even distribution of water over the cooling pads.

Float Valve: The float valve enables freshwater intake, checks the tank's water level, and prevents water overflow.

Drain Valve: The drain valve, as the name suggests, is used to drain the water from the evaporative air cooler's float valve as required.

[36] Piattelli, C., 2016. *Evaporative cooling*. Powrmatic. Available at: https://www.powrmatic.co.uk/blog/evaporative-cooling-work/

Technology Description:

This technology works on the basis of heat and mass transfer between air and water. Direct evaporative air coolers help reduce the air temperature through the process of evaporation of water along with the conversion of sensible heat into latent heat. During this process, the air passes through the cooling pad of the evaporative air cooler leading to direct contact between air and water. This leads to the addition of humidity in the cooled supply air. DECs can operate effectively in dry climatic zones, but are not recommended in places with high humidity or low dry-bulb temperature. This is because the ambient air in climatic zones with high humidity is highly saturated, and, thus, the evaporation process slows down, rendering the DECs ineffective.

This technology works on the basis of heat and mass transfer between air and water. Direct evaporative air coolers help reduce the air temperature through the process of evaporation of water along with the conversion of sensible heat into latent heat.

Working Principle:

The outside warm and dry air with sensible heat is drawn into the DEC and passes through the cooling pads, as shown below in Figure 5 & Figure 6.

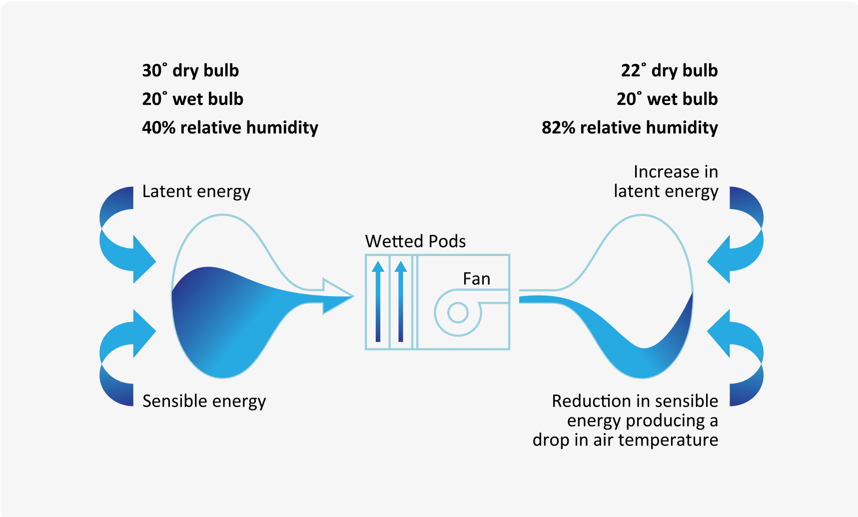


Figure 5: Sensible and Latent Heat in Evaporative Air Cooling Process [37]

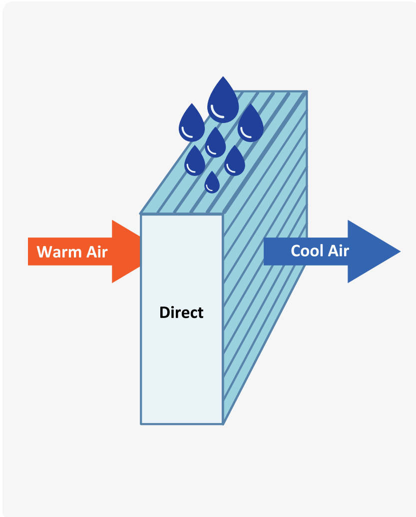


Figure 6: Working of a DEC [38]

As the dry and warm air passes through the cooling pads, the pump circulates and distributes water over the cooling pads. The water then absorbs the heat from the air resulting in the evaporation of water along with the conversion of sensible heat into latent heat, as shown above in Figure 5 & Figure 6, which cools down the air's dry-bulb temperature. During this process, humidity is added to the cooled air. The cooled air, with reduced dry-bulb temperature (because of the reduction in sensible heat) and added humidity, is then released into the room by a motor-driven fan. The wet-bulb temperature of air remains constant.

[37] Piattelli, C., 2016. *Latent Energy Vs Sensible Energy*. Powrmatic. Available at: https://www.powrmatic.co.uk/blog/evaporative-cooling-work/

[38] Fairconditioning. *Engineering Principle – Direct Evaporative Cooling, Evaporative Cooling*. Fairconditioning. Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500296799628-e5546709-43d940f0-dcf0

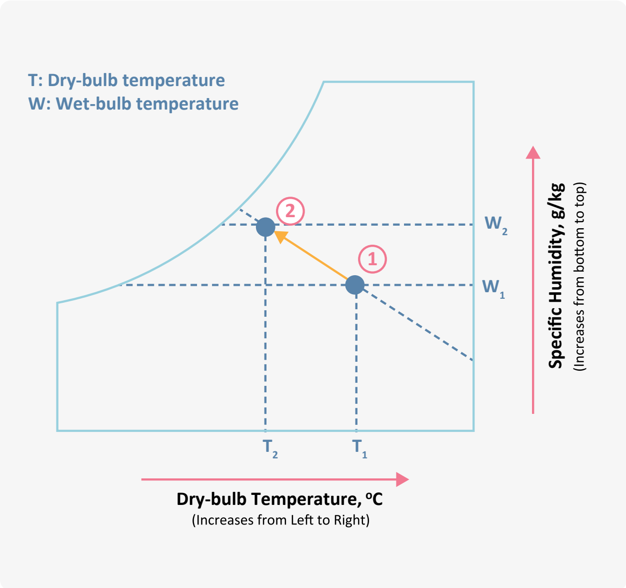


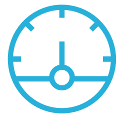
Figure 7: Psychrometric Chart of a DEC [39]

The psychrometric chart in Figure 7 above shows that due to evaporation, air moves towards the saturation or wet-bulb temperature, i.e. from 1 to 2, due to a reduction in dry-bulb temperature, increased humidity, and constant wet-bulb temperature. Evaporation, along with latent heat, results in evaporative cooling. Therefore, in DECs, there is a trade-off between the reduced air's dry-bulb temperature and increased humidity, resulting in no net change in enthalpy—the sum of sensible and latent heat—in the air. A DEC's wet-bulb effectiveness[40] ranges from ~70% to 95%[41], as there is direct contact with water and an exchange of mass.

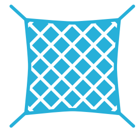
Thermal comfort is dependent on both humidity and temperature, but it is more commonly understood to be dependent on relative humidity (RH). The ability of air to hold water—and, thus, its relative humidity—depends on the air's temperature. If the air temperature is high (warm air), it can hold more water through rapid evaporation, as the air has less RH. In contrast, if the air temperature is low (cool air), it is saturated and already has high RH. Thus, it cannot hold more water; in this case, evaporation will either not take place or be very slow. Therefore, DECs work effectively in hot-dry or composite climatic zones with high temperature and low humidity.

Performance Estimation:

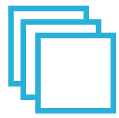
DEC efficiency is based on the following[42]:



Air velocity (supply airflow rate)



Type of cooling pad/media



Depth of cooling pad/media

Climatic conditions

The following formula can be used to calculate the maximum possible temperature-drop[43]:

$DB_S = (DB_A - WB_A)$ X Cooling Pad Efficiency

Where:

DB_S: Temperature drop of supply air

DB_A: Dry-bulb temperature of ambient air

WB_A: Wet-bulb temperature of ambient air

$(DB_A - WB_A)$: The wet-bulb depression, i.e. the lowest temperature that can be achieved through evaporation.

A DEC's wet-bulb effectiveness ranges from

~70% to 95%

as there is direct contact with water and an exchange of mass.

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[39] Sarkar, J., 2020. *Layout of DCE and processes on psychrometric chart.* Cooling India. Available at: https://www.coolingindia.in/evaporative-cooling-technologies-for-buildings/#:~:text=In%20the%20hot%2Ddry%20climatic,undergoes%20a%20composite%20climate%20zone.

[40] The maximum temperature drop that is possible through evaporation. It is also referred to as the evaporation or saturation effectiveness/efficiency or evaporative cooling effectiveness.

[41] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. A Review of Evaporative Cooling Technologies. *International Journal of Environmental Science and Development*, Volume V6.571.

[42] fairconditioning, 2019. *Evaporative Cooling.* [Online] Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500552370074-430ff37c-6e5440f0-dcf0

[43] Ibid.

Types of DECs:

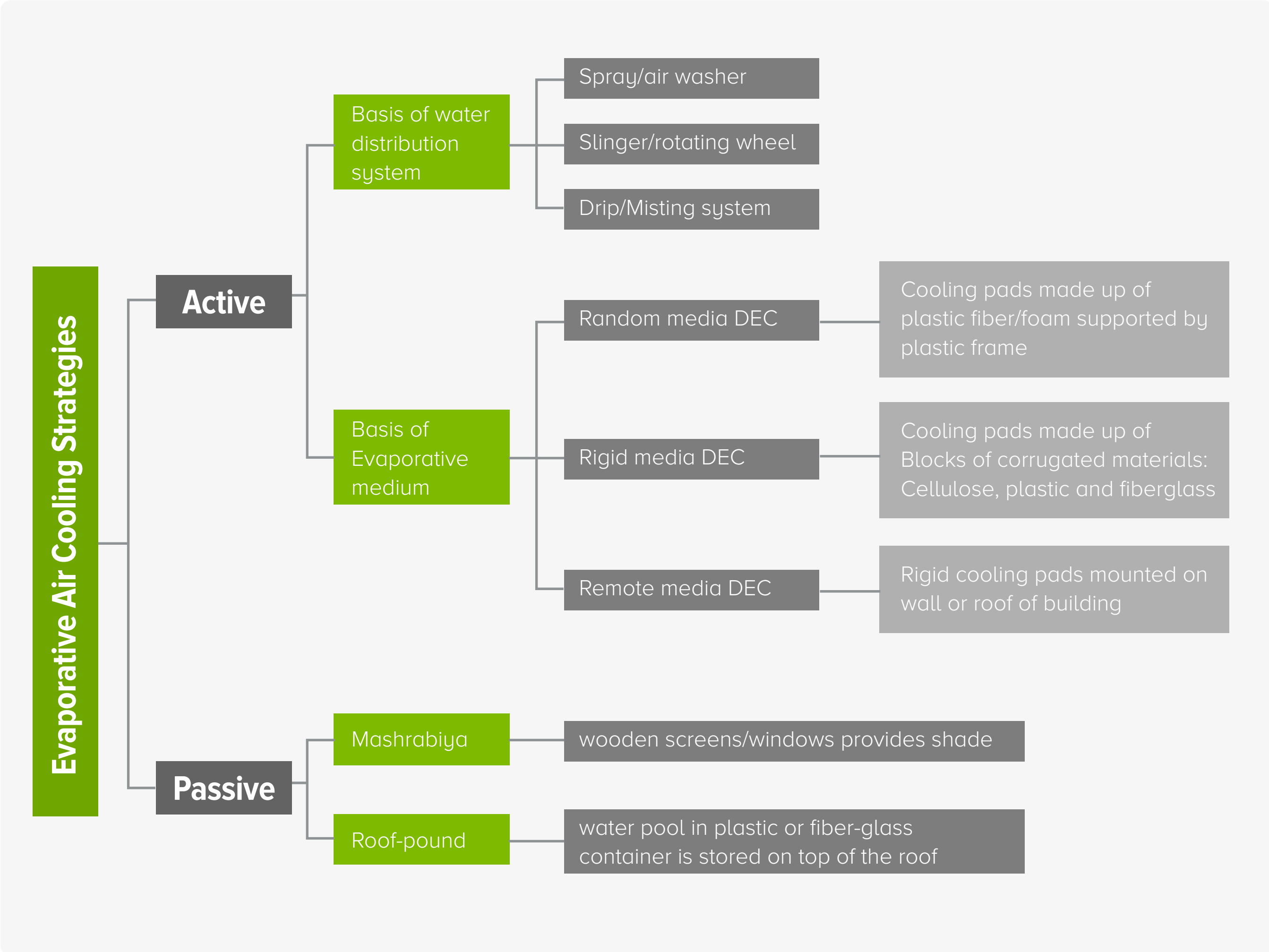


Figure 8: Evaporative Air Cooling Strategies [44]

DECs can be further classified into the following types based on their operational power consumption[45]:

- **Active DEC systems** require electrical power to function. As per the ASHRAE Handbook-HVAC Systems and Equipment 2008, they can be further classified according to the type of evaporative medium used and water distribution system, as shown above in Figure 8.
- **Passive DEC systems** are building design concepts. They are naturally operated systems with zero power consumption. They cool down the building temperature through passive strategies, and these strategies differ as per the climatic conditions, such as mashrabiya and roof-pound, as described above in Figure 8.

As per the information available on various e-commerce websites such as Amazon and Indiamart and the websites of individual manufacturers, the average capacity range of DECs sold by the key manufacturers, such as Symphony and Bajaj, is 10-120 Litres (L).

[44] Adapted from Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. *A classification of evaporative cooling systems in building cooling*. Available at: https://www.researchgate.net/publication/265890843_A_Review_of_Evaporative_Cooling_Technologies?enrichId=rgreq-6d19e6de5aa5b93ace10bbb7df1b0364-

[45] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. A Review of Evaporative Cooling Technologies. *International Journal of Environmental Science and Development*, Volume V6.571.

DEC Applications:

DECs have various applications, as mentioned below, for providing thermal comfort to the occupants, leading to an increase in productivity and reduction in problems related to heat-stress.[46]:

Figure 9: Applications of a DEC

2.2.2 | Indirect Evaporative Air Coolers

Structure:

An indirect evaporative air cooler (IEC) comprises a heat exchanger, blower fan, water tank, water distribution system including a water distributor and pipe, and pump (as shown in Figure 10). The functions of these components are the same as defined above in Section 2.2.1, except the additional component, the heat exchanger (HE), which is explained below:

- **Heat exchanger:** A device that enables heat transfer between water and air, without keeping them in direct contact[47].

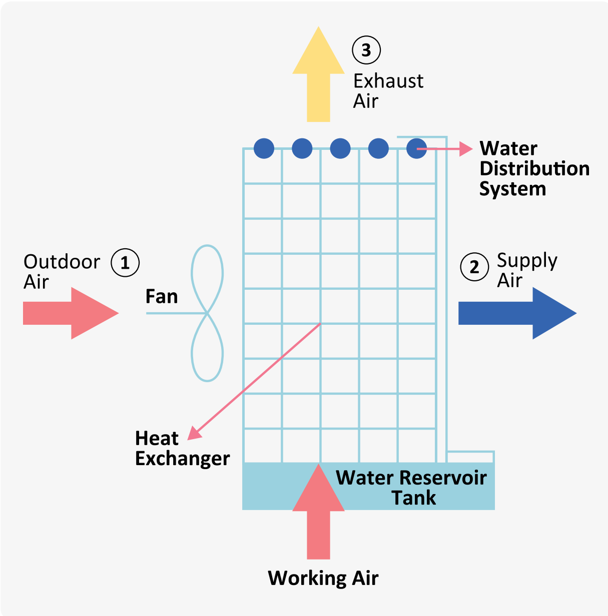


Figure 10: Schematic of an IEC [48]

[46] Fairconditioning, 2019. *Evaporative Cooling.* [Online] Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500552344002-ba9ef76c-c3a440f0-dcf0

[47] Zohuri, B., 2018. Chapter 12 - Heat Exchangers. *Physics of Cryogenics,* pp. 299-330

Technology Description:

The primary difference between an IEC and a DEC is that an IEC contains a sensible HE instead of cooling pads. The HE contains two streams: wet air streams and dry air steams, as shown in Figure 11. Unlike the direct evaporative coolers, the HE in the IEC keeps the air and water separate; there is no direct contact between air and water. This technology helps in reducing the air temperature through heat exchange and without adding humidity in the supply air. In this process, the exchange of heat takes place with no exchange of mass. In contrast to DECs, IECs can operate effectively in humid climatic zones.

Working Principle:

The warm air through the secondary air stream is channeled through the wet air stream panels in the HE, where water is percolating in from the top. This leads to evaporation of water; air containing moisture starts to exit from the sensible HE out through an exhaust fan, as shown in Figure 11 and Figure 12. During this process, the water cools down and is then used to indirectly cool the inlet primary air.

Simultaneously, the warm air from the primary air stream is channeled through the dry air stream panels (with cooled surface/HE panels) through the HE, resulting in cooling down of air due to the transfer of heat between the cooled HE panels and warm air. This cooled air is supplied to the room, with no added specific humidity. Specific humidity in the supply air remains the same as it was there in the inlet primary air; there is no addition or reduction in specific humidity.

The maximum cooling through IECs is possible until the secondary air stream reaches its wet-bulb temperature, i.e. its saturation level. Therefore, IECs' evaporation effectiveness is lower than that of DECs, ranging from ~40% to 80%[49].

IECs' evaporation effectiveness is lower than that of DECs, ranging from

~40% to 80%

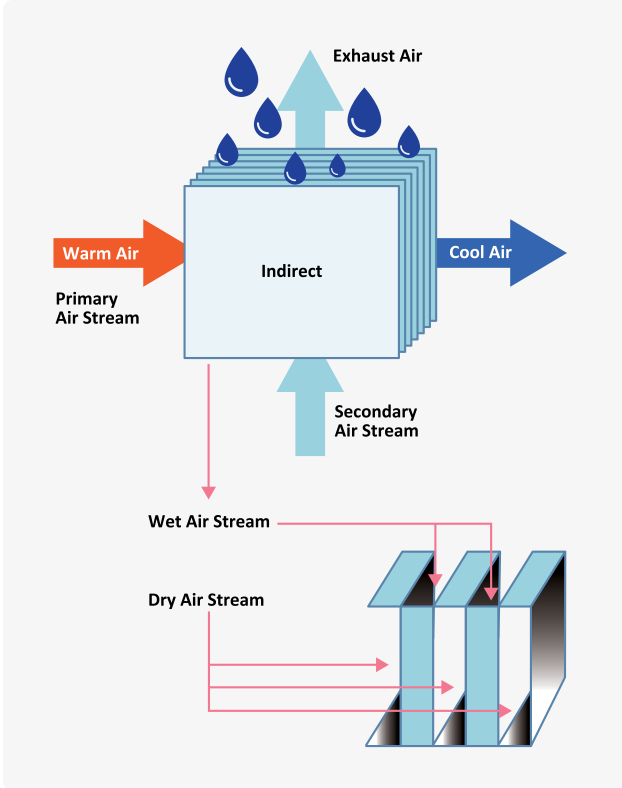


Figure 11: Working of an IEC [50]

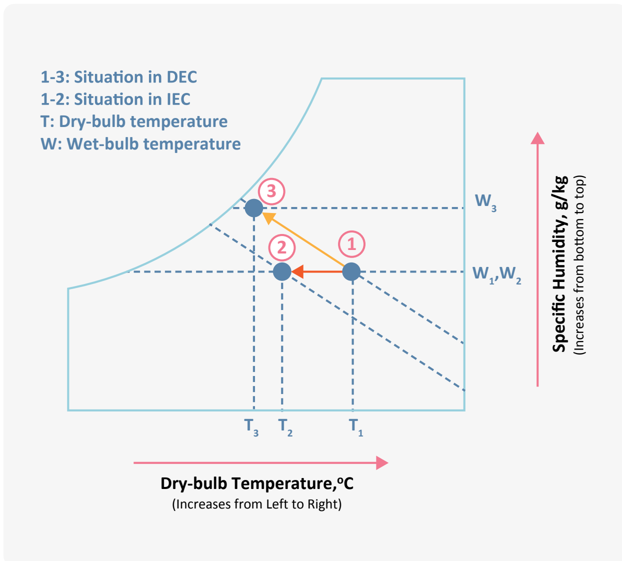


Figure 12: Psychrometric Chart of an IEC [51]

[48] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. *IEC structure*. Available at: https://www.researchgate.net/publication/265890843_A_Review_of_Evaporative_Cooling_Technologies?enrichId=rgreq-6d19e6de5aa5b93ace10bbb7df1b0364-XXX&enrichSource=Y292ZXJQYWdlOzI2NTg5MDg0MztBUzoxNjUxOTgyMjg4OTM2OTdAMTQxNjM5NzczNTk5Nw%3D%3D&el=1_x_3&_esc=publicationCoverPdf

[49] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. A Review of Evaporative Cooling Technologies. *International Journal of Environmental Science and Development*, Volume V6.571.

[50] Adapted from Fairconditioning. *Engineering Principle – Indirect Evaporative Cooling, Evaporative Cooling.*, Fairconditioning. Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500296799628-e5546709-43d940f0-dcf0

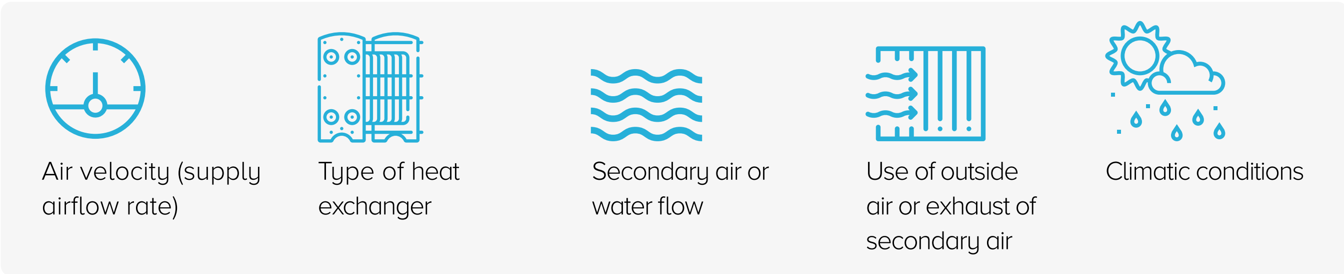
[51] Sarkar, J., 2020. *Layout of active IEC and processes on psychrometric chart*. Cooling India. Available at: https://www.coolingindia.in/evaporative-cooling-technologies-for-buildings/#:~:text=In%20the%20hot%2Ddry%20climatic,undergoes%20a%20composite%20climate%20zone.

As the moisture content remains constant with the decrease in the air's dry-bulb temperature, the air's wet-bulb temperature also decreases. On a psychrometric graph, in an IEC, air moves toward its saturation temperature, i.e. from 1 to 2, instead of from 1 to 3, as shown in Figure 12, as there is:

- Reduction in dry and wet-bulb temperatures
- Reduction in enthalpy of the air as there is a reduction in the sensible heat, but no specific humidity is added to the supply air

Performance Estimation:

IEC efficiency is dependent on the following[52]:



Types of IECs:

IECs can be further classified into the following types based on their operational power consumption[53]:

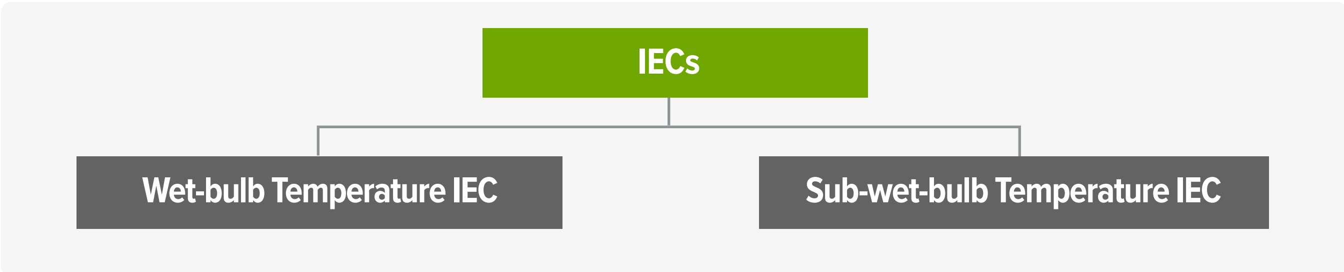


Figure 13: Types of an IEC

Wet-Bulb Temperature IEC System: This system consists of flat-plates that are stacked together acting as the cross-flow heat exchanger. This type of IEC helps decrease the supply air's dry-bulb temperature to close to the inlet air's wet-bulb temperature, but not below it, depending upon the type of heat exchanger used—the different wet-bulb temperature IEC types are heat pipe, plate-type, and tubular-type IEC. The working principle behind this system is that there are several pairs of wet and dry air stream panels placed adjacent to one another. The warm air from the primary air stream passes through the dry air stream panels, and the warm air from the secondary air stream passes through the wet air stream panels, as shown in Figure 11, which results in heat transfer in the wet-bulb temperature IEC system through a heat conductive plate, which cools the supply air with no addition of humidity[54].

Sub-Wet-Bulb Temperature IEC System: This system consists of a cross-flow heat exchanger and multi-perforated flat-plate. This type of IEC further enhances the effectiveness of the wet-bulb temperature IEC system as it reduces the supply air's temperature to below the inlet air's sub-wet-bulb temperature. The working principle behind this system is that the secondary air stream is first precooled in the dry air stream panels before entering the wet air stream panels for further heat transfer, thus cooling the HE plates. Simultaneously, the primary air stream is channeled through the dry air stream panels, which are being cooled by the precooled secondary air stream; this further enhances the cooling process, and no specific humidity is added into the cooled supply air[55].

IECs are generally available in Indian market in the range of 1000-80,000 cubic feet per minute (CFM)[56].

[52] Fairconditioning, 2019. *Evaporative Cooling*. [Online] Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500552370074-430ff37c-6e5440f0-dcf0

[53] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. A Review of Evaporative Cooling Technologies. *International Journal of Environmental Science and Development*, Volume V6.571.

[54] Ibid.

[55] Ibid.

[56] HMX, 2020. *HMX-IEC*. [Online] Available at: https://www.ategroup.com/hmx/product-family/product-description/hmx-iec-/

IEC Applications:

IECs have various applications for effectively and efficiently providing thermal comfort to the occupants, specifically in large commercial and industrial spaces, where an increase in humidity can cause probable harm to the setting or area in which IEC is used. IECs supply 100% outdoor and cooled air with no added specific humidity. This helps maintain IAQ and provides thermal comfort to the occupants[57].

IECs can be effectively used in the following settings[58]:

Figure 14: Applications of an IEC

2.2.3 | Indirect-Direct Evaporative Air Coolers

Structure:

An indirect-direct evaporative air cooler (IDEC) comprises a sensible HE, cooling pad, blower fan, water tank, water distributor, pipe, and pump. The functions of these components are the same as explained above in Sections 2.2.1 and 2.2.2.

During the first stage, air is cooled through indirect evaporative cooling, followed by direct evaporative cooling in the second stage

Technology Description:

An IDEC is also known as two-stage evaporative air cooler. During the first stage, air is cooled through indirect evaporative cooling, followed by direct evaporative cooling in the second stage, as shown below in Figure 15. Air from secondary and primary air stream doesn't come in direct contact. This technology, gives more cooling effect than IECs or DECs alone. The final cooled supply air has somewhat increased humidity. This technology is most suitable for composite and hot-dry climates.

This technology is most suitable for composite and hot-dry climates.

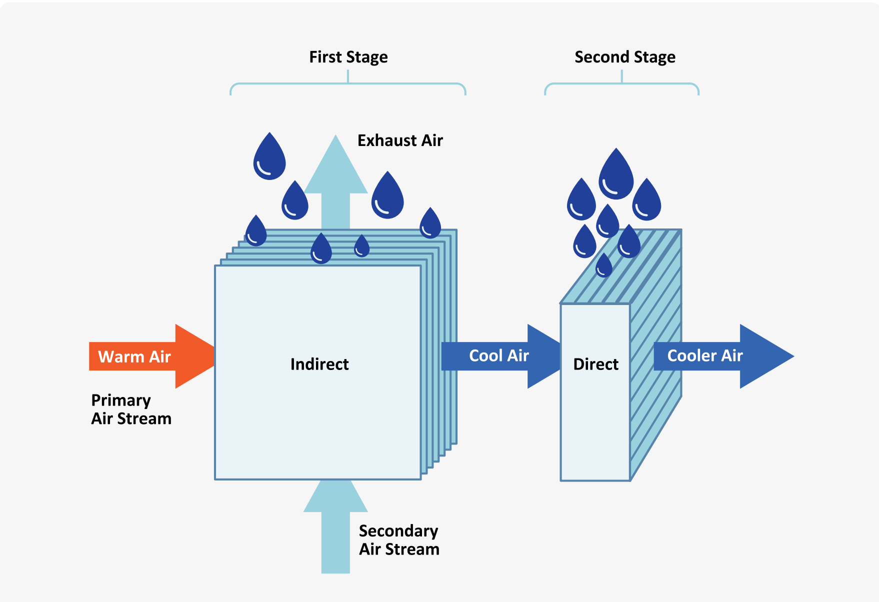


Figure 15: Schematic of an IDEC [59]

[57] Ibid.

[58] HMX, 2020. *HMX-IEC*. [Online] Available at: https://www.ategroup.com/hmx/product-family/product-description/hmx-iec-/

[59] Fairconditioning. *Engineering Principle - Indirect-Direct Evaporative Cooling, Evaporative Cooling*., Fairconditioning. Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500296799628-e5546709-43d940f0-dcf0

Working principle:

During First Stage: IEC

As shown above in Figure 11 and Figure 15, the warm air from the secondary air stream is channeled through the wet air stream panels in the sensible HE, where water is distributed. This leads to evaporation of water; air containing moisture starts to exhaust out from the cooler, and the HE plates cool down due to heat transfer. Concurrently, the warm air from the primary air stream is channeled through the dry air stream panels with cooled surfaces, in the HE, resulting in cooling down of air due to heat transfer. Thus, cooled air with no added specific humidity is supplied to the second stage.

During Second Stage: DEC

As shown above in Figure 15, the cooled air with no added specific humidity from the indirect evaporative air cooler system is channeled through the wet cooling pads. Here, cooled air comes in direct contact with water, evaporation occurs with a change from sensible to latent heat, and the cooled air further cools down, with a little addition of humidity. This cooled air with added moisture is then supplied via a blower to the room/space.

The psychrometric chart in Figure 16 shows that during first stage, air moves towards its saturation temperature, i.e. from 1 to 2, as there is a reduction in the dry and wet-bulb temperatures with no added specific humidity in the primary supplied air. Then, in the second stage, direct evaporative cooling takes place, and the dry-bulb temperature of the primary cooled air further reduces, but the wet-bulb temperature remains the same (as shown in Figure 16, from 2 to 3), with addition of specific humidity. Therefore, there is a reduction in enthalpy of air, due to presence of indirect evaporative cooling.

As the air coming into the DEC has already been cooled, its water holding capacity is lower than that of the secondary air stream. IDECs' evaporation effectiveness ranges from ~90% to 115%, as there is direct air-water contact, along with more cooled air supplied outside with the same specific humidity[61].

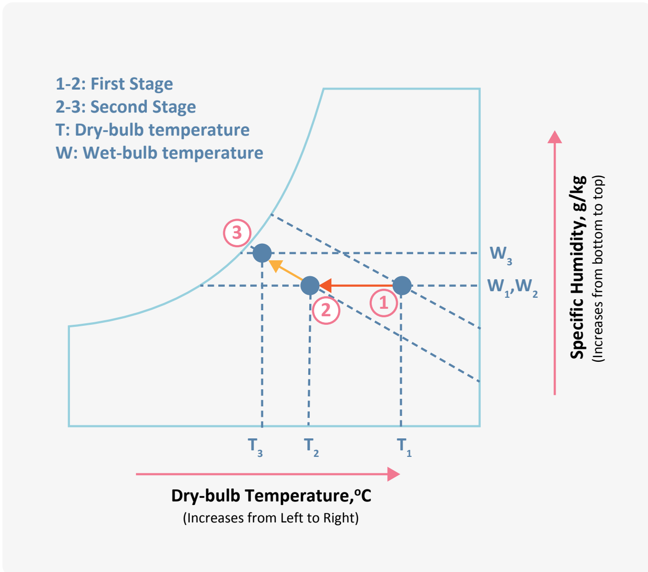
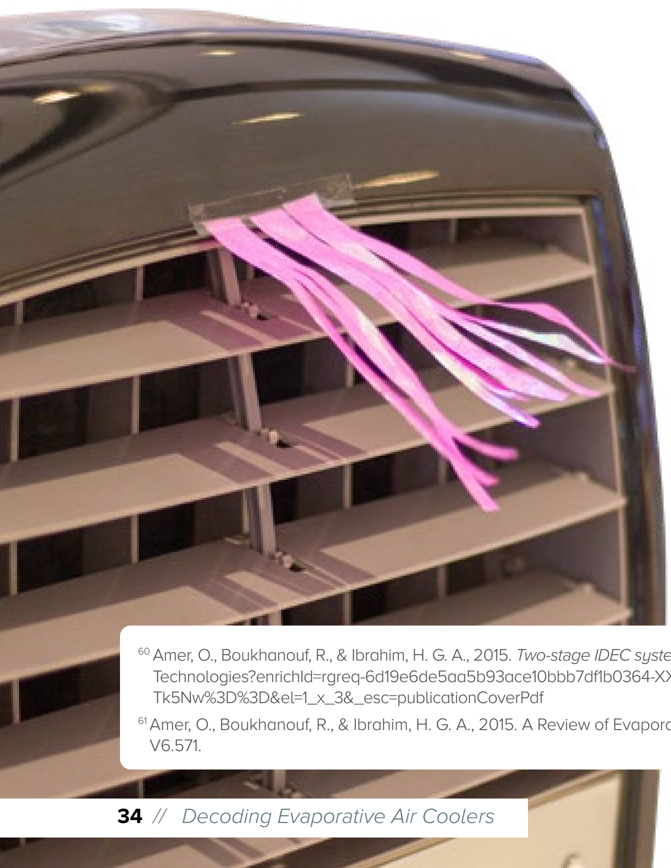


Figure 16: Psychrometric Chart of an IDEC [60]



IDECs' evaporation effectiveness ranges from

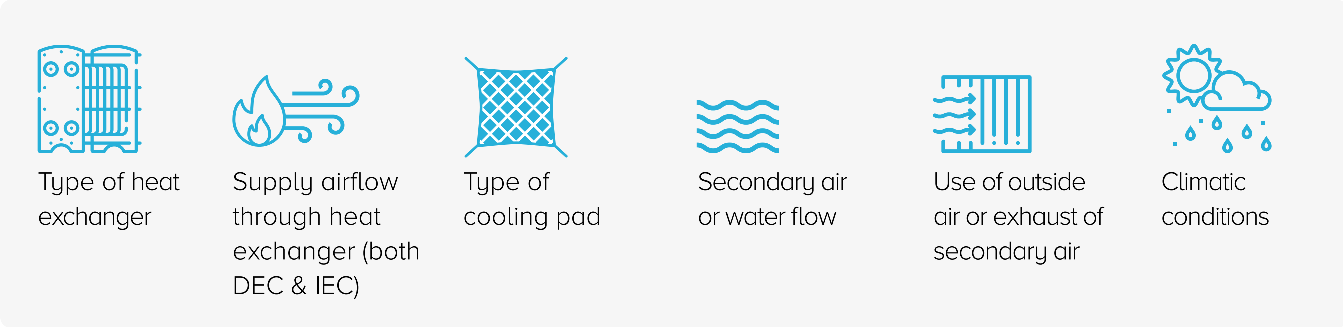
~90% to 115%

[60] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. *Two-stage IDEC system*. Available at: https://www.researchgate.net/publication/265890843_A_Review_of_Evaporative_Cooling_Technologies?enrichId=rgreq-6d19e6de5aa5b93ace10bbb7df1b0364-XXX&enrichSource=Y292ZXJQYWdlOzI2NTg5MDg0MztBUzoxNjUxOTgyMjg4OTM2OTdAMTQxNjM5NzczNTk5Nw%3D%3D&el=1_x_3&_esc=publicationCoverPdf

[61] Amer, O., Boukhanouf, R., & Ibrahim, H. G. A., 2015. A Review of Evaporative Cooling Technologies. *International Journal of Environmental Science and Development,* Volume V6.571.

Performance Estimation

IDEC efficiency is based on the following[62]:



To calculate the maximum temperature drop possible, the following equation can be used[63]:

For IEC: DB_{FS} (supply temperature) = DB_A – [(DB_A-WB_A) X Heat Exchanger Efficiency]

For DEC: DB_S= DB_{FS} – [(DB_{FS}-WB_{FS}) X Direct Evaporative Efficiency]

Where:

A: Ambient air

S: Supply air of second stage (DEC)

DB: Dry-bulb temperature

WB: Wet-bulb temperature

FS: First stage (IEC)

$DB_{\mathbf{A}}$-$WB_{\mathbf{A}}$: Dry-bulb depression: the lowest temperature that can be achieved through 100% evaporation/ maximum temperature drop that can be achieved through evaporation

IDECs are generally available in the Indian market in the range of 1,000-80,000 CFM and above[64].

IDEC Applications:

IDECs have various applications in large-scale commercial and industrial spaces, where there is a significant pressure drop requirement, but there is not much humidity or moisture content in the ambient air[65].

Therefore, this technology is best suited for spaces such as those mentioned below[66&67]:

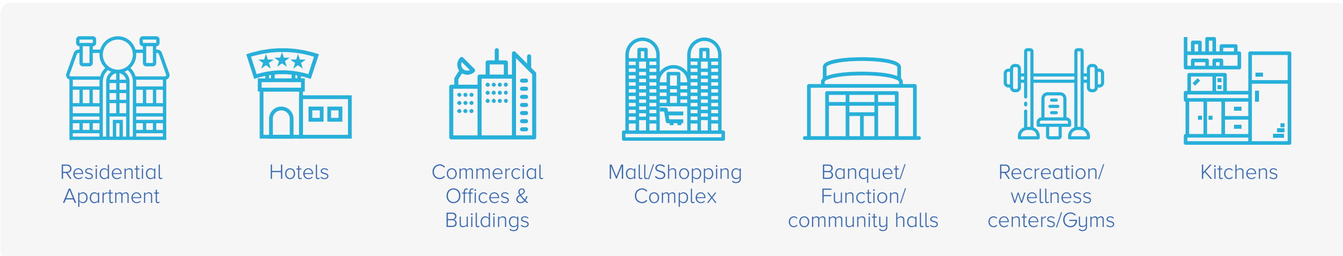


Figure 17: Applications of an IDEC

[62] Fairconditioning, 2019. *Evaporative Cooling*. [Online] Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500552370074-430ff37c-6e5440f0-dcf0

[63] Ibid.

[64] HMX, 2020. *HMX-Ambiator.* [Online] Available at: https://www.ategroup.com/hmx/product-family/product-description/hmx-ambiator/

[65] Ibid.

[66] Ibid.

[67] Fairconditioning, 2019. *Evaporative Cooling*. [Online] Available at: http://fairconditioning.org/knowledge/sustainable-cooling-technologies/evaporative-cooling/#1500552370074-430ff37c-6e5440f0-dcf0

2.3 | Comparison of Evaporative Air Cooling Technologies

The three primary types of evaporative air coolers can be compared based on their cooling medium, overall cooling efficiency, application, operation and maintenance, and adaptability to climatic zones, as summarised below in Table 1.

Table 1: Comparison of Evaporative Air Cooling Technologies

Parameters	DEC	IEC	IDEC
Capacity (approx.)	10-120 L[68]	1,000-80,000 CFM	1,000-80,000 CFM
Cooling medium	Cooling pad	Heat transfer through HE	Combination of DEC & IEC
Efficiency	More efficient than IEC	Less efficient than DEC	Most efficient
Specific Humidity content in supplied air	Yes	No	Yes, but less than DEC
Relation between enthalpy and dry and wet-bulb temperatures	Dry-bulb temperature: Decreases Wet-bulb temperature: Constant Enthalpy: No change	Dry-bulb temperature: Decreases Wet-bulb temperature: Decreases Enthalpy: Decreases	Dry-bulb temperature: Decreases Wet-bulb temperature: First reduces than remain constant Enthalpy: Decreases
Operation and maintenance	Easy in comparison to IEC& IDEC	Medium in comparison to IDEC & DEC	Difficult in comparison to IEC & DEC
Applications (most optimal)	Residential	Large-scale commercial and industrial spaces where specific humidity in the supply air has to be avoided	Large-scale commercial and industrial spaces where there is a significant temperature drop requirement and the ambient air has low humidity content
Adaptability with climatic zones	Hot-dry	Composite/Hot-dry	Composite/Hot-dry

Some manufacturers also manufacture hybrid/multi-stage evaporative air coolers, which can be a combination of various versions of hybrid systems consisting of a DEC or IEC, or IDEC and a refrigeration system. In some cases, a DEC combined with a refrigeration system or IDEC combined with refrigeration system. This type of device/system is best suited for a warm and humid climate, where dehumidification is required.

The next section presents an overview of the market outlook for evaporative air coolers in India, including a summary of the organised and unorganised market, major market players, distribution channels adopted by the different market types, and the demand in residential and commercial markets.

[68] This range is provided in litres, as DECs are mostly sold in the residential sector, and the range metric is defined taking into account the ease of understanding for the end-consumers.

2.4 | Evaporative Air Cooler Market in India

Providing access to sustainable and affordable space cooling solutions for all is one of the pressing needs in India. The vast majority of India's population—93% of residential consumers—lacks access to air conditioners for attaining thermal comfort due to their high cost[69]. Furthermore, it is anticipated that in the coming decade, a major share of households will still not have sufficient purchasing power for air conditioners[70]. With the growing population, lack of access to cooling, limited purchasing power, and India's commitment to reduce its emissions by 2030, the evaporative air cooler market seems to have promising growth potential.

As mentioned in Chapter 1, evaporative air coolers are much cheaper than air conditioners and consume significantly less energy[71&72]. At present, around 15% of Indian households are using evaporative air coolers[73]. India's evaporative air cooler market is projected to grow at a CAGR of 14.2% in 2019-25 and will achieve a market size of Indian Rupee (INR) 9000 crore by 2021[74&75].

Currently, the organised evaporative air cooler market in India accounts for 30% of the overall market, with the remainder captured by the unorganised market[76]. Manufacturers supplying evaporative air coolers in the unorganised sector usually target the market through offline distribution channels and retail shops. In contrast, while the organised market is relatively smaller, it is driven by the bigger manufacturing companies, such as Symphony Limited, Bajaj Electricals Limited, Havels India Limited, Honeywell International Inc., Usha, Orient Electric Limited, etc. These manufacturers target the market through both offline and online distribution channels.

There are various kinds of evaporative air coolers available in the market as per their application, placement, and the intended use; the different types include wall-mounted coolers, personal coolers, window coolers, tower coolers, outdoor coolers, etc., with low, medium, or high capacities. The market is divided into residential and commercial by its application. Preliminary stakeholder consultations conducted by AEEE indicated that DECs are largely in demand in the residential sector, and the demand for IDECs is expected to grow multi-fold in the commercial and industrial sector in coming years, due to their potential applications and low energy consumption compared to air conditioners.

To facilitate the uptake of evaporative air coolers in the current market, in addition to developing push and pull mechanisms for standardisation and market transformation, it is important to understand the associated institutional, policy, and regulatory framework. This framework is presented in the next chapter.

93%

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15%

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VS

the organised evaporative air cooler market in India accounts for

30%

of the overall market, with the remainder captured by the unorganised market

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[69] Ministry of Environment, Forest & Climate Change, 2019. *India Cooling Action Plan*, New Delhi: Ministry of Environment, Forest & Climate Change.

[70] Ibid.

[71] Grand View Research, 2019. *Air Coolers Market Size, Share & Trends Analysis Report By Type (Tower, Dessert), By Application (Residential, Commercial), By Region (North America, Europe, APAC, CSA, MEA), And Segment Forecasts, 2019 - 2025*, California: Grand View Research.

[72] Jain, A., 2020. *Bijli Bachao*. [Online] Available at: https://www.bijlibachao.com/air-conditioners/best-air-cooler-india-brand.html [Accessed 2020].

[73] Agrawal, S., Mani, S., Aggarwal, D., Kumar, C.H., Ganesan, K., & Jain, A., 2020. *Awareness and Adoption of Energy Efficiency in Indian Homes: Insights from the India Residential Energy Survey (IRES) 2020*, New Delhi: Council on Energy,Environment and Water.

[74] 6Wresearch, 2019. *India Air Cooler Market (2019-2025).* [Online] Available at: https://www.6wresearch.com/industry-report/india-air-cooler-market-2019-2025#:~:text=According%20to%206Wresearch%2C%20India%20Air,with%20the%20demonetization%20in%202016.

[75] Research and Markets, 2015. *India Air Cooler Market Outlook, 2021*, India: Research and Markets.

[76] Ministry of Environment, Forest & Climate Change, 2019. *India Cooling Action Plan*, New Delhi: Ministry of Environment, Forest & Climate Change.

3

Overview of National Institutional, Policy, and Regulatory Framework

This chapter examines the Indian institutional, policy and, regulatory framework established to improve overall appliance energy efficiency and quality. The aim of the chapter is to help build an understanding required for developing interlinkages to improve evaporative air cooler performance.

3.1 | Institutional Framework for Appliances

The institutional framework for appliances in India is governed by various ministries, regulatory bodies, state agencies, and associations, as shown below in Figure 18, in order to establish and implement the national level regulatory framework. These organisations can impact the appliance standards & labelling programme, specifically for evaporative air coolers. A summary of these organisations and their role in the appliance domain is provided below in Table 2.

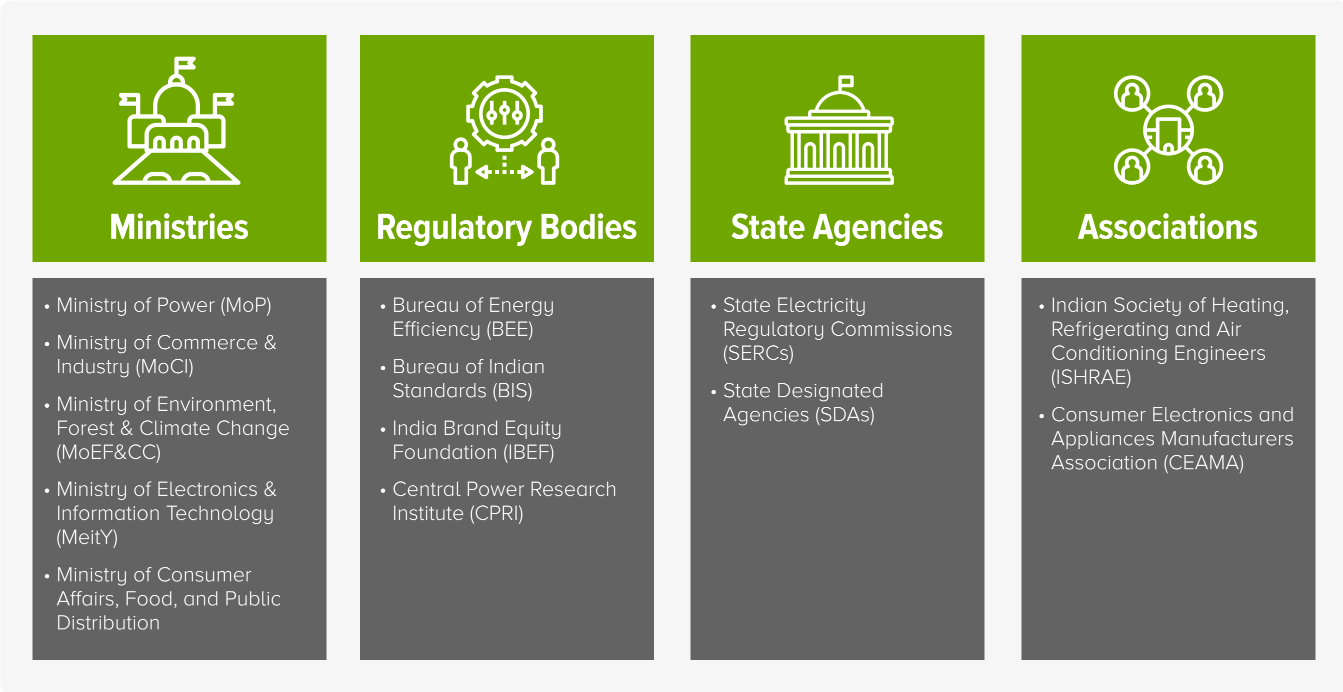

Figure 18: Indian Institutional Framework for Improving Appliance Energy Efficiency

Table 2: Role of Organisations in Indian Institutional Framework for Improving Appliance Energy Efficiency

S.No.	Name	Description	Appliance-Related Role
1.	Ministry of Power (MoP)[77]	The MoP focuses on policies, research, and the development of India's energy sector. The Energy Conservation Division under MoP is responsible for the formulation of energy conservation policies, rules, & regulations under the Energy Conservation (EC) Act, 2001.	MoP has established the Bureau of Energy Efficiency (BEE), which has initiated and governs the standards and labelling programme for energy-intensive appliances.
2.	Ministry of Commerce & Industry (MoCI)[78]	MoCI's primary function is to develop, implement, and monitor foreign trade policy to promote exports and imports. The ministry is also responsible for areas related to special Economic Zones, multilateral and bilateral commercial relations, trade promotion and facilitation, regulation of trade related commodities, and so on. It has two primary sub-departments - the Department of Commerce and Department for Promotion of Industry & Internal Trade. The Department of Commerce has established a key trust, India Brand Equity Foundation (IBEF).	The Department for Promotion of Industry & Internal Trade under MoCI issues mandatory trademark certificates under 'The Trade Marks Act' to the manufacturers, which act as a license for conducting commercial activities with consumer goods within the Indian market. This trademark certificate is required for the manufacturers to seek permission from the Bureau of Energy Efficiency (BEE) towards the usage of appliance star labels.

[77] Ministry of Power, 2020. *Responsibilities.* [Online] Available at: https://powermin.nic.in/en/content/responsibilities [Accessed 2020]
[78] Ministry of Commerce and Industry, 2020. *Vision, Mission and Message.* [Online] Available at: https://commerce.gov.in/ [Accessed 2020]

S.No.	Name	Description	Appliance-Related Role
3.	Ministry of Environment, Forest and Climate Change (MoEF&CC)[79]	MoEF&CC is responsible for the implementation of policies and programmes related to natural resource conservation. The ministry is also responsible for overall environment protection, undertaking surveys and conservation of flora and fauna, pollution control & prevention, and animal welfare. There are various division under this ministry, which are categorised under three main parts i.e. environment division, establishment division and forest & wildlife division.	The Ozone Cell under MoEF&CC has published ICAP in 2019, a flagship initiative. It is inclusive of a long-term integrated 20 year (2017-18 to 2037-38) outlook across all sectors regarding India's cooling demand, technology options, refrigerant use, and energy consumption. One of the ICAP objectives is to map alternative technologies that can cater to the nation's cooling requirement. It also sets a target of 25-30% reduction in refrigerant demand. Most importantly, under the space cooling in buildings, ICAP recommends the development of MEPS for evaporative air coolers.
4.	Ministry of Electronics & Information Technology (MeitY)[80]	MeitY is responsible for policies related to information technology (IT), electronics, and the Internet, as well as the promotion of IT-related services. Its vision is to facilitate the e-development of India.	MeitY issued the 'Electronics and Information Technology Goods Order, 2012', mandating Indian Safety (IS) Standards on the notified goods listed under the 'registration scheme' issued by Bureau of Indian Standards (BIS). This scheme was issued under the BIS Act, 1986. Under this scheme, manufacturers of the notified products have to compulsory register under BIS after testing their appliance/products in BIS-certified test labs. Products that are not registered or do not comply as per this scheme are not allowed to be sold or exported.
5.	Ministry of Consumer Affairs, Food, & Public Distribution[81&82]	The Ministry of Consumer Affairs, Food, and Public Distribution is further divided into two departments: Department of Food and Public Distribution and Department of Consumer Affairs.	The Department of Consumer Affairs was established in June 1997. Its objective is to give a boost to the nascent consumer movement in India. BIS is a one of the divisions under the department of consumer affairs and this department was responsible for the implementation of the Bureau of Indian Standards Act, 2016.
6.	Bureau of Energy Efficiency (BEE)[83]	BEE was established under the EC Act, 2001, with the mission to develop policies and strategies with a thrust on self-regulation. The major functions of the BEE include developing energy consumption and process standards, MEPS & labels for various appliances, and specific EC building codes, identifying designated consumers, and creating awareness, along with dissemination of information related to energy efficiency and conservation.	BEE launched the Standard and Labelling (S&L) programme in 2006 under Section 14 of the EC Act 2006. BEE has prepared a framework for assessing the performance standards and rating criteria. BEE defines the energy performance parameters for various equipment and appliances and assists in the programme's implementation and enforcement via awareness programmes, training, capacity building programmes, etc. The awareness programmes, along with the energy efficiency labelling and standards, help the consumer take a well-informed decision before purchasing an appliance.
7.	Bureau of Indian Standards (BIS)[84]	BIS's primary responsibility is to ensure the standardisation and quality certification of goods. Its standardisation, certification, and testing help provide credibility and assurance regarding the quality and safety of a product for consumer usage. It also acts as a catalyst in promoting the import and export of goods.	BIS certification is one of the prerequisites for any appliance to be covered/get registered under the BEE's S&L programme. The BIS has various committees that are involved in setting safety standards for appliances. BIS also carries out testing laboratory certification across India, along with developing test standards as per local climatic conditions.

[79] Ministry of Environment, Forest and Climate Change, 2020. *Introduction.* [Online] Available at: http://moef.gov.in/about-the-ministry/introduction-8/

[80] Ministry of Electronics & Information Technology, 2019. *Vision & Mission.* [Online] Available at: https://www.meity.gov.in/about-meity/vision-mission [Accessed 2020]

[81] Department of Consumer Affairs, 2020. *Vision and Mission.* [Online] Available at: https://consumeraffairs.nic.in/vision-and-mission [Accessed 2020]

[82] Department of Food & Public Distribution, 2018. *About Us*. [Online] Available at: https://dfpd.gov.in/about-us.htm [Accessed 2020]

[83] Bureau of Energy Efficiency, 2020. *About BEE*. [Online] Available at: https://beeindia.gov.in/content/about-bee [Accessed 2020]

[84] Bureau of Indian Standards, 2020. *About BIS*. [Online] Available at: https://bis.gov.in/index.php/the-bureau/about-bis/ [Accessed 2020]

S.No.	Name	Description	Appliance-Related Role
8.	India Brand Equity Foundation (IBEF)[85]	IBEF is a trust established to promote and generate awareness on the Made in India label and India's products & services in international markets. IBEF's three main pillars are export promotion, digital media, and knowledge centre. It works closely with cross-sectoral stakeholders on these topics.	IBEF is a well-established, credible trust, as it is the communication and branding partner for various trade exhibitions organised under the Department of Commerce. IBEF provides the necessary support to manufacturers to enable them to access untapped market segments, along with monitoring the Indian market's production and sales volume.
9.	Central Power Research Institute (CPRI)[86]	As the centre for applied research in electrical power engineering, CPRI assists the electrical industry in product development and quality assurance. It also acts as an independent authority for power equipment certification and testing.	CPRI is a member of the BEE Technical Committees for Appliance Labelling and provides necessary technical expertise regarding the development of performance testing procedures and protocols. CPRI also carries out check-testing for selected products supplied by the Bureau of Energy Efficiency and undertakes testing and certification for manufacturers.
10.	State Electricity Regulatory Commissions (SERCs)[87]	Under the provisions of the Electricity Act, 2003, SERCs were established with the objective to supervise and manage interstate electricity transmission, power-related disputes, electricity tariffs charged to consumers, etc. SERCs are designated with the function of setting the electricity tariffs and standards in the electricity industry, advising decision makers, and promoting competition, among other things.	The SERCs are empowered by the EC Act to carry forward the adjudication process after receiving non-compliance cases from SDAs. They appoint Adjudicating Officers to conduct these inquiries.
11.	State Designated Agencies (SDAs)[88]	SDAs were established as statutory bodies (as per Section 15(d) of the EC Act 2001) in each state/by their respective state governments to enforce the EC Act.	SDAs appoint an inspecting officer, as per the Energy Conservation (Inspection) Rules, 2010 and Section 17 of the EC Act, who ensures proper implementation and enforcement of the S&L scheme's provisions and norms for manufacturers. Any detected non-compliance is reported to BEE.
12.	Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE)[89]	ISHRAE was formed with the objectives of advancing the development of Heating, Ventilation, and Air Conditioning (HVAC) and refrigeration and related services, providing knowledge to its members and other interested actors in this domain, supporting students' career development, and fostering research in this field.	Under appliances, ISHRAE is focused on developing the standards and regulations for refrigerant gases for BIS and BEE. Apart from this, it also organises the conclave on HVAC and other services-related to industries. It also provides a platform for showcasing innovations and facilitating buyer-seller connections. ISHRAE also has appliance-specific technical committees. Recently, a technical working group "F101 : Evaporative Cooling systems" has been formed to foster research opportunities to increase evaporative air cooler performance.
13.	Consumer Electronics and Appliances Manufacturers Association (CEAMA)[90]	CEAMA aims to enhance the development of the consumer electronics and appliance industry and its components. Its objective is to ensure fair competition among manufacturers, dealers, and other stakeholders.	CEAMA has been working in the energy efficiency domain, specifically in the star rating programme, implementation of waste of electronic equipment, and digitisation of cable television networks. It is involved in the manufacturing of televisions and home appliances and catalyses the development of trade, entrepreneurship, technology, etc.

[85] India Brand Equity Foundation, 2020. *About India Brand Equity Foundation.* [Online] Available at: https://www.ibef.org/about-us.aspx [Accessed 2020]

[86] Central Power Research Institute, 2020. *About CPRI.* [Online] Available at: https://www.cpri.in/about-cpri.html [Accessed 2020]

[87] Bureau of Energy Efficiency, 2019. *Enforcement Machinery under Energy Conservation Act, 2001*, New Delhi: Bureau of Energy Efficiency

[88] Ibid.

[89] Indian Society of Heating, Refrigerating and Air Conditioning Engineers, 2020. *https://ishrae.in/Home/Aim_objectives.* [Online] Available at: https://ishrae.in/Home/about_ishrae [Accessed 2020]

[90] Consumer Electronics and Appliances Manufacturers Association, 2020. *Association Overview*. [Online] Available at: https://ceama.in/AssociationOverview.html [Accessed 2020]

To understand the significance of the institutions mentioned above in Table 2, in light of improving evaporative air cooler performance and energy efficiency, the next section will be elucidating about India's policy, programmes, and regulatory framework focused on improving appliance energy efficiency, with an emphasis on evaporative air coolers.

3.2 | Policy and Regulatory Framework Governing Evaporative Air Cooler and Appliance Energy Efficiency in India

This section provides an overview of the Indian standards for evaporative air coolers established by Bureau of Indian Standards (BIS) and energy efficiency programmes relevant for increasing appliance efficiency in India.

3.2.1 | Indian Standards for Evaporative Air Coolers[91]

Bureau of Indian Standards' (BIS) primary responsibility is standardisation and quality certification of goods sold in India. It's standardization, certification and testing procedure help in establishing credibility and assurance over a good's safety and reliability for consumer usage. BIS introduced the Indian standard (IS) 3315 for testing of evaporative air coolers in 1956, which was revised in 1974 and 1994 and reaffirmed in 2005 and 2009. The latest version of the standard came out in 2019.

The 1974 version included a method to test the airflow rating. In 1994, power consumption requirements, minimum cooling efficiency, the type of material to be used (plastic was permitted), safety requirements, and test conditions were specified. The latest IS 3315: 2019 revision incorporated noise level measurement protocol and additional material specifications. The revisions made over the years are summarised below in Figure 19.

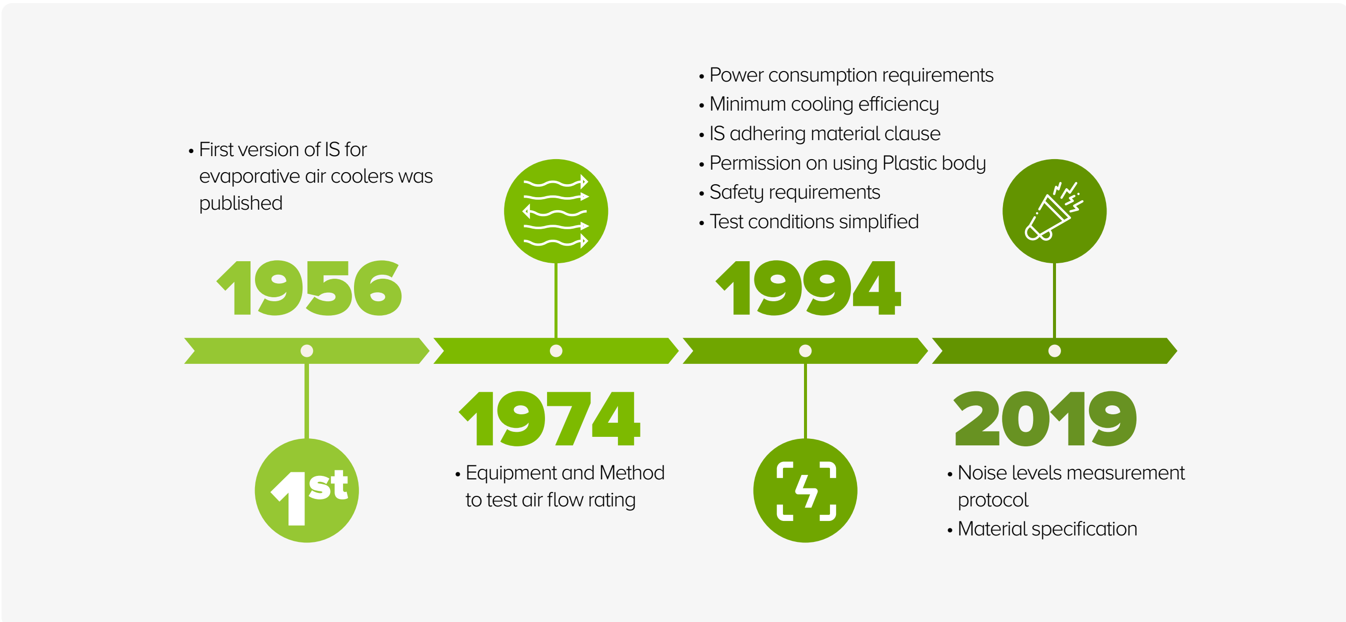

Figure 19: Evolution of the Indian Standard for Evaporative Air Cooler

[91] Bureau of Indian Standards, 2019. *Evaporative Air Coolers (Desert Coolers) — Specification (Third Revision). IS 3315: 2019*. New Delhi: Bureau of Indian Standards.

MoEF&CC released a notification on 17th May, 1996 (GSR 214[E]) for incorporating eco-labelling, i.e. labelling of environmentally-friendly products for evaporative air coolers, which is administered by BIS under the BIS Act, 2016.

Therefore, BIS has incorporated a few eco-labelling parameters such as noise level; quality, safety, and performance-related requirements such as cooling efficiency and power consumption; instructions for proper use to maximise performance, safe disposal of used appliances and reduced wastage; energy consumption as per the set baseline; and use of sustainable packaging.

In addition, manufacturers have to show the consent clearance as per the provisions of the Water (Prevention and Control of Pollution) Act, 1974, Water (Prevention and Control of Pollution) Cess Act, 1977, and Air (Prevention and Control of Pollution) Act, 1981, along with the authorisation, if required, under the Environment (Protection) Act, 1986, if they are displaying Eco-mark on their evaporative air coolers.

The latest IS 3315: 2019 standard is a comprehensive version, prepared by the Refrigeration and Air Conditioning Sectional Committee of BIS under the Mechanical Engineering Division Council MED 03. The Indian standard specifications for evaporative air coolers are summarised below in Table 3.

Table 3: Key Specifications under IS 3315:2019 for Evaporative Air Coolers

<table>
<tr><th>S.No.</th><th>Parameter</th><th>Key Specifications</th></tr>
<tr><td>1.</td><td>Air capacity</td><td>
• 750, 1000, 1260, 1500, 1800, 2000, 2500, 3000, 4000, 5000, 6000, and 8000 cubic meters (m3)/hour are the specified air capacities based on the delivery of air at 'zero' static pressure.
• For any other capacity, there may be mutual consensus between the manufacturer and buyer.
</td></tr>
<tr><td>2.</td><td>Manufacturing and Construction</td><td>
I. Design and Build
Outer Body Structure:
• The thickness of the outer body structure shall be mentioned.
• Galvanised steel sheets conforming to IS 277[92] shall be used for the outer structure.
• If a plastic body is used, it is mandatory for the manufacturer to mention its properties, such as weathering, ageing, impact to the colour due to exposure to sun light, heat resistance, etc.
• Non-corrosive material shall be used for the grill, with an option to let air travel both horizontally and vertically.
• For the water tank, a sheet of minimum 1 millimetre (mm) thickness shall be used, and for the rest of the cabinet, a sheet of nominal 0.8 mm thickness, with the tolerance as given in IS 277, shall be used.
• The capacity of the tank shall be as per Table 4.
<table>
<tr><th>Minimum Capacities (m^3/h) (2)</th><th>Sump Tank Capacity (litres) (3)</th></tr>
<tr><td>750</td><td>15</td></tr>
<tr><td>1000</td><td>20</td></tr>
<tr><td>1200</td><td>24</td></tr>
<tr><td>1500</td><td>30</td></tr>
<tr><td>1800</td><td>36</td></tr>
<tr><td>2000</td><td>40</td></tr>
<tr><td>2500</td><td>50</td></tr>
<tr><td>3000</td><td>60</td></tr>
<tr><td>4000</td><td>80</td></tr>
<tr><td>5000</td><td>100</td></tr>
<tr><td>6000</td><td>120</td></tr>
<tr><td>8000</td><td>160</td></tr>
</table>
Table 4: Water Tank Capacity Based on Minimum Air Capacity[93]
NOTE – Air coolers having minimum capacities up to 2000 m^3/h shall be regarded as portable.
• The appliance shall pass the drop test.

II. Fan Specifications
• The fan material can be sheet metal or plastic.
• The fan shall pass IS 2312[94] testing protocols.
• The fan motor shall be IS 996[95] certified.

III. The pump shall be IS 11951[96] certified.

IV. Cooling pads
• Wood wool/honey comb or environmentally-friendly material shall be used.
• They shall be placed in wire mesh or plastic parts to avoid sagging.
</td></tr>
</table>

[92] Indian Standard: Galvanised steel sheets (plain and corrugated)-specification

[93] Bureau of Indian Standards, 2019. *Evaporative Air Coolers (Desert Coolers) — Specification (Third Revision). IS 3315: 2019*. New Delhi: Bureau of Indian Standards.

[94] Indian Standard: Specification for Propeller Type ac Ventilating Fans

[95] Indian Standard: Single Phase A.C. Induction Motors for General Purpose

[96] Indian Standard: Pumpset for Desert Coolers - Specification

S.No.	Parameter	Key Specifications
3.	Performance	• **Noise level:** The appliance can pass the sound test as per IS 1391[97] (Part 2), and the decibel level should not be more than 65 decibels (dBA), when measured at a 1 m distance from the cooler in an anechoic (free from echo) room setting. • The air delivery shall be as per the minimum air capacities mentioned in Table 5 and shall not be less than the declared minimum capacity. • The power consumption at zero static pressure shall be as mentioned below in Table 5.

Minimum Capacities m^3/h (2)	Max Power Consumption(w) (3)
750	95
1000	125
1200	150
1500	185
1800	210
2000	225
2500	240
3000	250
4000	280
5000	350
6000	400
8000	500

Table 5: Power Consumption of Evaporative Air Coolers Based on Air Capacity[98]

S.No.	Parameter	Key Specifications
3.	Performance	• Cooling effectiveness shall be either greater than or equal to 65 percent.
4.	Tests	• The manufacturer needs to conduct both type and routine tests. • A routine test is a general test to be conducted by the manufacturer on every assembly and includes the following production routine tests: — General running — Protection against electric shock — High voltage — Insulation resistance — Current leakage — Earthing connections — Finish/Surface (corrosion and scratch-free) — Power consumption test (shall not exceed the values specified in Table 5) • The type test includes: — Verification of markings as specified in 7 of IS 302 (Part 1)[99] — Cooling efficiency test — Air delivery test — Power consumption test — All tests shall be as defined under IS 2312, except air delivery and power consumption tests — Cooling efficiency and air delivery test (may be conducted at any ambient temperature) More details about the BIS testing conditions for evaporative air coolers can be found in Annexure 1.
5.	Rating	• The rated voltage shall be in the range of 230-240 volts. • A rated frequency of 50 Hertz (Hz) shall be maintained.
6.	Additional Eco-mark requirements	• The evaporative air cooler shall conform to the safety, quality, and performance requirements as per the points mentioned above (points 2-5). • The cooler shall be sold with proper usage instructions to maximise the performance, along with biodegradable packaging. • Noise levels shall conform to the norms specified in the Environment (Protection) Act, 1986. • The power consumption shall be less than 5% of that specified in Table 5.

[97] Indian Standard: Room Air Conditioners — Specification Part 1 Unitary Air Conditioners

[98] Bureau of Indian Standards, 2019. *Evaporative Air Coolers (Desert Coolers) — Specification (Third Revision). IS 3315: 2019*. New Delhi: Bureau of Indian Standards.

[99] Indian Standard: Safety of household and similar electrical appliances, Part 1: General Requirements

In addition to the above-mentioned key specifications, the manufacturer shall provide an operating & maintenance manual. The manual shall cover the evaporative air cooler's possible applications, i.e. which capacity of evaporative air cooler is suitable for with which room size. Furthermore, the standard also specifies that the nameplate shall include the following information in a location that is accessible and visible to the user:

- Name of the manufacturer;
- Type or model number, serial number, and year of manufacturing;
- Minimum air capacity at zero static pressure;
- Normal total current and voltage;
- Power input;
- Sump tank capacity; and
- Cooling efficiency of the unit.

Information on the electrical equipment, instrument accuracy, and measurement and calculation of airflow temperature with an apparatus/instrument can be referred directly from the IS 3315: 2019.

Therefore, as per the latest BIS standard for evaporative air coolers, the air flow, outer structure material, noise levels, and evaporative cooling pad, fan motor, and water pump efficiency are the most critical parameters for evaluating the overall cooling efficiency of an evaporative air cooler. Evaporative air coolers adhering to all the above-mentioned conditions may be given BIS standardisation, that is, the IS mark, under the provisions of the BIS Act, 2016. One parameter missing in this standard that affects overall evaporative air cooler performance is the water consumption level. The next section presents all the programmes and initiatives at the national level with emphasis towards increasing appliance energy efficiency.

3.2.2 | Appliance Energy Efficiency Programmes in India

This section presents the national level programmes focused on enhancing appliance efficiency: BEE's Standards and Labelling (S&L) programme and National Mission for Enhanced Energy Efficiency (NMEEE).

3.2.2.1 | Standards and Labelling[100]

The S&L programme was established in May 2006 by BEE under the EC Act, 2001. The primary objective of this programme is to provide clear information to the consumers about the energy savings potential of an appliance through appliance-specific energy performance labels. This allows the consumers to make informed decisions when purchasing energy-efficient appliances.

The program focuses towards market transformation by maintaining energy consumption by MEPS for various energy-intensive appliances. In addition to MEPS, energy performance labels, as shown in Figure 20, are affixed on appliances, providing a visual representation of the S&L programme. Establishing MEPS requires either the establishment of an appliance's performance testing protocol, which aids in providing an estimate of the appliance's performance, or a set cap/energy performance target to be achieved.

[100] Bureau of Energy Efficiency, 2020. *Standards & Labeling*. [Online] Available at: https://beeindia.gov.in/content/standards-labeling

BEE Energy Performance Label[101&102]

The BEE energy performance label, as shown in Figure 20, reflects an appliance's energy performance (e.g. for air conditioners, there is the Indian Seasonal Energy Efficiency Ratio [ISEER]) and includes details such as the appliance type, capacity, model-specific star label (1-5 stars), period of validity, appliance brand and model, and electricity consumption.

BEE has classified the energy performance label into two categories comparative label and endorsement label. The comparative label, as shown in Figure 20, aids in the comparison of similar appliances based on their energy consumption and other criteria. An endorsement label, on the other hand, as shown in Figure 21, simply provides confirmation to the prospective buyer that the product is highly energy-efficient and good for purchase/usage. Up until now, only a few appliances, such as laptops and computers, have received an endorsement label.

Figure 20: Star Label for Air Conditioners: Comparative Label[103]

Figure 21: BEE Endorsement Label[104]

The energy performance labels range from 1-star to 5-star, 1 stands for minimum efficiency/minimum energy performance level, is given to the least efficient models and 5 for maximum efficiency, is given to the most efficient models. The labels and minimum energy performance level are periodically upgraded (approximately every 3-5 years) by BEE to maintain appropriate appliance efficiency levels as per the technological development. Timely upgradation ensures that very low-efficiency models are not supplied to the market.

Push & Pull Market Transformation Strategy[105]

The strategy of creating a 'push' & 'pull' in the appliance market to bring about market transformation is the pillar behind the success of S&L programme's success. The push for elimination of less energy-efficient models from the market by prohibiting their sale is created through establishment of MEPS, and a pull for consumers to opt for and purchase highly efficient appliances or equipment is generated through the application of informative energy performance labels for appliances. This mechanism enables standardisation of the market, especially the unorganised appliance market sector, by mandating manufacturers to manufacture and offer energy-efficient and standardised appliances and equipment, along with regularly upgrading appliance energy performance. In addition to the labels, governments and utilities also offer rebates, tax incentives, on-bill financing schemes, high profile product demonstrations, and other modes of promotion of specific qualifying appliances such as Light Emitting Diodes (LEDs), Brushless Direct Current (BLDC) fans, and room air conditioners.

The strategy of creating a 'push' & 'pull' in the appliance market to bring about market transformation is the pillar behind the success of S&L programme's success.

Appliance Selection Criteria Under S&L Programme

The selection criteria followed by BEE for incorporation of an appliance or an equipment into the S&L programme depends primarily on the appliance's market size, share of the organised & unorganised market, total energy consumption, energy saving potential, ease in implementing the standard, availability of appliance testing procedures, and test labs. Additionally, BEE also conducts its own baseline estimation study to finalise the inclusion of a particular appliance in the S&L programme. There has been a great emphasis on the test labs, as these play a crucial role in determining whether the appliance meets the set performance criteria through check testing and helps BEE develop realistic efficiency performance standards, along with their timely upgradation.

[101] Bureau of Energy Efficiency, 2019. *Impact of Energy Efficiency Measures for the Year 2017-18*, New Delhi: Bureau of Energy Efficiency

[102] Bureau of Energy Efficiency, 2020. *Star Labelled Appliances.* [Online] Available at: https://beeindia.gov.in/content/star-labelled-appliances

[103] BEE star label for air conditioner notification

[104] Bureau of Energy Efficiency, 2019. *Impact of Energy Efficiency Measures for the Year 2017-18*, New Delhi: Bureau of Energy Efficiency

[105] Bureau of Energy Efficiency, 2020. *Lab Capacity Building.* [Online] Available at: https://beeindia.gov.in/content/lab-capacity-building

Mandatory and Voluntary Appliances

BEE has divided appliances in the S&L programme into two categories: mandatory and voluntary appliances. Currently, BEE has established energy labels for 28 appliances, as mentioned below in Table 6, amongst which ten appliances fall under the mandatory regime, and the remaining eighteen falls under the voluntary regime:

Table 6: BEE S&L Programme: Mandatory & Voluntary Appliances[106]

Mandatory Appliances	Voluntary Appliances
1. Room Air Conditioners	11. Induction Motors
2. Frost Free Refrigerators	12. Pump Sets
3. Tubular Fluorescent Lamps	13. Ceiling Fans[107]
4. Distribution Transformers	14. Liquefied Petroleum Gas Stoves
5. Room Air Conditioners (Cassette, Floor Standing)	15. Washing Machines
6. Direct Cool Refrigerators	16. Computers (Notebooks/Laptops)
7. Colour Televisions	17. Ballasts (Electronic/Magnetic)
8. Electric Geysers	18. Office Equipment (Printers, Copiers, Scanners, Multi-Function Devices (MFDs)
9. Variable Capacity Inverter Air Conditioners	19. Diesel Engine Driven Mono-set Pumps
10. LED Lamps	20. Solid State Inverters
	21. Diesel Generator (DG) Sets
	22. Chillers
	23. Microwave Ovens
	24. Solar Water Heaters
	25. Light Commercial Air Conditioners; 27. UHD Televisions
	26. Deep Freezers; 28. Air Compressor

[106] Bureau of Energy Efficiency, 2020. *Standards & Labeling.* [Online] Available at: https://beeindia.gov.in/content/standards-labeling

[107] S&L mandatory norms for ceiling fans were originally slated to be implemented from July 1, 2020. The implementation of new norms has been postponed to January 1, 2022.

BEE runs the S&L programme with support from stakeholders such as manufacturers, Research & Development (R&D) institutions, industry & industry association representatives, academia, consumer organisations, other government organisations & regulatory bodies such as BIS, and other key private players. These stakeholders provide their holistic input regarding standards and labels, and do their due diligence before the actual implementation of standards and labels. For driving the S&L for each appliance, BEE establishes separate appliance-specific technical committees comprising of key experts and stakeholders, which play a significant role in establishing and timely upgrading MEPS & labels for a particular appliance, along with defining its implementation framework.

Permittee Guidelines

BEE has also established guidelines to be followed by permittees/manufacturers/organisations when registering their appliances under the S&L programme, as summarised in Figure 22[108].

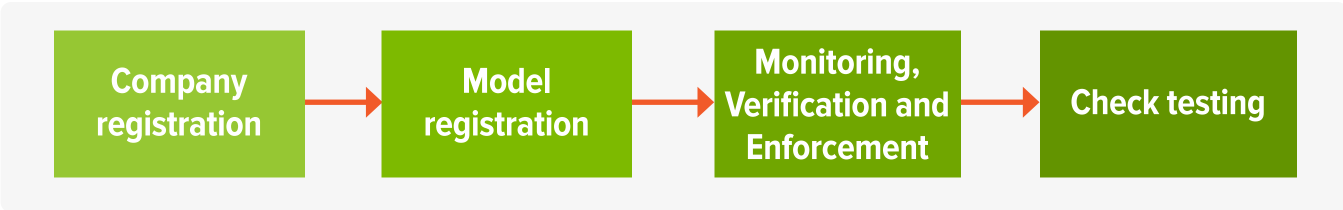

Figure 22: S&L Registration Process

1. Company registration

- Applicant/company has to register themselves on S&L web portal. A company has to register separately for each different brand under an appliance type.
- Submission of required documentation along with the application form: manufacturing area name and address, quality management system certificate, BIS license, trade mark certificate, covering letter and small scale industries (SSI) registration certificate.
- Documentation to be submitted within the six months of the declaration.
- 100,000 INR has to be deposited at the time of registration as security deposit to BEE. SSIs have to pay only 25000 for security deposit.
- In case of registration for voluntary labelling program, an applicant is required to sign a non-judicial stamp paper with BEE, showing their agreement towards the terms and conditions.
- Once the company is registered, they can track the status of their application.

2. Model registration

- After company's/applicant's registration, the model registration has to be done by depositing one-time registration fees of 2000 INR/model along with required documents that are covering letter, proof of payment through demand draft/online payment and test report from NABL accredited lab providing the energy efficiency performance value.
- In case manufacturer is providing in house test report then it should be submitted on organisation's letter head in the prescribed format and should not be old than a year.
- The appliance should comply with the relevant standards as per the regulation.
- The Independent Agency for Monitoring and Evaluation (IAME) will evaluate the application. After their approval, BEE will allow the applicant to add BEE star label on the registered product.

[108] Bureau of Energy Efficiency, 2016. *Guidelines for the Permittee-Standards and Labelling program of BEE*, New Delhi: Bureau of Energy Efficiency.

3. Monitoring, Verification and Enforcement

- Proper monitoring and verification, check and challenge testing of the labelled appliances will be conducted by BEE or its designated agencies such as IAME and SDA to evaluate and verify whether the energy performance of the labelled appliance under conditions mentioned in the appliance regulations are matching its performance claims.
- Check testing will be conducted in a third party NABL accredited laboratory.
- If first check testing fails, second check testing will be carried out by BEE.
- If the second testing also fails then the BEE provides two month time duration from the date of issuance of intimation to the applicant to either change the star label level or remove the defects from the appliance or remove all the appliance stock from the market.
- An action taken report has to be submitted by the applicant.
- If the report is not submitted within provided time frame or doesn't comply with BEE's directions then BEE will withdraw the permission extended to the applicant for displaying star label on the appliance.
- Challenge testing involves same steps as in check testing. It is done by BEE in a private lab when a written complaint is received related to any fraud declaration on the star label of the appliance. Applicant has to bear the cost of required testing, if fraud claims are affirmative.

Therefore, the cycle of any appliance under the S&L programme involves the following steps:

Selection of Appliance	Technical Committees	Technical/ Baseline Analysis	Launch of MEPS (Voluntary)	Enforcement	Conversion
• Market analysis: market size, total energy consumption, energy saving potential, ease in implementing the standard, & availability of appliance testing procedures labs	• Star level parameters • Star levels and upgrades	• Testing standard's baseline • Test data collection	• Online portal • Scrutiny of applications • Approval/ rejection for models • Market analysis • Upgradation planning	• Monitoring & verification: check testing • Penalty	• Based on market uptake of an appliance: conversion from voluntary to mandatory labelling • Upgradation planning

Figure 23: Typical Cycle for an Appliance Under BEE's S&L Program

The next section sheds light on the National Mission for Enhanced Energy Efficiency (NMEEE) which is focused on improving energy efficiency in energy-intensive industries. The section also elaborates on a sub-initiative-Super Efficient Equipment Programme (SEEP) focused on bringing market transformation towards super-efficient appliances.

3.2.2.2 | National Mission for Enhanced Energy Efficiency[109,110&111]

The NMEEE is one of the eight national missions under the National Action Plan on Climate Change (NAPCC) and focuses on enhancing energy efficiency and reducing specific energy consumption (SEC), which is a major concern amongst energy-intensive industries. The mission plans to raise the bar in its efforts to promote the energy efficiency market, which has an estimated value of INR 74,000 crore and could help avoid capacity addition of 19,598 MW, achieve fuel savings of around 23 million tonnes per year and greenhouse gas emissions reductions of 98.55 million tonnes per year at its full implementation stage. The MoP and BEE were entrusted with the task of preparing the NMEEE implementation plan. NMEEE consists of four initiatives with different focus areas, as described below:

- **Perform, Achieve and Trade (PAT):** A market-based mechanism to enhance the cost effectiveness of energy efficiency improvements in energy-intensive large industries and facilities, through the certification of energy savings that can potentially be traded[112].
- **Energy Efficiency Financing Platform (EEFP):** Creation of mechanisms to help finance demand side management programmes in all sectors by capturing future energy savings. Under this programme, Memorandums of Understanding (MoUs) have been signed with financial institutions for collaborative work on the development of the energy efficiency market and identification of issues related to this market development[113].
- **Framework for Energy Efficient Economic Development (FEEED):** FEEED promotes energy efficiency through fiscal instruments. Under this initiative, two funds have been created: Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE) and Venture Capital Fund for Energy Efficiency (VCFEE)[114].
- **Market Transformation for Energy Efficiency (MTEE):** MTEE focuses on appliances. It was launched to promote the usage of energy-efficient appliances in specific sectors through the development of innovative measures to make the products more affordable. Under MTEE, two programmes have been developed: **Bachat Lamp Yojana (BLY)** and **Super Efficient Equipment Programme (SEEP)**[115].

BLY, a CFL replacement scheme, was launched in 2009 to promote energy-efficient lighting in India[116]. This scheme was replaced by the Unnat Jyoti by Affordable LEDs for All (UJALA) scheme (LED replacement scheme), which was launched by Prime Minister Narendra Modi on 1st May, 2015 under the joint initiative of Public Sector Undertaking of the government of India (GoI), Energy Efficiency Services Limited (EESL) and the Electricity Distribution Company. SEEP was launched in February 2012 to provide financial incentives to super-efficient appliance manufacturers in the Indian appliance market, in order to enable total market transformation towards super-efficient appliances. The first appliances that received support under this programme were ceiling fans, with an aim to incentivise and push manufacturers to manufacture super-efficient 35 watt (W) ceiling fans with 50% more efficiency than the ones that are currently available. Comprehensive support was provided to increase fan efficiency through the formation of a multi-stakeholder technical committee to finalise the technical specifications and development of testing standards for ceiling fans. After the launch of this programme, BLDC fans gained popularity, and various manufacturers have started manufacturing BLDC fans, which are BEE 5 star-rated, i.e. the most efficient.[117,118&119]

To gain deeper understanding of the existing policy, regulatory, and institutional framework, the next section highlights prevailing gaps and gives recommendations to address them in near future.

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109 Bureau of Energy Efficiency, 2020. *NMEEE*. [Online] Available at: https://beeindia.gov.in/content/nmeee-1[Accessed 2020]

110 Ministry of Power, 2020. *Energy Efficiency*. [Online] Available at: https://www.powermin.nic.in/en/content/energy-efficiency[Accessed 2020]

111 Bureau of Energy Efficiency, 2018. *National Mission for Enhanced Energy Efficiency*, New Delhi: Bureau of Energy Efficiency

112 Bureau of Energy Efficiency, 2020. *PAT*. [Online] Available at: https://beeindia.gov.in/content/pat-3

113 Bureau of Energy Efficiency, 2020. *EEFP*. [Online] Available at: https://beeindia.gov.in/content/eefp

114 Bureau of Energy Efficiency, 2020. *FEEED*. [Online] Available at: https://beeindia.gov.in/content/feeed

115 Bureau of Energy Efficiency, 2020. *MTEE*. [Online] Available at: https://beeindia.gov.in/content/mtee-0

116 Bureau of Energy Efficiency, 2020. *BLY*. [Online] Available at: https://beeindia.gov.in/content/bly-1

117 Kanchwala, H., 2020. *BLDC Fans (super efficient fans) in India 2020 - Market Analysis*. [Online] Available at: https://www.bijlibachao.com/fans/bldc-fans-super-efficient-fans-in-india-market-analysis.html

118 Bureau of Energy Efficiency, 2020. *SEEP*. [Online] Available at: https://beeindia.gov.in/content/seep-0

119 Ministry of Power, 2020. *Energy Efficiency*. [Online] Available at: https://www.powermin.nic.in/en/content/energy-efficiency [Accessed 2020]

3.3 | Gaps and Recommendations for the National Institutional, Policy, and Regulatory Framework Related to Evaporative Air Cooler Performance

The gaps in the national policy, institutional, and regulatory framework discussed in this section, along with the associated recommendations, have been identified based on the evaluation of above mentioned extensive literature review and AEEE's preliminary stakeholder consultations. The gaps are divided into the categories of policy and regulatory, institutional level, and knowledge-related and are summarised in the following table.

Table 7: Gaps and Recommendations for the National Policy, Regulatory, and Institutional Framework Related to Evaporative Air Coolers

Categories	Gaps	Recommendations
Policy and regulatory	The IS for evaporative air coolers does not include water efficiency as a parameter, even though IS mentions eco-labelling for evaporative air coolers.	The IS for evaporative air coolers should also focus on water consumption and its efficiency level as a critical parameter, to cover the overall performance of evaporative air coolers.
	Lack of concrete research on the potential of evaporative air coolers and the market transformation potential, specifically for the commercial sector.	An in-depth market transformation potential study is required to identify the actual potential of evaporative air coolers in the commercial segment. SEEP for evaporative air coolers could be proposed, with high growth potential in the Indian appliance market.
	Lack of testing standards or protocols for different types of evaporative air coolers.	Civil society organisations or any associations working in the field of appliance efficiency could be appointed as knowledge-sharing bodies to support the S&L programme in framing energy efficiency performance testing standards for various types of evaporative air coolers.
Institutional level	Lack of harmonisation between governmental bodies, private entities, autonomous bodies, and industry associations working on improving evaporative air cooler energy performance.	BEE has technical bodies for defining and framing the S&L for a specific appliance, and BIS also has technical committees for individual appliance. In correspondence to that, on a holistic level, there could be formation of an association that is either led by manufacturers, focusing primarily on manufacturers, or is formed by manufacturers, as they are the key actors in the evaporative air cooler market.
	Lack of focus on improving the unorganised market for this technology.	Manufacturers from both the organised and unorganised sectors could be encouraged to come together and form a national association to work on improving evaporative air cooling technology. This association could work together in consensus with the ongoing S&L programme, governmental bodies, and other key players by following both the bottom-up and top-down approach. Similarly, the S&L programme and BIS could also collaborate with this national manufacturer association for the development, establishment, and upgradation of the standards & labels for evaporative air coolers Hence, inter-body coordination could be enhanced to enable better, fast-track establishment of MEPS for evaporative air coolers in India.

Categories	Gaps	Recommendations
Knowledge-related	Unavailability of electricity & water consumption and end-use appliance-specific information for Indian households.	In this era, where 'the consumer is king', customers should be provided information about the use of evaporative air coolers through an evidence-based approach, in order to increase evaporative air cooler adoption and usage. A mobile application could be developed that can be used in real time to capture and estimate various required parameters, such as the ambient temperature and setting (indoor/outdoor); while a customer is setting up an evaporative air cooler. This would help customer in determining the potential cooling effectiveness of an evaporative air cooler. The application would help customers in decision-making regarding evaporative air cooler capacity and type, that they should install for achieving thermal comfort. Thus, it could be an asset in awareness and evidence creation for both consumers and domain experts/industry players.

Therefore, based on the evaluation of the above-mentioned comprehensive literature review and stakeholder consultations regarding India's policy, regulatory, and institutional framework, it is evident that there is significant scope for improvement. Hence, there rises a need to look at and draw learnings from international best practices focused on improving evaporative air cooler energy performance, in order to develop a more robust policy, regulatory, and institutional framework for India's evaporative air cooler market. The following chapter presents these international best practices.

4

Overview of International Institutional, Policy, and Regulatory Framework on Evaporative Air Coolers

This chapter presents key findings from the detailed review of international MEPS, testing standards, and regulations on evaporative air coolers. In addition, it also highlights the key findings from the review of ASHRAE's testing standards for DECs and IECs, along with the initiatives taken by international organisations to improve evaporative air cooler performance.

4.1 | Country-Wise Evaporative Air Cooler Standards

Australia, USA (California), and Iran have been identified for the review of their institutional, policy and, regulatory framework developed to enhance evaporative air cooler performance. The criteria for selecting these three countries was based on their similar climatic conditions to India and the availability of information on the MEPS/testing standards/ regulations for evaporative air coolers. Table 8 provides an overview of the information about the selected countries on the basis of type and status of MEPS/testing standards/regulations for evaporative air coolers, implementing organisations, and target sectors of application.

Table 8: Global Institutional, Policy and Regulatory & Framework for Evaporative Air Coolers

Country	Implementing Organisation	Product	Standards & Labelling/ Testing	Target Sector	Mandatory/ Voluntery	Policy Adoption Date	Revision Date (if any)	Update Status
Australia[120]	Standards Australia Committee ME-62, Ventilation and Air conditioning	Evaporative air cooler	Energy performance testing standard	Information not available	Information not available	1987	2000 and reconfirmed in 2016	Up to date
USA (California) [121&122]	Institute of Standards and Industrial Research of Iran (ISIRI)	Evaporative air cooler	Appliance efficiency regulations	Information not available	Information not available	1976	2016	Up to date
Iran[123&124]	Institute of Standards and Industrial Research of Iran (ISIRI)	Heating & Air Conditioning, Evaporative Cooler	Comparative Label & MEPS	Residential	Mandatory	1999	2009	Under revision

4.1.1 | Australia[125&126]

Australia has a tropical climate, and the majority of its cooling demand is for DECs. Australia has established the AS/NZS 2913-2000 testing standards for evaporative air-conditioning equipment. The standards have been prepared by the Standards Australia Committee ME-062, Ventilation and Air Conditioning, Manufacturing & Processing under Standards Australia, which is an independent, non-governmental standard setting organisation. Australia does not have MEPS or labelling for evaporative air coolers [127].

The first version of this testing standard came in 1987, and it was then revised in 2000 and reconfirmed in 2016. The standard focuses upon the following parameters [128]:

- **Airflow**
- **Evaporation efficiency** [129]
- **Sound power measurements**
- **Power consumption**
- **Operating conditions**

[120] Standards Australia, 2016. *Australian Standard Evaporative airconditioning equipment*, Strathfield, NSW 2135: Standards Australia International Ltd.

[121] California Energy Commission, 2017. *2016 Appliance Efficiency Regulations. California Energy Commission*. CEC-410-2017-002

[122] Richter, C., Chase, A., Marver, J., Cunningham, K., Wilkins, B., and McLain, L., 2016. *Developing an Appliance Standards Compliance Improvement Program*. Pacific Grove, ACEEE Summer Study on Energy Efficiency in Buildings.

[123] CLASP, 2020. *Policy Details*. [Online] Available at: https://clasp.ngo/policies/iran-meps11[Accessed 2020]

[124] Effatnejad, R. and Salehian, A.B., 2009. Standard of energy consumption and energy labeling in evaporative air cooler in Iran. Jurnal IJTPE, 1.

[125] Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance:* Institute for Sustainable Systems and Technologies

[126] Standards Australia, 2016. *Australian Standard Evaporative airconditioning equipment*, Strathfield, NSW 2135: Standards Australia International Ltd.

[127] Ibid.

[128] Ibid.

[129] Evaporation effectiveness/efficiency: 100 x [(inlet air dry-bulb temperature (°C) - outlet air dry-bulb temperature (°C)) / inlet air dry-bulb temperature (°C) - inlet air wet-bulb temperature (°C)]

It specifies temperature conditions required for evaluating and rating the cooling performance, with inlet dry and wet-bulb temperatures of 38°C and 21°C, respectively, and a supply dry-bulb temperature of 27.4°C. However, energy ratings are not mentioned. For the abovementioned parameters, the standard provides a rating, testing protocols, and instruments/equipment verified for rating evaporative air coolers. It also focuses on construction requirements. This standard does not cover information related to IEC or IDEC indirect or two-stage evaporative air coolers, and there is no focus on evaluating water consumption. [130&131]

Apart from this, the Australian government, states, and territories and the New Zealand government collaborated to develop an integrated programme called the Equipment Energy Efficiency Programme (E3 Programme), which includes MEPS and energy rating labels for equipment and appliances used by households and businesses in Australia and New Zealand. The Energy Rating Label under the E3 programme is specifically for air conditioners (single phase, non-ducted), washing machines and dryers, dishwashers, televisions, refrigerators, freezers, and computer monitors. Greenhouse and Energy Minimum Standards (GEMS), which was introduced for creating a national framework for product energy efficiency in Australia, is the foundation for the E3 programme. Under the E3 programme, educational and training activities are also undertaken to help consumers with their purchase decisions of opting for an energy-efficient appliances. This includes interactions with retailers and traders who are in direct contact with the consumers.[132&133]

WELS and DMITRE have conducted a study that recommended focusing on developing and introducing water and energy performance labels for evaporative air coolers.

Australia has a separate Water Efficiency Labelling and Standards (WELS) programme under the Department of the Environment, Water, Heritage, and the Arts for taps, showers, dishwashers, washing machines, lavatory equipment, urinals, and flow controllers[134]. In 2009, the WELS, Australian Ministerial Council on Energy, and Department of Manufacturing, Innovation, Trade, Resources, and Energy (DMITRE) of Australia conducted a scoping study that concluded that evaporative air coolers should become the part of WELS scheme for overall water efficiency improvement and recommended an integrated approach that the labelling for both water and energy performance should be introduced together, in order to avoid any negative impact, such as increased peak demand or creation of less favorable market conditions for evaporative air coolers than air conditioners[135]. As per this study, the potential integrated label and testing methodology should focus upon various aspects of water efficiency, such as water bled-off rate, type of water bleeding/drain-off system, water consumption at different speeds, overall water quality (such as salinity level,) and various aspects of energy performance such as wet and dry-bulb temperatures, airflow rate, power consumption by the fan, pump, and control/remote systems, and pressure drop across the cooling system. Apart from this, the report also states that the evaporation rate, water bled-off rate, type of cooling pads and total dissolved salts (TDS) level, are other important parameters to consider in assessing the water consumption by an evaporative air cooler.[136&137]

Based on the review of Australian standards and ongoing studies and initiatives, it has been observed that currently they have not yet covered water efficiency as a parameter for testing evaporative air cooler efficiency. However, WELS and DMITRE have conducted a study that recommended focusing on developing and introducing water and energy performance labels for evaporative air coolers.

[130] Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance*: Institute for Sustainable Systems and Technologies

[131] Saman, W., Bruno, F., & Liu, M., 2009. *Technical background research on evaporative air conditioners and feasibility of rating their water consumption:* Institute for Sustainable Systems and Technologies

[132] Energy Rating, 2020. *ABOUT THE E3 PROGRAM*. [Online] Available at: https://www.energyrating.gov.au/about-e3-program [Accessed 2020].

[133] Australian Government, 2020. *Energy rating label.* [Online] Available at: https://www.energy.gov.au/rebates/energy-rating-label [Accessed 2020].

[134] Australian Government, 2017. *Inspections and enforcement.* [Online] Available at: https://www.waterrating.gov.au/enforce [Accessed 2020].

[135] Saman, W., Bruno, F., & Liu, M., 2009. *Technical background research on evaporative air conditioners and feasibility of rating their water consumption:* Institute for Sustainable Systems and Technologies

[136] Ibid.

[137] Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance:* Institute for Sustainable Systems and Technologies

4.1.2 | USA (California)[138]

California majorly has a Mediterranean climate, with hot and dry summers, making the use of evaporative air coolers feasible for achieving thermal comfort. The California Energy Commission established appliance efficiency regulations (California Code of Regulations, Title 20) in 1976. The latest version of this regulation, 'CEC-410-2017-002', dated January 2016, includes a process for evaluating and rating evaporative air cooler energy performance. These regulations were approved by the California Office of Administrative Law on December 31, 2016 [139].

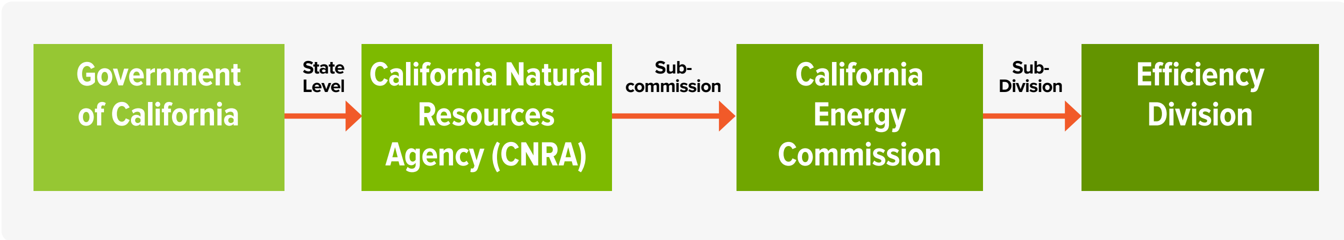


Figure 24: Institutional Framework for Appliance Efficiency in California

The California Energy Commission (former Energy Resources Conservation and Development Commission) was formed in 1974. It comes under the California Natural Resources Agency (CNRA), a state cabinet-level agency in the Californian government, and is the state's primary energy policy and planning agency. One of the primary functions of this commission is to develop, implement, and enforce California's Appliance Energy Efficiency Standards and Labels. One of its sub-divisions, the Efficiency Division, is responsible for developing and implementing cost-effective appliance standards to save energy and provide thermal comfort.[140&141]

Currently, twenty-one appliance categories are covered in this appliance efficiency regulation, including evaporative air coolers. The **Evaporative Cooler Efficiency Ratio (ECER)** is used as a parameter to evaluate energy performance and evaporation efficiency and is calculated using the following equation[142]:

$$ECER = 1.08\,(t_{room} - (t_{db} - E \times (t_{db} - t_{wb}))) \times Q/W$$

Where:

t_{room} = room dry-bulb temperature, °F

t_{db} = outdoor dry-bulb temperature, °F

t_{wb} = outdoor wet-bulb temperature, °F

E = saturation effectiveness/100

Q = airflow rate, CFM

W = total power, W

The specified conditions for calculating ECER include inlet dry- and wet-bulb temperatures of 32.8 and 20.6°C, respectively, and an assumed room outlet air temperature of 26.7°C[143]. These temperature conditions should be used in °F, while calculating the ECER. The regulation focuses on airflow, Evaporative Media Saturation Effectiveness (%) for DEC, Media Type (for DEC) and Cooling Effectiveness (for IEC), Total Power (W), and Airflow Rate (CFM). The regulation take into account ASHRAE's testing standard for both direct and indirect evaporative air coolers[144].

Based on the review of California's appliance efficiency regulations, California, like Australia, has not focused on including water consumption as a performance and efficiency assessment parameter for evaporative air coolers. The most important parameter they have used to evaluate performance is the ECER. The regulation only specify the testing methods for evaporative air coolers and haven't included their MEPS.

[138] California Energy Commission, 2017. 2016 *Appliance Efficiency Regulations. California Energy Commission*. CEC-410-2017-002

[139] Ibid.

[140] California Energy Comission, 2020. *About.* [Online] Available at: https://www.energy.ca.gov/about#:~:text=The%20Warren%E2%80%90Alquist%20Act%20established,and%20reliable%20supply%20of%20energy. [Accessed 2020].

[141] California Energy Comission, 2019. *Efficiency Division.* [Online] Available at: https://www.energy.ca.gov/about/divisions-and-offices/efficiency-division [Accessed 2020]

[142] Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance:* Institute for Sustainable Systems and Technologies

[143] Saman, W., Bruno, F., & Liu, M., 2009. *Technical background research on evaporative air conditioners and feasibility of rating their water consumption:* Institute for Sustainable Systems and Technologies

[144] California Energy Commission, 2017. 2016 *Appliance Efficiency Regulations. California Energy Commission*. CEC-410-2017-002

4.1.3 | Iran[145&146]

Iran largely has a dry climate and a high demand for evaporative air coolers. The Institute of Standards and Industrial Research of Iran (ISIRI) established the mandatory comparative labelling programme 4910-2 for evaporative air coolers in 1999 under the Energy Efficiency Labelling of Energy Consuming Products, which was revised in 2009[147&148]. The aim of this mandatory labelling programme is to encourage manufacturers to produce energy-efficient coolers complying with the standard performance criteria.

ISIRI is the official government body responsible for developing and implementing standards in Iran and operates under the supervision of the Ministry of Industry, Mines, and Trade, Islamic Republic of Iran. It has also established energy labels and MEPS for refrigerators, refrigerator-freezers, and hermetic compressors[149].

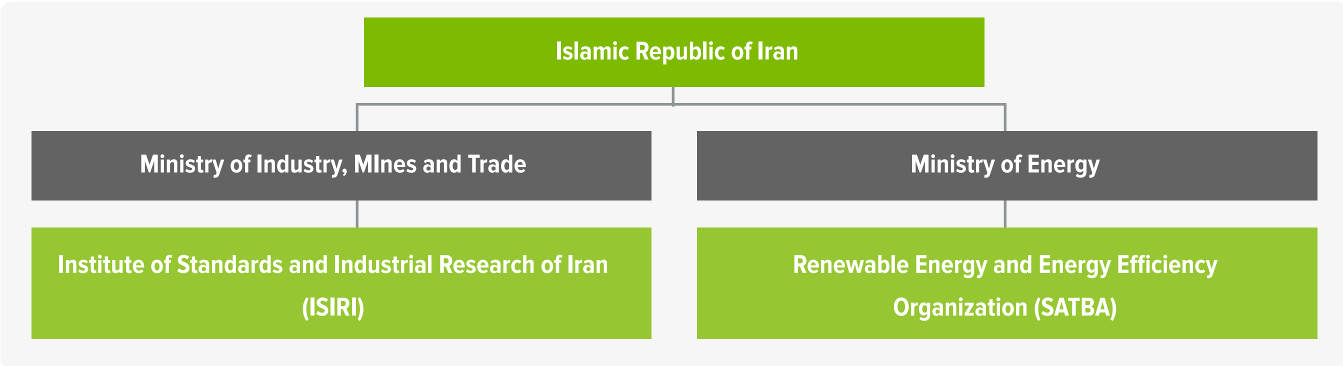


Figure 25: Institutional Framework for Appliance Efficiency in Iran

ISIRI is also an active member of the International Organisation for Standardisation (ISO) technical committees. ISIRI is working with the Iranian Ministry of Energy's Renewable Energy and Energy Efficiency Organisation (SATBA) to produce periodic reports on the energy rating of equipment which are subjected to mandatory compliance with standards. The aim of this collaboration is to increase consumer awareness on appliance power consumption[150].

During the pre-label design stage for evaporative air coolers, consultations with manufacturers were done to assess the key factors affecting evaporative air cooler energy consumption. The key parameters identified were the following[151]:

- **Fan and motor efficiency**
- **Evaporative cooling pad density**
- **Rate of water circulation**

In Figure 26, the label shows efficiency grades from 1, denoted as A (most efficient - the shortest bar, which is green), down to 7, denoted as G (least efficient - the longest bar, which is red). Manufacturers who find this label to be an effective marketing tool are promoting it.

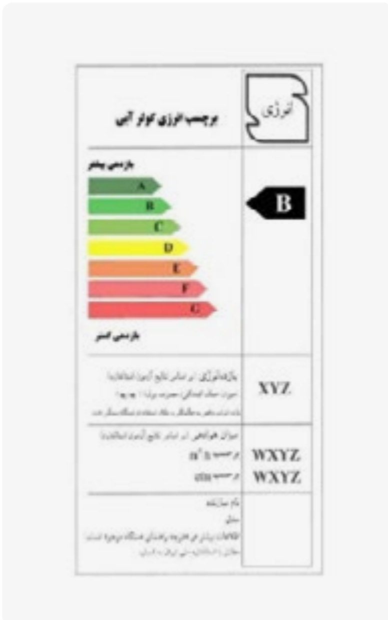


Figure 26: Iranian Energy Label[152]

145 Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance:* Institute for Sustainable Systems and Technologies

146 Effatnejad, R. and Salehian, A.B., 2009. Standard of energy consumption and energy labeling in evaporative air cooler in Iran. Jurnal IJTPE, 1.

147 Ibid.

148 CLASP, 2020. *Policy Details.* [Online] Available at: https://clasp.ngo/policies/iran-meps11[Accessed 2020].

149 Institute of Standards & Industrial Research of Iran, 2020. *Introduction.* [Online] Available at: http://www.isiri.com/about.htm [Accessed 2020].

150 Ibid.

151 Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance:* Institute for Sustainable Systems and Technologies

152 Effatnejad, R. and Salehian, A.B., 2009. Standard of energy consumption and energy labeling in evaporative air cooler in Iran. Jurnal IJTPE, 1.

Rating	EER Value
1	EER≥65
2	58≤EER≤65
3	50≤EER≤58
4	42≤EER≤50
5	34≤EER≤42
6	26≤EER≤34
7	EER<26

Figure 27: Energy Efficiency Thresholds for Iranian Energy Label[153]

The **Energy Efficiency Ratio (EER)** is used as an energy labelling parameter to compare products, as shown in Figure 27. EER is the ratio of the sensible cooling capacity of air power (kW) to the total input power (kW).

$$EER = \frac{q_s - Q.\rho.C_p.(t_{do} - t_{di})}{P_t}$$

Where:

q_s: sensible cooling capacity kW times
P_t: power consumption kW cooler times
Q: air flow cubic meter per hour or cubic foot per minute
ρ: air density according kg per square meter
C_p: specific heat of air at constant pressure, kJ.kg Kelvin times
t_{do}: dry air output temperature according to degrees Celsius
t_{di}: dry air temperature input according to degrees Celsius

The sensible cooling capacity of the evaporative air cooler can be defined as:

$$q_s = Q\ \rho\ C_p\ (t_{di} - t_{do})$$

The evaporative air cooler's cooling capacity is dependent on the evaporation effectiveness, inlet air's dry and wet-bulb temperatures, and airflow rate. If the value of cooling capacity is positive, this indicates that cooling has been achieved. Iran had to develop its own testing protocols, as it was the first country to develop and implement MEPS & labelling for evaporative air coolers. The testing is as per Iranian test standards No. 4910 and No. 4911, which use the Australia Standard 2913-2000 and BIS standards as their base test standards. There is no focus on water consumption[154].

In terms of unique features, Iran is the only county that has a set MEPS and mandatory comparative labelling programme for evaporative air coolers. Iran's label uses a star rating to define the most and least efficient evaporative air coolers and EER as an energy labelling parameter to compare various evaporative air cooler models. In order to increase consumer awareness on appliance power consumption, ISIRI, SATBA, and the Iranian Ministry of Energy work together to develop periodic reports on equipment energy rating, which are subjected to mandatory enforcement of standards.

Table 9 below summarises the temperature conditions specified for evaporative air cooler rating in the select countries.

Table 9: Rating Temperatures (°C) of the Select Countries

Rating Temperature (°C)	Australia (AS/NZS 2913-2000)	California (California Code of Regulations, Title 20)	Iran Appliance Label & MEPS
Outdoor Dry-Bulb Temperature	38	32.8	
Outdoor Wet-Bulb Temperature	21	20.6	**Information Not Available**
Indoor Dry-Bulb Temperature	27.4	26.7	

It was observed that none of the countries have taken into consideration water consumption as an element for improving overall evaporative air cooler performance.

The following section examines ASHRAE's testing standards for evaporative air coolers.

[153] Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance:* Institute for Sustainable Systems and Technologies

[154] Saman, W., Bruno, F., & Liu, M., 2009. *Technical background research on evaporative air conditioners and feasibility of rating their water consumption:* Institute for Sustainable Systems and Technologies

4.2 | International Testing Standards

This section highlights the key findings from the review of ASHRAE's testing standards for direct and indirect evaporative air coolers.

4.2.1 | ASHRAE Standard 133-2015: DEC Testing Method[155]

ASHRAE has established Standard 133, the international standard for DECs, which includes the lab testing procedures for calculating the overall cooling effectiveness of a DECs, in order to obtain related ratings.

The first version of this standard was issued in 2001, followed by a revised version in 2008, and the latest version came out in 2015. **The first version** provided the testing procedures for DECs under laboratory conditions to obtain a specific rating. **In 2008**, the test standards were modified, with a condition added to the testing procedures, namely, that no other sources of heat transfer shall be present during testing.

In the 2015 version, it was clarified that the density correction to saturation effectiveness shall be treated as a function of the actual airflow test standard. It covers the testing method for measuring the saturation effectiveness, air and water flow, and total power of packaged[156] and component[157] evaporative air coolers. The standards also focus on fan rotation speed and density of the air. The target users defined for this standard are evaporative air cooler end-consumers in residential, industrial/commercial, and agricultural settings. Figure 28 displays the key parameters for DEC testing as per the latest version of this standard.

Testing Requirements

- Determination/Measurement/Reading frequency
- Equilibrium condition
- Air flow rates
- Humidity & temperature condition
- Water quality standard and conductivity
- Water entrainmnet

Report & test results

- Perofrmance data and curve
- Method of supplying water
- Information related to test, model and person who conducted the test

Figure 28: Key Parameters Under ASHRAE Standard 133-2015 for DECs

[155] ANSI/ASHRAE Standard 133-2015, 2015, Method of Testing Direct Evaporative Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

[156] A self-contained unit, inclusive of a fan and fan motor, whose primary functions are (a) the conversion of the sensible heat to latent heat through the process of evaporating the recirculating or nonrecirculating water directly exposed to this air and (b) the movement of this air through the unit.

[157] A self-contained cabinet without a fan whose primary functions are (a) the conversion of the sensible heat to latent heat through the process of evaporating the recirculating or nonrecirculating water directly exposed to this air and (b) the movement of this air through the cabinet, which allows a portion of this water to evaporate.

Following are the key highlights of this standard:

- The airflow rate at which two different static pressure differential points or the bi-stable performance points can be measured shall be recorded. These points could be set to reduce or increase the airflow rate.
  - Standard water quality to be maintained with the conductivity meter with an accuracy of ±10% of observed reading shall be used to measure water's conductivity and for entrainment verification, the air testing equipment shall be kept safe from water entrainment, to avoid alteration in temperature readings.
- The acceptable temperature and humidity test conditions include the following:

Table 10: The Acceptable Temperature and Humidity Test Conditions under ASHRAE Standard 133-2015

Type of Temperature	Specified Temperature
Inlet air dry-bulb temperature: maximum	46°C (115°F)
Wet-bulb temperature: minimum	5°C (41°F)
Wet-bulb depression: minimum	11°C (20°F)

- The following parameters need to be calculated from the test data:
  - Standard airflow rate
  - Standard static pressure differential
  - Standard fan power
  - Standard power input
  - If the rotation speed varies from one reading to another, a correction will be required in the value calculated under the test conditions to convert it into a nominal fan speed at standard density.
  - The saturation effectiveness shall be called as the function airflow rate corrected to standard air
- The final lab test report on an evaporative air cooler shall include details about the object, results, test set-up, instruments for testing, test data on the evaporative cooler/cooling unit, and name of the test lab.

ASHRAE testing standard 133-2015's DEC testing method focuses on saturation effectiveness, dry and wet-bulb temperatures, air and water flow, the total power of the packaged and component evaporative air cooler, fan rotation speed, density of the air, static pressure, water quality, and water entrainment. Details on the requirements for testing, instruments, and methods of measurement, instructions for recording data, and information to be included in the report & test results can be found in Annexure 2. The information on the equipment and its set-up, along with the calculation of key parameters—i.e. air density & velocity, power input, airflow rate, saturation effectiveness, static pressure differential, and calibration corrections—can be obtained directly from the ASHRAE testing standard 133-2015.

4.2.2 | ASHRAE Standard 143-2015: IEC Testing Method[158]

ASHRAE has established the standard 143, an international standard for IECs that includes the lab testing procedures for calculating an IEC's cooling effectiveness and power requirement in order to obtain related ratings. Compliance with this standard is voluntary. The **first version** of this standard was approved in **2000,** and the **latest revision came out in 2015**. This standard is designed to estimate key parameters such as airflow and temperature (inlet and outlet) to calculate the pressure drop to achieve evaporative air cooling. Figure 29 displays the key parameters for IEC testing as per the latest version of this standard.

Sub categories

- Component indirect evaporative coolers
- Semi-packaged secondary indirect evaporative coolers
- Semi-packaged primary indirect evaporative coolers
- Packaged indirect evaporative coolers

Testing Requirements

- Airflow rates
- Temperature difference
- Measurement/reading frequency

Report & test results

- Performance curves
- Data realted to barometric pressure, primary and secondary air temperature, primary and secondary air flow rate, electric power input, and primary and secondary air static pressure drop
- Information related to model, test and person who conducted the test

Figure 29: Key Parameters Under ASHRAE Standard 143-2015 for IEC

Following are the key highlights of this standard:

- Under this testing standard, the IECs are sub-divided into the following four categories, as per their construction style: component IECs, semi-packaged secondary IECs, semi-packaged primary IECs, and packaged IECs. Details about these sub-categories are provided in Annexure 3.
- The final lab test report on an evaporative air cooler shall include details about the object, results, test set-up, appurtenances, testing instruments, and test data. It shall also provide information such as the IEC type, information on the specific evaporative air cooler model as per the manufacturer, test identification number, test lab, date of testing, and name of the person who conducted the test.
- The test report shall include data on the barometric pressure, primary and secondary air temperature, primary and secondary air flow rate, electric power input, and primary and secondary air static pressure drop.
- Performance curves of the electricity inputs and cooling capacity shall be included. In the case of IECs that do not have air-moving devices, their static pressure drop curves shall also be included.

ASHRAE testing standard 143-2015's IEC testing method focuses on the cooling effectiveness, power requirement, dry and wet-bulb temperatures, airflow, temperature (inlet and outlet), static pressure drop, and barometric pressure. Details on the requirements for testing, instruments, apparatus, testing methods, and test reports are provided in Annexure 3. The information on the compliance and calculation of key parameters—i.e. air density & velocity, total power input, airflow rate, cooling effectiveness, cooling capacity, and calibration corrections—can be refereed directly from the ASHRAE testing standard 143-2015.

Overall, ASHRAE's testing standards for direct and indirect evaporative air coolers cover the dry and wet-bulb temperature, airflow rate, water flow, power requirement, saturation effectiveness, water quality, water entrainment, and static pressure. They do not include testing of the type of material used in the outer structure, noise levels, or evaporative cooling pad effectiveness, which are also critical parameters for testing and evaluating evaporative air cooler's overall cooling efficiency.

The next section presents the initiatives taken up by international organisations to increase evaporative air cooler performance and energy efficiency.

[158] ANSI/ASHRAE Standard 143-2015, 2015, Method of Test for Rating Indirect Evaporative Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

4.3 | International Initiatives

This section will elucidate about the key findings from the review of voluntary rating standards for evaporative air coolers introduced by Eurovent Certita Certification (ECC).

4.3.1 | Eurovent Certita Certification's Rating Standard for Evaporative Air Coolers[159]

Eurovent Certita Certification (ECC) is an international private organisation founded in 1993 that has gained international recognition as a third-party product performance certification body for HVAC and refrigeration products. It is an accredited body for product certification fulfilling the requirements as per the ISO17065 standards. ECC has established rating standards, along with an operating manual, for certifying evaporative air coolers and evaporative air-cooling equipment with manufacturers in Europe and Australia.

ECC's rating standards for evaporative air cooling components and equipment is sub-divided as follows:

- Direct Evaporative Cooling
- Indirect Evaporative Cooling
- Evaporative Cooling Equipment (ECE)

These are voluntary sub-programmes, meaning that applicants can, but do not have to, participate.

4.3.1.1 | Standard RS/9/C/004-2018 for DEC certification[160]

Key performance data considered for the certification as per this rating standard:

- Cooling capacity (kW)
- Airflow [m^3/hr]
- Evaporation efficiency [%]
- EER
- Water consumption [L/hr] as per section 6.5 in ASHRAE 133-2015

For testing, the AS 2913-2000 standard and ASHRAE 133-2015 are used to calculate the following:

- Airflow (as per AS 2913-2000)
- Evaporation efficiency (as per AS 2913-2000), by calculating:
  - — Inlet dry-bulb temperature
  - — Inlet wet-bulb temperature
  - — Supply dry-bulb temperature
- Power consumption (as per AS 2913-2000)
- Water consumption

In addition to the above mentioned parameters, the following specific conditions are considered in the qualification and repetition test:

- Operating conditions specified for the test (as per AS 2913-2000):
  - — Inlet dry-bulb temperature: 38°C
  - — Inlet wet-bulb temperature: 21°C
  - — Room dry-bulb temperature: 27.4°C
- Water quality:
  The manufacturer has to provide the following details on the water being supplied to the water distributor:
  - — Range of conductivity
  - — Range of total hardness
  - — Range of pH
  - — Range of Total Salt Content (TSC) or TDS
- The inlet water temperature shall not be lower than 10°C
- The inlet temperature readings by sensors shall be as per EN 14511-3:2013[161]

[159] Eurovent Certita Certification, 2018. *Evaporative Cooling*. [Online] Available at: https://www.eurovent-certification.com/en/third-party-certification/certification-programs/ec-evaporative-cooling [Accessed 2020].

[160] Eurovent Certita Certification, 2018. *Rating Standard for the Certification of Direct Evaporative Cooling*, Paris: Eurovent Certita Certification.

[161] EN 14511-3:2013: Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling - Part 3: Test methods

Rating requirements:

- Standard air density of 1.20 kg/m3 shall be used in the calculations.
- A check-test shall be conducted to re-evaluate the performance under the standard test operating conditions, with the help of selection software. If the difference between the test result and re-calculated value is not as per the acceptance criteria shown below in Figure 30, the item fails the check-test.

	Accepted Relative deviation
Cooling Capacity [kW]	$\geq$-5%
Air Flow [m3/hr]	$\geq$-5%
Saturation Efficiency [%]	$\geq$-5%
Water Consumption [l/hr]	$\leq$-5%
EER	$\geq$-5%

Figure 30: Acceptance Criteria for DEC Rating[162]

4.3.1.2 | Standard RS/9/C/005-2018 for IEC certification[163]

There are two cases specified under this rating standard with a) primary outside air and b) separation of external and room air:

Case A: In this case, the IEC has air-moving devices for both the primary and secondary air passages, as shown below in Figure 31. As per the requirement, a single air-moving device may be used for the primary and secondary air.

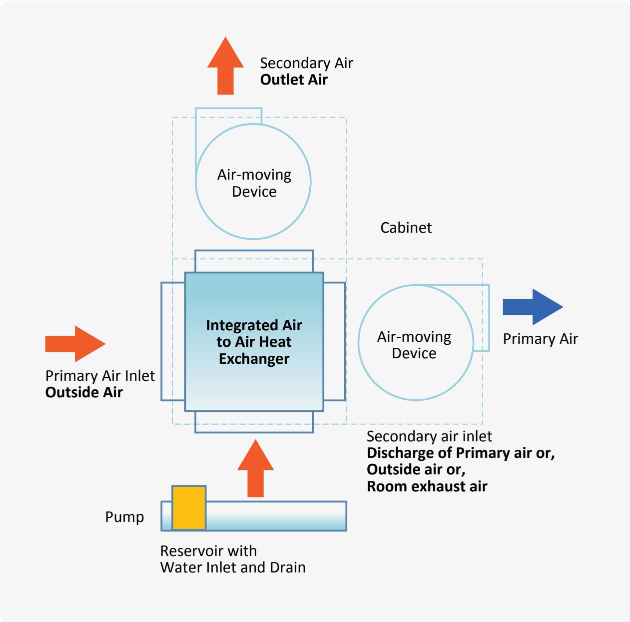


Figure 31: Standard RS/9/C/005-2018: IEC Case A[164]

Key performance data considered for certification as per this rating standard:

- Total cooling capacity [kW]
- Room cooling capacity [kW]
- Airflow [m^3/hr]
- Cooling effectiveness [%]
- Water consumption [L/hr] as per section 6.5 in ASHRAE 133-2015
- EER

Case B: In this case, a packaged IEC has air-moving devices for both the primary and secondary air passages, as shown below in Figure 32. For testing, ASHRAE 143-2015 is considered under this rating standard.

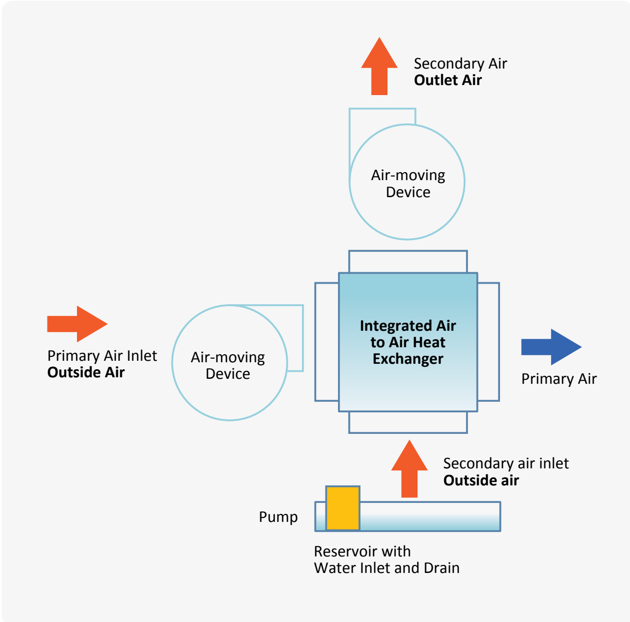


Figure 32: Standard RS/9/C/005-2018: IEC Case B[165]

Key performance data considered for certification as per this rating standard:

- Total cooling capacity [kW]
- Airflow [m^3/hr]
- Wet-bulb approach effectiveness [%]
- Dry-bulb approach effectiveness [%]
- Water consumption [L/hr] as per section 6.5 in ASHRAE 133-2015
- EER

[162] Eurovent Certita Certification, 2018. *Rating Standard for the Certification of Direct Evaporative Cooling*, Paris: Eurovent Certita Certification.
[163] Eurovent Certita Certification, 2018. *Rating Standards for the Certification of Indirect Evaporative Cooling*, Paris: Eurovent Certita Certification.
[164] Ibid.
[165] Ibid.

Rating requirements:

- Standard air density of 1.20 kg/m3 shall be used in the calculations.
- A check-test shall be conducted to re-evaluate the performance under the standard test operating conditions, with the help of selection software. If the difference between the test result and re-calculated value is not as per the acceptance criteria shown below in Figure 33, the item fails the check-test.

Case A	Accepted Relative deviation
Total Cooling Capacity [kW]	≥-5%
Room Cooling Capacity [kW]	≥-5%
Air Flow [m^3/hr]	≥-5%
Cooling Effectiveness [%]	≥-5%
Water Consumption [l/hr]	≤-5%
EER	≥-5%

Case B	Accepted Relative deviation
Total Cooling Capacity [kW]	≥-5%
Air Flow [m^3/hr]	≥-5%
Wet bulb approach effectiveness [%]	≥-5%
Dry bulb approach effectiveness [%]	≥-5%
Water Consumption [l/hr]	≤-5%
EER	≥-5%

Figure 33: Acceptance Criteria for IEC Rating[166]

4.3.1.3 | Standard RS/9/C/006-2018 for ECE certification[167]

The following types of evaporative cooling media can be considered under this rating standard:

- Water spray systems
- Cooling pads/media
- Ultrasonic units[168]

Key performance data considered for the certification as per this rating standard:

- Cooling capacity [kW]
- Evaporation efficiency [%]
- Water consumption [L/hr] as per section 6.5 in ASHRAE 133-2015
- EER
- Wet pressure drop [Pascal - Pa] & dry pressure drop [Pa]

The ECC's rating programmes for evaporative cooling components and equipment does not include noise level and water wastage/bled-off rate as parameters in their evaporative air cooler standards.

Table 11 below provides a comparison of the parameters covered with respect to evaporative air cooler performance under IS 3315, ASHRAE's testing standards, Australia standards (AS/NZS 2913-2000), California Code of Regulations, Title 20, Iran Appliance Label & MEPS and ECC rating standards:

Table 11: Comparative Summary of Evaporative Air Cooler Performance Parameters*

Parameters	IS 3315	ASHRAE Testing Standards (133 & 143)	Australia (AS/NZS 2913-2000)	California, USA (California Code of Regulations, Title 20)	Iran Appliance Label & MEPS (4910-2)	ECC rating standards (RS/9/C/004-2018, RS/9/C/005-2018, & ECE)
Water Consumption	⊗	⊗	⊗	⊗	⊗	✓ As defined in section 6.5 'Water Flow' in ASHRAE 133-2015
Water Entertainment	⊗	✓ ASHRAE 133-2015	⊗	⊗	⊗	⊗
Water Quality	⊗	✓ ASHRAE 133-2015	⊗	⊗	⊗	✓
Power Consumption	✓	✓	✓	✓	✓	✓
Noise Level	✓	⊗	✓	⊗	⊗	⊗

[166] Ibid.

[167] Eurovent Certita Certification, 2018. *Rating Standards for the Certification of Evaporative Cooling Equipment*, Paris: Eurovent Certita Certification.

[168] Units that generate fine mist by converting an electronic signal into a mechanical oscillation.

Parameters	IS 3315	ASHRAE Testing Standards (133 & 143)	Australia (AS/NZS 2913-2000)	California, USA (California Code of Regulations, Title 20)	Iran Appliance Label & MEPS (4910-2)	ECC rating standards (RS/9/C/004-2018, RS/9/C/005-2018, & ECE)
Design & Build	✓	✗	✗	✗	✗	✗
Air Flow	✓	✓	✓	✓	✓	✓
Evaporative Cooling Effectiveness	✓	✓	✓	✓	✓	✓
Static Pressure/ Pressure Drop	✓	✓	✗ Not Specified	✗ Not Specified	✗ Not Specified	✓
Testing Protocols	✓	✓	✓	✓	✓	✓
MEPS	✗	✗	✗	✗	✓	✗
Guidance & Instructions for Manufacturers	✓	✗	✗	✗	✗	✗
Eco-mark	✓	✗	✗	✗	✗	✗
Detailed Specifications w.r.t. Evaporative Air Cooler Type	✗	✓	✗	✗	✗	✓

✓ Parameter Covered   ✗ Parameter NOT Covered

For an evaporative air cooler, water and power consumption are the two main parameters that can affect its overall performance and energy efficiency. From Table 11 shown above, one can see that power consumption has been covered as a parameter by all the reviewed testing standards, regulations, and MEPS, both nationally and internationally. However, in contrast, water consumption has only been covered by the ECC's voluntary rating standards for evaporative air coolers, even though water consumption is an equally important parameter, because water is used as a refrigerant during the process of evaporation in evaporative air coolers. In addition to this, water entrainment, has only been touched upon briefly by ASHRAE 133-2015, the DEC testing standard, in terms of how it can be detected. Furthermore, water quality has only been covered by ASHRAE 133-2015 and the ECC voluntary rating standards.

The noise level has only been covered by IS 3315 and AS/NZS 2913-2000. The requirement for safety, exterior structure/design & build, as well as guidance & instructions for manufacturers, has only been covered by IS 3315. Other important parameters, namely, airflow, evaporative cooling pad effectiveness, and the rate of evaporation/evaporative effectiveness has been covered by all the abovementioned testing standards, regulations, and MEPS. Static pressure has been covered by IS 3315, ASHRAE 133 and 143, and the ECC voluntary rating standards.

Most important, information on the testing protocols for evaporative air coolers has been provided by IS 3315, ASHRAE 133 and 143, AS/NZS 2913-2000, California Code of Regulations, Title 20, Iran Appliance Label & MEPS (4910-2), and the ECC voluntary rating standards. One important finding from the review was that only Iran has introduced MEPS for evaporative air coolers. Eco-mark is also another critical parameter that came out of the literature review and has only been adopted under IS 3315. In addition to this, details/parameters on different types of evaporative air coolers have only been specified under the ASHRAE Testing Standards and ECC voluntary rating standards.

Furthermore, the recommendations based on the international policy review are provided in the following chapter.

5

Conclusion & Recommendations

From the review of international and national institutional, policy, and regulatory frameworks in regards to improving the performance of evaporative air coolers, the following gaps have been identified at the national level in terms of ‘policy and regulatory’, and ‘research and design’. The gaps are followed by recommendations to address them in the near future.

5.1 | National Level Gaps

The following gaps have been identified from the extensive literature review of international evaporative air cooler testing standards, regulations, and MEPS:

5.1.1 | Policy & Regulatory Related

- Absence of MEPS & labelling for evaporative air coolers.
- Lack of specification for different evaporative air cooler types in the existing standards.
- Lack of consideration for water consumption, water quality, and water bled-off rates as one of the critical parameters in the existing standards.
- Lack of focus on thermal comfort in the available appliance standards.
- Lack of evaporative air cooler testing infrastructure.

5.1.2 | Research & Design Related

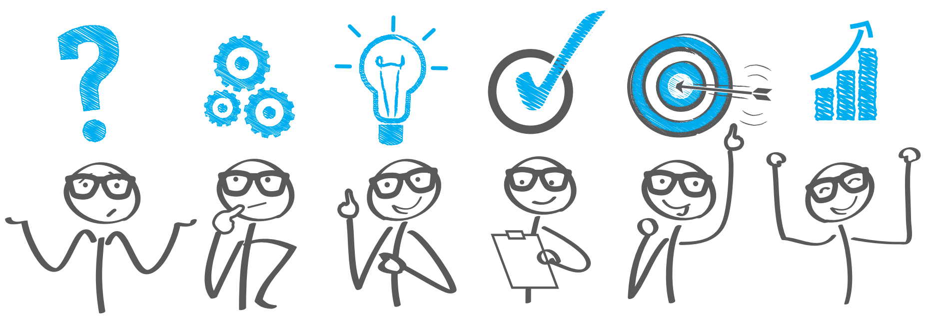
- Lack of discussion about thermal comfort or the need for space cooling technologies for academic institutions (such as schools, kindergartens, and universities) and evaporative air coolers' potential application in these settings.
- Lack of literature available and research done on unlocking the market and technology potential of evaporative air coolers in the commercial sector.
- IS 3315 2019 covered the design and construction specifications related to overall evaporative air cooler structure, cooling pad material, and blower fan material and quality. However, specifications related to different types of blower fans are not included. Moreover, the standard does not cover any information on the heat exchanger type, quality, and material.

5.2 | Recommendations

To address the above-mentioned gaps, the following is recommended for India, based on the learnings from the testing standards, regulations, and MEPS adopted internationally:

5.2.1 | Policy & Regulatory Related

The following recommendations could be taken up by **Ministries:** MoP, MoEF&CC, MoCI, and Ministry of Consumer Affairs, Food, and Public Distribution; and **Regulatory Bodies:** BEE, BIS, IBEF, and CPRI, in consultation with key **Associations:** ISHRAE and CEAMA, for robust policy uptake and adoption, and market transformation. **Industry** level stakeholders, **testing labs**, and other **private stakeholders** could provide support in disseminating technical knowledge and establishing testing infrastructure.



I. Establishment of MEPS

To establish MEPS for evaporative air coolers at the national level, the following parameters for evaluating evaporative air cooler output and performance should be considered:

- **Cooling Capacity:** The cooling capacity of an evaporative air cooler is dependent upon the evaporation effectiveness, inlet air's dry- and wet-bulb temperatures, and airflow rate. As specified in Section 2.2, the evaporative effectiveness ranges from 40% to 115%, depending on the type of evaporative air cooler, and the evaporative efficiency of the cooling pad is around 85%, depending on the pad type. The Seasonal Energy Efficiency Ratio (SEER) star rating bands should be designed taking these components under consideration.
- **SEER:** Similar to ISEER, which is used by BEE as the key parameter for evaluating the annual energy performance of air conditioners, and considering India's tropical climate, SEER would be an ideal parameter to evaluate evaporative air coolers' annual energy performance, where there is a change in seasonal temperatures, resulting in variation in the cooling needs and energy required to operate appliances.

SEER is the annual performance ratio of the total annual cooling capacity to the total annual electrical energy consumption of a particular unit, in a specific location, seasonally. In other words, it is a coefficient of performance that evaluates the ratio of the annual amount of heat removed by a cooling appliance to the total annual amount of electrical energy consumed by the appliance during this process, seasonally[169]. SEER considers the temperature at which the appliance operates. The higher the SEER rating, the greater the energy efficiency of the appliance. The following equation can be used to calculate SEER:

SEER of evaporative air cooler = total annual cooling capacity (kWh thermal)/Total annual electrical energy consumption (kWh electric)[170]

For calculating the total electrical energy consumption, the following should be included:

- Number of hours per year when cooling is required to provide thermal comfort.
- Number of hours per year when the system is unable to provide thermal comfort.
- Average daily electrical energy use for cooling under the location-specific design conditions.

MEPS could also be specified as per the different types of evaporative air coolers, i.e. DEC, IEC, and IDEC.

II. Development of Label

For the development of performance labels for evaporative air coolers in India, a comprehensive comparative assessment of different labels/labelling programmes worldwide should be undertaken, so that recommendations regarding labelling based on international best practices—which can be adapted to the Indian climatic conditions—can be provided.

[169] Purushothama, B., 2009. Humidification and ventilation management in textile industry. *Research Gate*, Issue 10.1533/9780857092847.

[170] Saman, W., Bruno, F., & Tay, S., 2010. *Technical Research on Evaporative Air Conditioners and Feasibility of Rating their Energy Performance*: Institute for Sustainable Systems and Technologies

III. Capacity Building and Awareness Generation for Faster Performance Label Adoption

- Capacity building and awareness generation strategies should be developed to increase the adoption of water- and energy-efficient evaporative air coolers and enhance potential consumers' understanding of the water & energy performance labels for evaporative air coolers.
- Incentivisation could help increase the uptake of water and energy-efficient evaporative air coolers.
- Behaviour change campaigns should be implemented to facilitate the transition in consumers' purchasing decisions to opting for a sustainable and Non-GWP refrigerant based space cooling technology.
- There should be consultations between the associations or Industry level stakeholders or the private stakeholders and retailers and shopkeepers, who are in direct contact with consumers, to make them aware of the benefits of energy-efficient and sustainable cooling technologies. This could aid in the dissemination of this information through word-of-mouth to potential consumers.

To establish effective MEPS & labelling for evaporative air coolers in India, the following parameters, shown below in Figure 34, should be considered under mandatory regulations and should be tested to evaluate the performance and overall water and energy efficiency of evaporative air coolers, once the steady temperature and testing conditions are achieved in a test lab at each selected speed level:

- Climatic conditions
- Relative Humidity (RH)
- Exterior structure/design & build: Type and quality
- Type of heat exchanger
- Temperature: Inlet and outlet dry and wet-bulb temperatures
- Total electrical power consumption: by the sub-components-fan, water circulation pump and variable speed control/remote system
- Evaporative cooling pad and rate of evaporation:
  - Type of evaporating medium
  - Thickness of cooling pad/media

- Hours of operation (before testing)
- Static Pressure drop
- Wet-bulb depression across the cooling system
- Sound level
- Water:
  - Inlet water quality
  - Total water consumption
  - Total water dumped off/wasted
  - Water pump type, motor and quality
- Air flow:
  - Fan type, blade size and quality
  - Air flow rates at different speed settings subject to a standardized pressure drop to allow for the ducting system.
  - Supply air flow through heat exchanger

Figure 34: Key Parameters for Evaporative Air Cooler MEPS & Labelling in India

These components will help in calculating the overall cooling capacity, evaporative effectiveness, and SEER or potential EER for evaporative air coolers. In addition to these parameters, policymakers should make thermal comfort a priority in the available appliance standards and accelerate the efforts towards mainstreaming the available energy-efficient space cooling technologies.

IV. Establishment of Testing Infrastructure

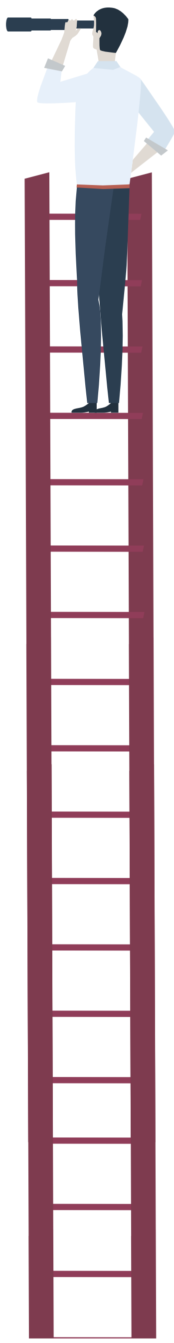
- Mapping of the existing government, private, and industry test labs in India available for evaporative air cooler performance testing should be undertaken.
- An assessment of the above-mentioned government, private, and industry test labs in India and their testing infrastructure should be conducted. The evaluation and gap assessment of the testing infrastructure would highlight the need for their upgradation as per the global standards on appliance testing.
- The test labs should be upgraded and new test labs should be set-up as required based on the gap assessment.
- A standard operating procedure (SoP) for the testing of evaporative air coolers and other similar Non-GWP refrigerant based space cooling technologies should be developed.

5.2.2 Research & Design Related

The following recommendations could be taken up by Civil Society Organisations (CSOs), private players, academic and research institutions, Original Equipment Manufacturers (OEMs), and technology providers for robust implementation and rapid information dissemination of information and evaporative air cooler technology.

- A technology assessment study should be undertaken in schools, kindergartens, universities, and other academic institutions to determine which type of evaporative air cooler is best suited for these settings, for achieving thermal comfort.
- An in-depth market transformation potential study is required to assess the actual potential of evaporative air coolers in the commercial segment. SEEP for evaporative air coolers could be proposed, as they have high growth potential in the Indian appliance market.
- A design SoP or design guidelines should be developed for heat exchangers and blower fans. Tentative design guidelines are provided in Annexure 4.

Other Possible Interventions



In addition to the above-mentioned recommendations, the following interventions can be introduced to support the implementation of MEPS for evaporative air coolers and increase evaporative air coolers uptake in Indian appliance market:

An HERS[171] index for the residential and commercial sectors could be developed to help consumers compare the energy consumption levels amongst the setting which has evaporative air coolers installed to the setting with energy intensive space cooling appliances which use refrigerants with GWP such as air conditioners. This will aid in altering consumer behaviour and fostering increase in uptake of evaporative air coolers. This index could also be sent to consumers who are currently using evaporative air coolers, to motivate them to continue using this Non-GWP refrigerant based space cooling technology to limit their energy consumption and do their bit in protecting the environment.

A pilot study to mainstream evaporative air coolers should be conducted that entails in-situ performance and energy consumption assessments in a sample household and commercial/industrial settings with evaporative air coolers. This study could be linked to an incentivisation mechanism such as a tax rebate or differential tariff pricing.

In terms of achieving thermal comfort, apart from the residential or commercial sector, there is one area that has been overlooked that is thermal comfort for children. Efforts should be made should be to provide thermal comfort in settings used by children such as orphanages, schools, kindergartens, and other academic institutions and areas that currently lack access to thermal comfort.

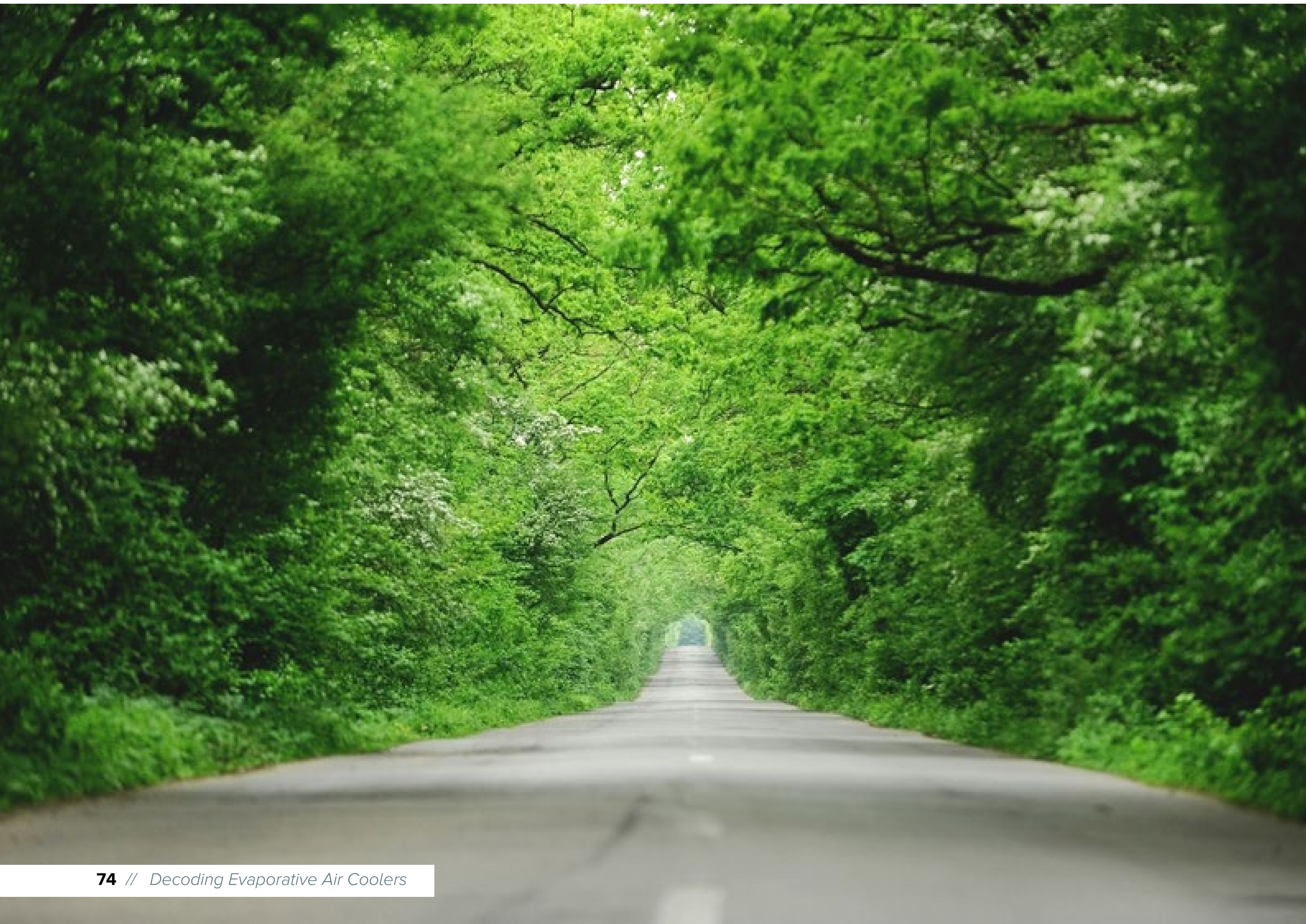
A 'pay-per-use' model or servitisation for evaporative air coolers should be adopted. In servitisation, the consumer pays the price of per unit energy consumed by them or service provided by an appliance. In this model, the technology provider remains the appliance owner and covers the capital and operational costs of the appliance. This service model is beneficial for both the manufacturer and consumers and could increase evaporative air cooler penetration. This, in turn, would promote the use of energy-efficient Non-GWP refrigerant based space cooling technologies, facilitating access to cooling and thermal comfort for all.

[171] The Home Energy Rating System (HERS) Index is sent to customers separately from their utility bills on a monthly, bimonthly, or quarterly basis. It includes a summary of the home's recent and historical energy use, energy efficiency tips (including utility energy efficiency programme offerings), and a normative comparison of the home's energy use to that of similar neighbours and offers rewards or incentives for reducing energy use. It is also frequently accompanied by a web portal, available to customers, that provides similar information.

Way Forward

The development of the MEPS framework will provide an opportunity to standardise this product segment, increasing its mass adoption and, ultimately, increasing access to cooling and thermal comfort for all, as well as providing other related co-benefits such as a reduction in GWP and GHG emissions. Nevertheless, it is essential to first assess the present market, future growth, and energy saving potential of evaporative air coolers in the commercial sector, as there is extremely limited information available on the commercial evaporative air cooler market compared to the residential air cooler market. Getting ahead of the demand curve and setting robust MEPS for evaporative air coolers could help in establishing market-leading performance and setting India's evaporative air cooler industry ahead of other international competitors. This could position India as the market leader for export opportunities, in addition to domestic trade, and could contribute towards economic recovery, along with supporting the Government of India's 'Atmanirbhar Bharat' initiative. Therefore, extensive, focused efforts are required to leverage the existing evaporative air cooler technology in the commercial sector and develop its MEPS to enable wider market adoption. AEEE's follow-up report on this subject will thus focus on a technology and market assessment of India's major evaporative air cooler market players in the commercial sector.

The development of the MEPS framework will provide an opportunity to standardise this product segment, increasing its mass adoption and, ultimately, increasing access to cooling and thermal comfort for all, as well as providing other related co-benefits such as a reduction in GWP and GHG emissions.



Annexure 1

BIS Standards test conditions for testing evaporative air coolers:

- Cooling efficiency and air delivery can be tested on any prevailing ambient temperature.
- Relative humidity for in-let air to be between 25 % and 55% with variation not more than ± 5%.
- Cooling pads shall be dry during air flow test.
- The static pressure difference between cooled supply air and the ambient conditions of inlet air cooler in the test room shall be adjusted to provide zero static pressure with the help of blower fan and damper.
- Power consumption shall be tested at zero static pressure.
- A cooler shall be operated under conditions when it is providing maximum air delivery and cooling efficiency, as desired. It shall operate in this condition until it reaches its thermal equilibrium.
- Standard operating condition is said to be achieved when the dry-bulb temperature is recorded at same position and it does not change more than 0.5°C within the interval of 15 mins. This test is continued until five successful readings are achieved.
- The dry-bulb temperature of the supply cooled air shall be around 1.5°C.
- The frequency and voltage supply to the air cooler shall be adjusted ± 2% of the motor rated voltage.

Annexure 2

Key highlights from review of the ASHRAE Standard 133-2015: Method of Testing Direct Evaporative Air Coolers are mentioned below[172]:

1. Requirements:

- Determination: A series of measurements are carried out for a particular point of operation of an evaporative air cooler, for estimating the performance variables as mentioned under this standard, from the range of shutoff[173] to free delivery[174] and are depended upon the various characteristic curves. Eight measurements shall be taken to determine the curves that are not smooth. In case of performance estimation at a point of operation than at least three measurements are required to determine the short curve inclusive of that point.

- Reaching equilibrium: Before starting to take actual measurements/readings, trial observations shall be made in order to check for equilibrium conditions or steady readings. The range of air delivery over which equilibrium can't be achieved shall be taken into considerations, as a reading.

- Stability: The airflow rate shall be recorded, at which two different static pressure differential points or the bi-stable performance points can be measured. These points could be set for reducing or increasing the airflow rate.

- Acceptable Standard Temperature and Humidity Test Conditions:
  - — Inlet air dry-bulb temperature: maximum: 46°C (115°F).
  - — Wet-bulb temperature: minimum: 5°C (41°F).
  - — Wet-bulb depression: minimum: 11°C (20°F).
  - — During the test, the difference between the upstream and downstream wet-bulb temperature shall not be more than 1°C (2°F) during the test.

- Standard water quality to be maintained:
  - — Conductivity meter with an accuracy of ±10% of observed reading shall be used to measure water's conductivity; which is being circulated to the water distributer. The conductivity shall be between 350 and 3500 microsiemens (µS). The meter shall be calibrated as per the manufacturer with the help of a certified calibration solution.
  - — Entrainment Verification: The air testing equipment shall be kept safe from water entrainment, to avoid alteration in temperature readings.

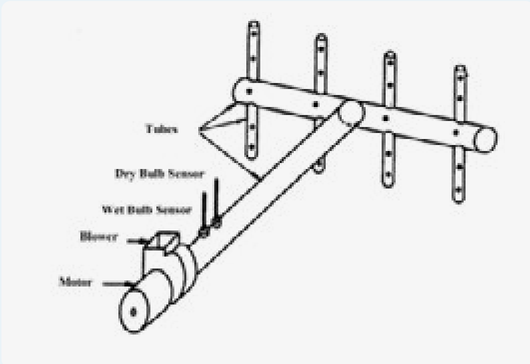


Figure 35: A measurement device for air flow: psychrometer with sample tree[175]

2. Instruments and methods of measurement:

- Air temperature measurements and measuring instruments shall be as per ANSI/ASHRAE Standard 41.1.[176] and shall display accuracy as mentioned below:
  - — Air wet-and dry-bulb temperatures: ±0.2°C (0.40°F).
  - — Other dry-bulb temperatures: ±0.30°C (0.50°F).

- The air temperature instrument shall be a psychrometer with sample tree, as shown in Figure 35, which shall be able to take nine equal samples in a chamber.[177]

- To avoid loss of heat and moisture while testing, the discharge from the instrument/ psychrometer shall be sent back to the chamber.

[172] ANSI/ASHRAE Standard 133-2015, 2015, Method of Testing Direct Evaporative Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.
[173] the point of operation where the airflow rate is zero
[174] the point of operation where the external static pressure is zero.
[175] ANSI/ASHRAE Standard 133-2015, 2015, Method of Testing Direct Evaporative Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta
[176] Standard 41.1-1986 (RA 2001), Standard Method for Temperature Measurement
[177] A chamber is a laboratory set up to stimulate the conditions faced by an evaporative air cooler

- The smallest scale division of the air temperature instrument shall not exceed twice the specified accuracy.
- Calibration of the instrument shall be done by comparing the value according to the National Institute of Standards and Technology (NIST) certified thermometer, if the accuracy closer than ±0.30°C (0.50°F) is measured.
- The wet-bulb temperature shall be measured only when evaporative equilibrium has been achieved and the air velocity is between 3.5 to 10 m/s (700 to 2000 ft/min) over the wet-bulb temperature.
- The pressure measurement shall be as per ASHRAE Standard 41.3.[178] The permitted accuracy is ±1% of the reading and the for the barometric pressure it is ±34 Pa (0.01 in. Hg).
- The static pressure shall be measured with the help of special taps for eliminating velocity.
- Air flow shall be calculated by measuring the pressure differential across the flow nozzles in the chamber and shall be defined as per ASHRAE Standard 41.2.[179] These nozzles are not required to be calibrated if maintained under specified conditions.
- The power shall be measured using a wattmeter with an accuracy of ±1.0% of observed reading, connected to the evaporative air cooler.
- Water flow shall be measure with a water meter of the accuracy of ±5.0% of observed reading along with a timing device to measure the rate of water flow.
- Speed shall be measured with the help of speed measuring devices such as chronometer and stroboscope or any other device with an accuracy of ±0.5% of the value being measured.

3. Instructions for recording data:

- The description of the test, its set-up and test readings shall be described/recorded.
- Data to be tested for inlet dry and wet-bulb temperature, downstream dry and wet-bulb temperature, Fan speed (N), power input to fan (Wf), Power input to pump (Wp), power input to appurtenances (Wa), static pressure differential, nozzle pressure differential and water conductivity.
- The nameplate information and evaporative air coolers dimensions shall be cross-checked with the available drawing.
- The instruments used for the tests shall also be listed. The information of the following shall be included and recorded: names, model numbers, serial numbers, scale ranges, and calibration.
- Name of the person conducting the particular test shall also be listed.

4. Performance corrections to nominal or standard airflow rate and speed:

Following parameters need to be calculated from the test data:

- Standard airflow rate
- Standard static pressure differential
- Fan standard power
- Standard power input
- If the rotation speed varies from one reading to another, then the correction will be required in the value calculated under the test conditions for converting it into a nominal fan speed at standard density.
- Saturation Effectiveness shall be called as the function airflow rate corrected to standard air.

5. Report & test results:

- The final lab test report of an evaporative air cooler shall include details about the object, results, test set-up, instruments for testing and test data, about of the evaporative cooler/ cooling unit and the name of test lab.
- Performance data shall be summarized in a table for both packaged and component evaporative air cooler types.

[178] Standard Methods for Pressure Measurement (2014)

[179] Standard 41.2-1987 (RA 1992), Standard Methods for Laboratory Airflow Measurement

- If the pump is not used for supplying water, then the method of supplying water along with the flow rate of water delivered to the coolers must be included in the final test report.
- All the components installed between the inlet and outlet boundaries of a testing setup shall be included as a part of the cooling unit and the test results shall clearly state these boundaries.
- Performance curves to be used for concluding the test results, with each reading taken/recorded to be plotted on the graph.
- Performance curve to be plotted by using test points/recorded readings. The curves shall not deviate from the test points by more than 0.5% for any test value, and the sum of the deviations shall be zero. If discontinuity occurs, it shall be displayed by broken lines.
- Performance curve for package evaporative air cooler: On x-axis evaporative air cooling flow rate and standard static pressure differential, power input, and saturation effectiveness to be plotted on y-axis. The fan's speed will have a separate graph with its value on Y-axis if all the other values are not nominal.
- Performance curve for component evaporative air cooler: On x-axis, air flow rate and static pressure differential, standard power input, and saturation effectiveness to be plotted as ordinates on y-axis.

Annexure 3

Key highlights from review of the ASHRAE Standard 143-2015: Method of Test for Rating Indirect Evaporative Coolers are mentioned below[180]:

1. **The indirect evaporative air coolers are sub-divided into the following four categories as per their construction style:**

- Component Indirect Evaporative Coolers: As shown in Figure 36, this type is a basic type of an indirect evaporative cooler have integrated heat exchanger. There are no primary and secondary air moving devices.

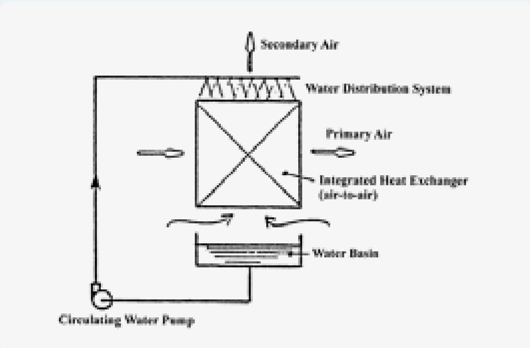


Figure 36: Component IEC[181]

- Semi-packaged Secondary Indirect Evaporative Coolers: This type of IEC includes secondary air moving device but no primary air-moving device as shown below in Figure 37 and Figure 38. There can be two types of semi-packaged indirect evaporative air coolers: the one with integrated heat exchanger and the other one with non-integrated heat exchanger and an evaporative precooler heat exchanger.

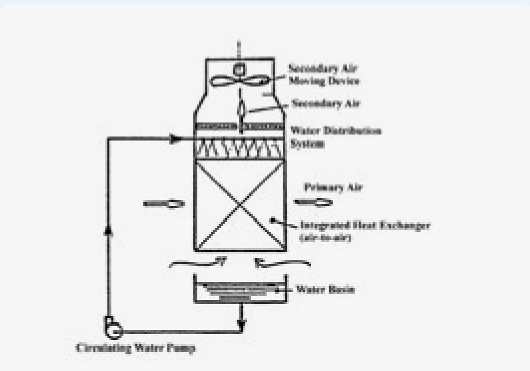


Figure 37: Semi Packaged Secondary IEC with integrated air-to air HE[182]

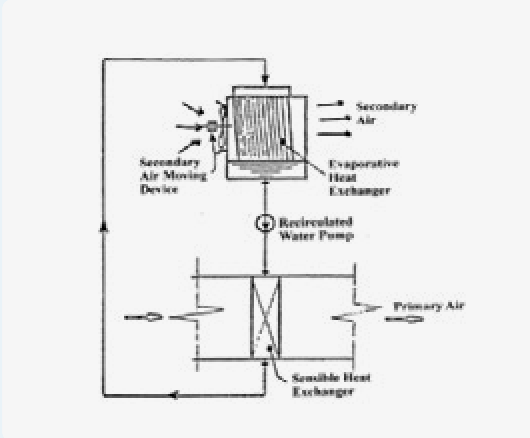


Figure 38: Semipackaged Secondary IEC with nonintegrated sensible and evaporative HE[183]

- Semi-packaged Primary Indirect Evaporative Coolers: This type of IEC includes an integrated heat exchanger with the primary air-moving device as shown below in the Figure 39.

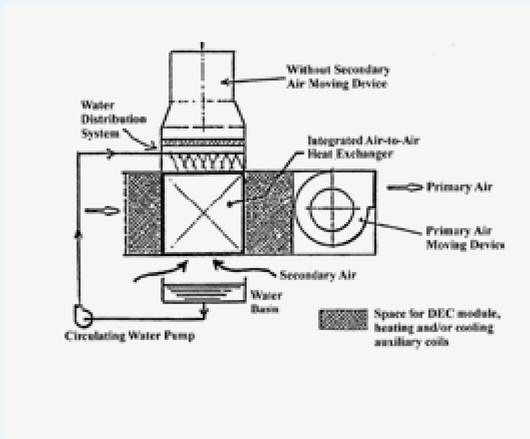


Figure 39: Primary IEC[184]

- Packaged Indirect Evaporative Coolers: This type of IEC includes an integrated heat exchanger with primary and secondary air-moving devices, as shown below in Figure 40.

[180] ANSI/ASHRAE Standard 143-2015, 2015, Method of Test for Rating Indirect Evaporative Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.
[181] Ibid.
[182] Ibid.
[183] Ibid.
[184] Ibid.

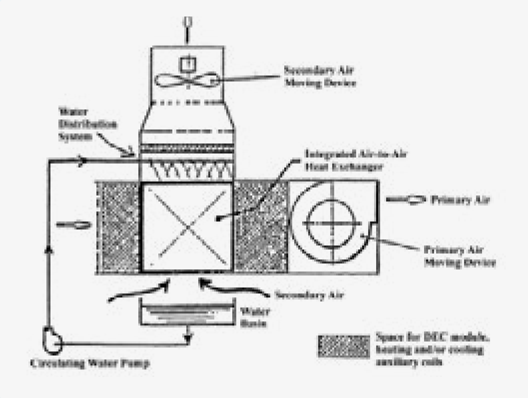


Figure 40: Packaged IEC[185]

2. Requirements:

- Airflow rates shall be measured for both primary and secondary air stream. Only when the following two conditions are met, then the measurement of secondary airflow rate won't be required but may be taken from the previous testing:
  - The appliance is a non-integrated indirect evaporative air cooler.
  - A cooling tower is used as one of the components of an indirect evaporative air cooler and is certified under CTI Code ATC–105.
- The temperature difference between the in-let primary and secondary air shall be at least 20°F (11°C).
- To conclude a complete test result report, a minimum of 5 readings is required to be taken. More than five readings may be required in case of discontinuities.

3. Instruments:

- Temperature measurement and their instruments shall be as per the ASHRAE Standard 41.1.
- The temperature measurement instruments shall show accuracy as per the following:
  - Air wet- and dry-bulb temperatures, ±0.40°F (0.20°C).
  - Other dry-bulb temperatures, ±0.50°F (0.30°C).
- The smallest scale division of the air temperature instrument shall not exceed twice the specified accuracy.
- Calibration of the instrument shall be done by comparing the value according to the National Institute of Standards and Technology (NIST) certified thermometer, if the accuracy closer than ±0.30°C (0.50°F) is measured.
- Wet-bulb temperature shall be measured only when evaporative equilibrium has been achieved and the air velocity is under the range of 700 to 2000 ft/min (3.5 to 10 m/s) over the wet-bulb, and preferably near 1000 ft/min (5 m/s).
- To measure the change in temperature at the supply and exhaust positions, temperature measuring instrument shall be used.
- During testing, psychometric measurement stations shall be located uniformly, downstream of the measurement station.
- Pressure measurement to be done with a liquid-column manometer as per ASHRAE Standard 41.3. The instrument shall permit measurements with ±1% of the reading.
- Airflow rate shall measure as per ASHRAE Standard 41.2 and shall be estimated by measuring the pressure differential across the nozzles. A detailed description for nozzle apparatus, construction and its use with the airflow apparatus, ASHRAE Standard 41.2 shall be followed.
- Calibration of the nozzles is not required if is maintained as per the specified conditions. The throat dimension L=0.6D is recommended for testing airflow of indirect evaporative air cooler and the throat velocity shall not be less than 3000 ft/min (15 m/s) nor greater than 7000 ft/min (35 m/s).
- All power devices shall have the accuracy of ±1% of the observed reading.

4. Apparatus:

Temperature Measuring Apparatus: The temperature measuring instrument shall be a psychrometer with sample tree, which shall be able to measure nine equal areas of the chamber. Both dry and wet-bulb temperature shall be measured from the air-sampling device. To avoid errors in reading, the discharge from the instrument/psychrometer shall be sent back to the chamber. All temperature measurements shall be as per ASHRAE Standard 41.1.3.

[185] ANSI/ASHRAE Standard 143-2015, 2015, Method of Test for Rating Indirect Evaporative Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

- Airflow Measuring Apparatus: For measuring air flow rate the chamber shall consist of a receiving, discharge and nozzles section. The nozzles shall be as per ASHRAE Standard 41.2.
- Pressure Measuring Apparatus: Special taps would be required to measure static pressure, for removing the effect of velocity. The static pressure at the inlet and discharge tap of indirect evaporative air cooler shall be set at zero.

5. Testing Methods:

The indirect evaporative cooling unit shall be installed in the test section as per the manufacturer. More information can be taken directly from ASHRAE Standard 143-2015, 2015.

6. Correct source of water and electricity shall be connected to the cooler. Wattmeter shall be connected to the record power consumption. The evaporative air cooler shall be checked with bubble solution for leaks and then repaired for leaks, before starting the testing.

7. Equilibrium shall be achieved before starting the testing. The airflow rate for both primary and secondary air stream shall be checked. Water distribution system and pump shall function properly. Equipment shall be allowed to run until the wet-bulb temperature stabilizes. Water temperature shall remain constant. Three consecutive readings shall be recorded within three minutes of the same value, to verify steady readings that is an equilibrium condition.

8. For semi-packaged or packaged indirect evaporative air coolers, the primary and secondary airstream at the inlet and outlet of the coolers shall provide zero static.

9. For testing and calculating the overall performance of an indirect evaporative air cooler, simultaneous reading at an interval of 2-mins shall be taken for electrical power consumption, temperature and pressure in order to calculate parameters such as density, thermodynamics, airflow and other parameters would establish the performance of the indirect evaporative air cooler.

- To calculate the overall pressure measurement; barometric reading, primary and secondary airflow, the pressure drop of both primary and secondary air are required to be recorded.
- To record the overall electric power required to operate an indirect evaporative air cooler, the individual power requirement of a pump, electric power input to appurtenances and the electric power input to the fan motor of the primary and secondary air moving devices shall be recorded.

10. Test Reports:

- The final lab test report of an evaporative air cooler shall include details about the object, results, test set-up, appurtenances, instruments for testing and test data. The report shall include information such as type of indirect evaporative air cooler, information on the specific model of coolers as per the manufacturer, test identification number, about the test lab, date of testing and name of the person who conducted the test.
- The test report shall include the data related to barometric pressure, primary and secondary air temperature, primary and secondary air flow rate, electric power input, and primary and secondary air static pressure drop.
- Performance curves of electricity inputs and cooling capacity shall be included. In the case of indirect evaporative air coolers who does not have air-moving devices, their static pressure drop curve shall also be included.
- Each recorded reading shall be shown on the performance curve as a circled point. The curve shall not deviate from the test points by more than 0.5% of any test value, and the sum of the deviations shall be zero. If discontinuity occurs that is if equilibrium can't be achieved for any reading then the curve joining those points shall be displayed by broken lines.
- Ratings for indirect evaporative air cooler is inclusive of the application ratings given/used at the time of selection of the appliance and conditions encountered. These application ratings may be presented in the form of curves, tables, etc.

Annexure 4

Evaporative air cooler's design guidelines for manufacturers:

- **For blower fan:** There are two primary types fans- Axial Flow fans and Centrifugal Fan, which should be allowed to be used as the components of an evaporative air cooler, as per the requirement and setting, as mentioned below in Table 12.

Table 12: Comparison Between Axial and Centrifugal Fans[186]

Parameters	Axial Flow fans	Centrifugal Fan
About	Create high air flow rate at low pressures	Best for high pressure applications. Provides steadier flow as of axial fans. They can handle contaminated air stream.
Type[187]		
Power required	Low power input required	High power input required
Sector suitability	Residential and small office spaces	Industrial

- For sensible heat exchanger: They should be tested for high thermal conductivity. The material type could depend upon the requirements of the heat transfer application. Materials such as copper, titanium, stainless steel heat exchangers, or plastics, should be allowed to be used for making a sensible heat exchanger.

[186] Bureau of Energy Efficiency, 2020. *Ch 5: 5. FANS AND BLOWERS*, New Delhi: Bureau of Energy Efficiency

[187] Ibid.

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