ASIA LOW CARBON BUILDINGS TRANSITION PROJECT

Life Cycle Assessment for Transitioning to a Low-Carbon Economy

2.4 Sustainable Cooling Solutions

November 2024

Supported by:

Federal Ministry for Economic Affairs and Climate Action

INTERNATIONAL CLIMATE INITIATIVE

on the basis of a decision by the German Bundestag

WHAT WILL YOU LEARN?

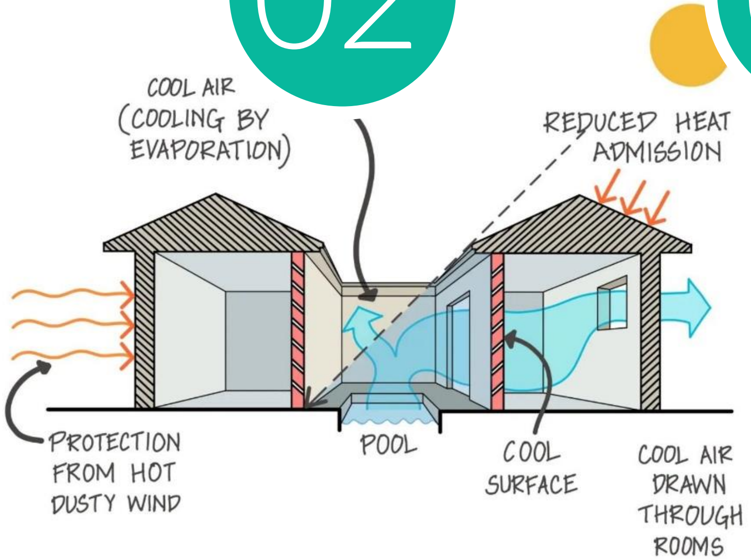
01 — Sustainable Cooling and its Need

02 — Approach

03 — Technologies

04 — Refrigerants

05 — Services, Policies and Financial Solutions



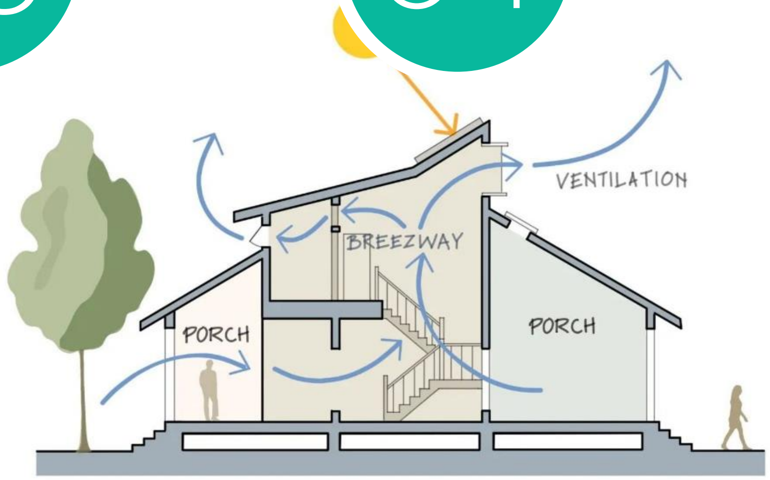


Image source: https://www.arch2o.com/passive-cooling-systems/

Sustainable Cooling

Needs and Relevance

Image source: https://www.ecohome.net/guides/1451/stay-cool-the-old-fashioned-way/

FUNDAMENTAL COOLING NEEDS

Basic applications

- **Comfort and safety:** For human thermal comfort and associated well-being; for productivity and linked incomes; and safety and health in extreme weather conditions
- **Food and nutrition:** For the agriculture sector to have access to cooling for food and nutrition security, rural incomes, and the agriculture cold chain
- **Health and care:** For safe medical clinics and the secure transport and storage of vaccines and medical products

	Thermal comfort		Removing heat and maintaining stable temperatures for industrial and commercial purposes		Maintaining stable temperatures for food and medicine transport and preservation	
Application	**Mobile Air Conditioning**	**Space Cooling**	**Industrial Refrigeration**	**Commercial Refrigeration**	**Transport Refrigeration**	**Domestic Refrigeration**
	Cooling in passenger cars, commercial vehicles, buses, trains, planes etc.	Indirect district cooling and room air conditioning or fans for human comfort and safety in buildings	Used on farms, and in food processing (including marine) and pharmaceutical factories and product distribution centres	Used in supermarkets, restaurants and other retail premises, e.g. display cabinets and cold rooms	Movement of goods over land and sea, preserving their safety and quality, and extending shelf life	Safe storage of food and extension of its shelf life
Technology	Mobile ACs	Heat pumps; Unitary ACs; AC chillers	Industrial refrigeration equipment	Commercial refrigeration equipment	Transport refrigeration units (TRUs) including shipping containers	Domestic refrigerators

Source: Sustainable Energy for All, 2019

SPACE COOLING

Emissions impact

1 Gt CO_2e

Global CO_2 emissions from electricity use for space cooling (2022)[1]

0.72 Gt CO_2e

Global non-CO_2 GHG emissions associated with the leakage of refrigerants used in space cooling (2022)[2]

3.2%

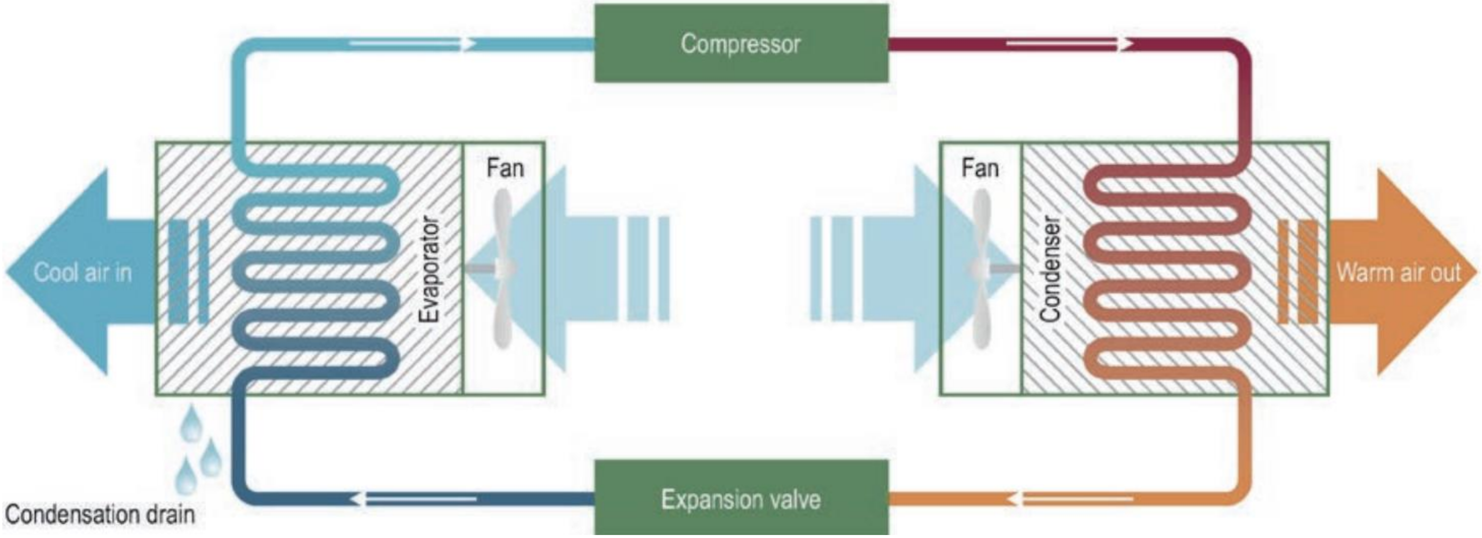
Percentage of total global GHG emissions[2]

Sources:
[1] International Energy Agency
[2] Ritchie, 2024

CONVENTIONAL AIR CONDITIONING

Emissions impact

- Conventional air conditioning is mainly based on **vapor compression refrigeration cycle technology**. This technology exploits a basic law of physics: when a liquid converts to a gas (in a process called phase conversion), it absorbs heat; and when it condenses again (to a liquid), it releases heat
- Air conditioning equipment uses phase conversion by forcing either natural or special chemical compounds, known as refrigerants, to evaporate and condense repeatedly in a closed loop of coils
- **Most refrigerants in use today are synthetic chemical compounds, with significant global warming potential**



Source: International Energy Agency, 2018

CONVENTIONAL AIR CONDITIONING

Major contributor to global warming

- **Air conditioning is energy intensive.** It is largely dependent on grid electricity, predominantly fueled by fossil fuels, indirectly driving greenhouse gas emissions
- **Uses refrigerants with overwhelmingly high global warming potential**, responsible for direct greenhouse gas emissions
- **Contributes to urban heat islands** by rejecting waste heat into the outdoors, thus warming the urban environment

Source: United Nations Environment Programme, 2021a

SUSTAINABLE COOLING

Implication

- **Sustainable or 'clean' cooling** means cooling that uses climate-friendly refrigerants and without other environmental damage including climate impact, in line with the objectives of the Paris Agreement on Climate Change and the Montreal Protocol
- Clean cooling must be accessible and affordable to help deliver societal, economic and health goals

Cooling needs, solution approach and solution pillars

Source: United Nations Environment Programme and International Energy Agency, 2020
Image source: https://www.seforall.org/chilling-prospects-2020/sustainable-cooling-solutions

SUSTAINABLE COOLING

The need

Cooling needs, solution approach and solution pillars

- Heat waves and related droughts have devastated lives and livelihoods across the globe in recent years. Many of the world's most vulnerable people have limited or no access to modern cooling technologies like air conditioners
- Cooling is increasingly being understood as a critical infrastructure service, akin to energy, water and others. Without adequate cooling, achieving global Sustainable Development Goals (SDGs) will be increasingly challenging
- It is urgent to meet people's needs for cooling and heat adaptation while also achieving GHG mitigation and development goals, conserving natural resources and improving the local environment. This requires a rapid transition to sustainable cooling

Source: United Nations Environment Programme and International Energy Agency, 2020
Image source: https://www.seforall.org/chilling-prospects-2020/sustainable-cooling-solutions

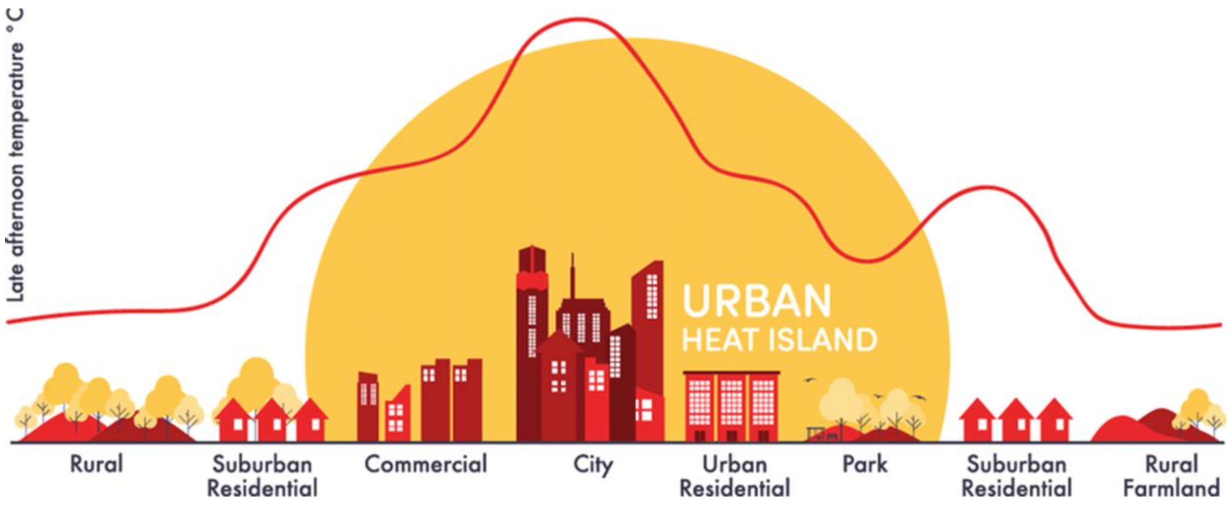
Sustainable Cooling

Approach

URBAN HEAT ISLAND

Heating up cities

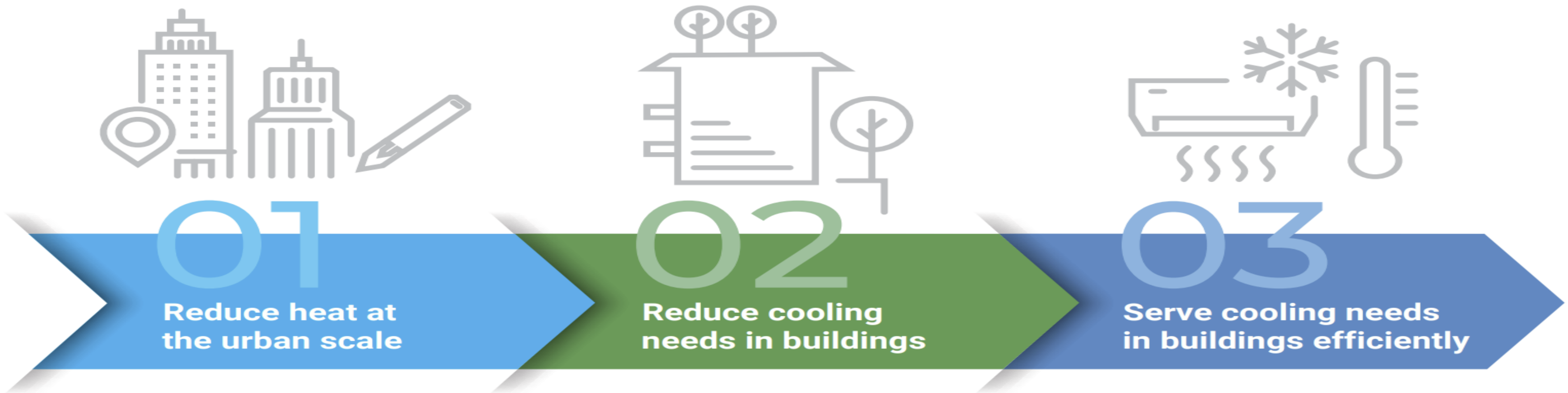
- An urban heat island (UHI) is **a metropolitan area that is significantly warmer than its surroundings**
- Many US cities have air temperatures up to 5.6°C warmer than the surrounding natural land cover
- This temperature difference is usually larger at night than during the day, and larger in winter than in summer, and is most apparent when winds are weak
- The main causes are changes in the land surface by urban development along with waste heat generated by energy use
- With the growth in urban centers, greater areas of land tend to change, which then undergo a corresponding increase in average temperature



Source: University Corporation for Atmospheric Research

SUSTAINABLE COOLING

Holistic approach



Efficient planning and design at the scale of the city or urban district, with an emphasis on heat minimizing urban form and design, nature-based solutions, and cool surfaces designed to reduce the urban heat island effect, in turn also reducing cooling loads in buildings.

Enhancing the thermal performance of buildings and minimizing cooling loads using passive building design practices, with an emphasis on leading-by-example city-owned buildings, and raising the floor with building energy codes and standards.

Efficient and best-fit cooling technologies and operations to deliver the required amount of cooling with the least amount of energy, emissions and anthropogenic heat.

Source: UNEP et al. 2021

Source: United Nations Environment Programme, 2023

SUSTAINABLE COOLING

Holistic approach for urban areas

Urban form and planning

Land use and building design controls adjusted to maximize effectiveness and ensure that the density and form of new development is appropriate for future climate conditions. They include:

- Leveraging cooling benefits of green open spaces and water bodies
- Promoting wind flow
- Reducing waste heat

Nature-based solutions

Integrating vegetation and water bodies in the urban fabric can reduce local and ambient temperature

Cool surfaces

Reflective urban surfaces, such as for buildings and pavements, can make cities cooler

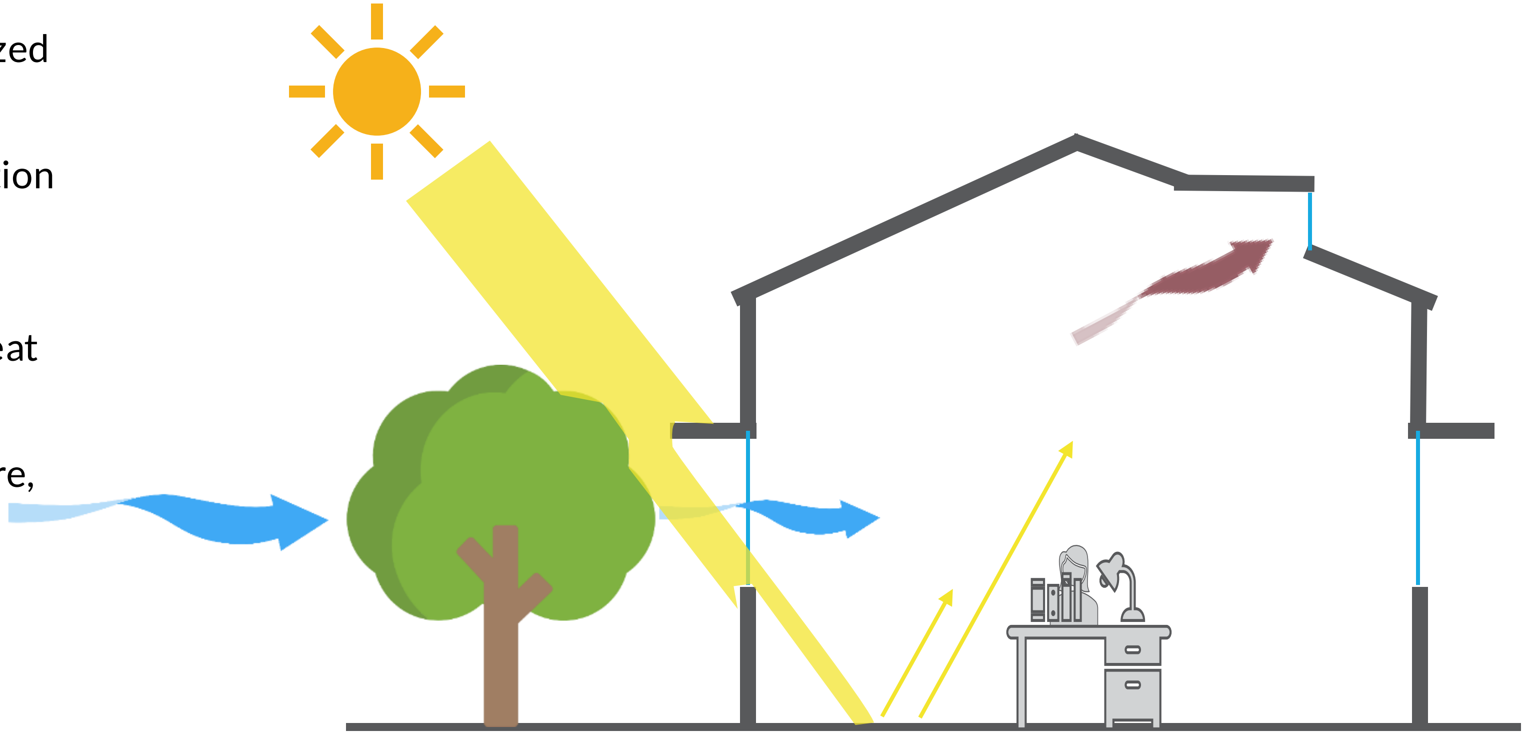
Source: United Nations Environment Programme, 2021a

SUSTAINABLE COOLING

Holistic approach to reduction of cooling demand in buildings

Cooling loads of buildings can be minimized through **passive design strategies:**

- Climate-appropriate building orientation
- Appropriate materials and design features in the building envelope like insulation and shading to minimize heat gain due to thermal transmittance
- Natural ventilation where temperature, humidity and air quality allow
- Thermal mass to stabilize interior temperatures



Source: United Nations Environment Programme, 2021a

SUSTAINABLE COOLING

Serving cooling needs efficiently in buildings

Selecting optimal cooling technology

A wide range of cooling technologies is available for buildings of different scales, climates etc. These can be made sustainable by:

- Improving minimum energy performance standards (MEPS)
- System design improvements to further improve energy efficiency
- Using low-GWP refrigerants

Efficient operations

Optimizing cooling operations by ensuring that cooling is delivered only where and when it is needed, and system performance is monitored and maintained, can be achieved by:

- Use of controls and sensors
- Load shifting
- User adaptations and behavior changes
- Good operations and maintenance and servicing practices
- Capacity building of service sector

Source: United Nations Environment Programme, 2021a

Sustainable Cooling

Technologies

Image source: https://fridgesworld.co.uk/blogs/news/sustainable-cooling-solutions-chillpro-s-commitment-to-eco-friendly-refrigeration-and-display-

SPACE COOLING

Generic technologies

Refrigerant-based cooling	Non-refrigerant-based cooling	Not-in-kind cooling
• Residential buildings: Room air conditioner (RAC) • Commercial buildings: Room air conditioner (RAC), chiller system, packaged direct expansion (DX) and variable refrigerant flow (VRF) system	• Fans and air coolers • Significantly pervasive in the residential sector • These do not provide the full utility that refrigerant-based vapor-compression cooling provides across all climatic conditions today	• Non–vapor compression cooling technologies, most of which use no or low-GWP refrigerants

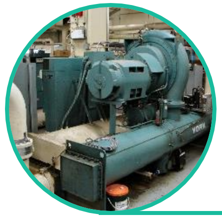
Sources: Ministry of Environment, Forest and Climate Change, Government of India, 2019; Khosla et al., 2022

REFRIGERANT-BASED COOLING

Overview

Room Air Conditioner

Non-ducted unitary systems, including mini or single split (fixed-speed and inverter types) and window/through-the-wall (fixed-speed type) configurations



Chiller System

Chiller systems (central chilled-water air conditioning systems) are the preferred choice for large commercial buildings. Other than the chiller itself, which is the largest energy-consuming component, the system comprises various auxiliaries, including chilled water pumps, condenser water pumps, cooling tower fans, air handling units and fan coil units

Variable Refrigerant Flow (VRF) System

Typically used in medium-size commercial buildings and high-income group residential units that have varying exposure and cooling loads. The outdoor units are connected to multiple types and numbers of indoor units, such as wall mounted, ceiling mounted cassette, ducted and DX AHUs

Packaged DX

Ducted and packaged systems, including rooftop and indoor packaged units in commercial air conditioning segment (also known as unitary and light commercial systems), typically cater to small-to-medium commercial buildings to avoid the complexities associated with chiller systems

Source: Ministry of Environment, Forest and Climate Change, Government of India, 2019

REFRIGERANT-BASED COOLING

Efficiency improvements

Multi-stage and Variable-speed Drives/Controls

- Modulating motor speed on compressors, the air conditioning system can more closely match the part-load cooling demand and improve seasonal efficiency by reducing losses when the system's full capacity is not required
- Variable-speed controls operate fan motors at their most efficient setting to meet the airflow needs of the system

Advanced Compressors

- Air conditioning compressor efficiency and performance has steadily improved
- Larger systems use multiple compressors to stage capacity and improve part-load performance
- Magnetic and oil-free compressor technologies can deliver significant energy savings

Improved Heat Exchangers

- Manufacturers have increased the size of heat exchangers (metal tube-and-fin) to improve system efficiency
- Advanced heat exchanger designs, such as microchannel heat exchangers and other small diameter designs, have further improved system efficiency, and reduced refrigerant charge, fan energy consumption and physical size

Electronic Expansion Valves

- Thermostatic expansion valves (TXV) improve upon earlier static capillary tube and fixed orifice expansion devices by modulating refrigerant flow based on refrigerant superheat temperature at the evaporator exit
- Newer electronic expansion valves (EEV) provide increased modulation capabilities to match more closely the needs of variable-capacity air conditioning systems

Source: Ministry of Environment, Forest and Climate Change, Government of India, 2019

REFRIGERANT-BASED COOLING

Efficiency improvements (continued)

High Efficiency Fans

- Many systems have incorporated more aerodynamic component designs (e.g., fan blades, condensing unit housing), high efficiency motors and variable-speed controls
- Manufacturers have applied these innovations to axial and centrifugal fans for both heat exchange and distribution of conditioned air throughout buildings

High Efficiency Motors

- Improved motor designs have a significant impact on overall air conditioning system efficiency
- Electrically commutated motors (ECM) have higher efficiencies than permanent split capacitor (PSC) motors for air conditioning fans and operate at a wider range of conditions using electronic controls

Advanced Controls

- Different occupancy sensing strategies can automatically alter thermostat setpoints when building occupants are away to reduce energy consumption
- Economizer controls enable air conditioning systems to use cooling energy from ventilation air or chilled-water cooling

Source: Ministry of Environment, Forest and Climate Change, Government of India, 2019

ACCEPTABLE REFRIGERANTS

As per the Montreal Protocol

For new medium-temperature retail standalone units

- R-448A
- R-449A
- R-449B

For new residential and light commercial air conditioning and heat pumps

- R-32
- R-452B
- R-454A
- R-454B
- R-454C
- R-457A

Source: CAREL Industries

NON-REFRIGERANT BASED COOLING

Overview

Fan

Includes ceiling, pedestal, table and wall-mounted fans. They are widely used in the tropics, in the residential and small to mid-commercial segment. Despite a rise in the penetration of room air conditioner in households, a significant portion of the population will still not be able to afford air conditioning in the next two decades and will continue to rely on natural ventilation and fan-assisted ventilation for thermal comfort

Air Cooler and Evaporative Cooler

These require a climate that is hot and dry. Water is evaporated on cooling pads and ventilated into the building by fans. Evaporating water absorbs a significant amount of heat, cooling the air in the same way that perspiration enables humans and animals to cool themselves. It is an important cooling appliance for users, especially across households and medium-size commercial buildings in hot and dry and composite climates

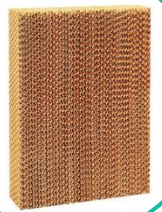
Sources: Ministry of Environment, Forest and Climate Change, Government of India, 2019; International Energy Agency, 2018

NON-REFRIGERANT BASED COOLING

Advancements

BLDC Fan

Typically, ceiling fans contain single phase induction motors, consume 70–80W and deliver air at 230–250 m^3/minute. Fans with brushless DC (BLDC) motors combined with better blade design have led to more efficient fans, which consume 30–35W and deliver air at 220–230 m^3/minute



Cooling Pad in Air Cooler

The patterns used on cooling pads have a significant bearing on the water absorption and evaporation process. Aspen (wood wool) pads are 75% efficient and honeycomb are roughly 85% efficient. The cooling pad area is also important – steel body coolers have a larger cooling pad area compared to fiber body ones, and are more efficient

Source: Ministry of Environment, Forest and Climate Change, Government of India, 2019

NOT-IN-KIND TECHNOLOGIES

Overview

- Not-in-kind cooling technologies are non–vapor compression cooling technologies, most of them use no or low-GWP refrigerants
- Most of these technologies are still in low technological readiness levels
- More research is required to improve the performance of technologies of low to moderate maturity
- Supportive deployment-oriented policies are necessary to increase the installation of cooling technologies with moderate or high technical maturity, e.g., evaporative cooling, absorption cooling, etc.

NOT-IN-KIND COOLING TECHNOLOGIES

Solid-state

- Magnetocaloric
- Elastocaloric / thermoelastic
- Electrocaloric
- Thermoelectric
- Thermionic
- Thermotunneling

Electro-mechanical

- Bernoulli heat pump
- Brayton cycle
- Pulse tube
- Thermoacoustic
- Vortex tube
- Critical flow cycle
- Evaporative cooling
- Membrane heat pump

Thermally-driven

- Liquid desiccant
- Solid desiccant
- Absorption
- Adsorption
- Duplex-Stirling
- Vuilleumier heat pump
- Ejector cooling

Source: Khosla et al., 2022

NOT-IN-KIND TECHNOLOGIES

Evaporative cooling

Evaporative cooling operates on thermal energy and water is used as a refrigerant. Water is evaporated in non-saturated air to produce a drop in dry bulb temperature and an associated rise in moisture content. It only works efficiently when the air to be cooled is relatively dry. There can be considerable water consumption

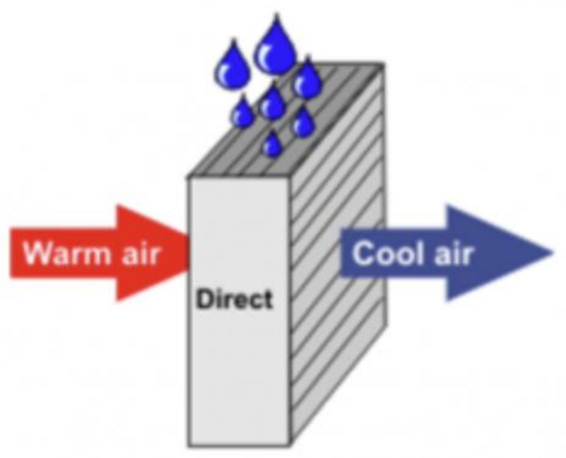
Direct evaporative cooling	The ventilation supply air is passed directly through a water spray before entering the space to be cooled
Indirect evaporative cooling	The ventilation supply air is passed through an evaporative heat exchanger, to be indirectly cooled. Unlike direct evaporative cooling, cooling of the supply air takes place without it absorbing extra moisture. However, the cooling efficiency is reduced
Indirect-direct evaporative cooling	Here, direct cooling follows indirect cooling. The intention is to maximize cooling potential while minimizing the increase in moisture absorption of the supply air

Source: International Energy Agency, 2000

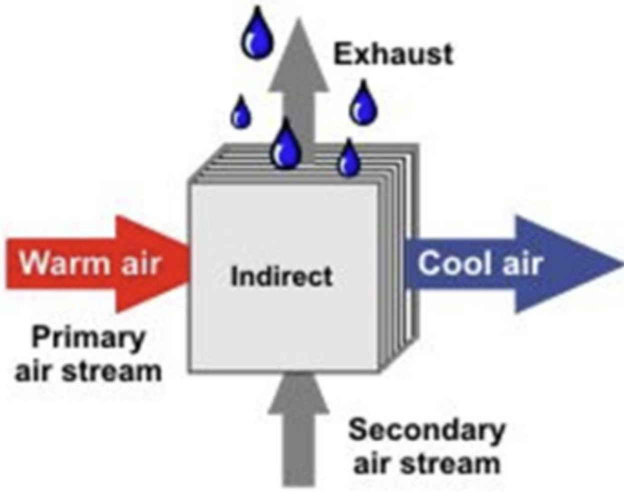
NOT-IN-KIND TECHNOLOGIES

Evaporative cooling

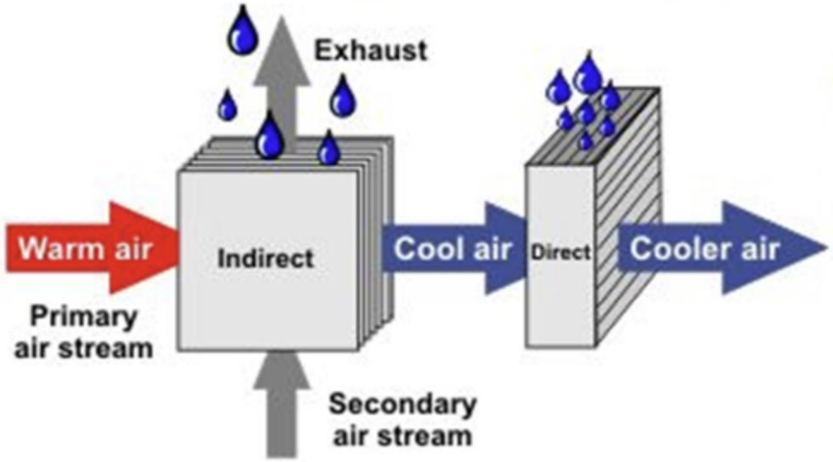
Direct evaporative cooling



Indirect evaporative cooling



Indirect-direct evaporative cooling



Source: Fairconditioning

NOT-IN-KIND TECHNOLOGIES

Evaporative cooling: Major applications

- Comfort cooling of commercial and institutional buildings
- Data center cooling
- Environmental control for processed food industry
- Provision of treated fresh air required in pharma and healthcare industry
- Animal house ventilation
- Industrial buildings, shop floors, warehouses etc.

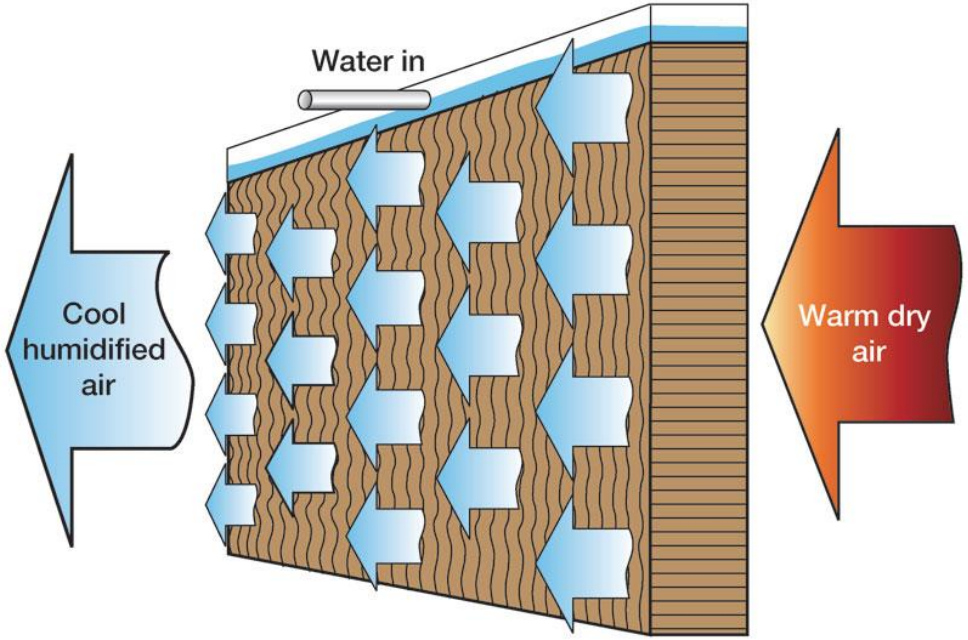


Image source: https://www.condairgroup.com/Energy-optimization/cool-humidification-evaporative-cooling-humidifier

NOT-IN-KIND TECHNOLOGIES

Case example: Evaporative cooling

Central University of Rajasthan, India

- Indirect-direct evaporative cooling system is used
- Indoor temperatures were between 31°C and 34°C when the ambient was approximately 44°C
- Energy consumption in the hostel building was reduced to one-third of a similar building with no major energy conservation measures and using conventional air conditioning systems
- The Energy Performance Index was 60–65 kWh/m^2/year (2012)

Source: United States Agency for International Development, 2014

NOT-IN-KIND TECHNOLOGIES

Case examples: Evaporative cooling

Industrial building, Jaipur, India

School (Classrooms), Jaipur, India

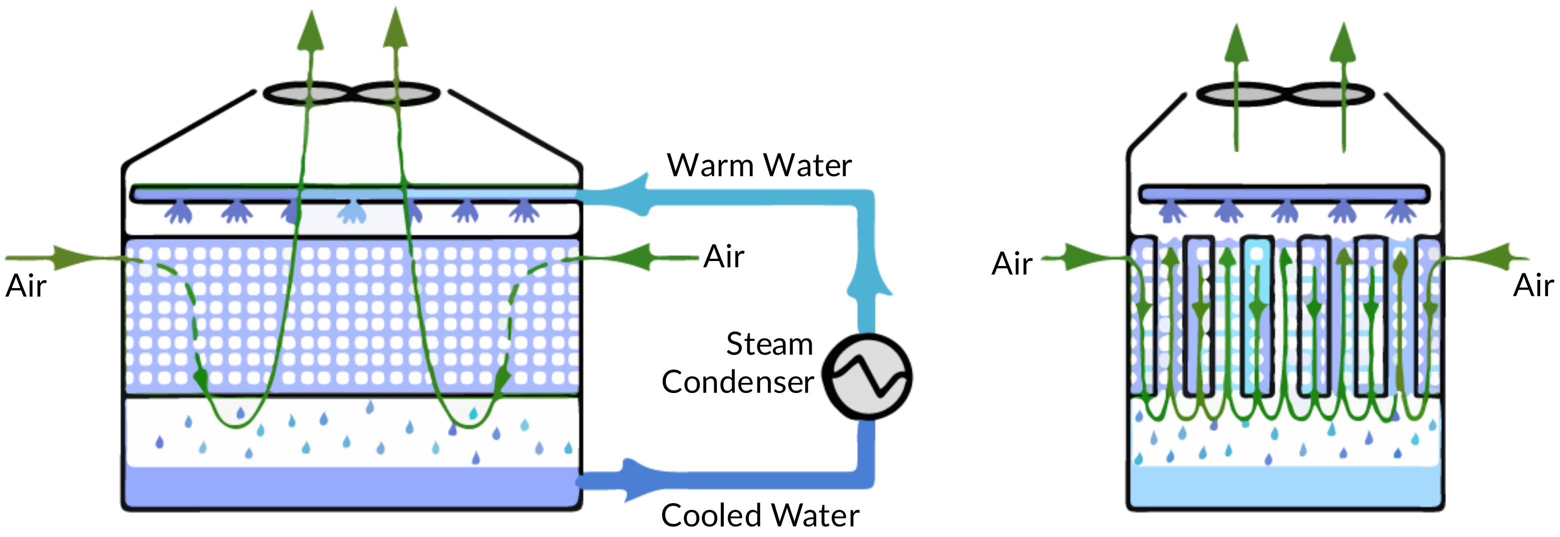
Hostel, Lucknow, India

Source: Evapoler

NOT-IN-KIND TECHNOLOGIES

Dew-point evaporative technology

- Evaporative cooling in its most common forms can cool air up to the ambient wet bulb temperatures
- Dew-point evaporative cooling, using a novel heat exchanger and flow path arrangement, has been seen to deliver un-humidified air below wet bulb temperatures consuming less water than direct evaporative cooling



Advanced dew-point cooling tower concept

Source: Glanville, 2011

Image source: https://www.researchgate.net/figure/Advanced-Dew-Point-Cooling-Tower-Concept_fig1_269692837

NOT-IN-KIND TECHNOLOGIES

Structure cooling

- In a structure cooling system, the heat accumulated in the building structure is removed by water flowing through pipes embedded in the building structure, mostly the slabs
- Structure cooling uses water supplied at 20°C–27°C to the piping network embedded in the building slabs to remove the heat
- The objective is to prevent the build-up of heat in the building thermal mass during harsh summers in tropical climates, keeping it at temperatures lower than the body temperature of the occupants. The skin will lose heat to the cooler surroundings by radiation
- Cooling tower, storage water or geothermal sink may be used as the cold-water source

Image source: https://www.attainablehome.com/what-is-radiant-floor-cooling-does-it-work/

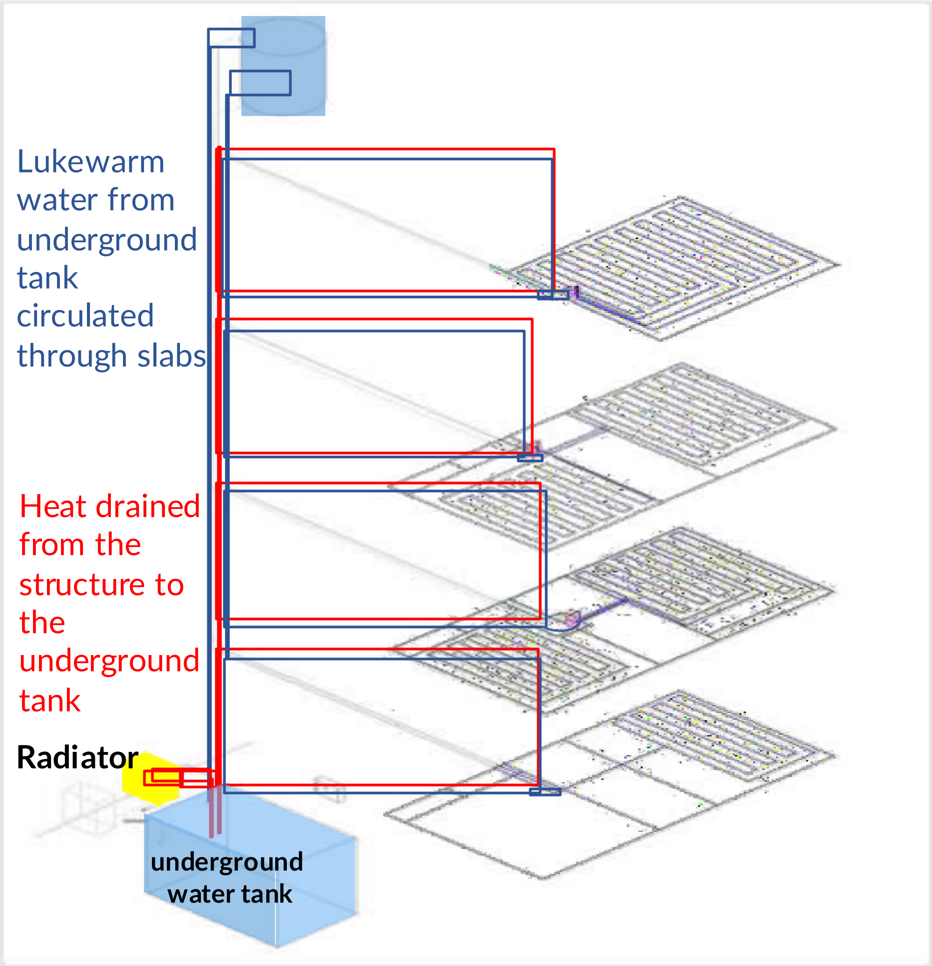
Sources: Yehuda, 2019; Solar Impulse Foundation

NOT-IN-KIND TECHNOLOGIES

Case example: Structure cooling

Greenspace Realtors' Office, Nashik, India

- The system laid 21mm diameter plastic pipes in a grid on the slabs of all floors
- The system is designed to remove 763 W/m^2 of heat from the slabs
- The water absorbs the heat from the roof and flows through a radiator, where most of the heat is released
- Lukewarm water is stored in the tank and recycled through the radiator at night, when the cool night air absorbs the residual heat. The cycle starts again the next morning
- Energy for the pump and the fan is supplied by a solar PV system



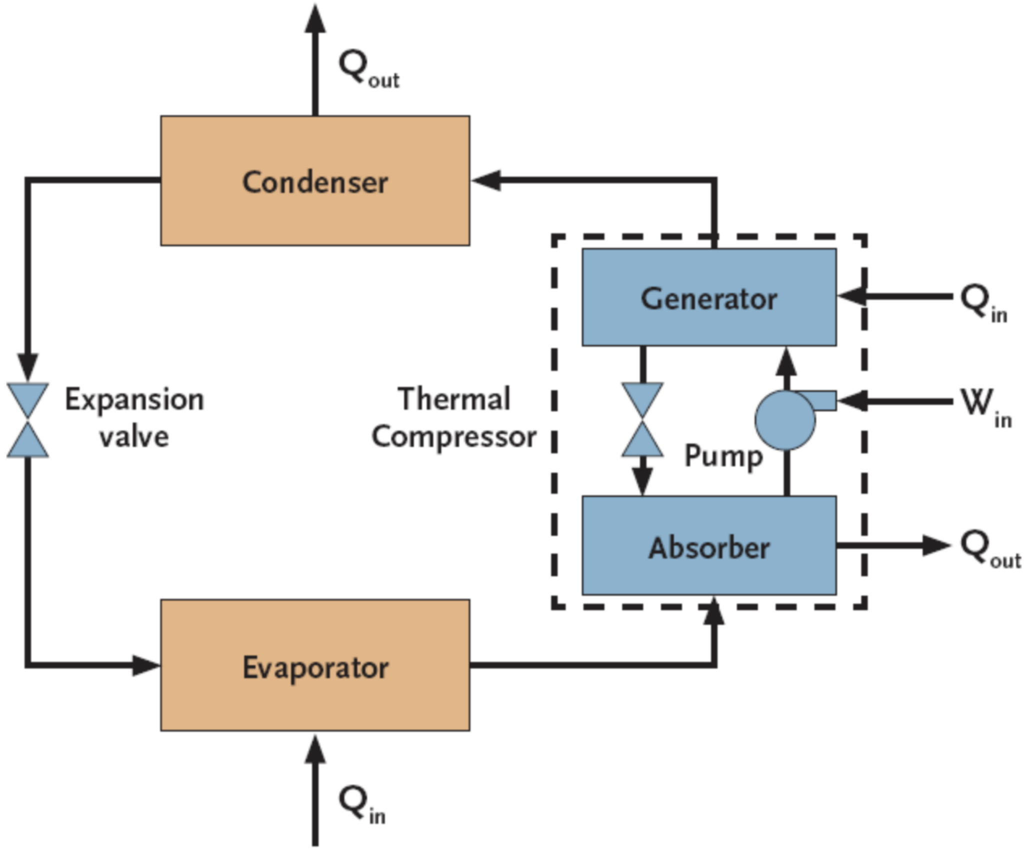
Structure cooling system installed in a office building at Nashik

Source: Yehuda, 2019

NOT-IN-KIND TECHNOLOGIES

Vapor absorption system

- Vapor absorption system produces chilled water for cooling using a heat source rather than electrical input as in the more familiar vapor compression cycle
- The vapor absorption cycle is similar to the vapor compression cycle in that it uses a circulating refrigerant, an evaporator, a condenser and an expansion device
- The difference is that the compressor of the vapor compression cycle is replaced by a chemical absorption process and generator, with a pump to provide the circulation and pressure change



Basic absorption cycle

Sources: Welch, T. 2009; Bhatia, A.

NOT-IN-KIND TECHNOLOGIES

Comparison between vapor absorption system and vapor compression system

Vapor Compression	Vapor Absorption
• Uses a compressor to create the pressure rise between evaporator and condenser, which requires energy in the form of electrical energy • Generally, uses refrigerants, like HFCs, with high environmental impact, ozone depletion or global warming potential • Coefficient of performance (COP) of conventional compression chiller is sensitive to load variations and does not reduce significantly at part loads • Has higher COP, but operating costs are higher • Can be noisy and requires more maintenance	• Uses heat to operate the cycle. This opens up options for its application and use, including solar energy and waste heat • Absorption cycle uses a liquid pump to create the pressure rise between evaporator and condenser • Uses different refrigerants that have no associated environment hazard, ozone depletion or global warming potential, e.g. lithium bromide absorption system uses distilled water as the refrigerant • COP of absorption chiller is not sensitive to load variations and does not reduce significantly at part loads • Has lower COP, but operating costs can be substantially reduced because they are powered by low-grade waste heat • Contains very few moving parts, has less noise and vibration, is compact for large capacities, and requires minimal maintenance

Source: Bhatia, A.

NOT-IN-KIND TECHNOLOGIES

Case example: Vapor absorption cooling

Solar Energy Centre, Gurgaon, India

- Example of solar thermal cogeneration
- 100kW cooling capacity standalone system is integrated with a triple-effect vapor absorption chiller (VAC) and solar parabolic concentrators. The VAC can use steam, hot water, gas, kerosene or oil to run continuously
- The integrated system is estimated to be 20% more efficient than VACs with no solar component. COP is 1.7, which is highest among the vapor absorption technology coupled with eco-friendly energy resource

Source: United States Agency for International Development, 2014

NOT-IN-KIND TECHNOLOGIES

Case example: Vapor absorption cooling

GAIL Jubilee Tower, Noida, India

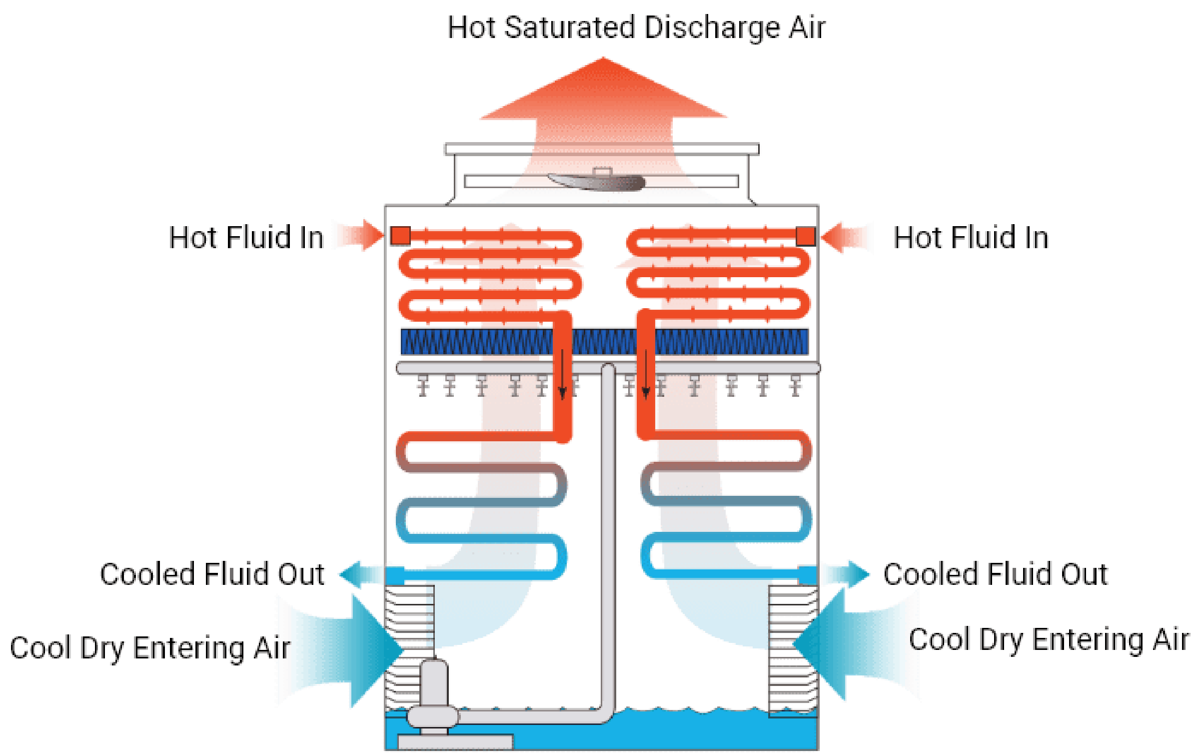
- Example of cogeneration facility to generate power and cooling
- **440 TR (220 TR X 2) of vapor absorption cooling**
- Heat source is hot water from waste heat of 1.6 MW (800 kW X 2 cumulative capacity) engines exhaust, with optional direct gas firing, if required

Source: Net Zero Energy Buildings

HYBRID SYSTEMS

Integrating not-in-kind technologies with vapor compression systems and other technologies

- The not-in-kind options can be integrated with conventional vapor compression systems to derive benefits of multiple technologies
- Heat/energy recovery technologies such as energy recovery ventilators (residential) or heat pipes, run-around coils or enthalpy wheels (commercial), when included in a cooling system, can help recover energy that would otherwise be wasted

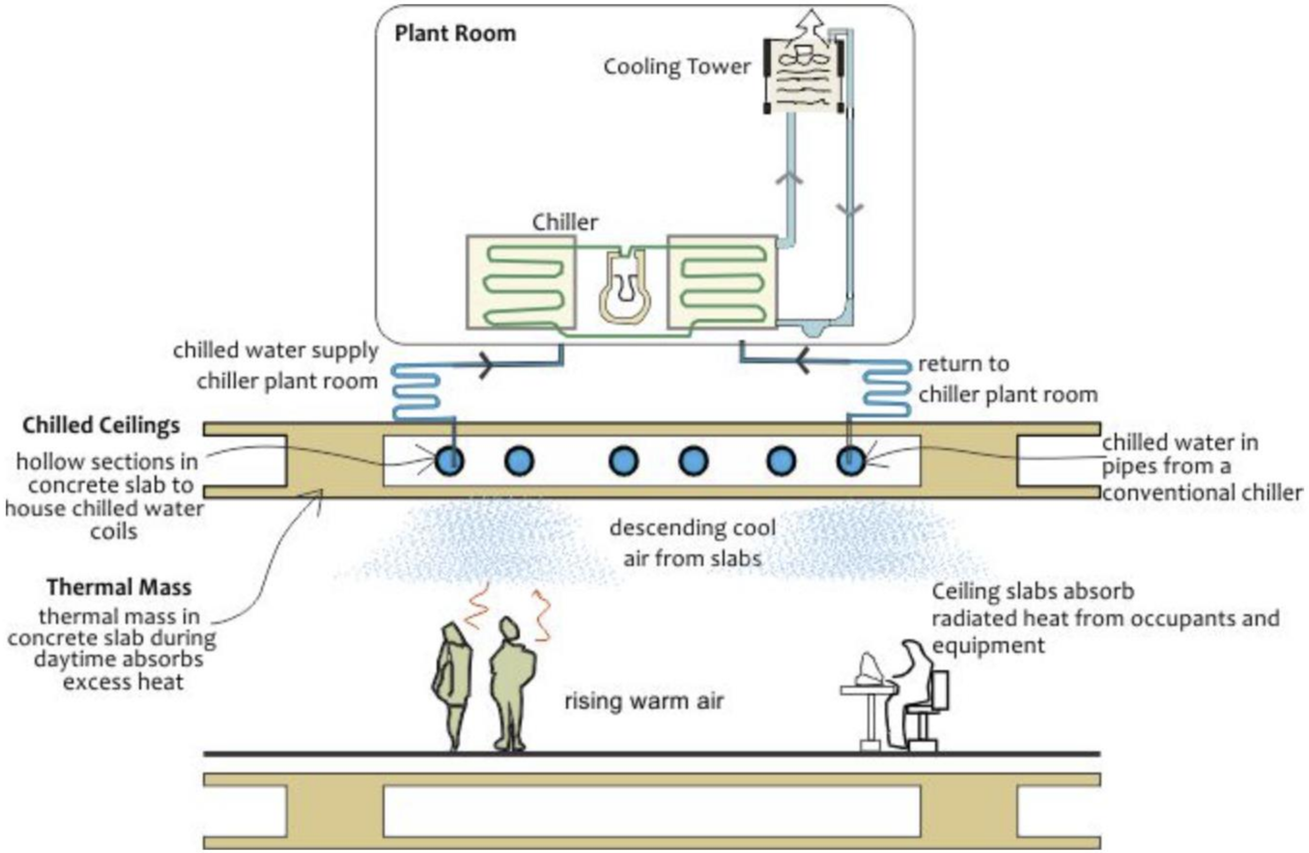


Source: Ministry of Environment, Forest and Climate Change, Government of India, 2019
Image source: https://www.flycoolingtower.com/products/hybrid-wet-dry-cooling-tower/index.html

HYBRID SYSTEMS

Radiant cooling

- Heat transfer to the space being cooled in conventional chiller-based air conditioning happens through convection. In a radiant cooling system, heat transfer happens through radiation
- Radiant cooling systems consist of coils, which carry chilled water generated either through conventional electric chiller (vapor compression) systems or low-energy chilled water generation systems like absorption chillers or desiccant chillers. Chilled water in the coils cools down the slabs or panels, which in turn act as heat sinks for sensible heat loads of internal spaces
- Condensation in humid conditions is a risk in these systems. An ancillary dedicated outdoor air system (DOAS) is required to avoid condensation



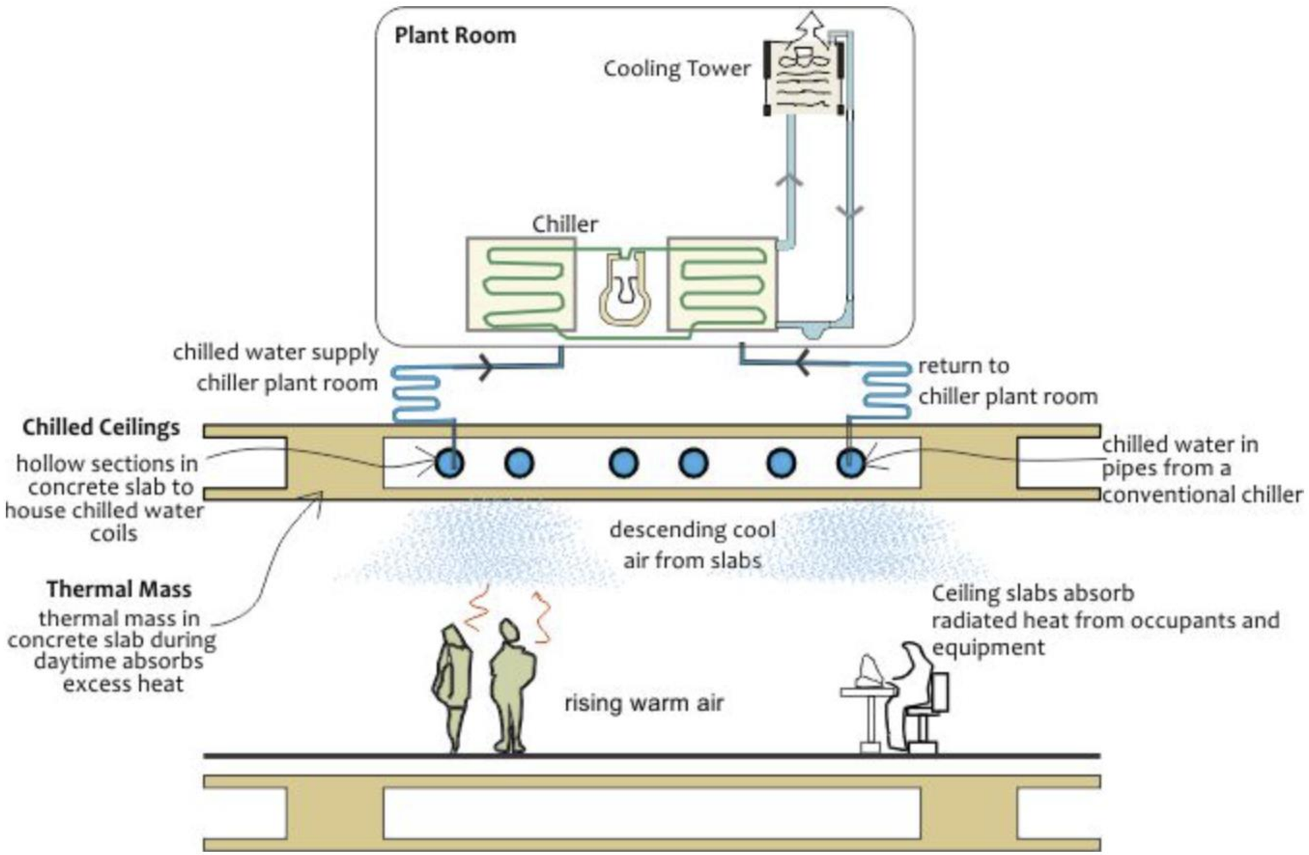
Source: United States Agency for International Development, 2014

Image source: https://pillarplus.com/radiant-cooling-system/

HYBRID SYSTEMS

Radiant cooling: Types

- **Chilled slabs:** Deliver cooling through the building structure, usually slab. Generally, cheaper than panel systems and offer the advantage of the thermal mass
- **Ceiling panels:** Deliver cooling through specialized panels. Offer faster temperature control and flexibility



Source: United States Agency for International Development. 2014

Image source: https://nzeb.in/knowledge-centre/hvac-2/radiant-cooling-systems/

HYBRID SYSTEMS

Case example: Radiant cooling

Infosys Software Development Building (SDB-1), Hyderabad, India

- The two symmetric halves of the buildings are cooled with different technologies. Conventional cooling system in one half, radiant cooling system in the other
- The radiant system is designed for a cooling output of 75 W/m^2
- Chilled water design temperatures for supply are 14°C and for return, 17°C
- Cooling tower approach temperature is 2°C
- Low-pressure piping and ducting distribution system is installed
- A DOAS with energy recovery system is installed to provide dehumidified air to offices

Cooling energy use for conventional system (2011–2012)
38.7 kWh/m^2

Cooling energy use for radiant system (2011–2012)
25.7 kWh/m^2

33% improvement in energy efficiency with radiant cooling system

Source: Net Zero Energy Buildings

HYBRID COOLING

Case example: Conventional air conditioning, fresh air dehumidification and evaporative cooling

Centre Point School, Nagpur, India

- Cooling mode switches between conventional chillers and evaporative cooling system, depending on the ambient temperature and humidity
- During operation of the conventional chillers, the treated fresh air (TFA) unit ensures adequate moisture removal from fresh air, permitting operation of the air conditioning at higher temperature setting
- During cool and dry ambient weather, chillers can be switched off, and chilled water is substituted by 'cold' cooling water from the cooling tower, thus, almost achieving 'free cooling', with minimal cooling tower fan power

Source: Centre Point School, Nagpur, India

HYBRID COOLING

Case example: Conventional air conditioning, fresh air dehumidification and evaporative cooling (continued)

Centre Point School, Nagpur, India

- Indirect adiabatic two-stage evaporative cooling, in addition to free cooling by direct use of outside cold air during favorable outdoor air temperatures to provide partial space cooling requirements
- During night, the strategy is to have the cool night air pass over the exposed interior surfaces to keep the surfaces cool at night
- All classrooms have three-speed fan coil units (with water coils) with controls for room temperature and humidity
- High efficiency, variable speed BLDC fans are used for room air circulation, for enhancement of thermal comfort, while operating chillers at higher chilled water temperatures

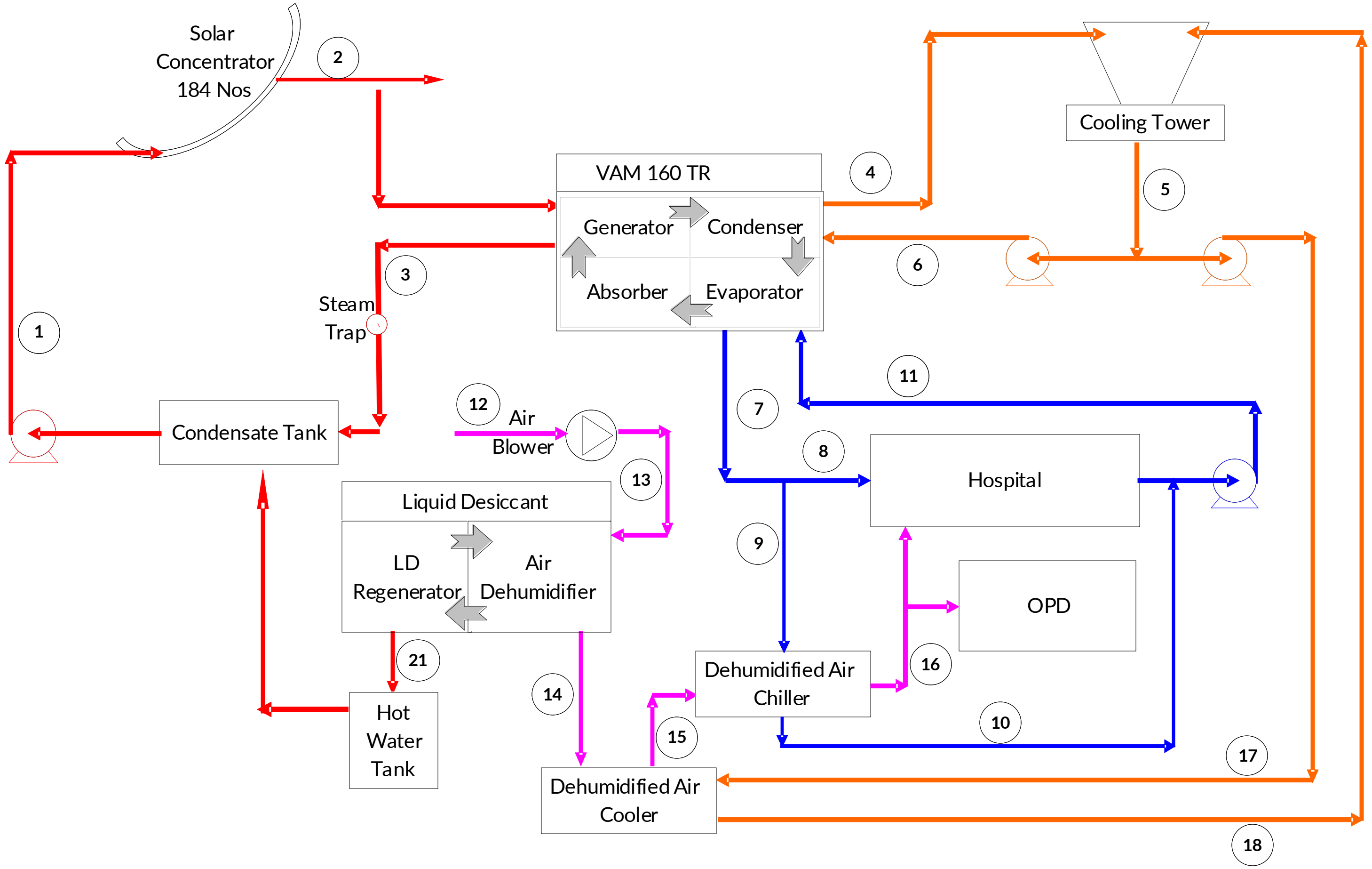
Source: Centre Point School, Nagpur, India

HYBRID COOLING

Case example: Vapor absorption cooling and liquid desiccant dehumidification

Chhatrapati Shivaji Maharaj Hospital, Thane, India

- The waiting area of the Out-Patients Department (OPD) has very high occupancy and is open from the sides
- A liquid desiccant dehumidification system (LDDS), along with a cooling tower, provides 'once-through' 100% fresh air at 26°C, at a dew point of 15°C, for adaptive cooling of the OPD waiting area, with chilled water generated by VAM



Source: Chhatrapati Shivaji Maharaj Hospital, Thane, India

HYBRID COOLING

Case example: Vapor absorption cooling and liquid desiccant dehumidification (continued)

Chhatrapati Shivaji Maharaj Hospital, Thane, India

- Scheffler solar thermal concentrators have been installed to provide steam and hot water for regeneration of liquid desiccant and heat source for the absorption chiller
- The solar-heated absorption chiller has a cooling capacity of 160 TR, which provides cooling to other areas of the hospital
- This system has substituted electrical chillers and LDO-fired boilers

Liquid desiccant dehumidification system

Scheffler solar thermal concentrators

Source: Chhatrapati Shivaji Maharaj Hospital, Thane, India

NOT-IN-KIND TECHNOLOGIES

Case example: Tri-generation with vapor absorption cooling system

Pushpanjali Crosslay Hospital, Ghaziabad, India

- Tri-generation systems are combined heat and power (CHP) systems integrated with a thermally-driven refrigeration system to provide cooling, as well as generate electrical power and heating
- The tri-generation system provides 1,000 TR cooling for air conditioning
- The system components to provide heating and cooling include a gas genset (1.7 MW), 600 TR capacity vapor absorption machines (VAM) with heat recovery, and electrical chillers of 400 TR capacity

Source: Net Zero Energy Buildings

ALTERNATIVE COOLING STRATEGIES

Thermal energy storage and tri-generation

Thermal energy storage

Thermal energy storage is a method of demand-side load management and must be integrated with cooling technologies. It can significantly reduce energy costs by allowing cooling equipment to be predominantly operated during off-peak hours (favorable electricity tariff periods). Ice banks, cryogenic liquids, phase change materials (PCMs) may be used as the storage medium

Tri-generation

Tri-generation can be used where there is a simultaneous demand for heat and power and uninterrupted availability of fuel. Advantages include: (i) onsite generation of electricity, heat and power; (ii) maximum total fuel efficiency; (iii) reduced fuel and energy costs; (iv) lower electrical demand during peak time; (v) elimination of HCFC/CFC refrigerants; and (vi) emissions reduction

Most vapor absorption cooling applications include tri-generation (heat, cooling and power) or co-generation (heat and power) systems

Source: Ministry of Environment, Forest and Climate Change, Government of India, 2019

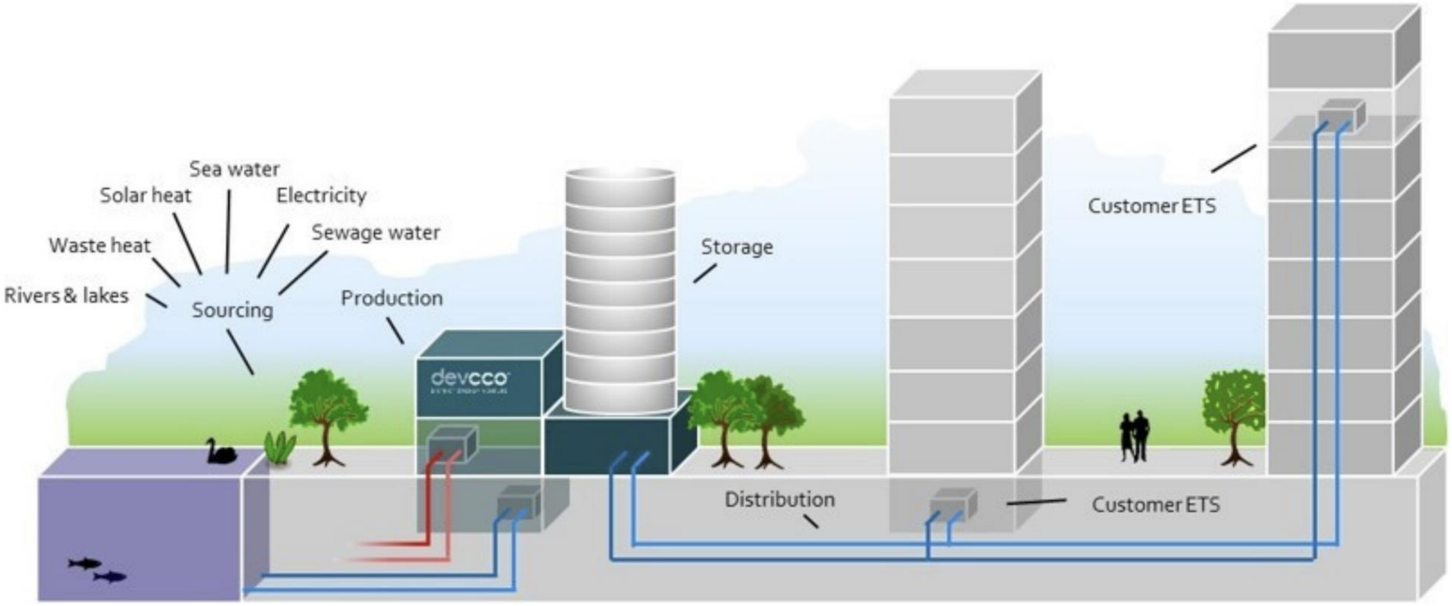
ALTERNATIVE COOLING STRATEGIES

District cooling

- District cooling systems provide cooling to an entire community from a network of centralized cooling devices. They supply chilled water produced in a central plant to buildings and industrial sites through a network of insulated pipes

Advantages

- Buildings do not require their own air conditioning systems, saving space and reducing the need to have surplus cooling capacity for peak loads
- Lower costs due to economies of scale, especially if it makes use of a low-cost source of energy, such as industrial waste, excess heat or geothermal energy



General scheme of a district cooling system

Sources: International Energy Agency, 2018; Calderoni et al., 2019

ALTERNATIVE COOLING STRATEGIES

District cooling

- The chilled water is typically produced using the same technology i.e., vapor compression system but generally at a much larger scale
- In some locations, the water may be chilled in part or in full using heat exchange with natural sources, such as groundwater, rivers and the sea, if environmental conditions and costs permit. Waste heat from industries, geothermal or even solar thermal sources, can also be used with absorption chillers
- District cooling systems often incorporate storage in the form of cold water, slurry or ice, to reserve cooling energy during low load periods to:
  - Reduce the need for extra capacity during peak loads
  - Minimize the partial load operation and maximize operation near full load to improve energy efficiency
  - Allow for flexibility to produce more cooling than required when electricity prices are low

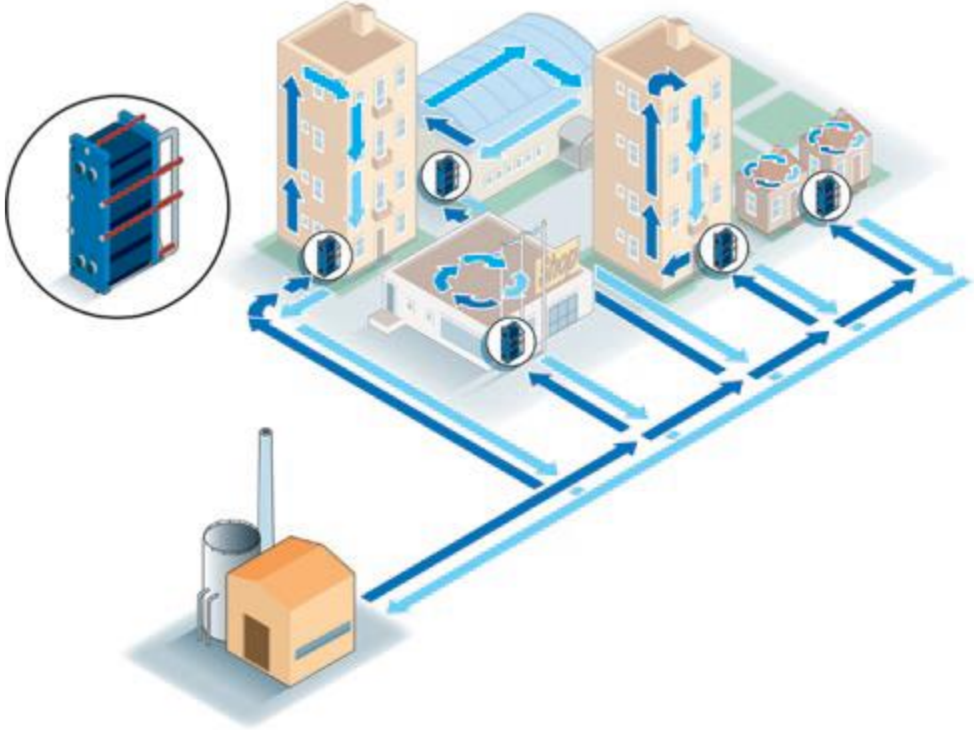


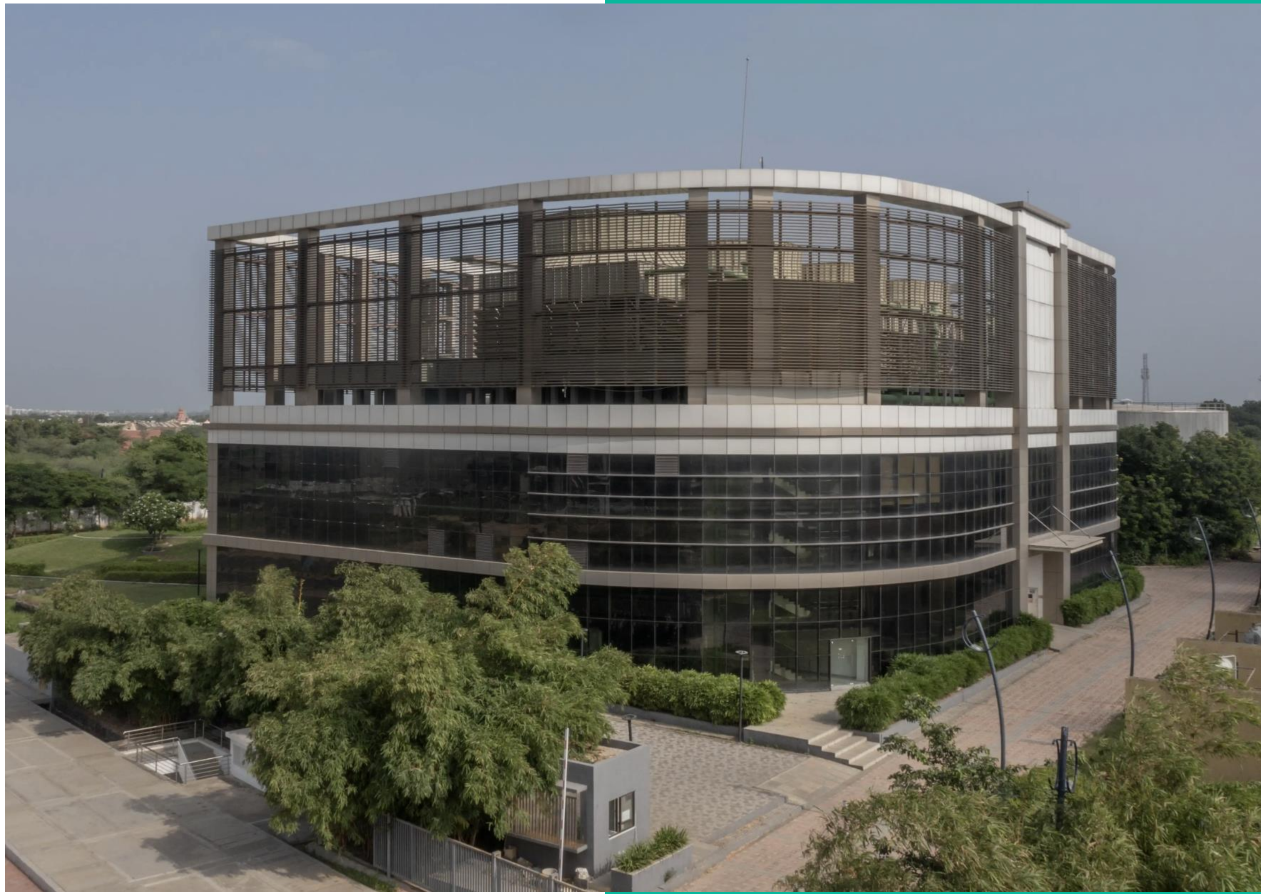
Image source: https://www.alfalaval.my/industries/hvac/district-cooling/what-is-district-cooling-system/

ALTERNATIVE COOLING STRATEGIES

Case example: District cooling

GIFT City, Gandhinagar, India

- Consists of office buildings, residential apartments, schools, a hospital, hotels, retail stores and recreational facilities
- When fully built, it will reduce the requirement for installed cooling capacity from 270,000 TR to 180,000 TR. It is expected to reduce the cooling power demand of the city, as compared to business as usual, by 105 MW of electricity
- The system will use low GWP refrigerant for cooling generation and include stratified thermal energy storage tanks that are used to meet the cooling loads during peak demand periods, reducing total power demand of the system



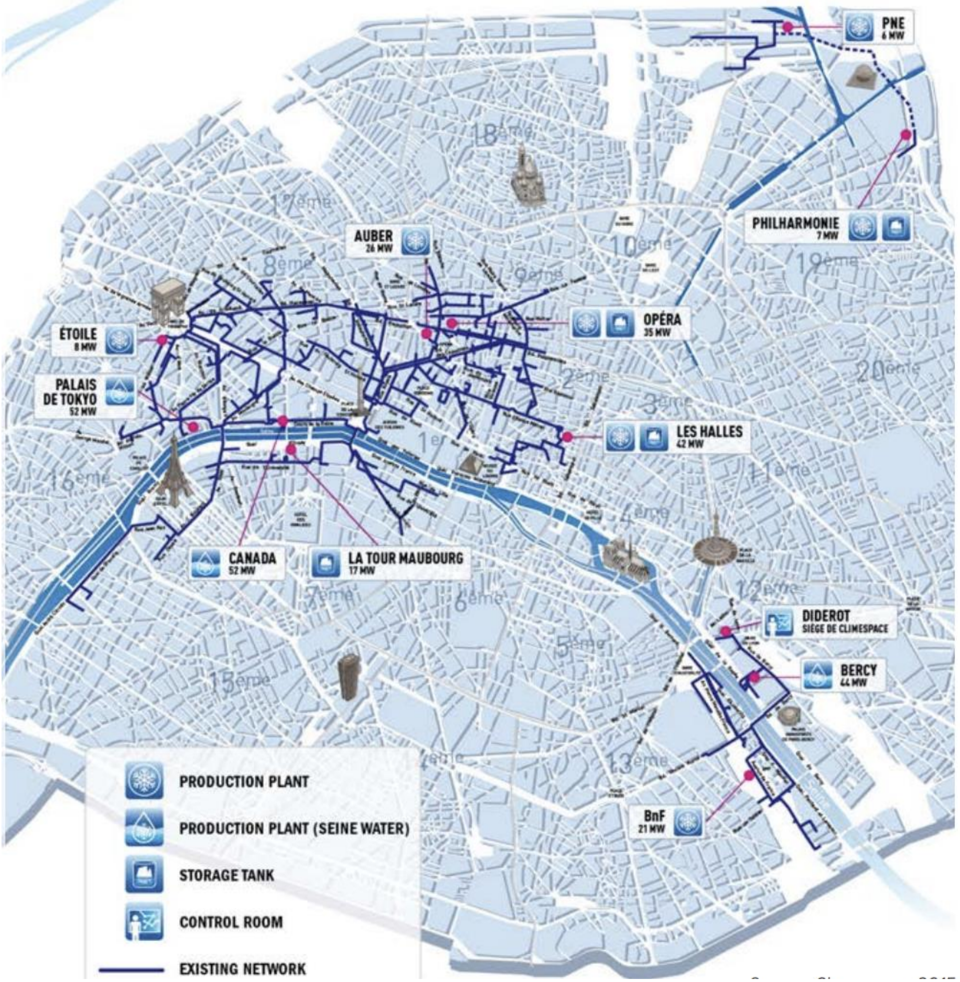
Sources: United Nations Environment Programme, 2021a; GIFT City

ALTERNATIVE COOLING STRATEGIES

Case example: District cooling

Paris, France

- It is the largest district cooling network in Europe, serving offices, banks, stores, hotels, museums and other buildings
- Leverages the Seine River as an available heat sink in 3 of its 10 production sites. When the water temperature is below 8°C, water from the Seine is distributed directly through these sites as free cooling
- During the night, when the demand for cooling is lower, it takes advantage of off-peak electricity and stores thermal energy as either chilled water or ice, which is then used during the hours of peak demand during the day. This storage has the potential to decrease peak power for cooling by 15%–50%
- Nearly 60% of the chilled water distribution system is routed through the city's sewage network



Sources: United Nations Environment Programme, 2017 and 2021a

District cooling network in Paris

Sustainable Cooling

Refrigerants

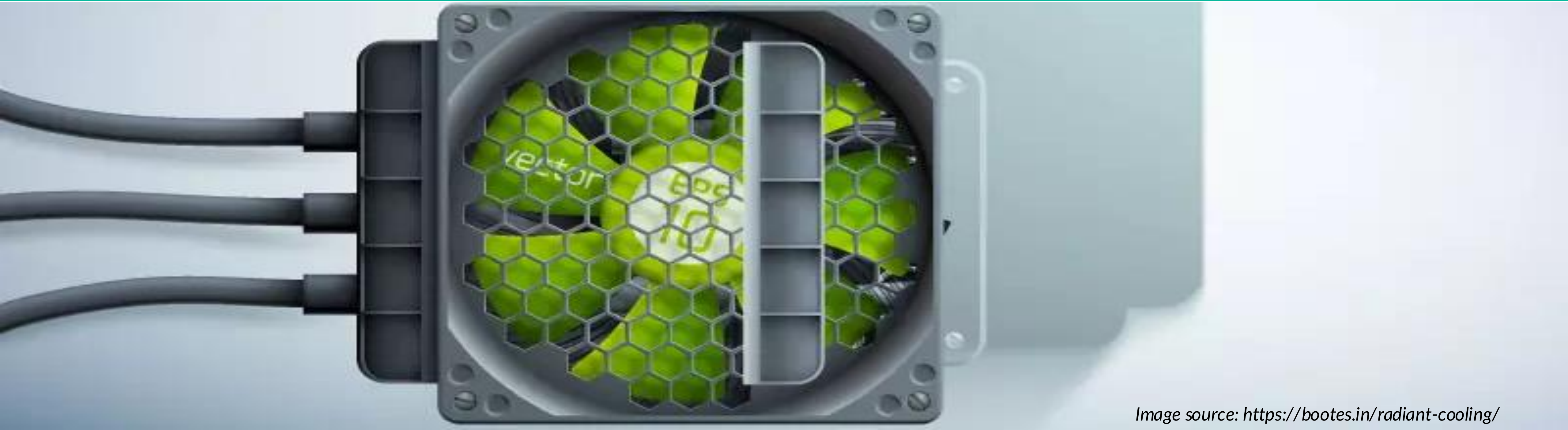


Image source: https://bootes.in/radiant-cooling/

REFRIGERANTS

The story so far .....

Early refrigeration technology	Refrigerants were flammable or toxic, confining their use mainly to industrial systems
Refrigerants for space cooling	Safer refrigerants, based on chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), were developed
Montreal Protocol 1987	This protocol mandated the phase out of CFCs and HCFCs due to their high ozone depletion potential (ODP). They were mainly replaced by hydrofluorocarbon (HFC)-based refrigerants with short-lived gases that have no ODP
Kigali Amendment to Montreal Protocol 2016	The GWP of HFCs is still high, ranging between 1,340 GWP_{100} for R134a and 3,940 GWP_{100} for R404a. The Kigali Amendment to the Montreal Protocol was initiated to phase down these high-GWP HFCs

Source: Khosla et al., 2022

REFRIGERANTS

Alternatives

Low-ODP and low-GWP refrigerants will need to balance the trade-offs between energy efficiency, safety, cost, availability, and environmental considerations of new refrigerants. Examples of alternative refrigerants are:

Hydrofluoroolefins (HFOs)	Natural refrigerants
• HFOs have GWP_{100} values of less than 1 • But they typically still need to be mixed, e.g., with HFCs, to obtain a non-flammable blend or for direct substitution in existing equipment, which results in higher GWP	• Use of natural refrigerants, such as ammonia and hydrocarbons, are commonplace in industrial systems where large equipment sizes are common, and flammability and toxicity can be more readily managed • Their use in residential space cooling is debatable due to smaller sizes, life cycle emissions and need for increased safety measures

Source: Khosla et al., 2022

ALTERNATIVE REFRIGERANTS

Current space cooling applications

Vapor absorption systems	• Refrigerants used are ammonia (0 GWP_{100}) and water • Used for comfort cooling in commercial and industrial buildings and process cooling
HC 290 air conditioners	• Hydrocarbon-based cooling system • Refrigerant used is HC 290 (5 GWP_{100}), which is flammable • Available for residential and commercial air conditioning
Solar-assisted cooling	• Solar-assisted vapor absorption cooling • Refrigerants used are ammonia (0 GWP_{100}) and water • Applicable for cluster air conditioning

Source: iForest, 2021

ALTERNATIVE REFRIGERANTS

Challenges in adoption

Lack of awareness

Decision-making on residential air conditioner purchase are not based on the refrigerant gas. In the absence of substantive awareness efforts on natural refrigerants, HFC-based air conditioners continue to be the mainstream choice

High cost

Natural refrigerant systems are found to have a high initial cost, due to small manufacturing capacity for these technologies and scarcity of expertise both in terms of technical experts and servicing technicians

Difficulty with retrofitting

Large number of existing equipment like chillers, VRF and packaged DX may not be suitable for retrofitting with natural refrigerant-based systems

Safety and lack of standards

Concerns around safety of natural and low-GWP refrigerants remain. Standards for system design and refrigerants become imperative for safety

Source: iForest, 2021

Sustainable Cooling

Services, Policies and Financial Solutions

SUSTAINABLE COOLING

Services solutions

Preparational services	Operational services
• Activities that support the preparation (e.g., theory and practical skills) to create or deploy more sustainable cooling solutions • Includes fundamental education, skills development and project services	• Activities to deliver and use more sustainable cooling • Includes direct operation of cooling services, the management that supports cooling services, and the maintenance that ensures the cooling services and technologies are operating sustainably

Source: Sustainable Energy for All, 2020

SUSTAINABLE COOLING

Policy solutions

Regulatory policies	Information policies	Incentive policies
Legally binding or 'stick' measures: • Building energy codes • Planning and zoning codes • Minimum energy performance standards (MEPS) • Disclosures through labels and certificates • Audits and evaluations • Utility obligations • Public procurement requirements • Import and export controls	Awareness generation measures: • Disclosures through public databases • Certification of education, product or service • Labels for branding, endorsement and comparison • Voluntary standards • Awareness through information and behavior campaigns	Motivational or 'carrot' measures: • Non-financial incentives such as expedited approval and expanded scope allowance • Policies to deliver financial solutions

Source: Sustainable Energy for All, 2020

SUSTAINABLE COOLING

Financial support

Finance solutions	Fiscal solutions	Funding solutions
• Loans • Risk sharing • Energy performance contracts or service agreements • Bulk purchases • Leasing • On-bill or on-tax repayment • Equity • Bonds • Sustainable or energy investment funds • Crowdsourcing	• Energy pricing and subsidies • Energy or carbon tax on unsustainable systems • Tax credits on more sustainable solutions • Import and export duties (reduced for sustainable solutions)	• Grants: Direct financial contribution • Rebates: Direct financial contribution as a result of purchasing a product or service • Subsidy: Direct financial contribution to reduce cost of product or service

Source: Sustainable Energy for All, 2020

Thank you!

For more information, visit us at https://ALCBT.GGGI.ORG
or scan the QR code below

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