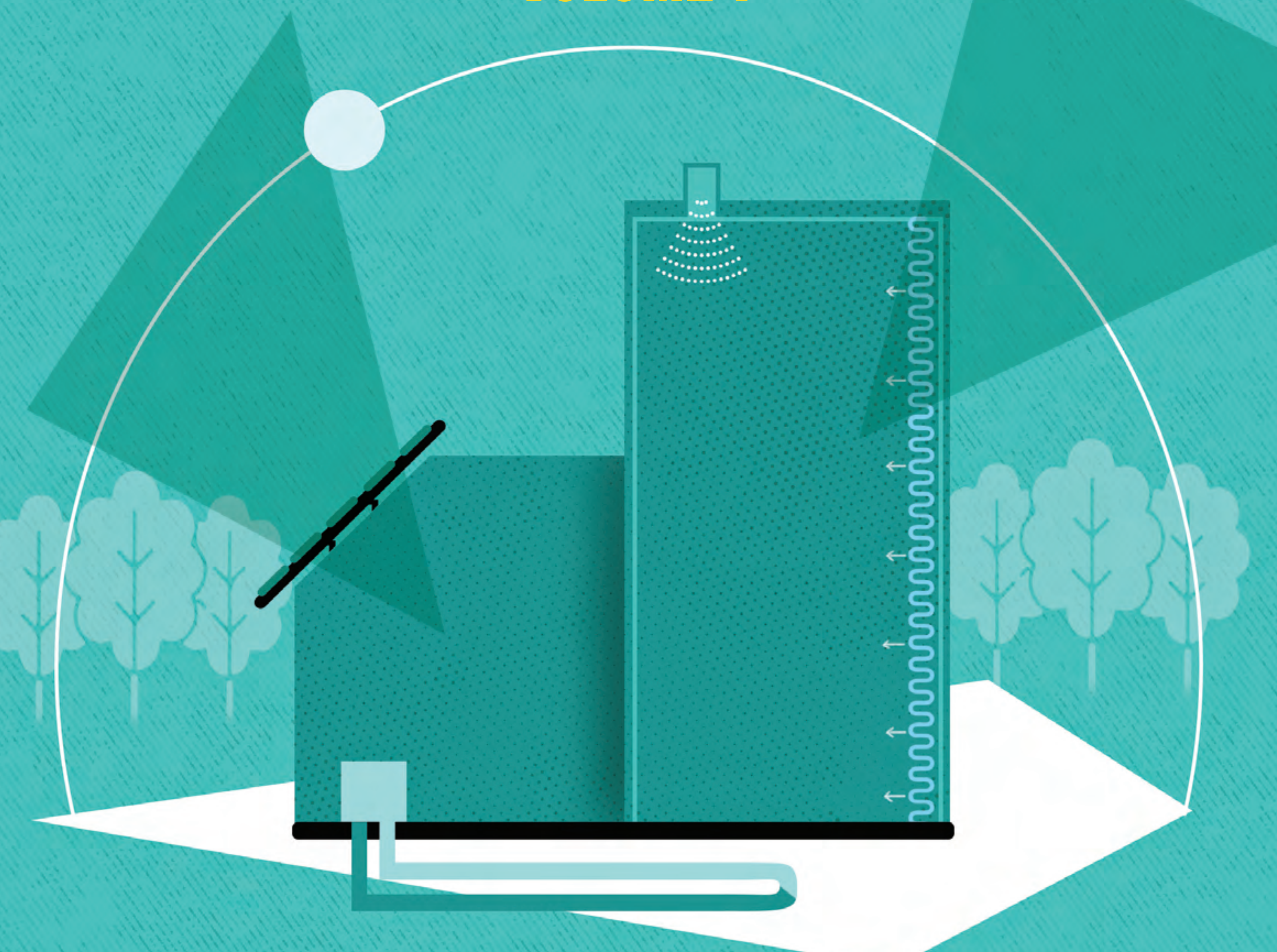
THE COOLING WEB

Calibrating cooling-energy requirements in buildings

VOLUME 1



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VOLUME 1

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Contents

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Introduction

Background

The building and construction sector is not only a massive consumer of energy, it also contributes significantly to carbon emissions. According to an estimate made by the *Global ABC Roadmap for Buildings and Construction 2020–2050*, in 2018 the construction and demolition sector accounted for 39 per cent of energy-related CO_2 emissions globally.[1] A major share of this consumption and emission is due to space cooling. NITI Aayog estimates that 65 per cent of the energy demand in India comes from space cooling and heating. However, heating constitutes a small part of the energy demand due to a very small geographical area falling under the cold climate zone. A warming environment, increasingly frequent episodes of heat waves and growing access to space cooling are set to bring about a surge in the energy consumption in the country.

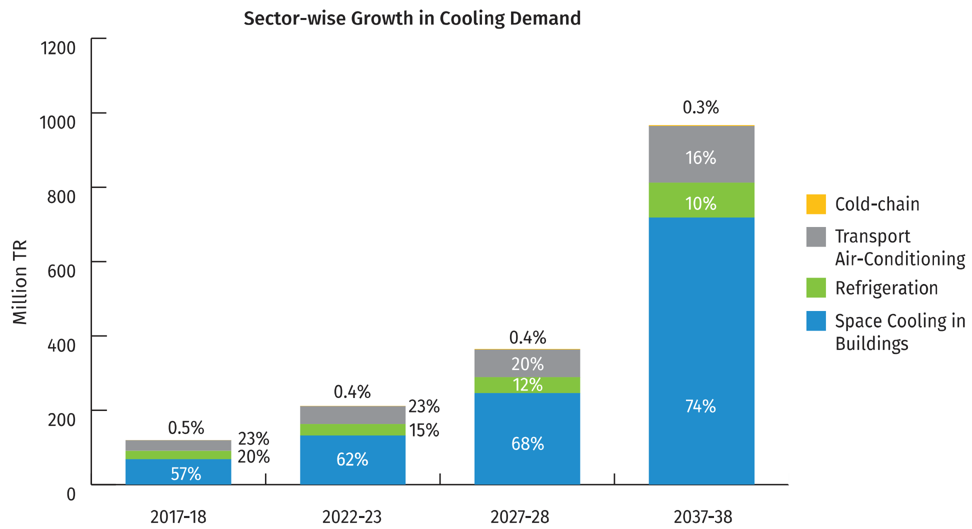
The *India Cooling Action Plan* estimated that the national per capita space cooling energy consumption in India was merely 69 kWh per person in 2018. India's non-reliance on active space cooling has, until now, ensured that this value remains much lower than the global average of 272 kWh per person. However, being a tropical country, this will rapidly change and immediate attention is required to address this from an environmental perspective.

The 2015 NITI Aayog report, *Energy Efficiency and Energy Mix in the Indian Energy System (2030)* has estimated that the prevalence of space cooling is going to increase from one AC per 100 persons in 2015, to 15 ACs per 100 persons by 2047. The Ministry of Environment, Forest and Climate Change (MoFCC) also recognizes this surge and estimates the cooling demand in buildings to grow 11-fold by 2037–38 when compared to the 2017–18 baseline.[2]

There are several reasons that can be attributed to this rise in the demand for cooling:

- India's per capita income is set to rise. According to Bloomberg Intelligence, India's per capita income is expected to rise to around 5,700 USD[3] in 2030 from the 2021[4] figure of around 2,256 USD. The increase in people's spending power will, in turn, trigger a rise in the demand for space cooling.
- Moreover, temperatures during summer have been on the rise across the country. According to estimates, summer temperatures might exceed 50 degrees by 2030.[5] This is further expected to push the demand for air conditioning.

Graph 1: Cooling demand in buildings will rise from less than 100 TR in 2017-18 to close to 800TR by 2037–38



Source: India Cooling Action Plan

- All these factors coincide with India's phenomenal rate of urbanization. According to the Bureau of Energy Efficiency (BEE), India adds close to 28,000 square metres of commercial floor space every day.[6] It has been estimated that a significant volume of buildings that will exist two decades from now has not yet been built. This puts India amongst the top countries that will witness an unprecedented boom in the construction of both residential and commercial spaces.

The *India Cooling Action Plan (ICAP), 2019* recognized these issues and placed the need for measures towards sustainable cooling. It also set targets for reducing the cooling demand across sectors by 20–25 per cent, cooling energy requirements by 25–40 per cent and refrigerant demand by 25–30 per cent by the year 2037–38. The plan suggests a combination of appropriate building envelopes, adoption of energy conservation building codes, adoption of thermal comfort practices and improvements in cooling equipment efficiency to achieve these targets and the larger goal of providing 'thermal comfort for all'.

The Centre for Science and Environment (CSE) has been mainstreaming thermal comfort in the built environment and ensuring the implementation of the ICAP. CSE's publication, *Optimizing the Third Skin*, offered guidance on appropriate building envelope through orientation, fenestration designs and shading devices. The publication also did an in-depth analysis of walling material choices prevalent in the market, their advantages and disadvantages over conventional materials and the effect they have on occupant thermal comfort.

CSE's publication, *Breathable Indoors* delved deeper into how building forms, clustering and heights affect ventilation and thermal comfort inside buildings. The guidance was further enhanced in the publication, *Guidelines for Affordable Housing in Telangana*, which included recommendations on tightness of envelope design and appropriate layouts for thermal comfort and energy efficiency.

CSE's current research takes this journey further by including microclimate enhancement and active cooling technologies that are refrigerant-based, non-refrigerant based and not-in-kind (district cooling, thermal energy storage etc.) to tackle the growing need for cooling and meeting the targets of the ICAP. The cases presented in this collage offer a 'bag' of holistic solutions that aim to provide guidance towards a logical and climatically appropriate cooling ecosystem. In cases where mechanical cooling has been employed, linking active cooling systems with renewable sources of power or cooling can drastically reduce their carbon footprint.

The cases captured in the current document have been selected from over a dozen that were researched during the study. The selected cases were chosen, due to the way they have inculcated a blend of traditional wisdom with modern solutions for providing thermal comfort to their occupants, hence successfully cutting down the resources required for cooling. In a country as vast and climatically diverse as India however, many such cases exist, each with their own contextual challenges. This book is a dynamic document which will keep evolving as more such exemplary cases are researched.

1. Climate appropriate cooling solutions

India has a rich history of traditional knowledge on climate-appropriate design and building material. Aspects such as building distances, window shadings and openability, use of water for humidification, thickness and reflectance of materials have been tweaked since millennia to provide occupant thermal comfort in varying conditions. This wisdom has shielded India's built environment from over-dependence on mechanical cooling systems. It is also one of the reasons why India's per capita space cooling energy consumption has been lower when compared to the global average. Modern architects have also adopted these principles while designing contemporary buildings in the country. India is a diverse country when it comes to climate conditions as well as the availability of resources. Hence, cooling solutions need to be seen from a contextual lens keeping in mind the resource availability of a region. Each site and context offers a different challenge and opportunity. Hence, there is no one-size-fits-all solution.

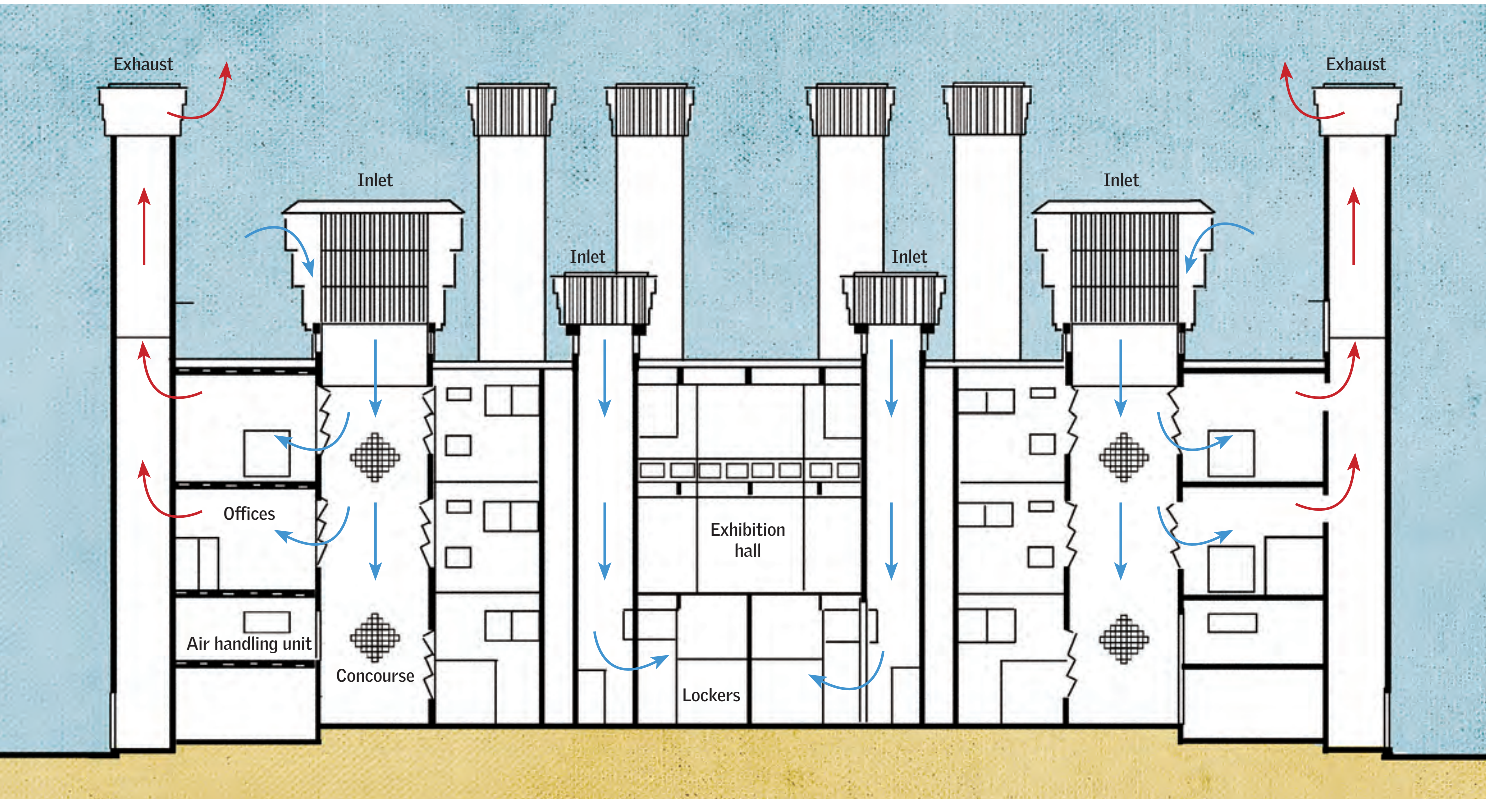
Some of the solutions towards low-carbon/efficient cooling, applied in contemporary buildings are:

1.1 Use of evaporative cooling

Evaporative cooling is an extremely effective way of cooling that has been used extensively in hot and dry conditions for centuries. One simple device that employs this form of cooling is the desert cooler. The process involves hot air passing through a medium that is saturated with water. The hot air then transfers heat to the water, causing it to evaporate and turn into vapour. As a result, the air is cooled and becomes more humid, providing thermal comfort for occupants.

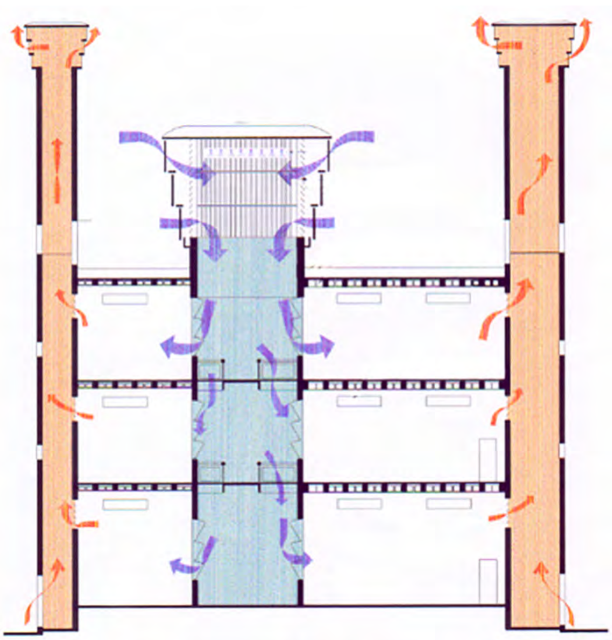
Torrent Pharmaceutical Research is situated in the hot-dry climate of Ahmedabad

Figure 1: The building uses a passive downdraft system which cools the building with the help of evaporative cooling



Evaporative cooling, in the form of ‘passive downdraft’ cooling, has been employed in several locations, including the Torrent Research Centre near Ahmedabad, S.S.S.V.V school in Nadiad and in the dining halls of Indian Institute of Technology in Gandhinagar. These areas have hot and dry climates, which is ideal for evaporative cooling since the ambient air can absorb moisture. However, this technology is not suitable for regions with warm and humid climates where the air is already saturated with humidity, and therefore, cannot be cooled further by evaporative cooling.

Figure 2: Inlet and outlet of air in Torrent Research Centre



1.2 Utilizing geothermal properties of earth

A few metres below Earth's surface, the temperature remains constant at around 24 degree Celsius. The Norwegian Embassy in Delhi and the NIIT University in Neemrana, Rajasthan have both taken advantage of the high thermal mass and geothermal properties of the earth, although in very different ways. The NIIT university campus has constructed earth air tunnels through which filtered ambient air is made to pass, exchanging heat with the earth in the process. By the time this air is introduced to indoor spaces, the air is cooler, hence providing thermal comfort to occupants while eliminating the requirement of an air conditioner to a large extent. The Norwegian Embassy in Delhi however, has used the same cooling property of the soil but for cooling the excessive heat produced by its HVAC system, making the system less energy-intensive.

Geothermal wells installed in Norwegian embassy helping in heat rejection by HVAC system.

Earth air tunnel at NIIT University at Neemrana.

1.3 Maximizing passive potential

Passive principles of architectural design refer to design strategies that use natural elements and features to improve the energy efficiency, comfort, and sustainability of buildings, and eliminating or reducing their reliance on active or mechanical systems.

Elaborative shading devices for shading northern and southern facing windows while presenting a window-less façade towards East to minimize heat gains in IIIT, Delhi.

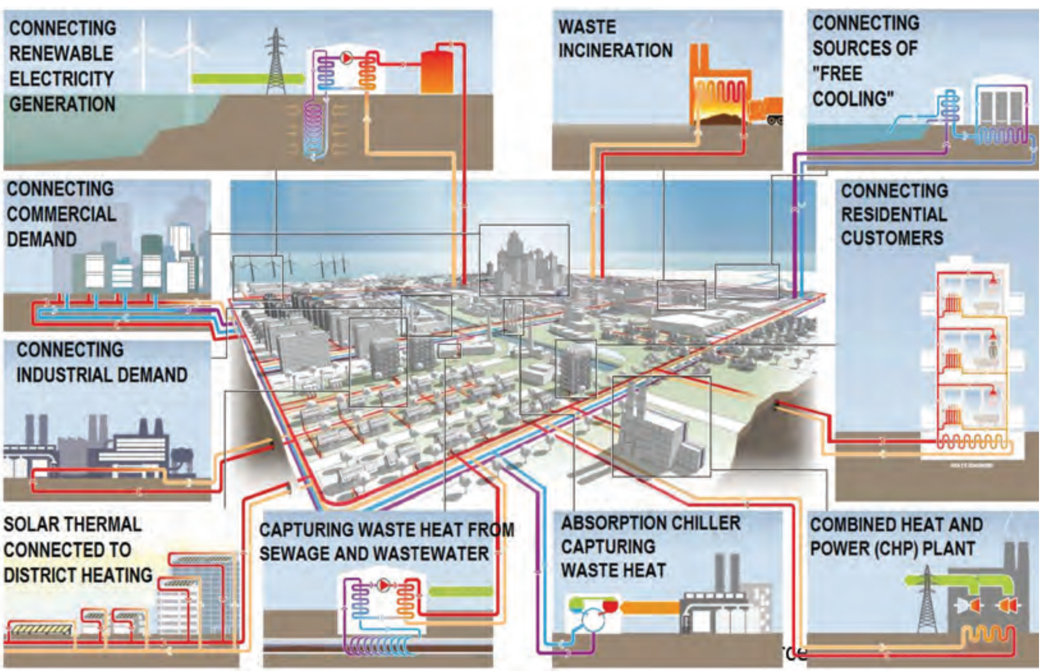
An external structure set a few feet away from the building envelope serves the dual purpose of working as a shading device while providing a medium for the plants to grow over, hence helping with the shade as well as enhancing microclimate through evapotranspiration for the western façade at IIPH Gandhinagar.

Campuses such as the Indian Institute of Information Technology in Delhi, the Indian Institute of Technology in Jodhpur and the Indian Institute of Public Health in Gandinagar have not attempted non-refrigerant-based cooling systems. However, they have worked extensively on maximizing their passive potential by careful building orientation, minimizing their east-west facade exposures and using proper window shading. Moreover, microclimate enhancement with the help of trees and vertical gardens have also been used to bring down the ambient temperature.

1.4 District cooling system opens doors to other sustainable technologies

District cooling system employs one central chilled water source for several buildings. This is in contrast with conventional heating, ventilation and air-conditioning (HVAC) systems that utilize either window units in each room in small buildings, or centralized air-conditioning in large buildings. District cooling systems are more energy efficient and require lesser installed capacity than conventional air-conditioning. Moreover, having a centralized chilled water production and heat rejection mechanism opens up several other doors towards low carbon cooling. IIIT Delhi, IIT Jodhpur and IIPH Gandhinagar have all employed small versions of district cooling systems.

Figure 3: A schematic of possibilities offered by district cooling systems.



Source: 'Converting Expectations' an experts' workshop to catalyse adoption of Energy Efficient Solutions Mumbai, 24th July 2018, Presented by Sudhir Sharma, Programme Management Officer, Energy and Climate Change UN Environment, Asia Pacific Office

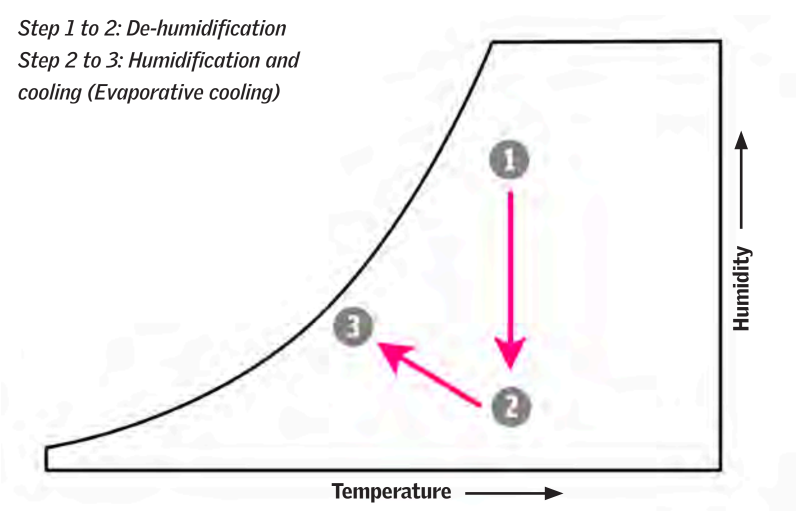
1.5 Cooling with renewable sources of energy

District cooling offers the possibility of converting excess heat into chilled water with the help of vapour absorption machines (VAM). This solution is being proposed for implementation at Nalanda University where agricultural waste, animal waste, sewage and solid waste will be converted into fuel. The resulting heat generated from this fuel will then be utilized for producing chilled water, reducing emissions and minimizing electricity consumption required for cooling. Hence, heat can be derived from renewable fuel sources and used for production of chilled water thus cutting down the emissions and electricity consumption due to cooling. The production of chilled water from renewable or excess heat sources (biofuel, biogas etc.) is not possible at the scale of individual air conditioners. The advantages of district cooling will be addressed in detail in further chapters.

1.6 Dehumidification for thermal comfort through renewables

This renewable source of fuel/heating can be used in various other forms to provide occupant thermal comfort. Nalanda University once again provides a good example in this regard where heat is used to dehumidify the air rather than just cool it. A desiccant-based evaporative cooler (DEVAP) system has been proposed that dehumidifies the air with help from excess/renewable heat and then using evaporative cooling to bring the air to a comfortable level. Significantly more energy is required to achieve the same results with traditional air-conditioning.

Figure 4: A dehumidification - evaporative cooling strategy proposed in Nalanda University presented in a psychrometric chart.



Source: Vastu Shilpa consultants

1.7 Water bodies as sinks for heat rejection

A centralized heat rejection system has its advantages. In areas close to water bodies, the heat rejection can directly take place in the water body itself, with the entire mass of the water acting as a heat sink. A version of this has been planned in IIM Udaipur where the water body is a part of the campus. In rare scenarios, the cold water can directly come from free sources such as the sea.

1.8 Use of radiant cooling technology

Innovations in cooling have not just been observed in large campuses but in smaller buildings as well. One such innovation is the use of radiant cooling. Radiant cooling is a type of cooling system that works by absorbing heat from indoor spaces through radiation. Unlike traditional air-conditioning systems that use air to transfer heat, radiant cooling uses chilled water or other fluids circulating through pipes embedded in the ceilings, walls, or floors of a building to remove heat.

This cools down the surfaces which then use radiation to absorb heat from sources such as humans and equipment. As a result, the temperature of the room drops, creating a comfortable and consistent cooling effect.

The Sehgal Foundation building in Gurugram has employed a radiant cooling system

The radiant cooling system also takes advantage of the thermal mass of concrete floors through which the chilled water pipes run. The coolth gets stored into these concrete slabs which continue to function as heat sinks even when the flow of chilled water is stopped. This reduces the operation time of the system. Overall, radiant cooling system is a relatively energy-efficient cooling solution, as it does not rely on large amounts of energy to move air around the building. The Sehgal Foundation building in Gurugram has used radiant cooling to cut down their cooling related energy consumption.

1.9 Night-time thermal storage to reduce peak daytime load

The Triburg headquarters in Gurugram has opted for thermal storage as a cooling strategy. The system works by storing ice in the basement at night and releasing the chilled water in the morning. This shifts some of the cooling peak load to off-peak hours. Moreover, it is more energy-efficient to shift some of the operation to off-peak hours (night time), due to cooler ambient temperatures which increase the heat rejection rate thus cutting down energy consumption.

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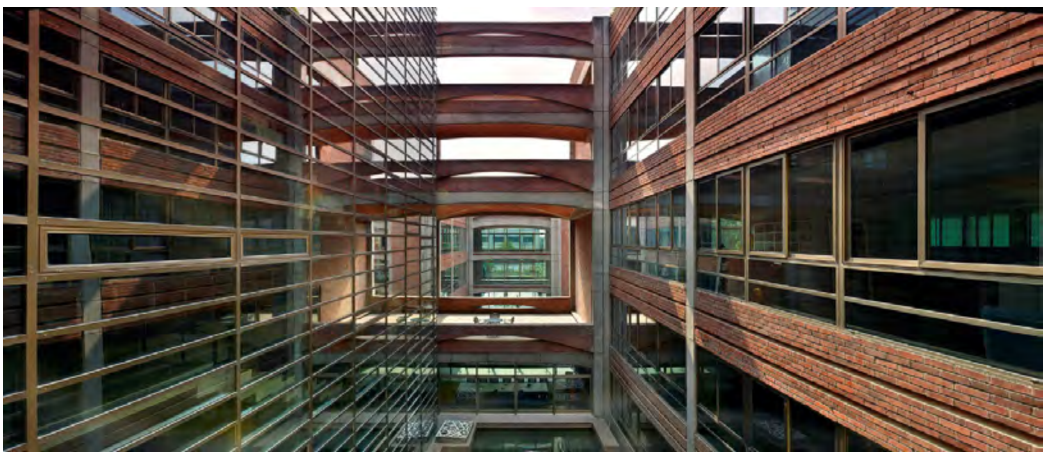


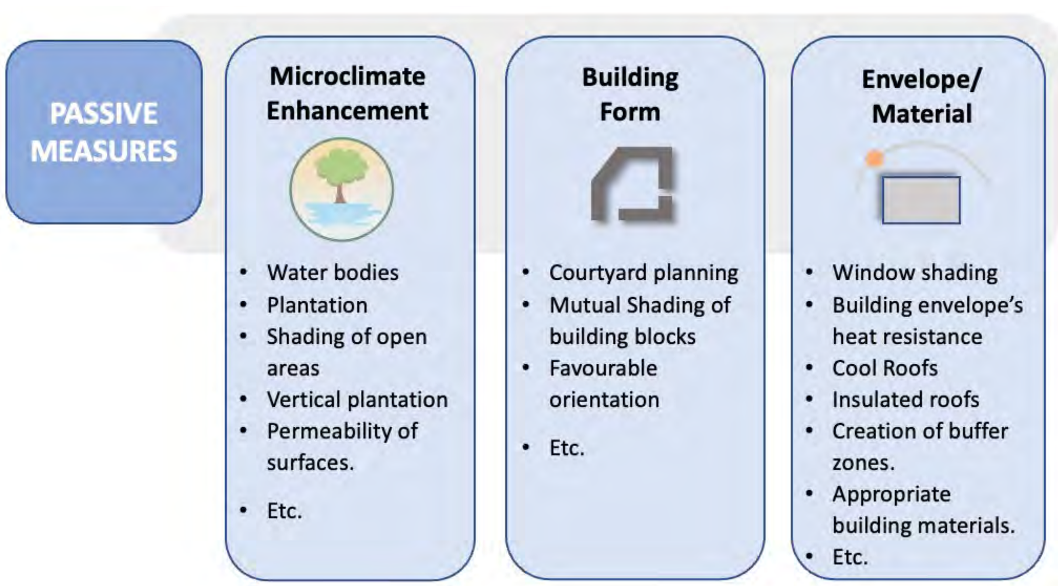
The Triburg headquarters building in Gurugram, apart from using passive features, also employs thermal storage for production of chilled water at night.

2. Towards a holistic cooling ecosystem

A logical and climatically appropriate cooling ecosystem should ideally exhaust all passive measures before moving to active cooling technologies. This includes measures such as microclimatic enhancement to cut down ambient air temperatures, using appropriate building forms and using efficient building envelopes. Passive measures should be the first choice of defence and could be sufficient in providing the occupants with their thermal comfort requirements.

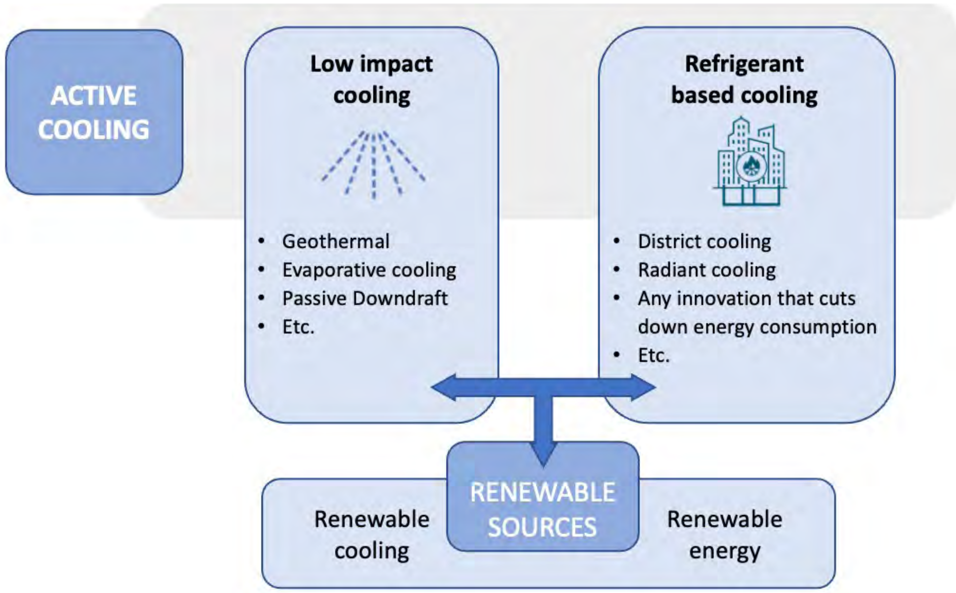
The requirement for active cooling may arise in some buildings. This can be met with non-refrigerant based low-impact cooling technologies that use nature-based heat sinks for coolth. However, these natural sinks are not always available or feasible. In such scenarios, refrigerant-based cooling technologies maybe used. EHowever, even in these scenarios, technologies such as district cooling, radiant cooling, and not-in-kind technologies should be preferred over conventional ones which are much more energy and resource intensive. Linkages between active cooling technologies with renewable forms of cooling/energy provide further opprotunities to cut down the environmental footrpint of cooling systems. This has also been captured in the case studies.

Figure 5: A holistic ecosystem of cooling solutions captured in the case studies



Source: CSE Research

Figure 6: A holistic ecosystem of cooling solutions captured in the case studies



2.1 Passive measures

The battle against the need for mechanical cooling should begin before the heat reaches the building envelope. This can be done by targeting the ambient air itself. The temperature of ambient air varies within the urban setting and high temperatures have been observed within highly built-up areas. This can be attributed to a phenomenon called the urban-heat-island (UHI) effect.

Due to increased instances of urban heat islands, heat waves have become a common phenomenon; their intensity has been getting stronger and they last for longer durations, thus exacerbating thermal risk for occupants. Multiple factors play a role in the urban heat island effect. These can range from the land cover of the site, building clustering, types of anthropogenic activities being carried out, reflectance of material used on outer surface and others. Hence, the following three aspects have been studied: microclimate enhancement, building form and envelope/materials.

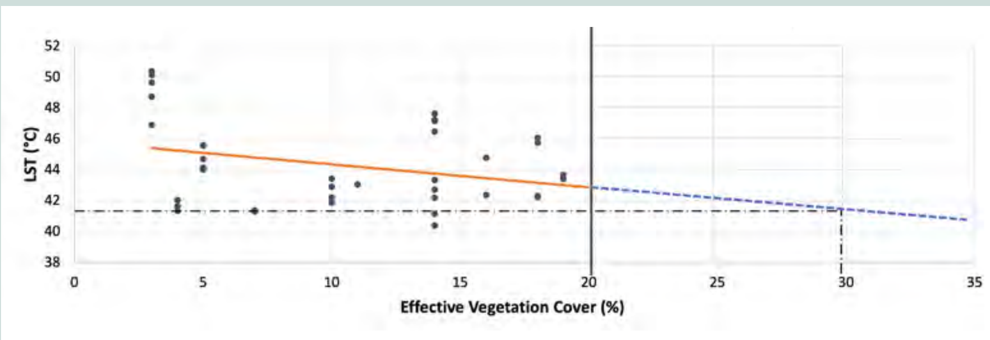
Microclimate enhancement

Lower ambient temperatures can potentially reduce the demand for mechanical cooling. Mechanical cooling is also more efficient when ambient temperatures are lower. Hence mitigating the heat-island-effect would be beneficial in both scenarios—in lowering or eliminating cooling demand as well as increasing the efficiency of mechanical cooling systems. Microclimate enhancement therefore, becomes a primary defence against heat and could be responsible for the temperature being several Celsius lower than surrounding air temperatures. This difference in ambient temperatures can influence the user's decision to use or forego air-conditioning. Even in cases where refrigerant-based cooling has been used, a more favourable microclimate makes for a better heat sink and increases the efficiency of the system. This is achieved by introducing natural heat sinks into the environment and shielding open areas from harsh solar radiation. This can be achieved by playing around with multiple strategies/tools such as:

1. Water bodies
2. Plantation
3. Shading open areas
4. Vertical plantations
5. Permeability of surfaces

The Centre for Science and Environment (CSE) conducted a study on selected sites in Pune. The study observed that if the composition of vegetation (in the form of a dense canopy with large foliage) is increased by 10–20 per cent, there is a potential reduction of 2–4°C in land surface temperature. The primary factor associated with this kind of cooling is enhanced evapotranspiration, wherein the incident energy is utilized to change the state of water content in plants/leaves from liquid to vapour, altering the latent heat and nullifying the sensible heat gains.

Graph 2: Variation of LST with changes in the effective vegetation cover for selected sites in Pune



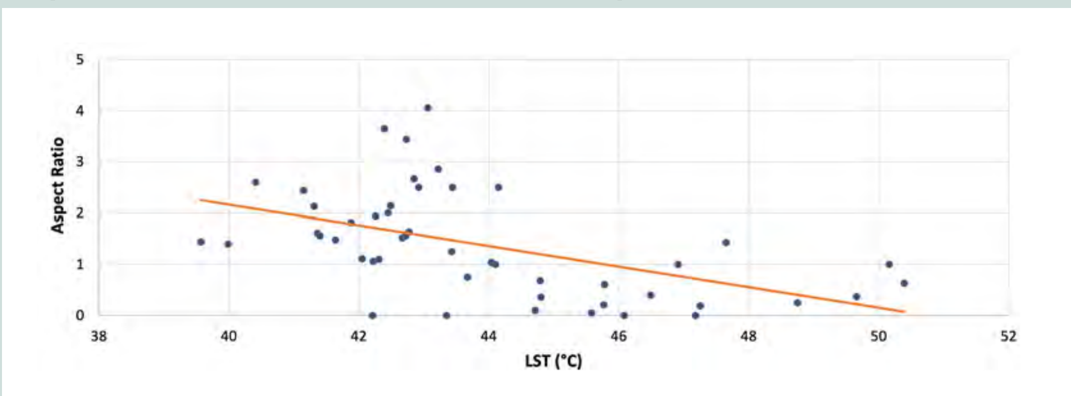
Building form

A cluster of buildings affects the way direct sunlight reaches the ground, is absorbed by the built mass, and is radiated back to the sky. It even affects how this heat gets trapped between buildings. The distance between buildings can also determine if they mutually shade each other or the ground between them. An indicator of this is the 'aspect ratio' which establishes the relationship between the open space and the height of buildings surrounding it. Aspect ratio primarily indicates how the built mass shades the open area and hence, affects its land surface temperature. It is calculated by averaging out the height of surrounding buildings and dividing it by the distance between them. Traditionally, hot and dry climates utilized higher aspect ratios as can be observed in Rajasthan. This affects the microclimate of the areas as well as the heat gain inside the building.

Figure 7: Traditionally, hot climates utilized higher aspect ratios so that open sapces remain shaded by surrounding buildings, as observed in the old cities of Rajasthan

CSE conducted a study on selected sites across Pune city to understand the effect of aspect ratio on the Land Surface Temperature (LST). It was observed that streets with higher aspect ratios (>1) were associated with 2–4°C lower LSTs, when compared to the ones with lower aspect ratios. This could be attributed to lower heat gains in the streets, owing to enhanced mutual shading and lesser exposed area.

Graph 3: Variation of LST with alterations in aspect ratio for selected sites in Pune



In Pune, the streets oriented in the N–S direction were observed to have approximately 1°C higher street surface temperatures than the ones that were oriented in the E–W direction.

Graph 4: Variation in LST with street orientation for selected sites in Pune

However, better effectiveness of this ratio can only be utilized when it is combined with a favourable orientation. The same aspect ratio but with buildings oriented differently will behave differently in terms of its shading the central space. A site plan where the major facades of the building face North-South will gain lesser heat as compared to East-West ones. CSE's research captured in the report, *Guidelines for Affordable Housing in Telangana*[7] found that a building with East-West facing façade had up to 17 per cent extra heat gain compared to the same building facing North-South.

Factors that can change this are:
1. Courtyard planning
2. Mutual shading of building blocks
3. Favourable orientation

Envelope/material

Passive features along with a building's internal layout as well as the materials used for the building envelope, all play a major role in a building's heat gain/loss. These factors—when applied in response to local climatic conditions—could be responsible for a drop in the internal temperature of the interiors, cutting down the need and duration of air-conditioning. The various tools determining this are:

1. Window shading that is appropriate to climate and orientation
2. Building envelope's heat resistance
3. Cool roofs
4. Insulated roofs
5. Creation of buffer zones for habitable spaces
6. Appropriate building materials.

2.2 Active cooling systems

While in some cases passive features can make a difference to the need for mechanical cooling, they are not sufficient in all scenarios, especially in buildings that have a high internal load due to equipment and a large number of people. In such a scenario, the use of mechanical cooling technologies become inevitable. While incremental improvements in the efficiency of air-conditionings can be expected over time, the emissions and energy consumption related to the overall cooling sector is expected to rise exponentially in the near future. Hence, this research pays special attention to cases where low energy intensive cooling has been used.

Non-refrigerant based cooling

Conventional air-conditioning functions by ejecting heat into the ambient air. The heat ejected by air conditioners increases the air temperature which further increases the demand for cooling. This ends up creating a vicious circle. The most adversely affected strata of society are the ones who cannot afford air-conditioning and end up suffering in the excessive heat. An increase in temperature can lead to a loss of productivity and increase in diseases. Non-refrigerant based cooling systems perform better at countering this problem.

The I*ndia Cooling Action Plan* also stresses on the use of non-refrigerant-based and not-in-kind cooling technologies. These technologies often have advantages of reduced energy usage and can provide the occupant with much more fresh air when compared to conventional air-conditioning that works on the re-circulation of air. Multiple techniques/strategies that constitute non-refrigerant cooling include:

1. Evaporative/misting cooling system
2. Earth tunnel/wells
3. Indirect evaporative cooling
4. Dehumidification system

Refrigerant-based cooling

This is the most prevalent form of cooling in medium to large buildings and is energy intensive. For this study, we have covered the refrigerant-based cooling systems which use innovation in design or operation to bring down energy consumption. This includes not-in-kind technologies such as district cooling systems which, by virtue of the technology, offer energy savings. The multiple components/strategies that affect the energy efficiency of refrigerant based cooling systems include:

1. Type of chiller used
2. Air vs. water cooled system
3. Geothermal as Heat Sink
4. Water body as Heat Sink
5. Thermal storage
6. Absorption cooling
7. Use of radiant cooling

Distribution system

Distribution system includes the equipment, piping and the way cool air or water is distributed in the building. The various parts included in this are:

1. 2 way vs. 4 way piping system
2. Use of FCU's or AHU's
3. Use of variable air volume in case of AHU's
4. Control systems provided to individual rooms

Operation optimization

While design and equipment play a huge part in making a cooling system efficient, the third pillar to bring in efficiency is optimization while operating the HVAC system. The most important practice that can bring down the tonnage of a system is utilizing cooling swap as a strategy (explained further in 'advantages of district cooling'). To capture operation optimization, the following aspects were captured.

1. Load diversity/ coolth swap
2. Building management system
3. Timer based controls
4. Use of variable frequency drives
5. Set point temperature
6. Coefficient of performance of chiller
7. Off-peak operation

3. District cooling systems

The rise in the demand for cooling is expected to be led by the demand for room air conditioners. As per an estimate made by the India Brand Equity Foundation, 2019, the number of room air conditioners sold in India stood at 30 million in 2017. This number is expected to increase to 55 million to 124 million by 2030.[8] According to another estimate, 47 per cent of urban households in India are set to own a room air conditioner by 2030. For context, nationally, less than 10 per cent of urban households own room ACs currently. This is alarming as refrigeration and air-conditioning (RAC) are already estimated to be responsible for 10 per cent of the global CO_2 emissions (ICAP).

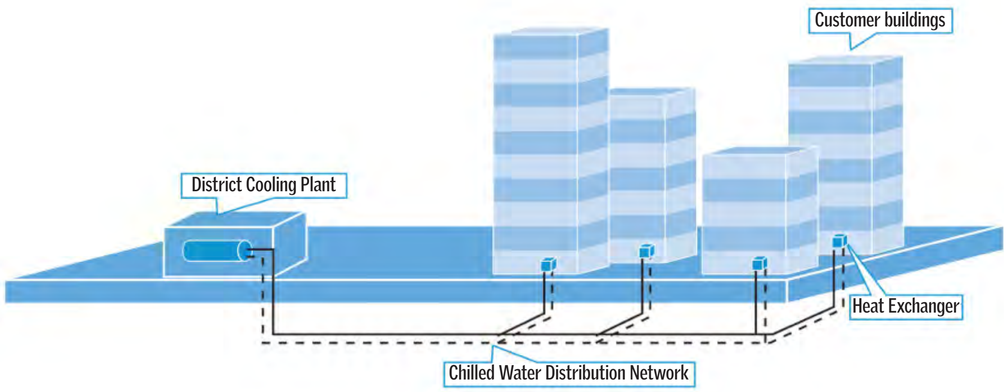
The possibility of linking room air conditioners with renewable energy/cooling sources is very low, their small size makes them inefficient and energy intensive. Often they are only required during a few hours of the day but end up consuming invaluable space throughout their lifetime. Hence, in area schemes with multiple buildings where refrigerant-based space cooling is inevitably expected to rise, district cooling systems provide a much more resource-efficient solution. As cities work towards more mixed-use developments striving to bring work spaces and residential buildings together, the feasibility of using district cooling system is set to increase. In this regard, buildings using smaller versions of district cooling system have also been captured in this study.

3.1 What is district cooling system?

In conventional cooling systems, each building is cooled by its own individual system the size of which is determined by the requirement of the building.[9] In such scenarios, the chilled water is produced individually in each building.

District cooling, on the other hand, depends upon centralized production of chilled water that is then distributed to multiple buildings (preferably withdiverse functions) using a closed loop network of pipes. District cooling system is well suited for buildings that are in close proximity and there is a steady demand for cooling.

Figure 8: District cooling serves multiple buildings in a local area



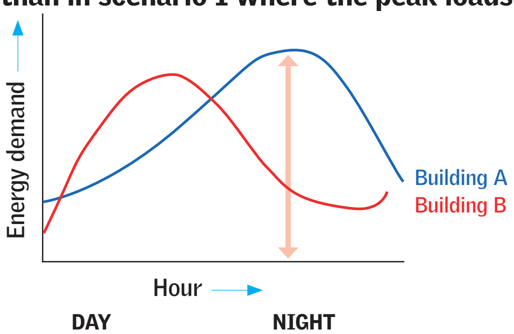
Advantages of district cooling

District cooling can be a more economical solution when compared to building-specific cooling. As per the ICAP, district cooling systems typically require about 15 per cent less capacity than conventional distributed cooling systems for the same cooling loads. The major factors that the reduction in installed capacity can be attributed to are:

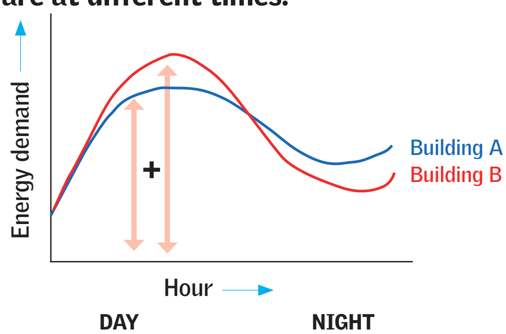
3.3 Asset and equipment sizing

- Load diversity in building peak cooling: When it comes to district cooling, each building will have its peak load at different times of the day. By utilizing this diversity in load, the district cooling system can be designed so that it has a significantly lower chiller installed capacity compared to the sum of the peak cooling demands of the individual buildings. This also implies that district cooling is best utilized where buildings have load diversity as well as different load demand peaks due to multiple functions as is expected in mixed-use development.

Graph 4: In scenario 2, both buildings have their peak load requirement during the day, hence the installed chiller (Peak loads of building A + B) will be higher than in scenario 1 where the peak loads are at different times.



Scenario 1: Peak load with Load diversity

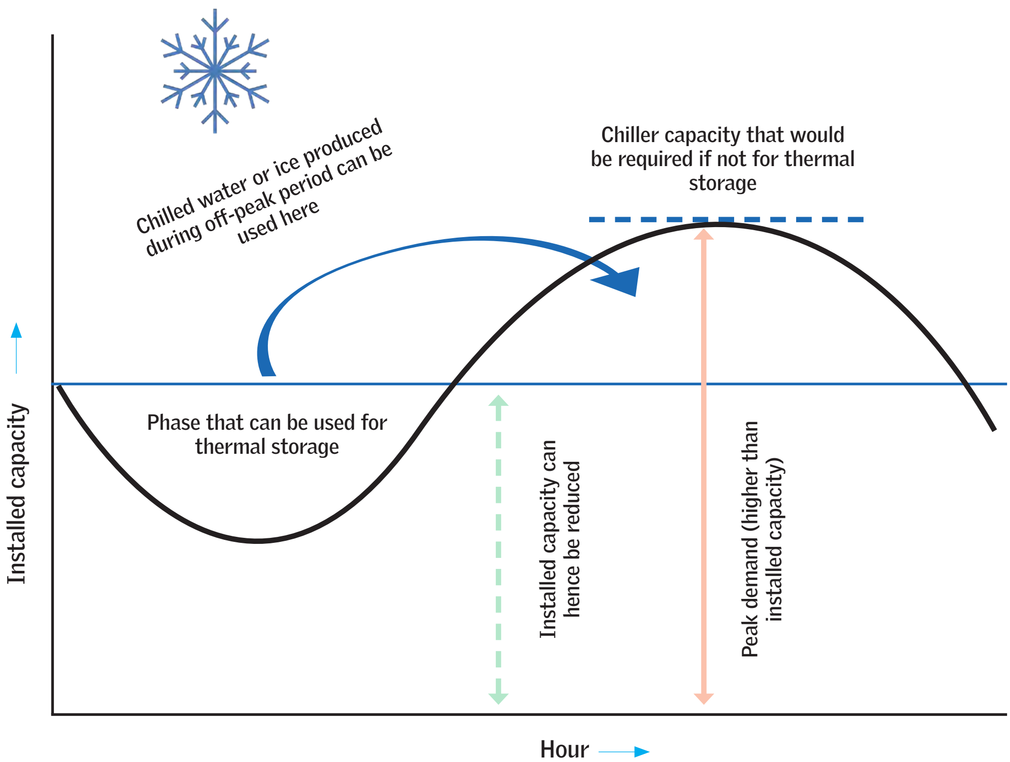


Scenario 2: Peak load with Load diversity

The savings in initial capital investment are further magnified when the requirement for equipment redundancy at the individual consumer building is considered.[10]

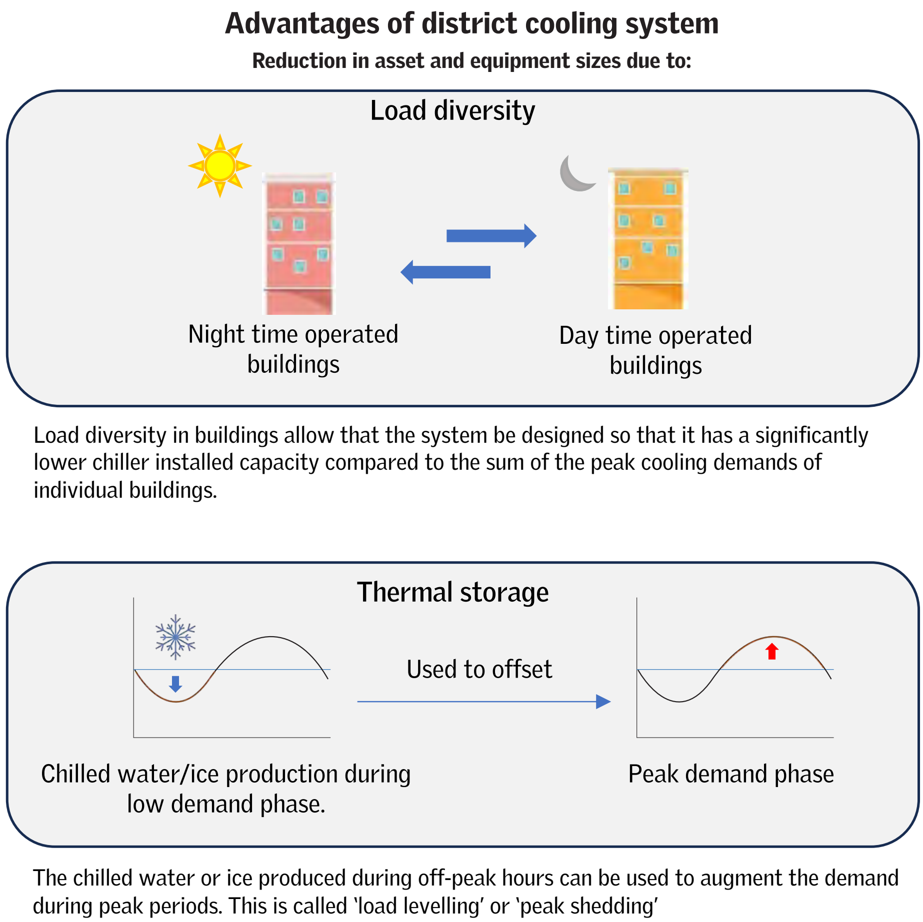
- Thermal storage can further reduce installed capacity: The large capacity of a district cooling system makes it favourable for use in conjunction with thermal storage. Thermal storage works by converting water into chilled water (or ice) during off-peak demand hours. This helps in decoupling the production of cooling energy from end-user demand. The chilled water or ice produced can then be used to augment the demand during peak periods. This is called 'load levelling' or 'peak shedding'.[11]

Graph 5: Chilled water or ice produced during off-peak period can be used to augment the demand during peak periods



In the absence of a thermal storage system, the operating chiller capacity would have to be sized to meet the peak load of the building which occurs in a day, even if this peak load lasts only for an hour.

Figure 9: Advantages of district cooling systems



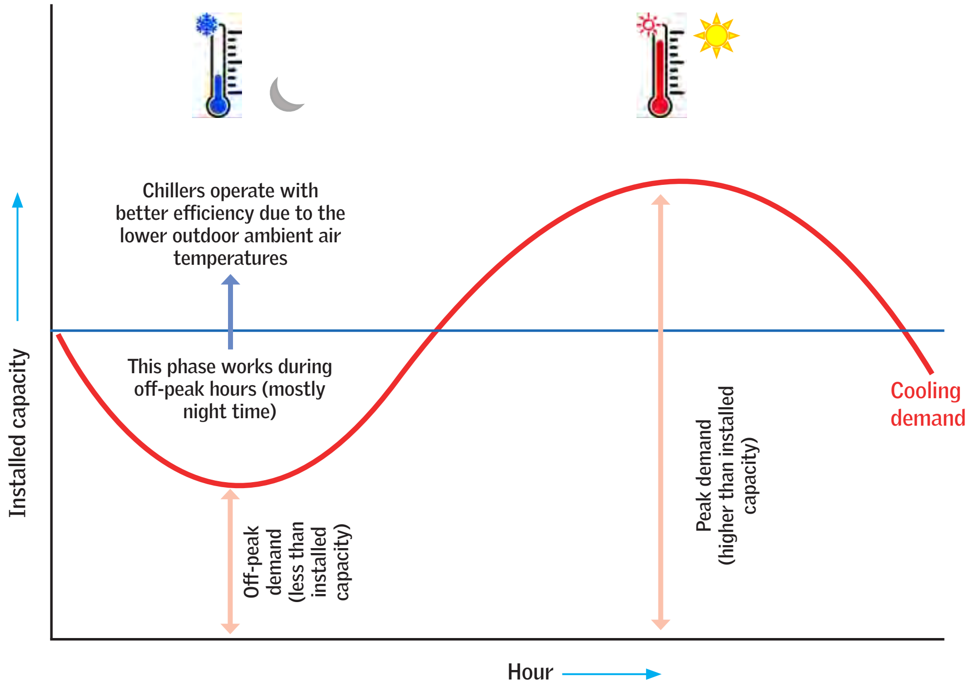
3.4 Energy efficiency

According to an IEA forecast, a combination of good building design, active interventions and the use of district energy models could reduce peak energy demand and GHG emissions by as much as 55 per cent when compared to the baseline scenario. The reasons for this are:

Energy efficiency due to thermal storage

Thermal storage technology provides another advantage in terms of energy efficiency: As the production of chilled water gets shifted to off-peak hours (which is night-time in most scenarios), the production of chilled water in itself becomes more energy efficient as the chillers operate with better efficiency due to the lower outdoor ambient air temperatures at night.

Graph 6: Chillers operate at better efficiency at night due to lower outdoor ambient temperatures



In addition to this, thermal storage also ensures that the chillers can be operated at full capacity thus further improving their efficiency and utilization.

Energy efficiency due to economy of scale

Even if thermal storage is not used, district cooling system in itself is more efficient than running small isolated systems. Since the central plant of the district cooling systems is larger, the economy of scale provides for more efficient equipment. Overall, the power demand and energy consumption in a district cooling system is almost half of the total cooling power requirement compared to distributed standalone cooling systems installed in each building (according to the white paper: Sustainable air cooling and district cooling system by India Smart Grid Forum)

Apart from lower energy bills and lower chiller capacities, the system is more economical for a large establishment in other aspects as well:

- A centralized district cooling plant aggregates cooling demand from multiple consumers; this optimizes the manpower required for the operation and maintenance of the system. The need for individual building owners to employ personnel for operation and maintenance of chiller plants is eliminated.
- Usable space in the building would increase as large rooms for housing individual cooling systems are no longer required.

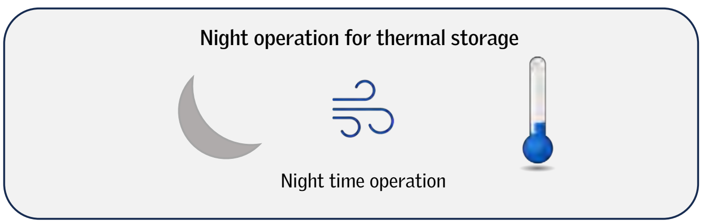
Energy efficiency by using district cooling in tandem with other technologies

District cooling as a technology enables higher flexibility and offers the potential of being used in tandem with other technologies (solar cooling, tri-generation, and waste cold). This can make it more sustainable.

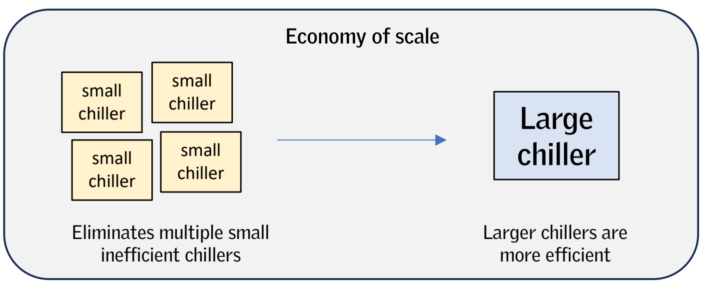
- **Absorption chillers can capture waste heat produced elsewhere:** Waste heat is often produced from industries, waste incineration etc. This heat cannot be captured by individual building chillers but can be tapped by district cooling systems where absorption chillers can be installed to convert the waste heat into chilled water.
- **Connecting sources of renewable cooling:** Large waterbodies or the earth four metre below the ground are renewable sources of coolth that cannot be utilized by individual cooling systems but work with large-scale district cooling systems. These can be used either as a heat sink for the condenser cycle or directly as a source of cool air or chilled water that is circulated in buildings.

Figure 10: Advantages of district cooling system

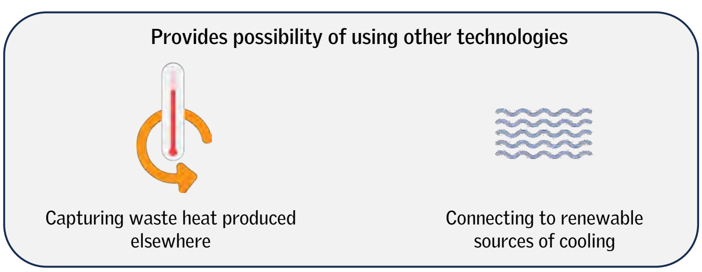
Energy efficiency due to:



Night time operations provide cooler ambient air temperatures making the chiller operation more efficient.



Since the central plant of the district cooling systems is larger, the economy of scale provides for more efficient equipment.

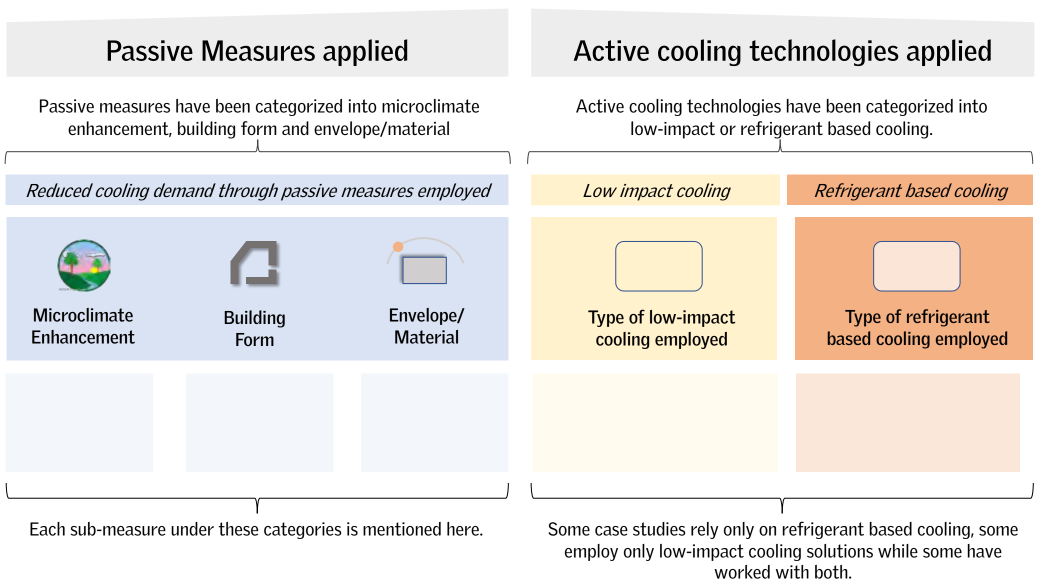


District cooling as a technology enables higher flexibility and offers the potential of being used in tandem with other technologies.

4. CASE STUDIES

This study highlights the solutions and practices that have been employed to create a sustainable holistic ecosystem for cooling in buildings across the country. Every case study begins with an introduction matrix that describes all the measures taken to achieve cooling in and around the building.

Figure 11: How to read the introduction matrix of each case study



ANIL AGARWAL ENVIRONMENT TRAINING INSTITUTE, Neemli

TOTAL SITE AREA
11 Acres

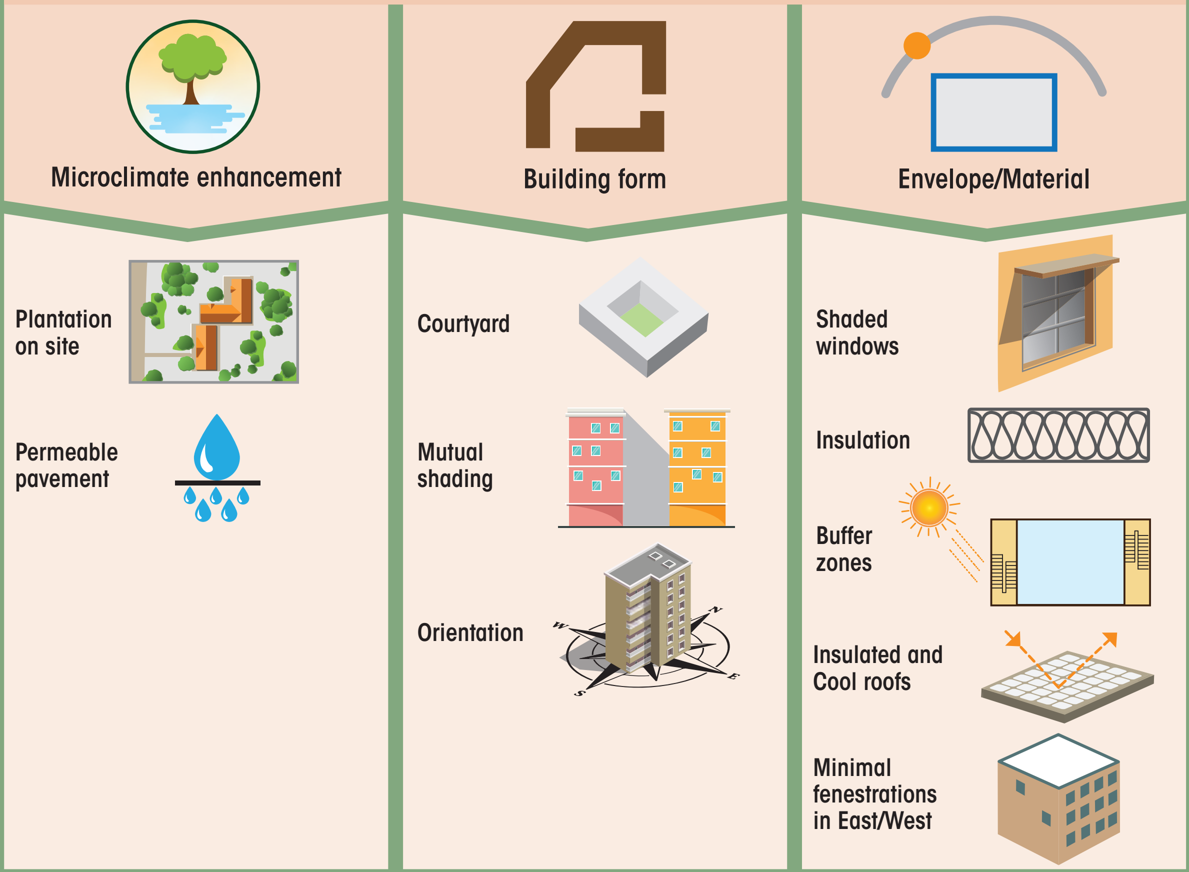
ESTABLISHED IN
2017

CLIMATE ZONE
Composite

LOCATION
Neemli, Rajasathan

PASSIVE MEASURES APPLIED

Reduced cooling demand through passive measures employed



Microclimate enhancement

- Plantation on site
- Permeable pavement

Building form

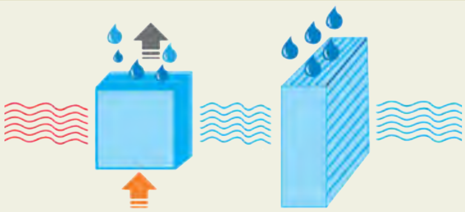
- Courtyard
- Mutual shading
- Orientation

Envelope/Material

- Shaded windows
- Insulation
- Buffer zones
- Insulated and Cool roofs
- Minimal fenestrations in East/West

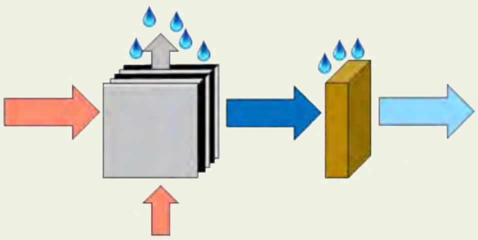
ACTIVE COOLING TECHNOLOGIES APPLIED

Low impact cooling



Indirect-Direct-Evaporative Coolilng

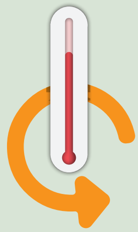
Campus employs a three stage cooling system



Refrigerant based cooling

HVAC System

Heat recovery for hot water generation



Use of natural refrigerant R 290

R 290

Anil Agarwal Environment Training Institute

Total site area: 11 acres
Established in: 2017
Climatic Zone: Composite
Location: Neemli, Rajasthan

Microclimate enhancement

The campus was conceptualized as a low carbon campus right from the design stage. Placement of the building blocks was meticulously planned to eliminate the need for chopping off any trees on the site, while also preserving the existing seasonal water channels. Additionally, hundreds of trees have been added to the campus since it started functioning in 2017. This dense tree plantation covers around 35 percent of the 11 acre campus and acts as a major heat sink due to evapotranspiration carried out by the trees.

Heavy plantation at AAETI campus

The non-motorable pathways have been kept permeable, and are shaded with trees from both sides. This permeability allows water to seep in and in times of extreme heat this water evaporates, thus cooling the ambient air.

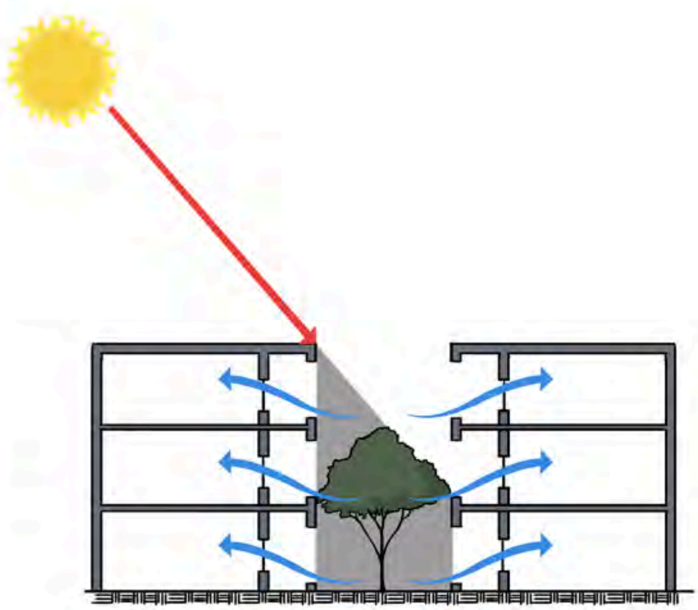
Shaded and permeable pathways in AAETI campus

Building form

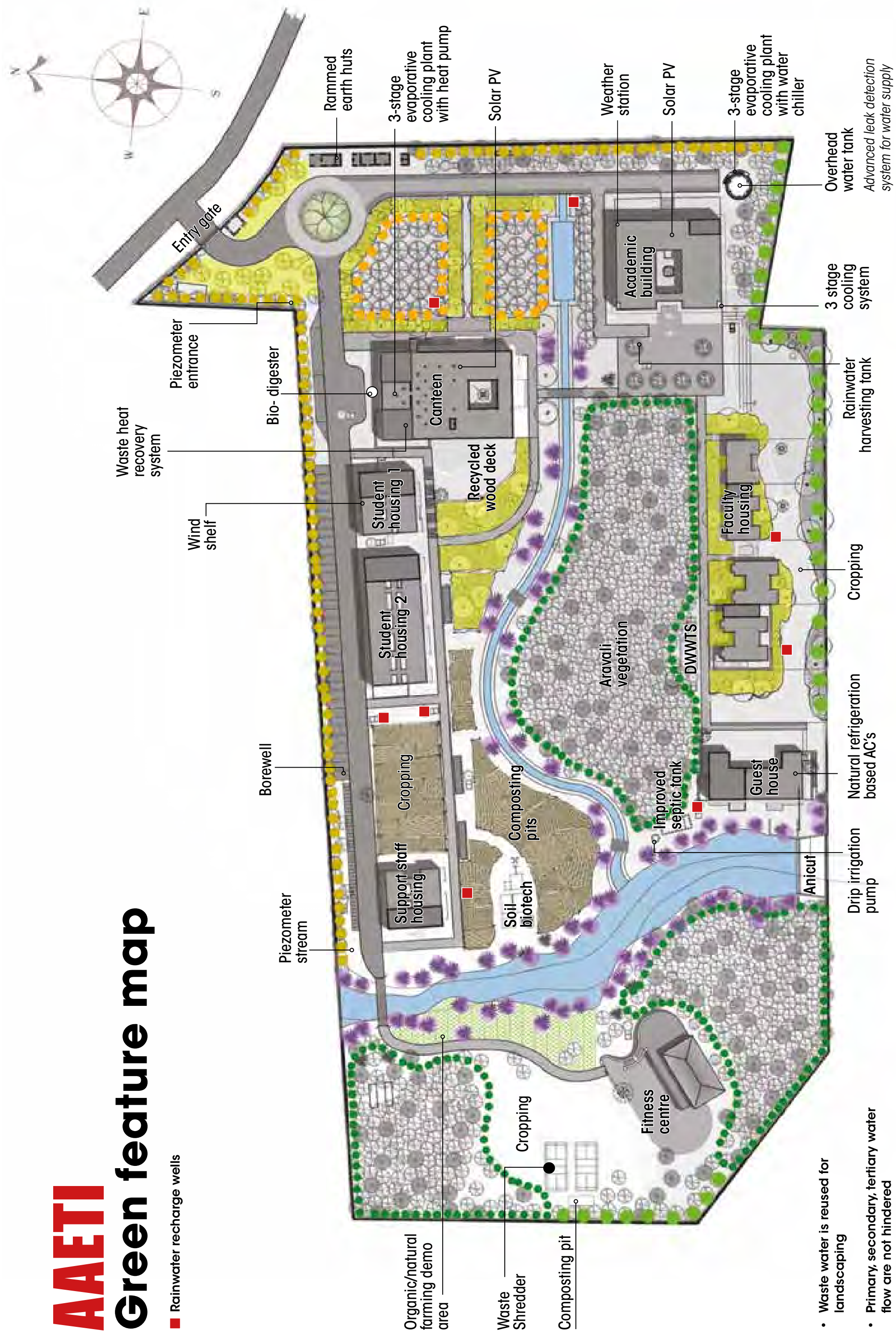
A majority of the building facades face North and South while windows towards the East and West have been kept at a bare minimum. This helps in reducing the heat gain inside habitable areas.

The academic block is built on a narrow courtyard typology with a tree in the centre. This creates a microclimate in the courtyard that benefits the surrounding class-rooms. The width of the courtyard is around 6.5 metres while the height of the surrounding building block is more than 12 metres. This ensures an aspect ratio of 2:1 between building height and courtyard width. The canteen building also uses a similar typology.

Figure 12: A narrow courtyard typology shades the interior courtyard where the temperature is further reduced due to vegetation



Further, the student and faculty housing buildings are clustered together in a way that their Eastern-Western facades get shaded due to adjacent buildings shadow.



Envelope and material

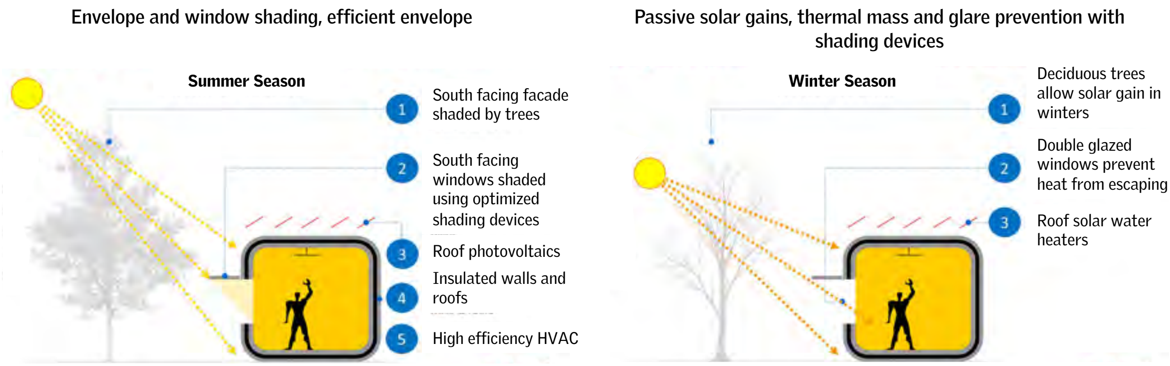
The campus has been designed with an overall low window-to-wall Ratio (WWR). WWR is a term used to describe the proportion of glazing (windows and doors) to the total wall area of a building. It is calculated by dividing the total area of windows and doors in a building by the total area of exterior walls.

WWR is an important factor in building design as it affects the energy efficiency and thermal performance of a building. A high WWR can result in increased heat gain and loss through windows, leading to higher heating and cooling energy. The WWR used in the AAETI campus is kept at 30 per cent which is even lesser than the maximum cap of 40 per cent WWR as prescribed in Energy Conservation Building Code 2017.

View of AAETI campus

Different shading strategies for summer and winter months have been adopted and trees also play a part in this. Windows on the building exteriors are well shaded to allow the winter sun to come in while blocking the summer sun out. This is achieved by using a climate appropriate projection factor for shading the windows. A projection factor refers to the ratio of the distance between the window and the shading device to the height of the shading device. This factor determines the amount of direct sunlight that can penetrate through the shading device and into the interior of a building.

Figure 13: Strategies for summer and winter months

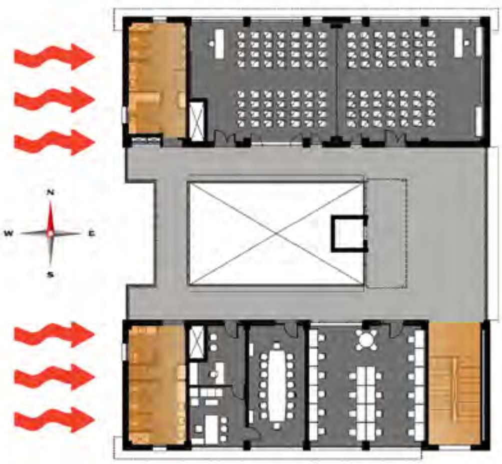


The design of the shading devices varies as per the direction of the façade. This variation in design is done keeping in mind the movement of the sun and how that affects the heat ingress in the building.

Projection factor of windows helps to shade during summer months and allows the winter sun to enter livable spaces.

The habitable spaces inside the building are further shielded from intense heat due to the clever placement of service areas such as washrooms and staircases on Eastern-Western sides. These spaces act as a buffer that shields classrooms from Eastern and Western façade walls that face the harshest brunt of the summer sun.

Figure 14: The staircase and toilets towards the East and West of the building help in protecting the classrooms from the harsh East-West sun

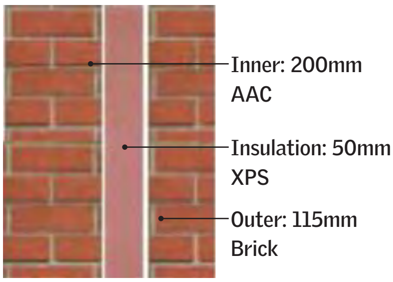


The western façade receives the brunt of the harsh summer sun; the classrooms are shielded from this by utilizing washrooms as buffer zones in academic block.

The walls of the buildings employ a combination on Autoclaved Aerated Concrete block and Extruded polystyrene (XPS). Both these materials have insulation properties and their combination provides a thermal transmittance (U-Value) value of 0.36 which transmits five to six times lesser heat compared to a conventional nine inch (230mm) red brick wall. Various options were explored before reaching this decision.

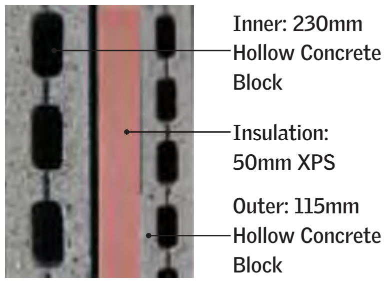
Figure 15: Options for explored for wall sections

Wall-section Option 1



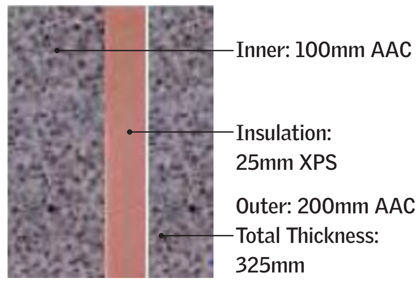
Total Thickness: 395mm

Wall-section Option 2



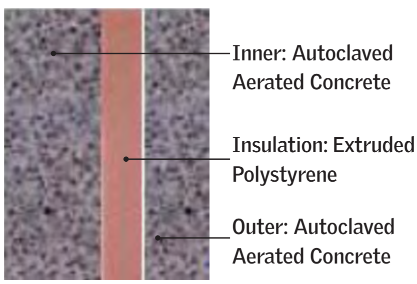
Total Thickness: 395mm

Wall-section Option 3

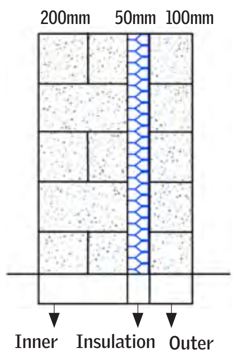


Total Thickness: 325mm

Figure 16: Final external wall assembly chosen for the building



Total Thickness: 350mm



350mm wall with combination of AAC blocks and XPS insulation

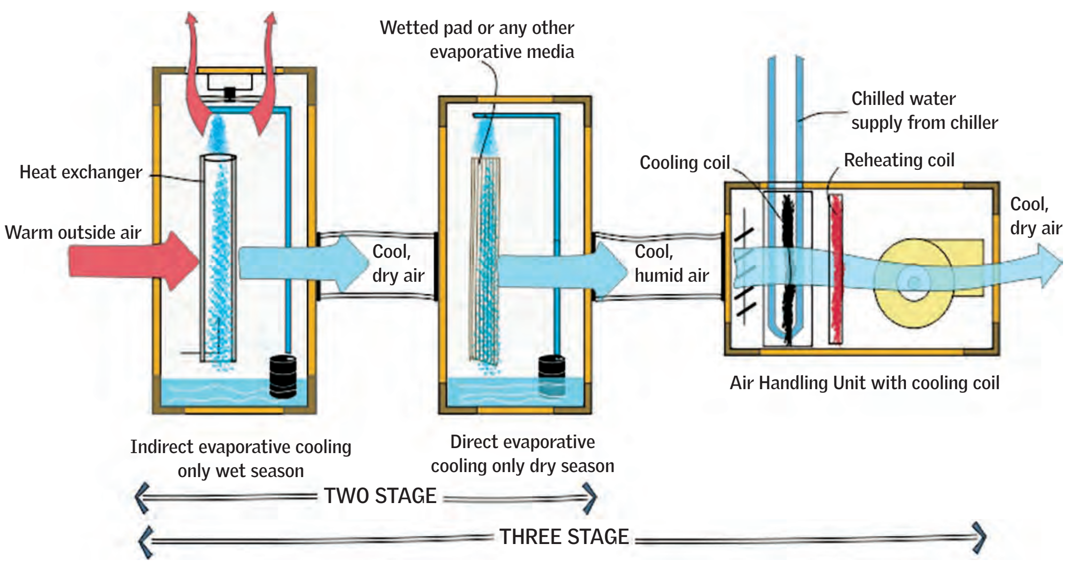
White shiny ceramic tiles of 13mm thickness cover the roof of buildings as they reflect the harsh sun rays and reduce heat gain. The roof also has a 100mm of XPS insulation below the ceramic tiles.

In order to minimize heat gain through windows, double glazed units with a U-value of 2.8 W/ m2K and effective solar heat gain coefficient (SHGC) of 0.25 (The SHGC of a glass is a number between 0 and 1, with lower values indicating that the glass blocks more solar heat). This low level of SHGC has been achieved with the use of high-performance glass, combined with heavily shaded windows.

Three-stage cooling system

All the rooms in the campus have been provided with ceiling fans to serve as the first means to tackle rising heat as they are the most efficient and prudent means to get cool if the temperature is off by a few degrees only. For rest of the times, a three-stage cooling system is installed.

Figure 17: Three-stage cooling system



Source: NZEB

Stage 1, Indirect evaporative cooling:

With Indirect Direct Evaporative Cooling (IDEC), the incoming air stream is cooled with Indirect Evaporative Cooling (IEC) with the help of pipes carrying water. The air however does not come in direct contact with the water but only with the pipes carrying it. The heat gets exchanged but the air does not gain any amount of moisture.

Stage 2, Direct evaporative cooling:

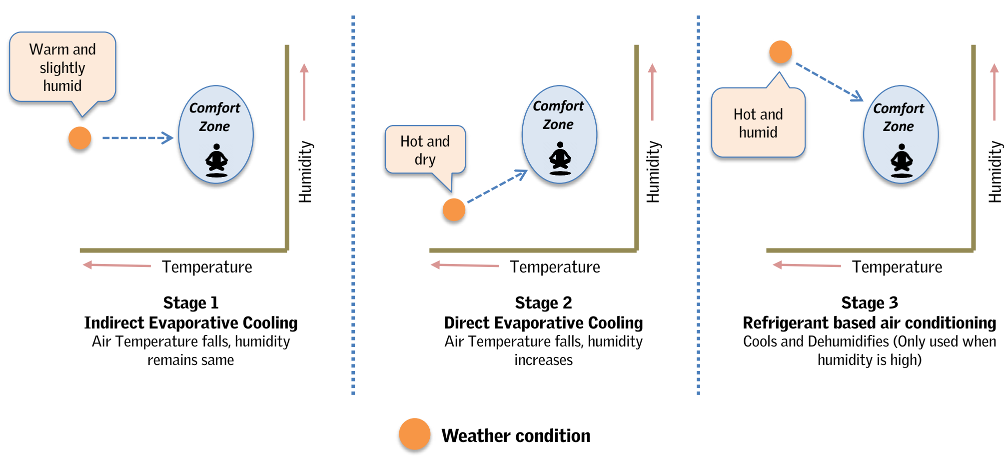
Air gains humidity and cools down after getting in contact with a wet cooling pad. This is an improved version of classic desert cooler and is perfect for hot and dry season which is the dominant weather in Rajasthan.

In combination, this is called Indirect-Direct-Evaporative Cooling, this system is an excellent upgrade over conventional air coolers. IDEC delivers 4-5°C lower temperatures and adds up to 60 per cent less moisture as compared to air coolers. IDEC is also an energy efficient alternative to conventional air-conditioning systems as IDEC consumes up to 60 per cent less power. A major advantage is that the system provides occupants with 100 er cent fresh air.

Stage 3, refrigerant based:

The third stage which uses the refrigerant for cooling instead of water kicks in only when the ambient air has too much humidity rendering evaporative cooling redundant. This system restricts the use of energy intensive cooling to 2-3 months of monsoon. Hot-water provided as the by-product of the system is used to meet hot water requirements of the campus. Additionally, it doubles up as space heating in winters.

Figure 18: Schematic for usage of various stages in the three-stage-cooling system at AAETI, the weather condition determines the stage to be used



Overall, the campus has used these combinations wherever suitable depending on the weather conditions. The academic and student housing blocks use a combination of IDEC and refrigerant cooling while the service spaces and canteen block only use IDEC.

Table 1: Types of cooling systems used in different spaces at AAETI

Sr. No.	Block	Machine installed
1	Academic block (Classroom 3 & 4)	Hybrid Air-conditioning
2	Academic block (Classroom 1, 2 & 5)	Hybrid Air-conditioning
3	Student housing block 1	Hybrid Air-conditioning
4	Student housing block 1	Hybrid Air-conditioning
5	Student housing block 2	Hybrid Air-conditioning
6	Services (all floors)	Indirect Direct Evaporative Cooling
7	Canteen	Indirect Direct Evaporative Cooling

CFM = Cubic Feet per Minute, TR = Tonnage of Refrigeration

Source: HMX

Refrigerant-based evaporative cooling details:

Total Tonnage of refrigeration: 44 TR + 32 TR + Individual units
Refrigerant used: R-134 and R-410
Chiller type: 44 TR Scroll chillers and 32 TR Screw chiller
Air or water cooled: 44TR – Air cooled an 32TR Water cooled
FCU/AHU: AHU's are installed, all of which have VFD's installed.
Individual controls: The campus buildings have been designed for thermal comfort conditions of 26 ffl 2°C in summers. No individual controls are provided in the hostel rooms.

INDIAN INSTITUTE OF TECHNOLOGY, GANDHINAGAR

TOTAL SITE AREA
399 Acres

ESTABLISHED IN
2008

CLIMATE ZONE
Hot and Dry

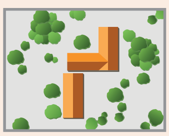
LOCATION
Gandhinagar, Gujarat

PASSIVE MEASURES APPLIED

Reduced cooling demand through passive measures employed

Microclimate enhancement

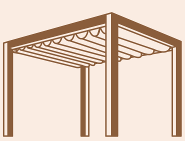
Plantation on site

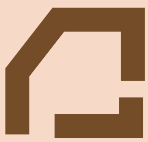


Vertical plantation

Permeable pavement

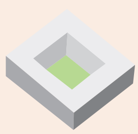
Open area shading



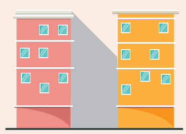


Building form

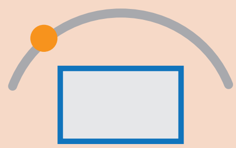
Courtyard



Mutual shading

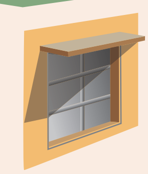


Orientation

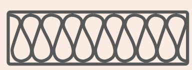


Envelope/Material

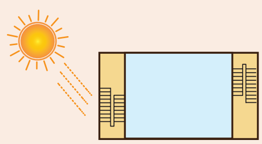
Shaded windows



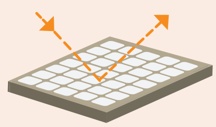
Insulation



Buffer zones

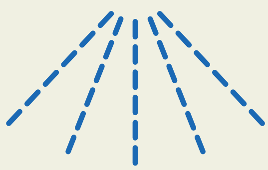


Cool roofs



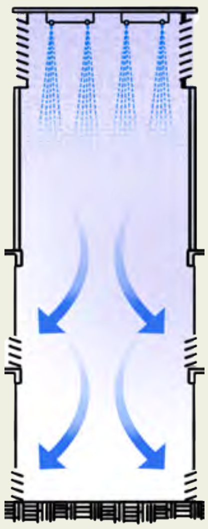
ACTIVE COOLING TECHNOLOGIES APPLIED

Low impact cooling



Passive Downdraft Cooling

Passive downdraft cooling using evaporative cooling



Refrigerant based cooling

District Cooling System

Total Tonnage: 1820 TR + 700TR

Total Air-Conditioned area: 610,165 sq. ft.

Refrigerant used: R-134a

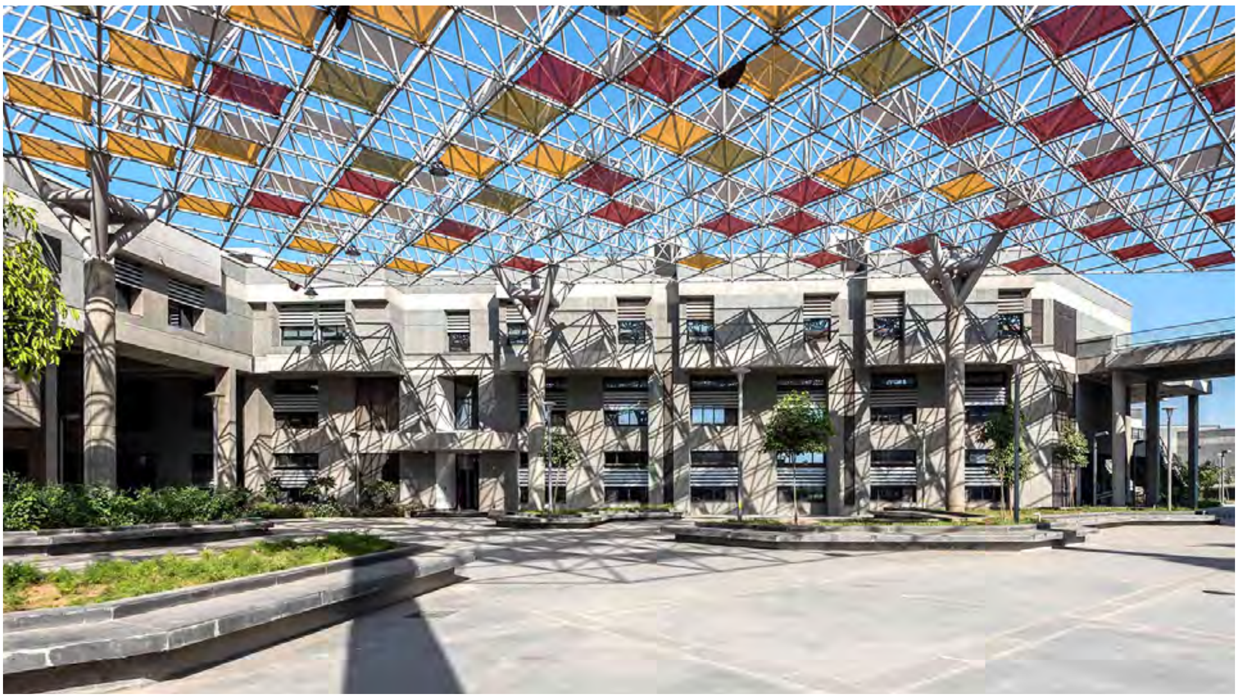
Chiller type: 305 TR X 4 Screw chillers and 600 TR Centrifugal chiller + 350 TR X 2 (For research park only)

Indian Institute of Technology, Gandhinagar

Total site area: 399 Acres
Established in: 2008
Climatic Zone: Hot and dry
Location: Gandhinagar

Microclimate enhancement

The campus has invested heavily in plantation since its inception. A central pergola acts as a shading device in the middle of the academic block and is amongst the most striking features of the campus. The areas between the academic and administrative buildings are also dotted with trees that cool the buildings and shield open spaces from the harsh Gandhinagar sun.



The central pergola acts as a shading device in the middle of the academic block

The strategy is carried onto the building as well. The guesthouse utilizes multiple strategies that enhance microclimate through the use of permeable surfaces, shaded courtyards, and vertical and horizontal vegetation. All these factors have played a part in bringing down the ambient temperature around buildings.

Vertical gardens have been used as a strategy that wraps around the building while shading and cooling the building facades and creating a cooler microclimate.

The narrow courtyard along with a pergola keeps the courtyard shaded while the evapotranspiration from the vegetation works to cool ambient air.

Pathways around the buildings have been kept permeable wherever possible so that less amount of heat gets absorbed by surfaces hence cutting down on the urban heat island effect.

Building form

The new hostel blocks are one of the latest additions to the campus. The hostel blocks have employed courtyard planning in their design which prevents direct sun rays from reaching the courtyards. The width of the courtyards has been kept between 10–14 metres while the height of the buildings is kept around the same, ensuring a 1:1 ratio between building height and courtyard width. This results in buildings offering shade to each other. Additionally, the courtyards and pathways have trees and other vegetation in them, helping create a cooler microclimate.

The proportions of the buildings and the distances between them have been kept as such that they allow for courtyard shading and mutual-building shading to take place.

Envelope and material

The building blocks have been aligned towards North and South so that most of the building surfaces and the habitable rooms face towards them. The lesser used spaces such as common toilets, corridors, staircase wells and elevator shafts have been constructed on the Eastern and Western sides so that they act as a buffer against the harsh setting and rising sun.

The roof is a major source of heat gain in the interiors and plays a significant role in low-to-medium rise buildings. Multiple buildings in the campus, including dining halls and the guest house, utilize white tiles to create a cool roof that shields the building's interiors from the harsh Gandhinagar sun. This cool roof technique can help reduce internal heat gains to up to five degrees and play a factor in bringing down the cooling load of buildings. This is especially useful for the dining room as it does not rely on refrigerant-based cooling and has a tall ceiling with an external roof. Hence the cool roof ends up benefiting a large number of people who end up eating here.

Many buildings in the campus use cool roof technologies to shield the top floor from blistering Gandhinagar sun.

Non-refrigerant based cooling

The dining halls utilize passive down-draft evaporative cooling that allows the cooler air to fall from the tower without the use of a fan. The system consists of a central tower of 20–25 metres height, with openings at the top in order to capture the higher wind velocities that flow at that height.

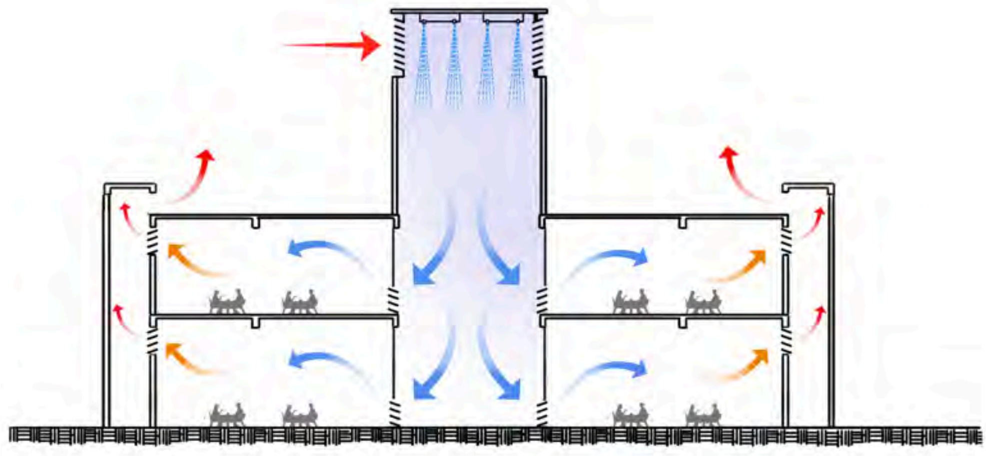
Air gets filtered at the top of the tower

Air enters from a central tower placed right into the centre of the building and gets filtered by the dust/net screen. A fine water mist is generated on top of the tower with the help of micro ionizers that convert water into tiny droplets.

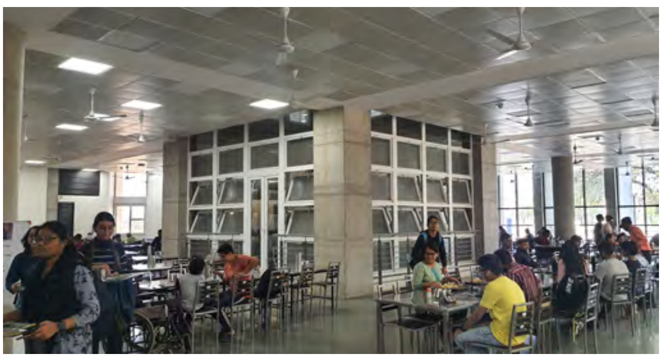
Fine water mist generated at the top of the tower by micro ionizers

This mix of cooled air and tiny water droplets being denser than warmer air rushes down the tower. The water evaporates hence leaving the air cooled and denser in comparison to ambient air. The system can be as effective as bringing down the internal temperatures by up to five degree centigrade.

Figure 19:The cooled air, being denser, enters the dining space area



This air exits through windows that are placed at the bottom of the tower and open into the dining space. Once the air enters the dining area, it absorbs the heat from its surroundings and exits through shafts placed around the dining hall.



The interior of the dining space with entry points through which cool air enters the space

Refrigerant-based cooling

Total tonnage of refrigeration: 1,820 TR (for academic and hostel blocks) + 700 TR (for the research park only)
Total air-conditioned area: 610,165 sq. ft.(Comprising of academic, hostel and research park buildings)
Refrigerant used: R-134a
Chiller type: 305 TR X 4 screw chillers and 600 TR centrifugal chiller + 350 TR X 2 (for Research Park only)

Co-efficient of performance of chillers installed:
305 TR screw chiller: 5.4
600 TR centrifugal chiller: 5.3

350 TR screw chiller: 6
Air or water cooled: Water cooled system
Two way pipes or four way pipes system: Two way piping system

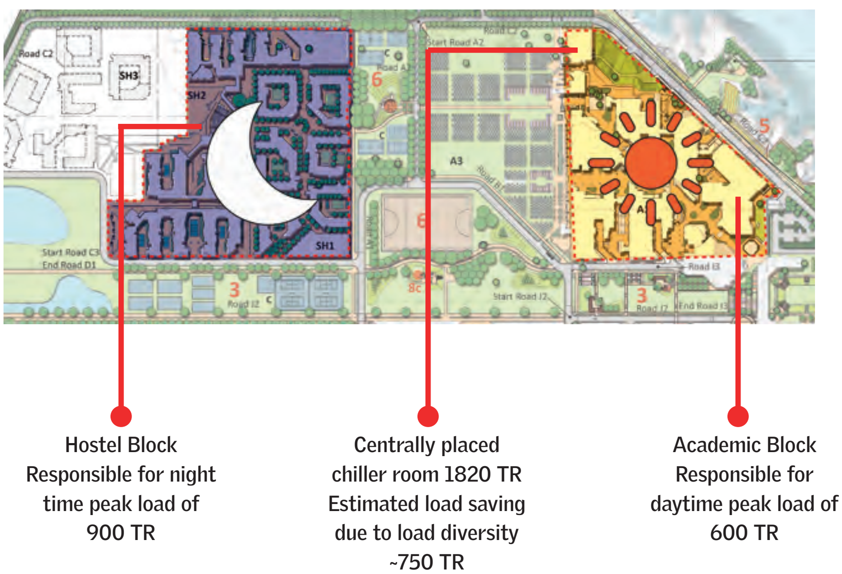
Fan Coil Unit(FCU)/Air Handling Unit(AHU): Majorly, AHU's have been installed in the system.

Building management system: Chiller plant manager exists for chiller plant. Variable frequency drives have been installed in the 600 TR and 350 TR chiller. Apart from that all secondary pumps (academic, hostel and research park) have VFD starters. centrifugal chiller and the plant room.

Individual controls: The air conditioner remotes installed in the hostel rooms have a set point temperature of 27 degree centigrade. Students cannot decrease the temperature below 27 degree centigrade. This has been done to ensure that students do not end up misusing the air conditioners.

Cooling swap/load diversity:
The cooling load is distributed amongst the academic and hostel blocks inside the campus. The academic blocks function primarily in the daytime while the hostels function at night. From April to mid-October, the air conditioning of the academic blocks function from 8 am to 7 pm while the HVAC works from 9 pm to 6 am in the hostels.

Figure 20: Hostel blocks function primarily at night while the academic blocks require cooling primarily during the day



As a result the peak night time cooling load requirement can be as high as 900TR which majorly includes the hostel block and a few night time functions in the academic block and labs. The daytime peak cooling requirement is above 600 TR. The centralized generation of chilled water in the district cooling system installed in the campus ensures that these two different loads is fed by the same plant placed centrally under one of the academic blocks. This 1820 TR (this includes extra chillers for backup) plant feeds the hostels at night time and academic functions in daytime. Close to a 1000TR of the chiller capacity has been saved in the campus due to the load diversity made possible due to the current district cooling system.

Another major advantage that centralizing the chilled water production has provided the campus with is the possibility for them to install higher efficiency equipment's eventually leading to energy savings as well.

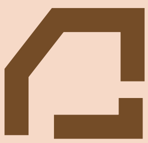
GUJARAT VIDYAPITH, SABHAKHAND
AHMEDABAD

TOTAL SITE AREA **1340 Sq.mt**	CLIMATE ZONE **Hot and Dry**
BUILD IN **2007-2008**	LOCATION **Ahmedabad, Gujarat**

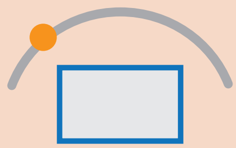
PASSIVE MEASURES APPLIED

Reduced cooling demand through passive measures employed

Microclimate enhancement

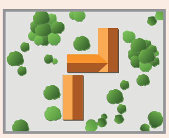


Building form



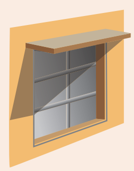
Envelope/Material

Plantation on site

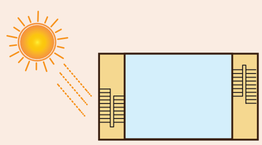


Caption

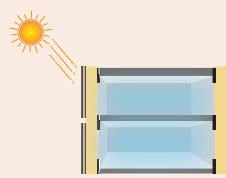
Shaded windows



Buffer zones

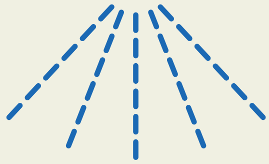


Double skin facade

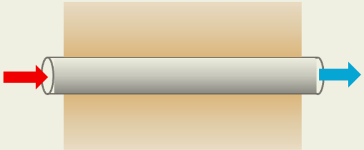


ACTIVE COOLING TECHNOLOGIES APPLIED

Low impact cooling

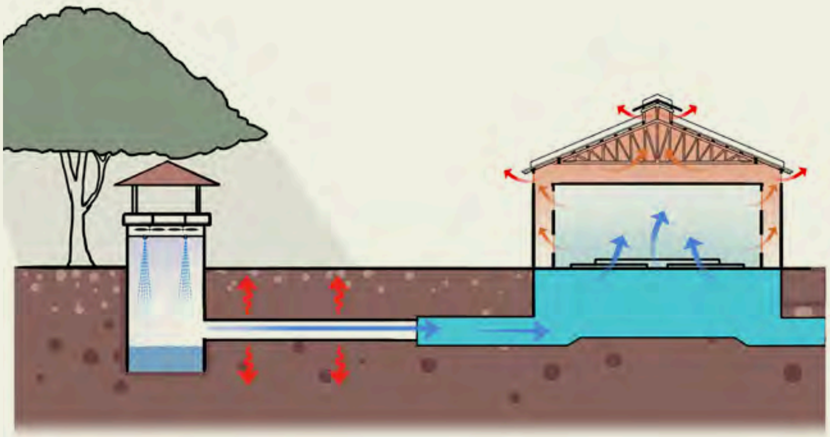


Evaporative/ Misting cooling system



Earth tunnel/wells

Combination of evaporative cooling and earth air tunnels



Gujarat Vidyapith: Sabha Khand (Auditorium) building

Total built-up area: 1,340 sq mt
Constructed in: 2007–08
Climatic Zone: Hot and dry
Location: Ahmedabad

The Gujarat Vidyapith campus lies in the heart of Ahmedabad and utilizes many sustainable features. The Sabha Khand building inside the campus is a 1,340 sq mt built up area auditorium that can seat up to 700 people and has a unique air cooling mechanism that provides thermal comfort without the use of refrigerant-based air cooling.

Microclimate enhancement

The Sabha Khand building sits amidst lush green plantation inside the Gujarat Vidyapith Campus that brings down the ambient air temperature.

The auditorium is surrounded by trees which, apart from creating a microclimate, also ends up shading the building itself by acting as the building's first shield of defence against the sweltering heat that Ahmedabad is subjected to.

Envelope and material

The building's next defence is in the form of an external skin which protects the interiors of the building from direct sunlight. A covered verandah runs around the hall on three sides. The outer wall of the verandah is made of bricks and jaalis that take the brunt of the direct sunlight, thus acting as a double facade for the inner auditorium space and stopping it from getting heated up. The structure in itself is load bearing and made of thick walls, providing the building shell with a layer of thermal mass that delays the heat transfer from the outside to its interiors. People gather in this verandah before they enter the main hall. The verandah also acts as a buffer space between external temperatures and the main hall.


ABHIKRAM

A double skin facade protects the interior spaces by adding a buffer zone

The double skin design is applied to the roof of the building as well. A false ceiling separates the roof of the building from the interiors. The roof blocks the harsh rays of the sun and the space between the roof and the false ceiling acts as a buffer for the heat.

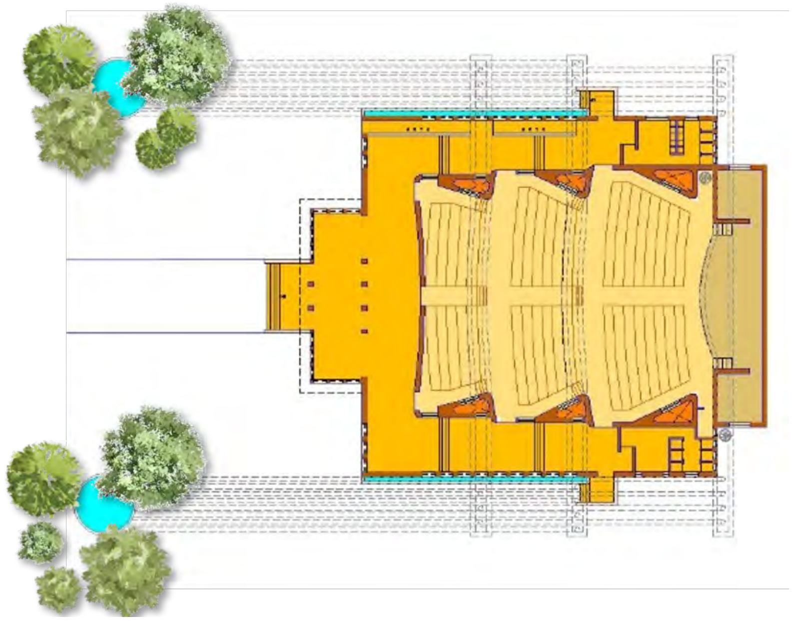
Non-refrigerant based cooling

The building uses a combination of evaporative cooling and earth tunnels to keep the temperature of the interiors within a comfortable range.

Entry point of air is through a well that is shaded by heavy plantation

There are two wells near the auditorium building from where the journey of the air begins. The wells are covered by a roof and are surrounded and shaded by heavy vegetation around them. This creates a microclimate which reduces the heat gain in the wells.

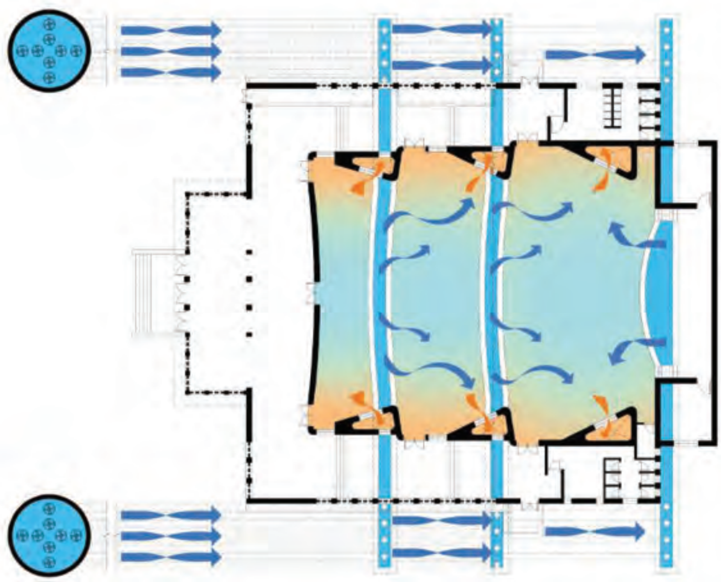
Figure 21: The air is cooled within the external shaded wells with the help of spray of water



ABHIKRAM

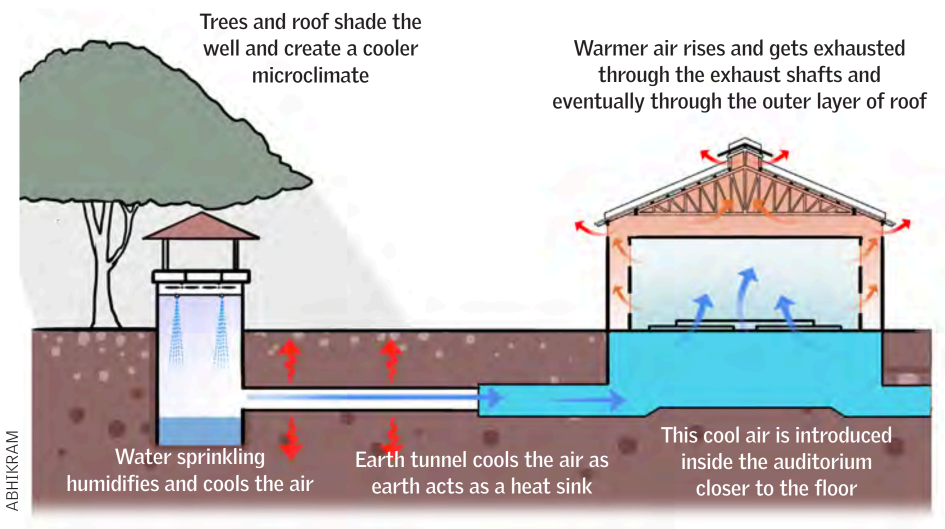
The air is cooled within the external wells by passing it through a spray of water which humidifies it and brings down its temperature. This air is then made to pass through pipes that are laid 4–6 metres below the ground. The temperature at this depth below the earth is relatively stable around 24–26 °C. This earth acts as a heat sink for the warmth present in the air, thus cooling it without humidifying it.

Figure 22: The air from the well passes through underground pipes before entering the auditorium building



ABHIKRAM

Figure 23: Schematic of cool air entering the auditorium from multiple inlets.



The cool air that is produced is introduced in the auditorium from various points close to the ground. As cold air is denser, it remains closer to the floor. Once the cool air starts warming due to interactions with people and equipment, it gets lighter and is exhausted through strategically placed exhaust shafts. This warm air is released in the space between the roof and the false ceiling. This is then released into the atmosphere from openings on top of the roof.

Warm air gets exhausted through openings in the roof.

Interior of the 'sabha khand' auditorium

INDRAPRASTHA INSTITUTE OF INFORMATION TECHNOLOGY, DELHI

TOTAL SITE AREA
25 Acres

ESTABLISHED IN
2008

CLIMATE ZONE
Composite

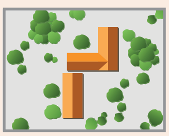
LOCATION
Delhi

PASSIVE MEASURES APPLIED

Reduced cooling demand through passive measures employed

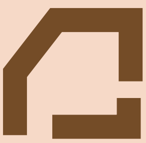
Microclimate enhancement

Plantation on site



Permeable pavement

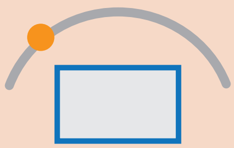
Pervious surfaces inside campus



Building form

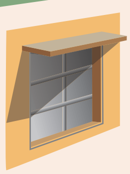
Mutual shading

Orientation

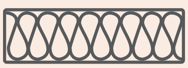


Envelope/Material

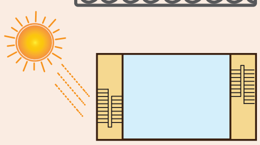
Shaded windows



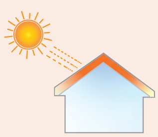
Insulation



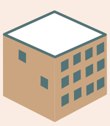
Buffer zones



Insulated roofs



Minimal fenestrations in East/West



ACTIVE COOLING TECHNOLOGIES APPLIED

Refrigerant based cooling

District Cooling System

Total Tonnage: 810 TR

Total Air-Conditioned area:
Phase 1: 24,891, Phase 2: 24,814

Refrigerant used: R-134a

Chiller type: 165 TR X 2 and 240 TR X 2 Screw chillers

Indraprastha Institute of Information Technology, Delhi

Total site area: 25 acres
Established in: 2008
Climatic Zone: Composite
Location: Delhi

Microclimate enhancement

The campus was designed in a way that only nine trees in the whole site were cut down while the rest were saved and the buildings designed around them. Plantation has been carried out since the inception of the campus to enhance its microclimate. Additionally, permeable pavements have been integrated inside the landscape to counter the urban heat island effect.


Permeable pavements and surfaces inside the campus

Building form

Despite the odd shape of the site, the buildings are majorly oriented towards the north and south so as to cut down the heat gains into the interiors. The eastern and western facades offer a rather blank face towards the respective directions while most of the windows have been placed towards North or South directions.


There is a stark contrast in the number and sizes of the fenestrations in the Eastern/Western Facades vs. those facing North/South

The library building in particular, has been designed to incorporate cut-outs so that no window directly faces the west direction, while the indentations in the design allows windows to open towards the North and South.

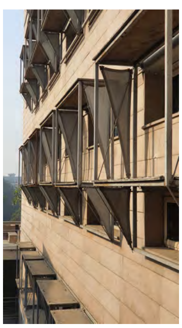

E-W facade acquires no fenestrations to minimize heat gains

The library building is window-less towards the west so that the harsh Delhi western-setting sun can be avoided. Meanwhile, the ventilation of the building opens towards the northern and southern directions that are much easier to shade.

Envelope and material

The first phase utilized a combination of red brick and dry cladding of stone for the walling. The gap between the stone and brick wall acted as a buffer to stop direct radiation. The second phase improved upon this by using AAC blocks to resist the heat. The insulation material for the roof was also shifted to PUF insulation from the initial 50mm XPS used in the first phase. White mosaic tiles have also been used over the insulation to reject and reflect direct sun rays falling on the roof.

The window shades are amongst the most iconic features of the campus and have been intricately designed. They are set apart from the main building envelope by a gap between the stone façade and the window shading structure. This has been done so that the heat gained by the shading structure is not transferred to the interiors of the building easily. Light-coloured fabric has been utilized to reject heat from direct sunrays falling on them while absorbing as less as possible owing to their lightness.




The glass used for the windows is high-performance double-glazed-units with vacuum to offer good insulation.

Refrigerant-based cooling

- **Campus size:** 22.4 Acres
- **Number of buildings:** 18
- **Total tonnage of refrigeration:** 810 TR
- **Total air-conditioned area:** Phase 1:24,891, Phase 2:24,814
- **Refrigerant used:** R-134a
- **Chiller type:** 165 TR X 2 and 240 TR X 2 screw chillers
- **Co-efficient of performance of chillers installed:** 5.53

- **Air or water cooled:** Water cooled system. Grey and black water generated in the campus is treated and used in water cooled system.

- **Two way pipes or four way pipes system:** Two way pipes

- **Fan coil units (FCU)/air handling units (AHU):** The campus has a mixture of air handling units (AHU) and fan coil units (FCU). The initial phase of the campus had one air handling unit serving four rooms. This was disadvantageous and wasteful as all four needed to be cooled even if only one was needed for use. To solve this, the second phase of construction was planned in a way that the individual faculty rooms and labs now have FCU's so that air-conditioning can be shut off in unoccupied rooms.

- **Variable air volume:** All AHU's have been fitted with variable air volume devices.

- **Individual controls:** The hostel rooms have individual control systems but the remotes are set in a way that the temperature cannot go below 26 degree Celsius.

- **Cooling swap/ load diversity:** The cooling load is distributed amongst daytime functions (such as use in the academic blocks) and night time functions (hostel blocks inside the campus). The air-conditioning in the academic blocks runs from 8 am to 6 pm while the HVAC works from 8 pm to 4 am in the hostels.

The phase 1 of the building has a 330 TR chiller plant, in the first phase, the peak night time cooling load requirement can be 300TR which majorly includes the hostel block. The daytime peak cooling requirement—close to 300 TR—is highest during the day and mainly serves the academic block. The centralized generation of chilled water in the district cooling system installed in the campus ensures that these two different loads are fed by the same plant. This diversity in load saves close to 270 TR of chilled installed capacity.

The phase 2 of the building works on a similar principle. It has a 480 TR chiller plant, for the buildings built in second phase, the peak night time cooling load requirement can be 400TR which primarily serves the hostel block. The daytime peak cooling requirement is close to 350 TR and mainly serves the academic block. Thus, this diversity in load saves close to 270 TR of chilled installed capacity in the second phase as well.

In total, close to a 540 TR of the chiller capacity has been saved in the campus due to the load diversity made possible by the current district cooling system.

NIIT UNIVERSITY, NEEMRANA

TOTAL SITE AREA
100 Acres

ESTABLISHED IN
2009

CLIMATE ZONE
Composite

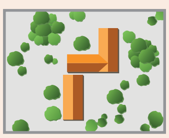
LOCATION
Neemrana, Rajasthan

PASSIVE MEASURES APPLIED

Reduced cooling demand through passive measures employed

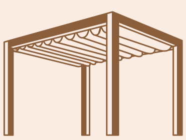
Microclimate enhancement

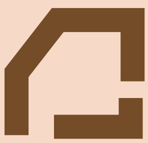
Plantation on site



Permeable pavement

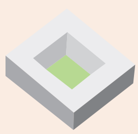
Open area shading



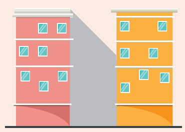


Building form

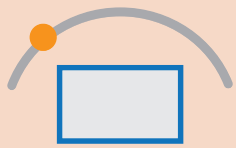
Courtyard



Mutual shading

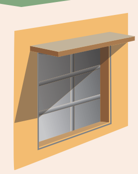


Orientation



Envelope/Material

Shaded windows



ACTIVE COOLING TECHNOLOGIES APPLIED

Low impact cooling

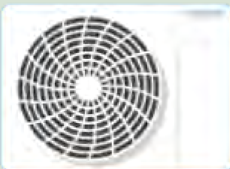
Earth tunnel/ wells

Evaporative Cooling Pads

Earth Air Tunnels

Entrance tower to earth air tunnels

Refrigerant based cooling



HVAC System

NIIT University, Neemrana

Total site area: 100 acres
Established in: 2009
Climatic zone: composite
Location: Neemrana, Rajasthan

The campus lies in the Alwar district of Rajasthan somewhere in the middle of Jaipur and Delhi, the built-up area of the first phase of the campus is close to 40,500 sq m. The campus is designed as a compact low-density settlement largely inspired by the local architecture of Rajasthan.

Microclimate enhancement

The campus has conducted heavy plantation drives during the course of its existence and this has not just been limited to spaces inside the campus but also outside the site through plantation drives. The results of this are clearly visible and it has contributed significantly towards bringing down temperatures as well.

Images of site plan: 2014, 2015, 2016, 2020 showing progression in plantation around the buildings.

The tree plantation drives have transformed the sandy area into a green haven that forms the first level of defence against the blistering heat by creating a cooler microclimate around the site.

Additionally, the materials chosen for the pathways are kept as permeable as possible. Hard, non-permeable surfaces absorb heat and slowly release it, making the atmosphere around warmer. To avoid this 'urban heat island effect', permeable pavers have been used. Owing to them having voids (and hence, lesser area exposed to the sun), these pavers absorb lesser heat and the grass growing in the voids helps with evapotranspiration, thus cooling the surface. A pergola has been placed over the pathways with non-permeable surfaces exist.

Impermeable pathways and shaded walkways have reduced the amount of heat that is absorbed by ground surface.

Building form

The institute adopted a narrow courtyard typology for the campus buildings. This helps in keeping the courtyards shaded as well as the buildings shade each other. The buildings are also oriented majorly towards the North and South directions so that they gain less heat.

The distances between the buildings are kept narrow to ensure that the buildings mutually shade each other.

Non-refrigerant based cooling

The earth tunnel system used in the campus is its most prominent feature. Four wind towers catch the ambient wind, the louvres from where the air is made to enter is kept at a few metres above the ground to avoid the pollutants lurking close to the surface. The air is then filtered at the base of the towers through bag filters to prevent dust and insects from entering the system.

Wind intake towers

Cement pipes of diameters ranging from 1 to 1.2 metres have been installed at a depth of four metres below the ground and have a length of approximately 90 metres. The air runs through these pipes and exchange heat with the surrounding earth which remains at a constant 25-27 degree centigrade even when the ambient temperature has reached its peak.

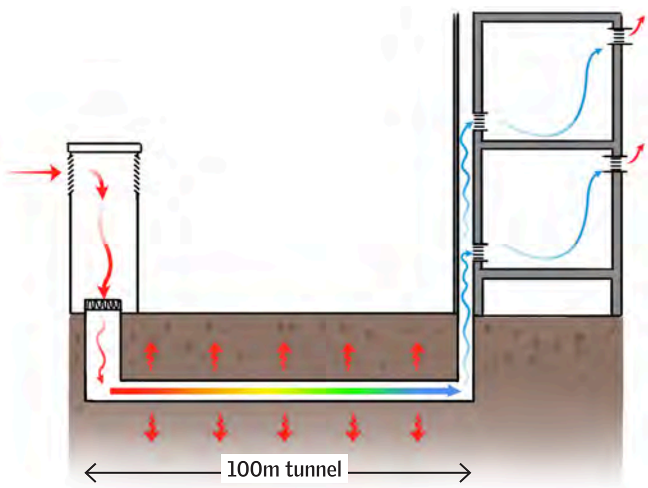
View inside the earth air tunnel

The system utilizes 3 stages of cooling:

Phase 1: cooling using earth air tunnels:

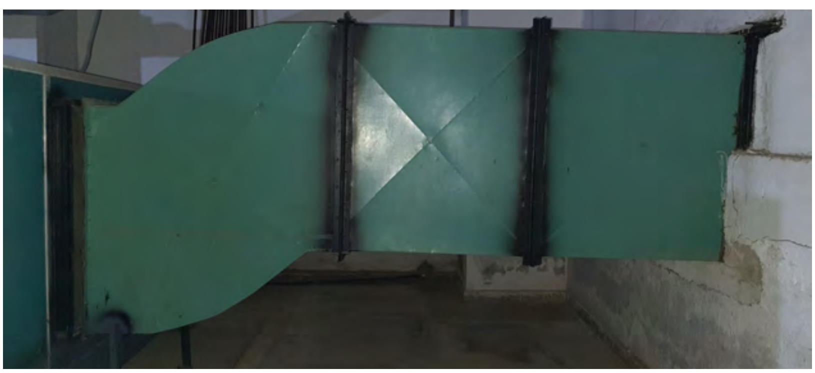
The air, while passing through the earth air tunnels, gets cooled. This loss in heat could be as high as 10–12 degree Celsius during the start of the summer season. The effectiveness of this cooling however gradually goes lower during the peak season. This stage consists of three tunnels with 1.2 metre diameter (18,000 CFM) and five tunnels of one metre diameter (12,000 CFM).

Figure 24: Air travels through earth air tunnels for around a hundred meters before being introduced into indoor spaces.



Phase 2: cooling using evaporative cooling.

The air is then passed through cellulose pads of 200 mm thickness. These pads are made of water absorbing acetate paper in a honeycomb design and have an efficiency of 90 per cent. The honeycomb Celsius through evaporative cooling. The effectiveness of the evaporative cooling is dependent on the ambient air conditions, hence this phase of the cooling system is less effective in the monsoon when the ambient air is saturated with moisture.



Duct joining the exit of earth air tunnel with other cooling stages

In the monsoon season, the fresh air quantity from the tunnels is reduced and a chilled water cooling coil is also used in order to further cool and dehumidify the air. The requirement for the third stage is dependent on the ambient air conditions and the decision to switch it on is taken considering the response of the occupants.

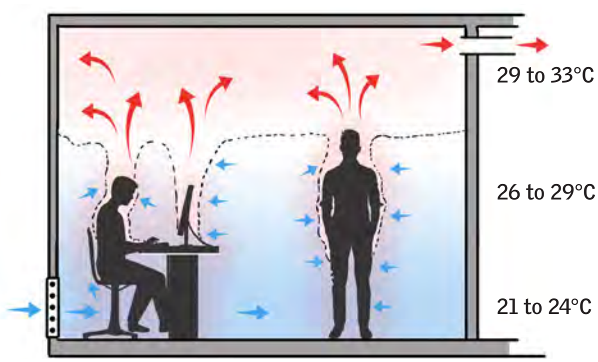
Displacement ventilation

The air is introduced in the room close to the floor with the help of specially designed perforated plates with holes of 3–4 mm in diameter spaced so as to provide air velocity of approx. 0.25 metre per second.

Inlets for conditioned air inside the building spaces.

This air spreads slowly across the room similar to how water fills up a tank. The cold air becomes warmer as it encounters a heat source such as humans or equipment. This warmer air rises along the body and creates a movement which is good enough to make the person comfortable. This method of ventilation requires only 1/4th of air quantity as is required for normal air distribution from the ceiling.

Figure 25: Air pattern of displacement ventilation



The air is exhausted through vertical risers on the outer face of the room via conventional grilles. The natural buoyancy of heated air is sufficient to carry the air to the terrace for exhaust.

Interior of classroom with an inlet in the bottom left and outlet at the top right

The air is then exhausted cowls at the top of each shaft.

Warmed up air gets exhausted through the shafts and exits through cowls

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The Ministry of Environment, Forest and Climate Change (MoFCC) foresees an astonishing 11-fold surge in the demand for cooling in buildings by 2037–38.

The Cooling Web is a guidance document and a compilation of case studies that brings out a range of cooling solutions that are diverse and comprehensive and do not rely on conventional energy-guzzling practices. This involves measures to enhance microclimate, thoughtful designs for building envelopes, judicious selection of material, and context-specific cooling approaches. These solutions blend traditional wisdom on passive design with modern techniques and provide optimized solutions so that energy consumption is minimized. These solutions are also a guide towards achieving a rational and climate-appropriate cooling ecosystem that not only ensures resource efficiency but also maintains thermal comfort for building occupants.

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