

Course Name: Bioclimatic Architecture: Futureproofing with Simple and Advanced Passive Strategies

Professor: Dr. Iyer Vijayalaxmi Kasinath

**Department of Architecture,
School of Planning and Architecture, Vijayawada**

Week: 12

Lecture 04

Recap

and

Conclusion

Hello, dear students. So today, we come to the close of this course, and in this last lecture, as part of this course, we will look at what we have learned in this course. So, what are the lectures, and what is the gist of what we have learned? That is what we will see today. So, we saw what bioclimatic architecture is. So, bioclimatic architecture is defined as the design and construction of buildings that consider environmental conditions and use the environment to benefit the needs of the users.

Bioclimatic architecture and buildings built with due bioclimatic considerations respect the environment. Bioclimatic architecture is a way of designing buildings based on the local climate, with the aim of ensuring thermal comfort using environmental resources. They must also blend into natural surroundings. And further in this lecture, we also saw the other things that bioclimatic architecture considers. And how we have to respect the local climate and how our buildings must respond to the local climate.

Then we also saw passive strategies. So, what is the meaning of passive strategies? So, passive strategies refer to the set of design approaches that focus on utilizing the natural environment to provide heating, cooling, ventilation, and lighting to a building. The pursuit of human comfort shows that the flaw of seeking stability is inherently dynamic to the system.

We evolved in environments that varied in temperature, humidity, light, and wind conditions. Our activity levels, such as yours, what we do during a particular period,

whether we sleep, walk, sit, or stand; clothing levels; our state of mind, mood, and other factors can also change either inadvertently or deliberately based on the conditions that we provide for a given house. Environmentally responsive passive solar buildings they operate within prescribed limits of comfort.

The climate-responsive approach to architectural design includes the integration of the following parameters that I have shown here. So, the simple passive architecture includes orientation, building massing, which means the thermal mass, thermal zoning, wind flow, meaning wind speed, wind direction, and shading devices. So, what is all about shading devices? The type of shading devices that we use, the dimensions of the shading devices, and the building material specifications.

Based on this, we can also use low embodied energy materials, but we did not go too much into low embodied energy materials because that is not the actual focus of this course, and that itself is a course by itself. Then we also saw What are all the ways in which we can design our building in a passive manner? So, passive building design will include protecting the building from heat and gaining heat from the sun in places that are cold.

So for cold places, we have to design in such a way that we gain heat from the sun. And heat protection must be in such a way that in warm places, we can use these strategies. And some places can have heat rejection strategies also. So if we look at heat protection, how do we protect a building from becoming warm? We can do it by insulating the building.

We can have windows insulated. We can stop the infiltration of cold air if it is an air-conditioned building. We should also have solar control. So how will we have insulation? We can have insulation with organic material, mineral material, oil-derived material, or any other like agro-based material or animal-based material like sheep wool, which also comes under organic.

Or it can even be some phase-change material. We can have insulated windows with insulated panes and insulated frames. Solar control can happen by permanent shading features like cantilevers, vertical fins, egg-crate devices, or So these are the ways. We can have fixed shading devices, or we can have movable or adaptive shading devices.

We can also have solar control glazing by means of using glass or films that will support solar control. Then, in places where we need to gain heat, we can have direct solar gains. We can have solar buffer spaces like winter gardens or double facades, or we can have indirect heat gain in the form of trombe walls, water walls, attached sunspaces, thermosiphons, and so on. When we need to reject heat through ventilation, we can use comfort ventilation. Or we can use night flushing or nocturnal ventilation.

We can also have evaporative or adiabatic cooling through direct or indirect means. So, we have seen direct evaporative cooling in this course. We can have ground cooling, which we have seen in this course in the form of earth berming as well as Earth-air pipes. So, these are the two techniques that follow ground cooling.

Then, we can have hydrothermal, deep lake, ocean cooling, and radiative cooling. We further classified and split the passive techniques into the following components. We saw what advanced passive techniques are classified as, and we also saw what the simple passive techniques are. So, simple passive techniques are techniques that do not require any apparatus, gadget, contraption, or any equipment to store and dissipate heat. You do not require any contraption.

So no contraption is required. So if you have to orient a building in a particular way or layout, you don't need any particular equipment or any other constructional detail to be added in excess. Similarly, the spacing between buildings must be appropriate. Provision for air movement is necessary. Opening sizes should be appropriate.

Opening positions must be properly positioned with respect to the wind direction. We must protect the openings with shading devices. We should use appropriate walling material to gain thermal mass. The same applies to roof material. Protection from rain and stormwater is essential.

When it comes to advanced passive strategies, we saw passive cooling strategies and passive heating strategies. Under passive cooling strategies, we saw natural night ventilation, night flushing, or nocturnal ventilator cooling, named by any of these. We saw earth-to-air heat exchangers and evaporative cooling techniques. Passive downdraft evaporative cooling, radiant cooling pipes, green roofs, cool roofs, wind towers, double-

skin facades, and double roofs. We also saw passive heating in the form of trombe walls, solariums, water walls, and phase change materials.

Earth air exchangers, thermal siphoning, and also earth air tunnels as passive heating systems. Then we saw what the strategies for passive design are, that is, simple passive strategies. So, what are simple passive strategies? Strategies that do not require any contraption to capture energy. Store and dissipate heat in cold climates or to absorb heat in warm climates; it should not be able to absorb the heat.

So, these strategies do not require any kind of equipment, special buildings, special construction, or anything to make the indoor cooler in a warm climate. These are building orientation: north, south, east, west, long axis. So, how is the building oriented? Building organization and spatial layout. Whether you organize buildings in a grid form, if you have a campus development, whether you do it in a grid form or in a staggered form.

So, that is Building organization and spatial layout. The size of the opening matters. The volume of space matters. Opening details.

How do you design your windows or openings? The orientation of the opening. How do you protect the opening with sunshades, vertical fins, or louvers? What are your shading device strategies? Sometimes it can also be internal shading, like internal blinds.

Then water elements can be used in hot, dry places. And what is the nature of your building material? So these are some of the simple passive strategies. We have seen more than all of these. I am just listing a few of them.

Then we saw how you even classify climate. And we saw how Köppen is a widely accepted classification of climate. So Köppen has a first level of classification, which is climate classified as tropical, dry, temperate, continental, and polar. Then it has a second degree of classification, which is under tropical rainforest, monsoon, savanna dry winter, and savanna dry summer. Under dry climate, it has arid desert and semi-arid steppe.

Under the temperate classification, you have places with dry winters, places with no dry season, and places with dry summers. Under the continental classification, you have dry winters, no dry season, or dry summers. Then there is a third degree of classification where,

under dry, you have hot. Under temperate, you have hot summers, warm summers, and cold summers. Under continental, you have hot summers, warm summers, cold summers, and very cold winters.

Under polar, you have tundra and ice caps. So, how can we describe a climate based on this first, second, and third degree of classification? If you think a place is dry, arid, and hot, that place will be written as BWH. If you think a continental climate has dry winters but warm summers, then it will be written as D, W, B, and if you think a continental climate has dry summers and very cold winters, then it will be written as D, S, D, and so on.

So, this is how Köppen classifies, and therefore you have a number of sub-classifications of this first degree of climate classification as given by Köppen. And we also saw why we should understand the climate of a place. Only if we understand the climate of a place will we be able to classify the climate. In India, we classify climate based on either Bansal or as per SP 7 2005.

Which is more or less the same. It has very minimal differences. So Bansal classifies India to have a hot dry climate, warm and humid climate, moderate climate, cold and cloudy climate, cold and sunny climate, and composite climate. And the classification is based on the temperature and relative humidity combination of the place. Similarly, SP7-2005 also classifies the climate in India as hot and dry, warm and humid.

Moderate is called temperate in SP7. So even in my lectures, if I use moderate and temperate interchangeably, it is still the same. Because if you see the temperature and relative humidity, The definition of moderate and temperate is the same. Then it gives only one cold classification and not two as given by Bansal, and there is a composite climate.

So this is how the climate of a place is classified in India, and this is what we follow in India. Then we saw temperature. We primarily design buildings with an understanding of climate, and the main aim is to make the indoors comfortable. So we need to understand what you mean by comfortable. So what is thermal comfort?

So we saw thermal comfort is that state where at least 80% of the people in that condition or in that room feel comfortable. So there is no one definition or no one condition which

we can say is comfortable. It is a place or a situation where at least 80% of people say it is fine, it is comfortable. Then we say that environment.

That combination of temperature, relative humidity, and wind speed defines a comfortable condition. Then we also saw what are the factors on which thermal comfort depends. So there are personal parameters. So what are the personal parameters? Metabolic rate.

Now metabolic rate means what? It is the metabolism of a person. That depends on age, gender, and activity level. Now if a person is sitting idle, then his metabolic rate will be different. But if he is running on a treadmill inside a room, his metabolic activity will be different.

Metabolism also depends on age. The metabolism of young people, say a 24-year-old male, will be much higher compared to a 65-year-old male. Similarly, the metabolism of a 60-year-old male will be different from that of a 60-year-old female. Then we saw what the environmental parameters governing thermal comfort are. Under this, we saw air temperature, radiant temperature, air speed, and humidity; all of these will determine whether someone feels comfortable or not.

All of these in combination, not separately. So as a combination, how it is. So these factors are considered and incorporated into the steady-state heat transfer model, which was developed by Fanger. Then we also saw that perception also influences. What do people prefer?

I prefer a warmer condition. So that also determines whether I will feel thermally comfortable or not. How I feel? What is the humidity and air movement? Then we saw the behavior of people.

Controllability, adaptation, expectation. So all these I will also call acclimatization. A person who has stayed in Chennai will find Vijayawada to be alright, bearable. But a person who who has been a native of Shillong or Manali will find Vijayawada like a furnace.

That is what I call acclimatization. Then we saw how background also influences lifestyle, culture, and so on. How these are all the factors that influence thermal comfort. We saw thermal comfort models. What are the models of thermal comfort?

We saw the ASHRAE 55 and handbook of fundamentals. We saw the adaptive comfort model given by ASHRAE 55 in the year 2010. We saw the ASHRAE handbook pre-2005 model also. And we saw the California Energy Code 2013. We saw the European Union Code 2013.

We also saw IMAC, which is for Indian conditions. Under this, we saw that most of these models, all these models, either follow the steady-state method or are suitable for mechanical ventilation, which is basically HVAC in the Indian context is more about air conditioning and less about heating. And we also saw which models are suitable for naturally ventilated buildings. We also saw what the criteria are that make people feel comfortable in naturally ventilated buildings.

What options should be given to them? Like they should be able to operate the windows, have operable windows, and so on. So we saw all this in the lecture covering thermal comfort and thermal comfort models. Then we looked at simple tools to understand design with climate. First, we saw all the strategies, passive strategies.

Then we listed all the Strategies which are simple passive and advanced passive. Then we saw what climate is. How to understand climate? And then we need to overlap both of these to understand for which climate which strategy must be used.

For that, we have learned about the Mahoney's table. We saw the psychrometric chart. And we learned about Climate Consultant. We learned that the Mahoney's table is a set of reference tables which is used in architecture as pre-design analysis and a guide to climate-appropriate design. The various tables are used for

The various tables are used for data collection, thermal stress analysis, determination of necessary remedial actions, and specifications for sketch and detailed design recommendations. And this is named after the architect Carl Mahoney, who worked on this table together with John Martin Evans and Otto Koenigsberger. Otto Koenigsberger is the one who designed Bhubaneswar. So, the psychrometric chart is a set of tools that essentially is used for understanding the complex interplay between building design, climate, human comfort, and arriving at which strategy is going to push the boundaries of human comfort. Then we saw Climate Consultant.

To arrive at detailed design considerations for a combination of climate, metabolism, clothing level, activity, etc. Then, if we do not follow any of this, what happens? The buildings will become warm. Outside will also become warm. So we saw what is an urban heat island.

So, the urban heat island effect happens when we do not follow simple and advanced passive strategies, ultimately leading to increased energy consumption. We also saw what the causes of the urban heat island are. So, the common causes of the urban heat island are lack of vegetation, urbanization, having too many concrete surfaces, emission of a lot of heat, poor building morphology, very dense buildings in a particular place, surface material characteristics, anthropogenic heat, meteorological conditions, urbanization, air pollution; all of these can lead to the urban heat island effect.

This is what we saw. And we also saw what must be done to mitigate the urban heat island. We saw that we should have more trees and vegetation. Green roofs can help. Cool roofs can help.

Cool pavements can help. There should be smart planning and design of buildings. Then, after this, we saw that the bioclimatic chart and psychrometric chart. Under the bioclimatic chart, we saw that with a combination of air temperature and relative humidity, there is a particular set of conditions of air temperature and humidity where people will feel naturally comfortable.

People can extend their limits of how they feel comfortable to some extent. Beyond that, you need strategies. When you have conditions which are like this below the green zone, it means under those conditions people will feel very cold, and above these conditions people will feel very warm. And above this, it is almost impossible to be comfortable at all. Say at 45 degrees centigrade and 70% humidity, people will have huge health issues.

So the bioclimatic chart gave us a small glimpse of this and how we feel. We will feel sweaty here. We will feel very humid here and so on. And here you will have frostbite and so on. Then we saw what a psychrometric chart is.

So under the psychrometric chart, you have almost all of the climatic parameters integrated and represented as a graph. You have air temperature, wind speed, relative humidity, dew point, specific point, everything integrated. And it also says that normally this is the zone of climatic parameters where people will feel comfortable. But suppose the climate extends beyond this and the conditions are here, then for each of the zones, the psychrometric chart gives a strategy.

For example, for this zone, evaporative cooling is a good strategy. So, in this If the climate is in this zone, then there should be evaporative cooling. If the climate is in this zone, then there has to be a need for high thermal mass. Again, so this will require comfort ventilation.

In this zone, people will require high thermal mass along with night flushing or nocturnal ventilated cooling. Beyond this zone, conventional air conditioning is the only way to feel cool. So, and on this side, conventional heating is required. So, the psychrometric chart gives us a brief understanding of the conditions

under which various simple and advanced passive strategies can be used. So, we saw some simple passive strategies like orientation and form, where we explored the integration of natural elements and design strategies to create energy-efficient and comfortable built environments. We saw the importance of solar orientation, the role of building form in enhancing thermal comfort, and various strategies for optimizing orientation and form to promote sustainability. By understanding how they contribute to sustainability by reducing energy consumption and human well-being.

So we saw openings, house size of openings, position of openings, shading devices, window size, All of this shows how it helps. What are the types of shading devices? How are these positioned? And what is the impact with respect to energy consumption?

We saw all of these for warm, humid, and hot, dry climates. Of course, we also saw some case studies in India based on primary field studies as well. We saw both. Then we moved on to advanced passive strategies. Now, because of the earth's physical properties and potential for thermal conservation, earth shelters are defined as buildings that use the earth's mass against the building wall as an external thermal mass.

Under earth berm structure, there is minimizing heat loss and keeping the temperature indoors constant throughout the year. Because it works on the principle that the temperature of the soil 4 meters below the earth remains fairly constant throughout the year, and that temperature is actually the annual average temperature of that place. Annual average temperature of that place. So, this is the basic principle.

Then we saw what the ways are in which earth-burning can happen. We can have hillside-burning, we can have completely burned areas, we can have underground or earth-covered structures where no Only one part of the building is exposed to the outside, and so on. So we saw various types of earth-covered structures, their advantages, their limitations, and issues in having these kinds of structures. Then we saw what a solar chimney is.

So a solar chimney is a natural way of ventilating a building using passive solar energy. It is actually a vertical shaft utilizing solar energy to enhance the natural stack ventilation through a building. A solar chimney operates on the principle of buoyancy or the stack effect. The chimney is coated with black material to absorb maximum sunlight, with openings at the top for hot air exit and at the bottom for room air intake. The chimney can also be used to recirculate hot air for heating in colder regions.

It can be applied by integrating it into a building as a natural ventilation device. Sunrooms can also be designed to function like a solar chimney. This can be integrated into buildings as a heating device too, in places which are very cold. Then we saw the roof pond system. So, under the roof pond system, water evaporation is one of the most important elements that is used in the roof pond system.

Now, due to air exposure, the water in the roof pond evaporates. Then, heat absorption also happens. In order to evaporatively cool the surrounding air, energy must be extracted. This is a natural and energy-efficient cooling, which is produced by the cooled air circulated within the building. How does that happen?

On a summer day, the roof pond, which is a water pond on the roof. This is covered. So, in summer, when this is covered, especially with the reflective surface, the heat gets reflected, and the coolness of the water ensures that the indoors remain cool. At night, what happens? This cover is removed, and

The water, which has become warm because of having absorbed the heat from the room, throws away its warmth to the night sky. And in that process, the water becomes cool. The water becomes cool. And during the day, you cover the cool water, and that cool water will chill the rooms below. So, in this roof pond system, there is one major thing that we use, which is using the night sky as a heat sink.

So the night sky is used as a heat sink in a roof pond system. The system we saw was high-performance glazing and multi-pane glazing. So double-glazed windows have been commonly made since the 20th century. This is done by employing the space between the panes as a thermal barrier. They help to minimize energy consumption in buildings and while also boosting material insulation capabilities. There are four distinct configurations of double-glazed panes with an air gap, including transparent, absorbent, low-E, and reflecting glass. Reflecting glass, in particular, has the ability to save up to 72.9% of energy use which equates to a 50% decrease in heat losses over single-glazing glass. Double-glazing windows have 2.5 times lower heat transfer rate than single-glazed windows, and that results in about a 50-67% reduction in heat input in warm areas.

Then we saw what a double roof is. So a double roof typically refers to a construction technique where there are two layers or levels of roofing. Basically, a structure located just above the roof shades the roof and allows the warm air, which builds up between the roof and the structure, to move and escape. So in the double roof, there is an existing structural roof. And on top of that roof, there is another roof.

This roof protects this from direct solar radiation. And also, because there is direct solar radiation on the double roof, there is heat buildup here. But because of this gap between the first and the second roof, the hot air is flushed outside continuously. So basically, the structure is located just above the roof, shading the roof and allowing the warm air to escape. This is mostly equipped in hot climates as a passive cooling strategy.

A double roof system involves two separate roof layers or skins or structures. The upper layer is typically lightweight, made of materials like timber, thatch, metal with wood decking or metal sheet covering. The lower roof layer often uses regular roofing material like concrete. Then we saw what a cool roof is.

So, a cool roof is a roofing style that features a light-colored outer membrane or coating, such as white, light, or gray pigment. Unlike traditional dark-colored roofs, a white roof system reflects a substantial amount of sunlight and quickly releases any heat collected by the roofing membrane or coating. A lower roof temperature implies less heat enters the building through the roof membrane or coating. Lowering this can actually increase your comfort inside because the inside can become cool. Comfort inside because the inside can become cool.

Also, the life of the roof can be extended. So cool roofing is an effective approach for lowering building energy expenditures, greenhouse gas emissions, and the urban heat island effect. Cool roof membranes or coatings can be created from a number of materials such as polyvinyl chloride, thermoplastic polyolefin, EPDM, ethylene propylene diene terpolymer, and so on. They include unique pigments that reflect sunlight and protect the roof from ultraviolet rays.

Then we saw the concept of passive downdraft evaporative cooling. The concept of passive downdraft evaporative cooling is actually an old concept which can be traced to the Middle East, where they had wind towers, wind catchers, or wind scoops to create natural ventilation within the buildings. These towers were referred to as Malkaf or Bawadgir in Egypt and Iran-Iraq, respectively. So, according to Bernoulli's theory, these towers rise above building roofs and draw air into the inside through pressure differences, which are caused by wind blowing over wind scoops and the building. Passive downdraft evaporative cooling uses a direct evaporative cooling system that uses the adiabatic humidification principle to cool the air

at the top of the tower. The downdraft airflow depends only on buoyancy force in the absence of wind, and in this instance, it is necessary to use fans to enhance their distribution. These can be integrated with dehumidifiers in a hot and humid climate. So, depending on the climate, there can be constructions placed here, which can be shower heads, mistifiers, or you can have chilled water pipes, or you can have a combination of chilled water pipes and mistifiers.

So we saw this PDEC passive downdraft evaporative cooling as well. Then we saw what root zone treatment is. So root zone treatment is a kind of water surface, and this is above the substrate. In this, the black water is let into the artificially created wetlands, and these artificially created wetlands have a unique kind of flora. These are voracious eaters, and they consume a lot of nitrogen.

So this concept is used for root zone treatment, where black water is treated without any use of energy. This promotes the ecosystem, and this can be used where evaporation is not a major concern. The only disadvantage it has is that it needs a lot of space. And these wetlands are further classified as horizontal flow and vertical flow constructed wetlands. And this consists of a sealed basin with a porous substrate of rock or gravel.

So we saw this system, which does not use any electricity and yet processes the human waste or black water. From a building in a very sustainable manner using certain plants. Then we saw a solar collector. What is a solar collector? So a solar collector is essentially a flat box, which is made up of three major parts.

A transparent cover, tubes that deliver, and an insulated rear plate. The solar thermal collectors operate By sucking in fresh outside air and passing it through a maze of black metal with a specific selective coating that collects far more heat than it produces. This warm air is then blasted into the house by a solar-powered fan. The next technique which we saw is the trombone wall.

Now, a trombone wall is a well-known example where the incident solar radiation on the system is captured by its absorbent surface and stored by means of its high thermal mass. After conduction, the thermal energy passes through the wall and is then released into the interior through convection, long-wave radiation from the interior surface, and And air thermo-circulation. The air thermo-circulation is controlled by appropriately activating vents and takes place in an air gap created between a huge wall and a glazed facade that is intended to prevent long-wave radiation from the outside wall surface to the internal environment. The next room receives thermal energy from the airflow rate

That is heated in the air gap due to thermo-circulation. Generally speaking, thermo-circulation is important because, in some conditions, an airflow inversion may exacerbate

the heat losses. An extension of this is the water wall. So, we saw that the water thermal mass It is a type of passive solar heating and cooling system that uses water instead of solid materials like concrete or masonry to store thermal energy.

Tubes or tanks are filled with water and these are embedded within the wall. Water has a much higher specific heat than concrete, and therefore the water wall is also effective. We also saw the case study of the Bayer house, which has incorporated a water wall. Then we saw a thermosiphon. What are thermosiphons?

A thermosiphon is a passive heat exchange device that circulates a liquid or vapor naturally through convection. It does not require a mechanical pump or other moving parts. The circulation of liquids and volatile gases in heating and cooling applications, such as heat pumps, water heaters, boilers, and furnaces, is another usage of thermosiphons in addition to passive heating. The most well-known kind of solar water heaters in use today operates on the same idea. The idea behind the thermosiphon solar heater collector is

that hot air rises because it is lighter than cold air, which falls and is drawn back to the thermosiphon system. Then we saw thermal mass. Now, thermal mass is the ability of a material to absorb and store heat energy. A lot of heat energy is required to change the temperature of high-density materials like concrete, bricks, and tiles.

They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass. Appropriate use of thermal mass throughout the home can make a big difference to comfort and heating and cooling bills. Objects with high thermal mass absorb and retain heat. This slows the rate at which the sun heats a space and the rate at which a space loses heat when the sun is gone.

Without thermal mass, heat that has entered a space will simply re-radiate back out quickly, making the space overly hot with sunlight or extremely cold without the sunlight. We can never talk of thermal mass in isolation when we talk of night ventilation. Night ventilation works on the principle that night cooling is the major reason we can cool the buildings inside without the use of any extra energy. So the principle that It uses is that natural ventilation, whether it is wind-driven or thermal buoyancy, should be allowed.

You know, it warms and then stale air can all be replaced by bringing in the cool outdoor night air. Because of this, the room gets fresh air, and the building mass also gets cooled. So in this process, what happens is you open the windows and the ventilators of the house at night. The cool air enters the building at night. The room, the thermal mass, the wall, the floor, and the roof, which have become warm during the day, lose their heat to the cool air, and the thermal mass becomes cool at night.

Early in the morning, quickly seal the rooms by closing the windows. Therefore, the inside remains much cooler than it would be if we do not use night ventilation. So, this is the principle of night ventilation, or you can call it night flush, nocturnal ventilation, or nocturnal ventilative cooling. You can call it by any name, but this is its principle. Then, we saw the double-skin green facade.

Now, a double-skin green facade is a type of green wall that offers both thermal performance and psychological benefits. In a double-skin green facade, the framework is installed at a distance from the wall, creating a gap or cavity between the wall of the building and the plants. The distance of the cavity influences the rate of heat exchange, which affects the wall surface temperature and indoor air temperature. As the distance of the gap increases, the temperature inside the cavity decreases, resulting in higher wall surface temperature and lower indoor air temperature. The distance of the gap can be from 0.3 meters to even more than 0.

1.8 meters. The next strategy we saw is the wind towers. So, there are two main wind catcher functions. The first function is to catch the prevailing wind and direct it down to the interior spaces of the building. The second function extracts the stale and polluted air out, thus supplying clean ventilation.

This works on the principle that natural pressure and temperature differentials can cause air movement. Air movement is created by the rising of warm air and the lowering of cool air. As the air above the land gets warmer, it rises and creates an area of low pressure. When air continues to rise, it moves toward water surfaces. There, it falls and creates an area of high pressure, pushing cold air toward the land.

This movement of air is what creates the wind. The badgir, or wind tower, functions by trapping the faster-moving air above the dense settlements of the region. It exploits pressure differentials existing between the vents above roof level and room outlet level. These towers work by directing cold wind that is circulating at higher levels with high density, and this is pulled downward and enters into the interior space with high pressure.

Once the cool air enters the space, the warm air circulating inside the interior space is pulled out through openings created on the opposite side. The next strategy we saw is the cavity wall. A cavity wall is a form of masonry wall construction consisting of two parallel walls of masonry separated by a continuous air space or cavity. Cavity walls may or may not include insulation within the cavity. The cavity itself acts as a natural barrier to moisture, and insulation can be added for thermal performance.

The primary purpose of this design is to enhance thermal efficiency and reduce heat loss or heat gain from the building. Proper insulation helps reduce heat loss in colder climates and minimizes heat gain in warmer climates. Heat transfer across the air gap within the wall will occur through convection. The next strategy we saw is the sun spaces. So the next strategy we saw is the sun spaces.

The main principle of south-facing sun spaces and conservatories is similar to the Trombe wall. But with a large and functional air cavity. Glass allows solar beams to penetrate through the external glazing but keeps the heat inside. Part of the heat is stored in the thermal storage media, like the wall and the roof, which will be redistributed back to the space at a later time, say at night. Part of the heat can be directly carried into the space through air convection via the vent openings in the wall when heating is needed immediately.

After this, we saw what a green roof is. So a green roof is a roof that is partially or completely covered with vegetation and soil. Planted over a waterproofing membrane. This should be used when heat needs to be moderated. Having a green roof also has the advantage of reducing the urban heat island effect.

Then we saw phase change material incorporated windows. Phase change materials are substances that can absorb and release thermal energy during the process of changing from

one phase to another, that is, from solid to liquid or vice versa, at a specific temperature. Phase change material integrated glazing units operate based on the principles of latent heat storage and release thermal during phase transitions. The primary goal is to enhance the energy efficiency of buildings by utilizing the thermal properties of phase change materials in combination with glazing systems.

PCM incorporated glazing units refer to innovative building materials that combine phase change materials with glazing systems to enhance the energy efficiency of buildings. Then we saw earth air tunnels. This works on the principle that soil temperature at a depth of about 12 feet, approximately 4 meters or more, stays fairly constant throughout the year and is approximately equal to the average annual ambient air temperature. The ground can therefore be used as a heat sink for cooling in summer and as a heat source for heating in winter.

We also saw how this technique is used in summer and winter. We saw how the piping can be laid. It can be a single pipe, multiple pipes, it can be one layer pipe or there can be multiple layers of pipes, one below the other, and so on. Then the next system we saw is radiant cooling.

So, the radiant cooling pipe system is an energy-efficient cooling technology that, unlike traditional forced air systems that cool the air, employs chilled radiant surfaces like ceilings, floors, and walls to directly absorb the heat radiated by objects and people within a space. It creates a comfortable, even distribution of coolness without the need for visible and noisy equipment. Radiant cooling systems work by circulating chilled water through a network of polymer pipes installed in floors, walls, and ceilings.

This network of pipes can turn the floors, walls, and ceilings of a conditioned space into cold surfaces that evenly absorb heat energy. Radiant cooling works best in a tightly sealed building that integrates radiant with a downsized forced air system to meet the building's fresh air requirements. After this, we saw what the appropriate passive strategies are for each of these climate types: warm, humid, hot, dry, composite, moderate or temperate, and cold. We saw first

What are the climate classifications? We saw the characteristics of each of the climates. We saw the tools that can be used to assess strategies to make the rooms comfortable in each of the climate types, such as Mahoney's table, climate consultant, and psychrometric chart. Climate consultant is a combination of Mahoney's table and psychrometric chart.

And we saw the intense use of Climate Consultant as well. We saw a small demonstration of how it can be used. Then we saw all the simple and advanced passive strategies with their working principles, variations, advantages, limitations, and case studies. In some cases, even research papers. And after that, we started looking at each climate separately, and for each of these climates, warm and humid, for example, we identified the most appropriate passive strategies. We saw this through the use and demonstration of Climate Consultant, taking one city as an example of that climate type.

As an example of that climate type. And we saw for that particular city. What happens for each solstice period. How the strategy that can be adopted. For December, March, June, and September.

That can change. And how, as architects, it is our responsibility. To optimize which strategy must be used. In order to make the building thermally comfortable throughout the year for the occupants. And with this, we concluded this course and lecture series.

So, my dear students, I hope in this course you have learned enough strategies. And ways to assess which strategy should be applied with the appropriate tools. But the prudence of picking and listing the strategy is ultimately in your hands as a designer. I thank you all for having taken this course and completed it. And my best wishes to each and every one of you.

Thank you.