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

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Lecture 01

Passive Design Strategies for Hot-Dry climate

Hello everyone. In our last class, we saw case studies of buildings in warm and humid climates. Today, let us look at the passive strategies that have to be adopted in hot and dry climates. So, if we look at the suggestions that come out of Mahoney's tables, for a hot and dry climate, the table suggests that the simple passive strategies in hot and dry climates include orienting the building along the north and south with long axes along east and west.

The building must be protected from hot and cold winds. Double-banked rooms, with temporary provisions for air movement, must be made available. Medium-sized openings of 20% to 40% must be available, and heavy external and internal walls must be designed. Roofs must be heavy with a time lag of 8 hours.

Space for outdoor sleeping could be provided, and protection from heavy rain may also be necessary in some months. Now, having seen how passive strategies are selected using Mahoney's table, let us see how passive strategies are selected for a hot, dry climate like Jaipur, using the software Climate Consultant. So, first, let us see how to make the indoors comfortable for the month of March in a hot, dry place like Jaipur.

So, left to itself, 322 hours or 43.3 percent of the time is comfortable in March. Whereas, sun shading of windows makes 228 hours out of 744 hours comfortable. Using high thermal mass with nocturnal ventilator cooling or night flush will make 223 hours out of 744 hours comfortable. Using direct evaporative cooling can make 226 hours out of 744 hours comfortable, amounting to 30.4%. Whereas, two-stage evaporative cooling can further push 233 hours amounting to 31.3%. Adaptive comfort ventilation can push 211 hours, amounting to 28.4% of the time to be comfortable. Whereas, fan-forced ventilation can make 52 hours comfortable, which is just 7%. Whereas, internal heat gain can also help for 184 hours.

So, if you see in Jaipur, according to Climate Consultant for the month of March, you do not need any active means, and 100% of the hours, that is 744 out of 744 hours, become comfortable just by adapting passive strategies. So, there is no need for an active strategy for the month of March in a hot-dry place like Jaipur. Now, let us see what happens in the form of how this translates into design guidelines.

On hot days, ceiling fans or indoor air motion can make it seem cooler by 2.8 degrees centigrade. Thus, less air conditioning may be required. This can be used on hot days with closed windows. Traditional passive homes in hot, windy, dry climates use enclosed, well-shaded courtyards with a small fountain that provides wind-protected microclimate variation by bringing in moisture or humidification. To the air that enters inside.

Earth sheltering, occupied basements, or earth tubes will reduce heat loads in very hot, dry climates because the earth stays near the average annual temperature. So, you can have the earth air tunnel as a way of making the indoors comfortable, or you can simply have berming of walls to make the indoors comfortable. Use light-colored building materials and cool roofs with high emissivity to minimize conducted heat gain. So, use materials with a high solar reflectance index for maximum emissivity to minimize the amount of heat that is absorbed by the roof and also for reflectance and emittance, and you must check the data from the manufacturer.

Humidify hot, dry air before it enters the building from enclosed outdoor spaces with spray-like fountains or misters, which will add mist inside, or having wet pavements, so have roads on which you spray water or have cooling towers. Window overhangs must be designed appropriately for this latitude, or you can have operable awnings or sunshades that you can extend in summer, and this can reduce or eliminate air conditioning. In order to produce stack ventilation, even when wind speeds are low, maximize the vertical height between air inlet and outlet through open stairwells, double-storied height spaces, roofs, attics, mezzanine floors, etc. Flat roofs will work well in hot, dry climates, especially if they are light in color.

Now, what happens next? In the month of June, what passive strategies can be adapted to maximize comfort hours, and how much are those comfort hours maximized just with the help of passive strategies? So, if you do not apply any passive strategies, the indoors will be uncomfortable all the time. Whereas, if you adopt sun shading of windows, then 257 hours become comfortable out of 720 hours, amounting to 35.7%. Direct evaporative cooling amounts to 16 hours becoming comfortable, which is about 2.2% of the month.

Then, two-stage evaporative cooling shifts the comfort hours by 65 hours. Whereas, adaptive comfort ventilation will give indoors 77 hours of comfortable time. With these strategies, 19.7% of the month of June, which is approximately 20%, will be comfortable. However, 80% of the time will be uncomfortable with just passive strategies. With passive strategies.

Now, how to make 100% of the time comfortable? So, we have already seen that if you don't adapt any strategies, then nil. The whole month will be uncomfortable. Whereas, solar shading will make 257 hours comfortable. Direct evaporative cooling will make 16 hours comfortable.

Two-stage evaporative cooling will make 65 hours as comfortable. Adaptive comfort ventilation will make 77 hours as comfortable. However, it will not make 100% of the hours comfortable unless you use an air conditioner, and the air conditioner will make 578 hours, or the remaining 80% of the hours, will become comfortable only if you use air conditioning, and that is how we can achieve 100% comfortable hours for the month of June in a hot, dry climate like Jaipur.

What are the strategies that must be followed to make indoors comfortable for the month of June? So, on hot days, ceiling fans or indoor air motion can reduce indoor temperature, and that can reduce the load on air conditioning. Shaded outdoor buffer zones, such as a porch, patio, or lanai, oriented to the prevailing breezes, can extend living and working areas in warm or humid weather. We can provide double-pane, high-performance glazing, which is actually low-E glazing on the west, north, and east, but clear on the south for maximum passive solar gain if needed, or we can use appropriate finishes for the glass so that you do not invite heat inside. To facilitate cross-ventilation, we can locate door and window openings on opposite sides of buildings, with large openings facing up winds if possible. To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and air outlet through open stairwells, two-story spaces, and roofs in the form of attics or mezzanines. What are the strategies that can be followed for the month of September to make the indoors comfortable? Only with passive strategies left to itself, the hot, dry climate of Jaipur for the month of September will have six hours comfortable without any intervention, whereas

Solar shading of windows will push 251 hours out of 720 hours to become comfortable. By using adaptive comfort ventilation, 351 hours out of 720 hours become comfortable. Thus, only 49% of the total month of September will be comfortable if we use a passive strategy. But we want to make the remaining 51% also comfortable.

How do we do that? If we want to make the remaining hours also comfortable, then you will have to adopt an active strategy. Passive strategy. Such as not indulging in much intervention, solar shading of windows, and adaptive thermal comfort will cause a shift in comfort hours by 6 hours, 251 hours, and 351 hours respectively. Whereas, for 100% comfort,

We need to dehumidify the air, which will push 191 hours into comfort. Whereas using air conditioning will push the building into comfort mode by 307 hours, which is 42.6% of the month. Thus, we can get 100% comfortable hours for the month of September in a hot, dry place like Jaipur. So, how does this translate into design guidelines? So, for design guidelines, on hot days, the ceiling fan or indoor air motion can reduce the indoor temperature by approximately 2.8%.

Shaded outdoor buffer zones, such as porches, patios, or lanais oriented to the prevailing breezes, can extend living and working areas in warm or humid weather. Good natural ventilation can reduce or eliminate air conditioning in warm weather. If windows are well shaded and oriented to prevailing breezes, using light-colored building materials and cool roofs with high emissivity can minimize conducted heat gain. To facilitate cross ventilation, we must locate the door and window openings on opposite sides of the building, with larger openings facing the windward side as far as possible. Window overhangs should be designed, or we can use operable sunshades that extend in summer and can reduce or eliminate air conditioning.

To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and air outlet by having open stairwells, double-height spaces, or two-story spaces and appropriate roofing. So, these are the strategies for the month of September as suggested by Climate Consultant. Now, for the month of December, what are the passive strategies that we must use to have 100% comfortable hours? So, left to itself, 204 hours are comfortable without any intervention. Whereas, sun shading will make 87 hours comfortable.

Using direct evaporative cooling will push 24 hours out of 744 hours into comfort mode. Having adaptive comfort ventilation will push 155 hours out of 744 hours into the comfortable zone. Internal heat gain can make 314 hours comfortable, whereas Passive solar direct gain with high mass can make 192 hours comfortable. Thus, using only passive strategies, we can have 83% of the month of December as comfortable.

However, if you want to make the remaining 17% also comfortable, then what should you do? Then you must go for an active strategy. Because 204 hours are comfortable without any intervention for December, 87% can become comfortable with appropriate solar shading. 24 hours can become comfortable with direct evaporative cooling. 155 hours can become comfortable with adaptive comfort ventilation.

314 hours can be comfortable with internal heat gain. 192 hours are comfortable with direct solar high-mass walls. While having heating and humidification, if necessary, will push the remaining 123 hours also into comfort mode. Therefore, in order to make 100% comfortable, there will be an intervention of 16.5% as an active strategy for December 2021. For a hot, dry climate like Jaipur, now how does this translate into design guidelines? So, for December in Jaipur, which falls under a hot and dry climate, sunny, wind-protected outdoor spaces can extend living areas in cool weather.

Like seasonal sunrooms, enclosed patios, courtyards, or verandas. You must either be able to have designed overhangs or you can have collapsible overhangs like awnings, and that can reduce the air conditioning load. For passive solar heating, you must face most of the glass areas south. This will maximize winter sun exposure. But for these windows, you must also have adequate overhangs so that you don't end up overheating in summer.

You should organize the floor plan so that winter sun penetrates into daytime use spaces with specific functions that coincide with solar orientation. Use high-mass interior surfaces such as slab floors, thick floors, high-mass walls, and a stone fireplace. to store winter passive heat and summer night cooling. Heat gain can also occur from lamps, lights, various equipment like televisions, computers, rice heaters, and so on, and this greatly reduces heating needs. That keeps the home tight, well insulated to lower the balance point temperature of the heating equipment.

If we look at a comparative analysis of how we can strategize design for a hot, dry climate like Jaipur with just passive strategies. 100% of the month of March can become comfortable, while in June only 20% of the month is comfortable with passive strategy. 49% of September is comfortable with passive strategy, while 83% of December is comfortable with just passive strategies. The Other passive strategies that we need to use in order to achieve these percentages are sun shading of windows, which is applicable throughout the year, whereas for March, the strategies which lead to 100% comfort hours are high thermal mass with nocturnal air ventilation.

Direct evaporative cooling, two-stage evaporative cooling, adaptive comfort ventilation, and fan-forced ventilation cooling along with internal heat gain for a few hours. Whereas in June, you require direct evaporative cooling just like it was required in March. Whereas you do not require direct evaporative cooling. You require that only in the month of December. Two-stage evaporative cooling is required in June just like it is required in March.

Adaptive comfort ventilation is required throughout the year, including March, June, September, and December. Internal heat gain is required for March and December, while passive solar direct gain from high mass is required in December. To meet 100% of the hours as comfortable, no active strategy is needed for March, whereas cooling and dehumidification are needed for June. In September, cooling and dehumidification are required, whereas only dehumidification will also push many hours into comfort. For December, heating and humidification are needed.

Thus, for a climate like Jaipur, there are some months where no intervention is needed. In terms of using active energy, some months require active energy along with passive strategies. In some months, just passive strategies are enough to push all the hours of the month into the comfort zone. So we will see these applications now. Let us look at the detailed passive strategies for hot and dry climates.

1. First is the building orientation and form. The form and orientation constitute two of the most important passive design strategies for reducing energy consumption and improving the thermal comfort of a building's occupants. It affects the amount of sun falling on surfaces, daylighting, and the direction of wind. A properly oriented building maximizes the amount of solar radiation in winter and minimizes it in summer. In predominantly hot regions, buildings should ideally be oriented to minimize solar gain. The reverse is applicable for colder regions. The longer walls of the building should face the north and south and avoid west orientation.
2. Second is ventilation and openings. There isn't much to discuss about ventilation and openings because the size of the windows must be kept minimal or very small, as this can increase heat if they are kept bigger.
3. The third technique is to have an earth air tunnel.The principle of the earth air tunnel is that it is a technique used to generate cool air in the summer and hot air in the winter. The process involves moving the outside air through a duct system that is installed deep inside the earth's surface. Because of the earth's constant temperature throughout the year, it exchanges heat while passing through the ductwork. The working of the earth air tunnel is that a wind tower or a wind catcher is installed outside the main building in the direction of the flow of air around the area. It is then connected to an underground duct or tunnel to force the air to move in the direction of the main building.

The depth of the tunnel should be more than 2 meters or between 3 meters and 4 meters. The optimal ground temperature required for conditioning the air is 3 meters below the ground. At any other depth, the temperature is not of the optimal value. Through the duct, it reaches an area where it is treated for temperature, humidity, and to remove dust particles. From here, it reaches inside the building, and the air is circulated throughout the building.

4. Fourth is Earth Sheltering or Earth Berming. A building can be called earth-sheltered when it has a thermally significant amount of soil or substrate in contact with its external envelope, i.e. having earth against its walls, on its roof, or being underground. There is an Underground Earth Shelter. Its working principle is that as we go about 4 meters below the earth's surface, the ground temperature is stable and almost equal to the average annual temperature of that place.

Annualized Geothermal Solar or AGS uses a separate solar collector to capture the heat. The collected heat is delivered to a storage device, which is soil, a gravel bed, or a water tank, either passively by the convection of the heat transfer medium, that is air or water, or actively by pumping it. This method is usually implemented with a capacity designed for six months of heating. In the Passive Annual Heating Storage, PAHS, solar heat is directly captured by the structured spaces through the windows and other surfaces in summer and then passively transferred by conduction through its floors, walls, and sometimes even the roof into adjoining thermally buffered soil.

It is then passively returned by conduction and radiation to those spaces which are cooler in winter.

5. Fifth is evaporative cooling. Now, the principle of evaporative cooling is that it is a passive cooling technique that uses the natural process of evaporation, mainly of water bodies, to cool the air inside the building. This effect lowers the indoor air temperature and provides a cool ambient temperature inside. It is effective in hot and dry climates where humidity is very low.

This system is mostly used in Indian desert areas and works as a desert cooler for them. The design recommendation includes having pools, ponds, and water features immediately outside windows or in courtyards that can pre-cool air entering the house. As water evaporates, it draws a large amount of heat from the surrounding air. In public buildings, pools and fountains can be used as cooling elements along with cross-ventilating arrangements of openings. Cooling towers may be used to evaporate pre-cool ventilation air for one or more air handling units.

This reduces the load on the mechanical cooling system. Use of porous materials. Roof materials can cause an evaporative cooling effect. That is, the siliceous shale is able to reduce the roof surface temperature by about 8.63 degrees centigrade as compared to a regular RCC mortar roof. Air is in direct contact with the cooling medium, which is water.

Indirect evaporative cooling. Indirect evaporative cooling. The most commonly used methods are water bodies and water sprays.

6. Sixth is the use of thermal mass. Thermal mass is the ability of a material to absorb, store, and release heat.

Thermal lag is the rate at which a material releases stored heat. The higher the thermal mass, the longer the thermal lag. High thermal mass materials, like heavyweight construction materials such as concrete, brick, and stone, can be used. Low thermal mass materials consist of typically lightweight construction materials like timber frames, and this is not advisable. In hot and dry climates, high thermal mass can help to passively heat and cool the home at a low cost.

Thermal mass, or the ability to store heat, is also known as volumetric heat capacity. Volumetric heat capacity is calculated by multiplying the specific heat capacity by the density of the material. Specific heat capacity is the amount of energy required to raise the temperature of 1 kg of a material by 1 degree centigrade. Density is the weight per unit volume of the material, i.e. how much a cubic meter of material weighs.

The higher the VHC, the higher the thermal mass. When it comes to design recommendations, it is recommended to use thermal mass in climates with high diurnal temperature variation. As a rule of thumb, diurnal ranges of less than 6 degrees centigrade are insufficient. 7 to 10 degrees centigrade can be useful depending on the climate. High mass construction is desirable for a diurnal range of over 10 degrees centigrade.

Moderate mass is best for a 6 to 10-degree centigrade diurnal range. Mass levels should vary according to solar factors such as glazing type, orientation, area, and shading. The appropriate mass color with low reflectivity includes dark, matte, or textured surfaces.

7. The next cooling strategy we see is blinds and jalis. Jalis are perforated screens used as shading devices in buildings to reduce heat gain and promote passive cooling.

These block direct sunlight from entering the building while allowing for the circulation of fresh air. Blinds are used on glass doors, windows, and openings to reduce the amount of heat directly entering the building. These are made with different materials like wood, bamboo, fabric, etc. And can be adjusted to control the amount of heat and light entering them. Jalis are typically made of wood, stone, or metal and are designed to provide shade and ventilation while still allowing for privacy and air movement.

The perforations of the screens allow for better circulation of air, which can help to reduce the temperature inside the building.

8. The next cooling element is vegetation. Plants can be an effective passive cooling strategy for buildings as they can help lower heat gain, block direct sunlight, improve air quality, enhance visual comfort, and provide natural ventilation. Using vegetation as a strategy can be a low-cost and low-energy shade provider. Their working principle is

It reduces direct sun from striking and heating up building surfaces and lowers the outside air temperature. This, in turn, affects the heat transfer from outside to the building envelope and interior. The benefit of having vegetation in a building is that it shades the building and the open spaces around it.

9. Roof gardens or green roofs can be one of the elements where we use vegetation in a building. Shading of vertical and horizontal surfaces through green walls is another method.

This vegetation helps in changing or redirecting the direction of the wind. They create buffer zones against cold and hot winds. When we use vegetation, it is recommended to use the existing terrain of the site and natural topography. Use of local species for vegetation, which are accustomed to the variation in temperature, rainfall patterns, soil, etc. for that region makes the vegetation less maintenance-free.

We must select low-maintenance vegetation in terms of water usage and that which is resistant against local pests. Also, reduced lawn area in the garden is better in order to reduce the amount of water needed for irrigation.

10. The next strategy is Use of vegetation in various areas. When vegetation is used along pavements, reduce the area of hard-paved surfaces through the use of grass pavers.

The absence of hard surfaces also ensures a lower ambient temperature. It is more pleasant for pedestrians to walk on a green, soft surface that does not radiate heat. Deciduous vegetation can be used where it can be considered a flexible shading device. During winter, the vegetation will shed its leaves and allow the penetration of sunlight into the same occupied space that it would shade in the summer.

11. Next is the green roof, which is also a variation of vegetation.

Green roofs are roofs that are partially or completely covered with vegetation. They help in reducing the amount of heat absorbed by the roof, reflecting sunlight and providing extra thermal insulation. The roof lowers the temperature of the building through the process of evapotranspiration. The design considerations include, while designing the structure, that green roofs have several layers that add some extra load to the roof. A soil depth of 300 mm is sufficient for the green cover.

When it comes to the waterproofing layer, it is extremely expensive to repair the waterproofing layer after installation. Adobe Now, let us look at some building materials that can be ideal in hot, dry climates. Considering that we have studied that high mass is ideal for hot and dry climates.

i. First is adobe. Adobe is a natural building material. It is made from sun-dried clay bricks with the addition of sand, silt, and straw. This type of brick has a high thermal mass and can be used to store and absorb heat during the day and release it at night.

ii. Second is stone. Stone has a high thermal mass and can be used to absorb heat.
iii. Third is rammed earth. Rammed earth is a building material made up of soil that is compacted into forms. It has a high thermal mass and can be used to absorb and store heat.
iv. Fourth is terracotta tiles. These are also made with clay that is fired at a high temperature, which provides a high thermal mass and works the same as adobe bricks.

If we need to look at the **design considerations**, then usually locally available natural sources as building materials are the best to go with. Also, go with materials that have high thermal mass and natural cooling properties. Select materials that are lighter in weight and color.

12. The next strategy that we will study is the cool roof. A cool roof is designed to reflect more sunlight and absorb less heat.

It is made up of highly reflective materials, such as white or light-colored coatings, that help to reflect the sun's rays into the atmosphere. It uses solar-reflective surfaces that maintain a lower floor temperature. Cool roofs reduce the temperature by 7 to 10 degrees Celsius. Materials that can be used for cool roofs include wood shingles, polymer shingles, clay tiles, concrete tiles, slate tiles, metal shingles, special coatings, and special thermal-proof sheets.

13. Well, the next strategy that we will look at is the radiant cooling system.

The radiant systems are installed in combination with large thermal mass to facilitate absorption and radiation. They are also used for optimizing the performance of the systems, and this coil should be installed in floors or ceilings. For heating purposes, it is used in floors, and it is used in ceilings for cooling purposes. Radiant floor cooling and heating has a system of pipes that runs across the roof in such a way that when the building needs to be cooled, cool water is pumped into the tube, and through the process of conduction and radiation, it brings chillness into the room or absorbs the heat and makes the indoors cooler.

When the indoors need to become warm, the water that is pumped inside must be warm water.

14. Next is night flushing. Night flushing works by opening up pathways for wind ventilation and stack ventilation throughout the night to cool down the thermal mass in a building by convection. Night flushing is most effective in climates with large diurnal temperature differences. The building acts as a sink throughout the day.

The cool mass absorbs heat from the occupants and other internal loads. At night, when the building is not occupied, the outside air is cooler, and the envelope is opened, allowing cooler air to pass through the building so that the stored heat can be dissipated by convection. Night ventilation in winter should be avoided. Temperature swing and time lag of the thermal mass of the material are the key factors to be included in the quantification of nighttime temperature.

15. The next strategy is the wind tower.

The wind tower, also known as a wind catcher or badgir, is a traditional cooling architectural element that has been used in countries that are severely hot. They have two main characteristics. The first function is to catch the prevailing wind and direct it down to the interior spaces of the building. The second function is to extract the stale and polluted air outside, thus supplying clean ventilation.

The limitation is that during the winter, the traditional badgir still allows cold air into the building and shifts the warm air out. The effect of the tower depends upon the height of the wind catcher, which is directly proportional to the wind speed, and the cross-sectional area of the wind catcher shaft, which is directly proportional to the amount of air introduced inside the building. Air inlet and outlet openings affect the speed. The entry opening should be perpendicular to the wind direction. The outlet opening should be near the ground.

A minimum number of outlet openings should be present. Glazing is assumed to be clear and single-glazed, covering about a 14% window-to-wall ratio. The construction of the walls. It is a single uninsulated leaf wall with a concrete block wall. Traditional wind catchers in hot, dry climates were built either of mud brick or, more frequently, of baked brick covered with mud plaster.

They can be combined with earth cooling or evaporative cooling techniques for greater effect.

16. And one of the last strategies we will see today is the roof pond. The roof pond system is a passive technique that uses water stored in a pond located on the roof of a building to lower the indoor temperature through the process of evaporation. It is based on the property of higher heat capacity in water. Roof ponds can be inexpensive, enclosing water in plastic bags, metal or fiberglass tanks with rigid transparent plastic covers.

They could have a pond liner that prevents water seepage and ensures the integrity of the roof structure. Inlet and outlet vents are also present. Openings are strategically placed to allow air circulation and the exchange of cooled air with the building's interior. This technique can be easily adapted for heating and cooling as required. It is also cost-efficient.

However, it must be designed well to avoid seepage as well as leaks. So, with this We stop today's class where we have seen the strategies that must be followed or the simple and advanced passive strategies that can be used in a hot and dry climate. We stop our class here and continue our next class with case studies of buildings in hot and dry climates. Thank you.