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

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Lecture 04

Orientation and form

Hello dear students. So, welcome back to another lecture for this NPTEL course, Bioclimatic Architecture, Future Proofing with Simple and Advanced Passive Strategies. In the last few classes, we had seen what are simple passive strategies, what are the advanced passive strategies. I had also indicated in brief what are those strategies exactly along with case study applications here and there. From this class onwards we will be taking each strategy separately and studying them in detail along with some case study applications. In this context, today we will look at the first simple passive strategy, which is the orientation and form of a building.

Orientation alone must not be seen in isolation; it must be studied along with the form of the building. So, today we will see how orientation and form play an important role in making the building more energy efficient and sustainable. So, in this lecture, we will discuss orientation and form, where we will explore the integration of natural elements and design strategies to create energy-efficient and comfortable built environments. Throughout this session, we will dwell into 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 these elements interact and influence building performance, we can unlock insights that not only reduce energy consumption but also prioritize human well-being and environmental stewardship. Form and orientation are key elements in passive design strategies as a part of bioclimatic architecture for optimizing energy consumption and enhancing thermal comfort in buildings. These strategies play a vital role in achieving energy goals by leveraging natural elements such as sunlight, the prevailing winds, Normally, these are the two key elements we discuss. We rarely discuss about precipitation, role of precipitation in indoor thermal performance. We discuss those elements, like precipitation, to understand if that should be permitted inside the building or not.

The form of a building influences the volume of space that requires heating or cooling, with more compact shapes being more efficient in minimizing heat gain or loss because if they are compact and placed close to each other, self-shading helps in minimizing the heat gain inside the building. In contrast, orientation determines how much sunlight enters the building, affecting its energy efficiency throughout the year. Understanding these principles is crucial for designing sustainable buildings that prioritize energy efficiency and occupant comfort. For example, compact shapes are beneficial in hot and dry regions to reduce heat gain and in cold climates to minimize heat losses. Energy efficiency can be greatly impacted by selecting the best orientation to maximize daylight and reduce summer heat gain and winter heat loss, especially if doing so prevents or uses less air conditioning.

For example, north-facing windows receive very little solar gain in warmer climates, while the main construction axes that point east or west frequently provide the advantages. Because of the low sun angles during certain times of the year, east or west-facing windows are more difficult to protect against direct sunlight. Also, the nature of sunlight along the west is extremely harsh. South faces are generally simple to control and receive both direct and diffuse radiation. Buildings should be angled to enhance sun gain in mostly cold locations.

The exact opposite is advised for warmer locations. Both of the circumstances could occur in areas with significant seasonal variations. An orientation that is somewhat east of south is preferred in cold climates, particularly one that is 15 degrees east of south, as the exposure of the unit to more morning sun than afternoon sun allows the house to start heating during the day. The building form determines the volume of space inside a building that needs to be heated or cooled. Thus, the more compact the shape, the less wasteful it is in gaining or losing heat.

The more compact the shape is for a given building volume, the less wasteful its heat gain or heat loss is. Because of this, buildings in hot, dry and cold climates are compact, and they have low surface-to-volume ratio to minimize heat gain and heat loss, respectively. So, it is better that buildings in hot, dry and cold climates are compact because that will minimize heat gain in hot-dry conditions and minimize heat loss in cold climates. The airflow pattern surrounding a building is determined by its form which has a direct impact on ventilation. So, if we look at the perimeter to area ratio in extreme climates, you can see that the minimum perimeter is for a circle and then it increases to a square.

The rectangle has more perimeter to area, and then the L-shaped building has more perimeter to area ratio compared to that. A courtyard plan has a higher perimeter-to-area ratio compared to the previous form. The sixth form, which is Y-shaped, has even a larger perimeter-to-area ratio, and an I-shaped, an H-shaped, or a form-H-shaped form has the greatest of all these. So, if you want to avoid too much exposure to the sun, it is better that you do not provide forms that have a higher perimeter-to-area ratio because the surface extent increases, and that kind of gives more opportunity for solar radiation to enter the house for the same given area. But we cannot talk of form alone in isolation; we have to talk of orientation also.

For the same orientation, if we look at any of these forms, it is going to have greater exposure to solar radiation as compared to each of these. Also, the air flow also matters because, depending upon the form, the surface area exposed could permit air flow. That is one, but there is another aspect because of the form and the orientation because of the form and the orientation - the self-shading aspect—when it comes to solar gain or solar heat loss and formation of vortices, and then the way the building is going to create pressure differences that can bring in airflow inside the building will vary. So, the depth of the building also affects how much artificial lighting is needed. The deeper the building, the more artificial lighting is required.

For example, if we look at these cases, you can see that there is exposure, more exposure, and the building depth is much lesser. So, the building of this profile would require very little artificial lighting as compared to the building of profile 3. So, profile 6 is much better for natural lighting as compared to profile 3. The amount of space inside a building that requires heating or cooling, as well as how much of the envelope surrounds that space, has an impact on the building's thermal performance. So, the building form determines the parameter and this parameter is largely defined by the surface to volume ratio.

Building height. This is another criteria because building shape is governed by building height. Building shape is governed by the following parameters:. First is the building height, second is the roof type, third is the front gradient, and then the ratio of the building, the ratio of the building length to the building depth in the plan. So, these are examples of geometrical variables that define a structure's design, which has a significant impact on heat gain and loss. The ratio of surfaces that make up the surroundings to the volume determines how much heat a particular structure loses or gains.

Building energy performance is influenced by a number of elements, including form and volume surface rate. The geometric shape of a structure and its energy performance are directly correlated. Compact building forms minimize the impact of the surrounding environment since they have a comparatively little exposed surface area for a given floor space. Less space may be needed for the provision of horizontal and vertical services, especially air duct work in a compact design. Nevertheless, there might be more complicated servicing if commercial demands and/or a compact design result in a deep plan or more than 15 meters below the surface.

Here you can see that the first case is a tall, slender building. Because of the number of floors, as we had already discussed, height is a criteria because of his increased height, it gets additional exposure to the sun. This results in higher heat gain, which is not alright in a warm climate, and higher heat loss, which is not alright in a cold climate. So, you need to optimize the height. Then if we look at a shallow plan, a shallow plan in this case too, a shallow plan can also have higher heat loss.

It has increased daylight. And it has more scope for natural ventilation. So you need to optimize the form for these following aspects. One is heat loss or heat gain, as the case may be. Second is ventilation airflow inside the building.

Third is the lighting levels. So, how much of day lighting is allowed inside? Day lighting inside the building. How much is the building reliant on artificial light or daylight? You could also consider acoustics. When I say acoustics, I mean permitting exterior sound, exterior noise inside. So, you need to optimize a form for all of these because a particular form, which functions very well for optimum heat gain, may not be functioning very well for either ventilation or lighting. So, you have to optimize it. So, if you look at a shallow plan, there is provision for higher heat loss There is a possibility of higher heat loss if we are looking at a cold climate. There is adequate daylight, but there is also the possibility of ventilation. So, ventilation gain may also happen, which is something that you have to decide whether in that particular climate it is needed or not.

Then we move on to another plan form, which is a deep plan. In a deep plan, you have lower heat loss; the heat loss is less, and the daylight is less because even if you provide windows here on all of these sides, daylighting is possible only in this zone. Even if you provide in all four sides, if you provide openings with appropriate shading devices, you will notice that only this side, only this portion inside the floor, will have adequate daylight. and a large portion will remain dark. So, this portion will have to rely on artificial lighting, but this is going to cause a lower heat loss.

Then you have a deep plan with an atrium or a courtyard, which is effectively, in a way, a shallow plan. We can call it a shallow plan because these two are exposed areas on these two surfaces. and this surface is an exposed surface in a way. One is primary exposed, another is secondary. So, we can have lower heat loss, increased daylight penetration, and the potential for natural ventilation is there, but does the climate need it? That is something we have to see.

Then research was conducted to explore the potential of building forms to improve energy performance and interactions with sun rays. So, surface insulation, cooling, and heating loads as performance indicators were studied using many methods, such as the IESVE suncast package, the energy plus engine with the design builder interface, and the mathematical calculations. A simple building geometry was used to study the form configuration in order to make the most of the impact of the studied parameters. This was done to develop new forms using the best angle from step 1 and find the best building form with the minimum annual energy reduction when compared to a base case. Forms with a high self-shading, that is, forms 3, and form 6.

Both of these forms had high self-shading, and they have low cooling loads in the hot period from May to October. Their energy consumption is more than 20 percent lower than that of the base case. The study results showed that forms with an inclined south wall performed better than forms with a vertical wall for a hot humid climate. The inclination in the north wall that is form 3 increased the area of the facade exposed to solar radiation. Thus, more energy was required for cooling.

All forms reduced energy consumption for cooling by more than 22% on average; increasing the inclination angle of up to 30 degrees decreased the cooling load by an average of 15% to 23%. The building forms generated from the optimal inclination angles had a remarkable influence on the performance. So, this influence on energy consumption and cooling load was very good when these forms were generated with the correct amount of inclination. The best performance was exhibited by the buildings, which were staggered, as they provided the most shading to the lower floors. You can see this entire wall, that falls under the shadow region because of the shading provided.

So, because of this shading and because of this shading even the roof gets shaded in this area. So, the staggered form seems to perform better as compared to the non-staggered form. The configuration of the south facade had a greater impact on cooling load than the configuration of the north facade. So, there have been several studies that have clearly said that two aspects—one is self-shading of walls and roofs, especially with staggered forms—provide provides best insulation from heating.

So, heat gain is lowered. So, which are the climate types where heat gain must be lowered? Those are primarily hot-dry and warm-humid. So, in both of these climate types, it is better to go for forms like these. And then buildings must be designed to be responsive to solar orientation on their sides as the angle of sun varies significantly throughout the year. During winter, the sun is at a lower angle and to the south of the east-west axis, while in summer, its path rises to a higher angle and slightly north of the east-west axis. This alteration in the sun's path has a direct impact on solar radiation penetration patterns during different seasons, consequently affecting the heat gain and loss within a building.

In winter, when the sun is lower in the sky, buildings should be designed to maximize solar heat gain. This can be achieved by having larger windows on the southern side to allow more sunlight to enter and warm up the interior spaces. Additionally, using thermal mass material on the southern side can help store and release heat, contributing to better thermal comfort and reduced heating needs. On the other hand, during the summer, when the sun is higher and more intense, buildings need to minimize solar heat gain to maintain comfortable indoor temperatures. This can be achieved by using shading devices such as overhangs, awnings, or lowers on the southern side to block direct sunlight.

Ventilation can also be incorporated to enhance cooling without relying heavily on mechanical systems. By understanding and incorporating these solar orientation principles into building design, we can create more comfortable spaces that respond bioclimatically and intelligently to the varying angles of the sun throughout the year. Let us now look at the importance of orientation and form in bioclimatic architecture and its benefits. So orientation and form are fundamental pillars of bioclimatic design, crucial for optimizing energy efficiency and enhanced occupant comfort. This is especially true because it doesn't really cost much to understand which orientation is best to place a particular building design.

For a given spatial requirement, the building plan form should also be arrived at in such a way that it helps in the energy efficiency of the building through bioclimatic design. And these actually do not cost much because this is actually the process and the work of the designer. The strategic alignment of buildings with the sun's path allows for effective solar gain in winter and minimizes heat gain in summer, reducing the need for mechanical heating and cooling systems. Additionally, proper orientation and form facilitate natural ventilation and daylighting. So, having a proper orientation and form can impact energy consumption because we can design buildings that are comfortable just by proper orientation and a proper form, therefore reducing the load on the mechanical system and giving us an energy-efficient building.

Such buildings can also enhance the thermal comfort inside. Third due to the strategic location of openings due to proper orientation and having a proper form, we can enhance natural ventilation inside the building, and then this can also enhance the day lighting inside the building. We can try to bank on getting the tapping the maximum natural light. Again, a very important aspect is sustainability because having proper thermal comfort, energy-efficient buildings, using natural ventilation, and daylighting—all of this gets translated into having a sustainable building. So, this not only improves the energy performance, but it also creates spaces that prioritize comfort, sustainability, having good natural ventilation, having a well-lit building, and therefore also giving cost savings as the load on artificial lighting mechanical systems gets reduced.

So, in total, we can see that longer facades of buildings can be strategically oriented towards the north to provide glarefully natural light during summer and allow for optimal winter sun penetration from the south in colder regions. This orientation maximizes daylighting benefits while minimizing heat gain, contributing to improved thermal comfort and energy efficiency. Another important aspect of orientation is taking advantage of prevailing winds for natural ventilation. Buildings should be oriented to facilitate airflow and cross ventilation, especially in hot and humid climates. In cases where multiple buildings are present on a site, their arrangement should be planned to avoid built forms falling in the wind shadow region that is created by the other buildings.

The placement of buildings should consider both solar orientation and enhanced ventilation optimizations to achieve optimal thermal comfort. If you look at some of these cases, a building like this positioned like this will cause this whole surface to fall under the wind shadow region. And therefore, it is better to stagger the building because you would have the wind flowing across the plan, and therefore, none of the faces will fall under a complete wind shadow region. Besides, height is an important criteria. So, when there are multiple buildings, you should design the building in such a way that the stilts will allow in hot humid climate; it becomes very important actually.

to allow the building to be surrounded by flowing air because heat gain that actually starts to build up will start breaking down or will get carried away because of the breeze. In tropical climates like India, the orientation of buildings is a crucial factor in optimizing comfort and energy efficiency. A preferred orientation is to have long facades of buildings oriented north-south, as this allows for better utilization of prevailing winds for natural ventilation. Aligning the longer axis or north-south of the building perpendicular to the prevailing wind facilitates maximum airflow and cross ventilation, which helps in cooling the indoor spaces without relying heavily on mechanical ventilation systems. It is recommended to orient buildings at an angle between 0 and 30 degrees with respect to the prevailing wind direction to optimize airflow while avoiding excessive wind pressure.

In buildings with courtyards, particularly in climates where cooling is desired, orienting the courtyard at a 45-degree angle from the prevailing wind direction is beneficial. The orientation maximizes wind flow into the courtyard, promoting natural cooling and enhancing cross ventilation within the building. By harnessing natural ventilation through strategic orientation, buildings can achieve better thermal comfort for occupants and reduced energy consumption associated with artificial cooling in hot and dry climates, such as desert regions. The design emphasis must shift towards minimizing heat gain. This is achieved by adopting a compact building form with a low surface-to-volume ratio.

Compact plants exhibit greater thermal efficiency, with square plants being more thermally efficient than rectangular ones due to the reduced exterior surface area, which we have already seen in the previous slides. By reducing heat gain through thoughtful building forms, occupants can enjoy a more comfortable indoor temperature without excessive reliance on air conditioning. For composite climates like Delhi or Gurgaon, a combination of strategies is recommended for optimal building performance. This includes adopting a compact form with a low surface-to-volume ratio, incorporating a square form with a courtyard for enhanced cooling and ventilation, and orienting the building with its longer axis along the north-south direction to minimize direct sunlight exposure on east and west facades. Additionally, protecting east and west orientation with buffer spaces, shaded walls, or vegetation further helps reduce heat gain and improve overall thermal comfort.

These principles of building orientation and form are integral to bioclimatic design, ensuring sustainable and comfortable built environments tailored to specific climate conditions. Let's look at strategies in a cold climate. The surface area to volume ratio for buildings is a crucial factor in the thermal performance in a cold climate, particularly in terms of heat loss. A lower surface area to volume ratio, such as that approached by a cube or a hemisphere, is desirable to minimize unwanted heat loss. This design approach helps to create a more thermally efficient building envelope, reducing the need for excessive heating in colder climates.

In cold climates, the orientation of buildings becomes crucial for maximizing solar gain and also for heating opportunities. In bioclimatic architecture, the ideal form of a building is closely related to achieving optimal thermal comfort for occupants, especially in extreme climates. A compact building form with a low surface-to-volume ratio and a low perimeter-to-area ratio is considered ideal for several reasons. First, it causes reduced heat gain.

Second, it minimizes heat loss. Third, there is provision for mutual shading. Fourth, it is more energy efficient. So, the ideal form of building is characterized by compactness and optimized by surface to volume ratio and the low perimeter-to-area ratio. So, it becomes important to have an integrated design in bioclimatic architecture. The integration and form and orientation, is fundamental in bioclimatic architecture, as it directly impacts the building's performance in terms of energy consumption, thermal comfort, environmental sustainability, daylighting, and ventilation.

So, as I had already said, one needs to optimize building orientation and form for solar gain and loss, solar gain or solar loss, heat loss for visual comfort, optimizing heat gain through materials, and optimizing natural ventilation. So, for these four aspects, a building form must be optimized along with its orientation. So, let us summarize this. Bioclimatic architecture prioritizes passive design strategies to enhance energy efficiency and thermal comfort in buildings. Key considerations include optimizing solar orientation to maximize solar gain in winter and minimize it in summer.

Building orientation strategies are tailored to different climates, focusing on airflow and cross ventilation for natural cooling. Compact building forms with low surface area to volume ratios are preferred for minimizing heat gain or heat loss. An integrated design approach combines form and orientation to achieve optimal energy performance. Strategies for optimizing orientation and form include considerations for visual comfort, daylighting, heat gain through materials, and natural ventilation. Overall bioclimatic architecture emphasizes sustainable design practices that harness natural elements for improved building performance and occupant well-being.

So, in today's class, we have seen the importance and significance of orientation and form as a simple passive tool. We will meet next class with yet another simple passive strategy. Thank you.