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

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Lecture 03

Earth Air Tunnels

Hello, dear students, welcome once again to another lecture on advanced passive strategies. So today's advanced passive strategy that we will see is the earth-air tunnel. So we will look at the earth-air tunnel as an advanced passive strategy. Now let us look at the principle of the earth air tunnel is that the temperature of the soil at about 4 meters depth remains fairly constant throughout the year and is approximately equal to the annual average ambient temperature of that place. Now what does that mean? It means now if this is the ground level and for this place, for this location the summer temperature is about 38 degrees Celsius and the winter temperature is about 20 degrees Celsius. Then what it means is that at the depth of 4 meters from the ground, the temperature of the soil will be the average of the summer and the winter temperature.

So this is 38, which is summer temperature, and 20, which is winter temperature; the average of those is 29 degrees Celsius. The temperature of the soil at a depth of 4 meters will be 29 degrees centigrade. And in this strategy, the ground will be used as a heat sink. What do you mean by ground will be used as a heat sink? Excess heat that you want to throw away, you will throw that into the earth.

And this acts as a heat sink for cooling in summer. So cooling in summer means what? It means that if the summer temperature is 38 degrees Celsius, then we know that the soil temperature at 4 meters depth is 29 degrees Celsius. Therefore, we will arrive at a system in such a way that this 38-degree centigrade becomes 29 degree centigrade without use of much external energy. Similarly, in winter, the outdoor temperature is 20 degrees Celsius. We will extract the heat from the earth, which is at 29 degrees Celsius, to make the indoors warm.

Whereas in summer we will throw the heat into the soil. So the soil will absorb this heat. And the air will become 29 degrees Celsius. So this is the principle of an earth-air tunnel.

For example, in Bangalore.

The temperature at a depth of 12 feet is 24 degrees centigrade. And this remains fairly constant throughout the year. Whereas in Delhi, the earth's temperature at 4 meters or 12 feet is a constant at 23 degrees centigrade throughout the year. There are two strategies for using this principle. One is the direct earth-air cooling technique.

And this technique I will not be dealing with in depth because this technique is similar to the earth-berming technique, which we have already seen in detail. But I will make a small mention of this. The second is the burry pipe cooling technique, and this we will look at in depth in this lecture. A study was done by Arshdeep Singh and his colleagues Ranjit Singh on the analysis of an earth-air tunnel system used for air conditioning a college room, which was published. Now what they did in this research is a separate apparatus was made by attaching a T-type thermocouple to a long stick.

So what they did was they took a long stick, and to this long stick they attached thermocouples. These thermocouples were, you know, attached to the stick at an interval of 2 feet. So, totally, they had 6 of these thermocouples. So they had 6 thermocouples attached to a stick at a distance of 2 feet or 60 cm. They dug a ground for a depth of 10 feet, and the thermocouple apparatus was inserted into the dug ground.

So they inserted this into a pit, which they had dug up. So they dug a pit like this, and into that they had let in these thermocouples at two feet distance each, and the depth of the pit was 10 feet, or approximately 3.3 meters. And this hole was then filled with soil. So what they did was they covered this with soil after putting this apparatus.

This they continued doing this experiment of monitoring the temperature for a year. Small changes were ignored, and then they made a plot between atmospheric temperature and the optimum underground temperature. And this is what they found. The ambient temperature is actually the maximum day temperature that is recorded. And this is averaged over one whole month.

So if you take say the month of January, what they did was they plotted the temperature, which is the average of the maximum daytime temperature. So like this, they plotted for each month: January, February, March, April, May, June, sorry June would come here, July, August, September, October, November, and December, and all of this is the average of the maximum day temperature for that month. And the underground temperature is the optimum temperature which is recorded at 10 feet. So at 10 feet below the soil, which is approximately 3.3 meters below the soil, this is the temperature.

And you can see that when the January temperature is about 17 degrees Celsius, February is about 19.5 degrees Celsius. The June temperature is about 41 degrees centigrade. Irrespective of that, the temperature of soil at a depth of 10 feet or 3.3 meters remains fairly constant throughout the year, and that is at approximately 25 degrees centigrade.

So this is what this study has shown. In that same study, what they did was plot since the thermocouples were let in at a depth of every 2 feet. What they did was plot the temperature during the summer. So I am going to denote the summer temperature with a red line for clarity. And the winter temperature I will denote with a blue line.

So the temperature of soil at every 2 feet was mapped starting from 0 feet, which is subsurface temperature, 2 feet, 4 feet, 6 feet, 8 feet, and 10 feet. And they found that as the thermocouple went towards 10 feet, that is, as the soil depth increased, the temperature of the soil moved closer to the average temperature of that place. And in this experiment, you can see that the ambient temperature of the earth on the surface during summer is about 40 degrees Celsius, and it is 17 degrees Celsius during winter. Then, at say, about 6 feet, the summer temperature. When it is summer, the temperature of the soil at a depth of 6 feet, which is about 2 meters, is 27 degrees Celsius.

Whereas during winter the temperature of the soil at a depth of 6 feet is about 20, 20, sorry, so this is, so the temperature of the soil at a depth of 6 feet during summer is approximately 30 degrees Celsius and during winter it is about 22 degrees Celsius. However, you can find that at a depth of 10 feet, whether it is summer or winter, the temperature remains the same. This is the principle that is used in this kind of advanced passive technique, which is an earth-air tunnel. Since the subterranean temperature is generally less than the outside temperature because the earth's subsurface has insulating properties. The ground acts like a thermal buffer, and it absorbs and releases heat more slowly than the atmosphere.

This results in a more stable and moderated temperature underground compared to the fluctuating temperatures experienced on the surface. During the day, the soil temperature at depth will be lower than the outdoor air temperature and room temperature. At night, when the air temperature drops significantly, the heat stored in the ground will be released into the environment. So what happens is, during summer, the wind is very hot, and this hot wind enters the shaft. A tube is buried inside, and a pipe is buried inside the soil at a depth of 2 meters, which is very little, anywhere between 2 meters and 4 meters depending on the place.

It is buried, and the hot air flows in through this pipe. When it flows in through this pipe, suppose the temperature outside is 25 degrees Celsius, and for this place the soil temperature is about 25 degrees Celsius. Then what happens is the air in the pipe gets cooled because heat from the air that passes through the pipe is radiated to the soil below. Why does that happen? Simply because heat flows from hot to cold always and not vice versa. Therefore, what happens is that the air in the tube, which is warm, radiates its heat to the outside, and in that process, it becomes cool, and this cool air enters the room.

When the cool air enters the room, the hot air escapes because hot air, warm air tends to rise up and cool air always settles down. Therefore, warm air that rises up escapes through vents, which are designed to be placed at the top level of the room. During summer, what happens? The outside temperature is about 35 degrees centigrade. So T outside is 35 degrees Celsius, whereas the temperature in the buried pipe is approximately 25 degrees Celsius because of its contact with earth, which has a lower temperature. What happens? The warm air passes through the tube and, in that process, radiates its heat to the soil outside, and in that process, this air becomes cool, and this air enters the room, and when it enters, it enters at 25 degrees Celsius.

So you can clearly see that we are able to reduce the temperature of the air that enters a room by 10 degrees Celsius. What happens during winter? During winter, suppose the temperature of this place is 6 degrees centigrade. Then it is very cool. What we need to do is make the indoors warmer. In which case, this cool air that enters the ground absorbs the heat from the soil.

In the summer it radiates, in the winter it absorbs, and it becomes either 16 or 20 degrees Celsius, and this air enters the room at about 16 or 20 degrees Celsius depending upon the soil temperature of that place. I am only telling you the principle of how it works during summer and during winter. So straight away, when the outside temperature during the summer is 6 degrees Celsius and the temperature inside is about 16 to 20 degrees Celsius, you get a temperature increase of about 10 to 14 degrees Celsius straight away. without using any extra energy, electrical energy, or energy from the grid. There are two types of earth heat exchangers.

One is an open-loop system; another is a closed-loop system. Now, what are an open-loop system and a closed-loop system? So, different types of earth heat exchangers are used to reduce the building's energy consumption. It can be an open-loop system, as we are discussing here, or it can be a closed-loop system. In an open loop, intake air comes through the inlet continuously, passes through the buried pipes, which are underground, into the room, pool, or heater space, and moves out through ventilation. Outside air is delivered only to AHU or the room directly.

So in this open loop system, what happens is that you have a separate inlet through which warm air in summer or cool air comes. It changes its temperature because of either radiating heat to the ground or absorbing the heat from the ground, and this flows into the room, and what it does in that process is either make the room cooler during summer or make the room warmer during winter. And this air escapes based on the temperature. So in an open-loop system, you have a loop that is open and does not get closed. Whereas if we look at a closed-loop system.

In a closed-loop approach where the air is distributed frequently into the room through the underground pipes. No air is exchanged with the outdoor air in this system. So in this system, what happens is you have a pipe that acts as an inlet and outlet pipe. It is the same. So what happens is air from the room comes through this pipe.

And when it comes, suppose it is summer, it gives out its heat. What heat is this? This is the heat that it has absorbed from the occupants or the apparatus like computers or some other machines that this room may be having. And in that process, the earth makes this air cooler, and this air flows back to this room. Then this cooler air will absorb the heat from the occupants. The occupants generate heat; the apparatus, contraptions like computers or machines, generate heat.

Because of which the indoor air becomes warm. What happens is this air becomes warmer. Again passes through the same loop. Again, it becomes cool.

And this cycle continues. So in a closed-loop system. The inlet air and the outlet air. It does not open to the outside, but it is only in contact with the soil. So it is considered more viable than the open loop since the cold or warm air is redistributed inside the pipe cover underground. The closed-loop earth-air tunnel system is actually not preferred over an open-loop earth-air tunnel system because it does not give the building or the room fresh air, and sometimes it may not meet the building's fresh air requirement.

I will just briefly tell you about the direct earth contact because I have told you already we have seen this in the earth bombing as a separate technique. But since it is the same principle, I have included a little bit of it. So in this case, the building is coupled with the earth. There is direct contact of the building with the earth, and the building gets its coolness or sheds its warmth to the soil directly.

There are no buried pipes or anything like that. Directly it sheds or directly it sends the heat to the soil. It has some advantages. The advantages include limited infiltration and heat losses because it's in direct contact. There is solar protection and heat protection to the building during the summer.

There is a reduction of noise and vibration. Fire and storm protection is there. There is improved security. It also has some disadvantages. The first disadvantage is it has condensation issues.

It can give a slow response to changing conditions. It gives poor day lighting because it is buried in the soil. Also, indoor air quality can be poor because what happens is if you open this, then cold draft will come in. And what will happen if you have too much cold draft coming in? The earth may not be able to make the indoors as comfortable as it would, and therefore that can result in poor indoor air quality. Our main interest is buried pipes cooling and the concept of this is to pass air through The air gets cooled or it gets heated depending upon the temperature outside and the temperature of the ground. The air gets cooled or heated, and this can be used directly for a conditioned space or indirectly with air conditioners or heat pumps.

So you can send this air to the AHU, because of which there is a lot of savings of energy, or you can send it directly to the room. So the concept of buried pipes involves the use of either metallic tubes or PVC pipes, which are buried at a depth of 1 to 4 meters below the soil like this. These are buried pipes below the soil. Now which system should we use? On what basis will we determine? Whether we should use open loop, closed loop, what material, etc. So we need information on the physical issues of the soil.

We need to understand the depth of water. So physical issues mean we need to understand whether the soil has a lot of organic matter, has leaves, has garbage, or was previously a garbage dump. or what was the condition of the land there. We need to understand the depth of water because what will happen when you start digging? Say you know that the water table is very high. What will happen? You will start getting water when you start digging, then how can you lay the pipe? So depth of water is important for us to understand.

Third is the depth of bedrock. Suppose you are digging and you end up hitting rocks or a quarry area. Then how will you lay the pipe? Then we need to understand the type of soil, whether the type of soil is clayey, sandy, or made up of moorrum, or what the nature of the soil is. We should understand the thermal properties of the soil, such as its diffusivity, density, and thermal conductivity. All these will guide the designer to choose the correct type of earth-air heating equipment system.

And based on that, he will be able to design this system. Let us look at the factors affecting the conductivity. Conductivity of the soil. can be affected because of the moisture content of the soil. What happens when the soil is very moist? Now the conductivity will not be the same as that of dry soil. The density of the soil is another important factor in understanding the conductivity of The soil conductivity also depends on the soil composition, whether it has lot of mineral components or organic component.

So what is the composition of the soil? It also depends on the texture of the soil, whether the soil is angular or whether the soil is rounded. So all this impacts the conductivity. Also vegetation, whether soil there is vegetation below as you dig, whether you will encounter this or you mean by vegetation, which is actually organic soil which is embedded below the earth, so all this will affect the conductivity of the soil. The next important design parameter is the pipe depth.

tube depth must be optimal. What do you mean by optimal? Tube depth should not be, say, this is the soil; it should not be too shallow. Tube depth should not be too shallow, or tube depth should not be too deep either. What will happen when you have a very shallow depth of the tube? Now the temperature here may not be appropriate for you to have a considerable difference between X minus Y. So this temperature difference has to be considerable. If it has to be considerable, then the depth of the soil has to be optimal.

It cannot be shallow. If it is too deep, it is meaningless because two things will happen. You will have to use pressure to send the air and to pump the air out if the depth is too much. Besides, if the temperature of the soil here is T1, it is going to be T1 here also. So, or there will be very minimal difference between the two. soil temperature at this depth and soil temperature at this depth, in which case it is meaningless to go too deep.

It should tap the correct ground temperature. That is what I explained. Between T1 and say T1 plus delta T, there may not be much difference, and therefore optimizing is important. So ground temperature will depend on what this T1 or T1 plus delta T, etc. will depend? It will depend on the external climate. Whether it is a very hot place or a very cold place, because I said it will be the average temperature of that place.

Second is soil composition. whether you have organic matter, inorganic matter, mineral composition, etc. What are the thermal properties of the soil? Its conductivity, emissivity, diffusivity, etc. The moisture level of the soil and the texture of the soil. So these are the factors on which ground temperature will depend.

The next important parameter is the pipe length and pipe radius. So the heat transfer takes place through the surface of the pipe. So surface of the pipe means what happens, what becomes important? It is the diameter and the pipe length. This is what will add surface. And heat transfer takes place because of the contact of soil on this surface, and therefore the radius and pipe length matter a lot. The longer the pipe, the greater the opportunity for conduction because there is more contact with soil.

But if the pipe is too long, then the internal air temperature and soil temperature will become the same. Then there is no use of a longer pipe. So if you have an optimal pipe length where the temperature of the soil says if the temperature of the air that comes in here is 32 degrees Celsius. By the time it reaches here, if it is 28 degrees Celsius because the soil temperature is about 27 degrees Celsius, then any further movement of the air is going to only minimally improve the air temperature.

So, there is no point in having very long tubes because it has other issues. When you need, when you start using longer pipe, you need more space, and the site may not have that much space. So, apt length or optimum length is an important criteria for efficiency. Third is soil type. So, soil type is very important.

So, you should have undisturbed soil temperature. So, the soil temperature should not be disturbed. It will normally not be disturbed unless there is a water body or something like that. Next is thermal conductivity. The thermal conductivity of the soil is very important.

The third aspect is moisture content. Fourth is soil mineral composition. Fifth is the compaction level or density of the soil. Sixth is void ratio and porosity. Seventh is particle size and grading. So these criteria of soil are very important.

Then the velocity of air that passes through is again very important. So let us look at this important design parameter. Now here we have a case scenario where the velocity of air here is 5 meters per second. The velocity of air, this air, is about 2 meters per second. The velocity of this air is 3.

2 meters per second, and this is at 4 meters per second. Now you can see various sections have been used. T1 along the pipe, so along the pipe at inlet, if the temperature is 20.5 degree centigrade, based on the velocity of air, so if the velocity of air is 5 meters per second, you can see that the temperature at the outlet, the outlet air temperature, is about 24 degree centigrade. So, at 5 meters per second, it becomes 24 degrees centigrade. Whereas when the velocity of air is 2 meters per second, then the outlet temperature is about 25 degrees Celsius.

Then there are certain important design parameters. The pipe characteristics. The pipe material will depend on the pricing or cost, the durability, the strength and durability, and the ability to withstand moisture. Pipe installation. The size of earth-air tunnels varies depending on the site's requirements. In general, a 100- to 120-meter earth-air tunnel requires a depth of 6 to 8 meters. The pipe material can be HTPE or it can be concrete, and the diameter of the pipe should approximately be 450 to 500 mm.

These are all thumb rules that I am telling, and experts in this will be able to design it using

CFD calculations also. That is where the velocity of the soil, the previous slide that we saw, shows a correlation between the outlet temperature of the air and the velocity of air. So these are done using either experiments or simulation. So all the dimensions that I mentioned here, which are the length of the tube, the depth at which it should be laid, and the diameter of the tube, are all thumb rules that can be followed.

The pipe work should be done on time so that it does not have air leakage. If air leakage happens, then it is not going to be effective. Or any other issues like moisture or water creeping in or roots of soil can creep in through the hole. So how is the piping arrangement? Now there are two kinds of piping arrangements. One is a one-tube system where only one there is only one inlet and one outlet.

When this is the ground, there is only one inlet and there is only one outlet. So it will look like you know if this is a pit, then you will have only one pipe coming like this and leaving the soil. And you also have multi-tube systems in which you have more than one pipe that flows through the earth. These are embedded in the earth, and it can have multiple pipes. Outlets also. Multiple inlets, multiple outlets also. So here is an example of a multi-pipe where a network of pipe is buried into the soil. This is an outlet hole and air would come from somewhere else. Or you can even have it in two layers. This is one layer, and you have another layer also, as shown here. So there can be varying pipe arrangements.

Don't think it is just a single tube that can be used. We can have multiple tubes, multiple tubes at the same level, and multiple tubes at various levels of the earth. So the earth is dug with the help of an excavator, and then the system consumes very little electricity. See here it is a single tube, but the single tube is making full use of contact with the soil. This goes in a spiral manner, and therefore there is more contact area or more contact surface of the tube with adjacent soil.

So this system consumes very little electricity as compared to air conditioners. This is also eco-friendly and does not harm the environment, but its initial investment is high. So various piping systems can be there. We can have a vertical loop system, we can have a horizontal loop system, or we can have a spiral loop system.

Let us look at the advantages of earth-air tunnels. First, it is non-toxic. There is no question of adding any other gas or any other kind of metal or element. So it is completely non-toxic. It has no emissions. So it does not add load to the environment by pumping in harmful gases and so on.

It is environmentally friendly. It has a long life. Once you lay the pipes, that's it; nothing will happen. It is very low in maintenance because it's anyway not accessible. So there's nothing much to maintain as far as the pipes are concerned. Sixth, it has low operational costs.

You hardly have to do anything because natural ways of heat transfer take over. Seventh, it has low energy. That is, one-third of the conventional air conditioning system's power requirement can get reduced. What happens if your outside air temperature is 36 degrees centigrade? This is temperature outside, and you actually want 26 degrees Celsius as your indoor temperature. Then, if you do not have an earth air tunnel, then the air conditioner will have to convert 36 degrees Celsius into 26 degrees Celsius. But if you have an earth-air tunnel, this can become 29 degrees Celsius and will get converted into 26 degrees Celsius.

So with an AC, there has to be a drop of 10 degrees Celsius. But when you have earth air tunnels, the AC has to only take the load to convert the air from 29 degrees to 26 degrees, which is just 3 degrees. Therefore, the AC system's power requirement can get dramatically reduced. Next, you can have better indoor air quality. You can have 100% fresh air circulation in the premises, and a minimum of 28 degrees Celsius can be maintained during peak summer generally.

There are certain limitations. First, it is space-consuming. I mean, on a site like this, you will have to allocate and segregate space for air. The pipes to be laid and the building can come only in one part. It has a higher initial cost because you have to spend for the tubes.

Third, air entering the system during the day is hot and humid. So sometimes mold can be formed. Mold means fungus can be formed. And you can also have condensation issues. So you have to be careful about condensation issues. We will quickly see one example of a buried pipe technique that is used in SD works.

So by day the earth to air heat exchanger cools down the supply air flow. So concrete tubes which have a diameter of 80 centimeters. So these concrete tubes these are concrete tubes with 80 centimeter dia and 40 meters length. So imagine you will have to have a site like that. They are buried at 3 to 5 meters depth.

So this is 3 to 5 meters depth and connected to the ventilation system like this. So here it is seen That the maximum temperature in summer never exceeds 22 degree centigrade. So this is the earth to air. I will say earth to air heat exchanger temperature is never exceeds 22 degree centigrade on the first floor.

And the maximum temperature on the second floor. So this is the first floor. Here the temperature is always. around 22 degree centigrade or less than that. And on the second floor, it is always between 23.5 to 26 degree centigrade. This is during the summer period.

So, you can see the humongous amount of energy savings that can happen because of using earth air tunnel. So here in this picture we can see how the temperature during summer on the of the earth air tunnel. So here you can see how the temperature of earth air tunnel air never exceeds 22 degree centigrade even though the external temperature is about 31 degree centigrade anywhere between say 24 to anywhere between 24 degree centigrade to 31 degree centigrade and earth air tunnel temperature is anywhere between 15 degree centigrade to 22 degree centigrade. The outlet temperature I mean. So this will be the outlet temperature because the temperature of the soil is going to be constant only. So because of which you can see that the first floor and the second floor temperature which is this and this is also more or less similar and as we said it does not exceed 22 degree centigrade on the ground floor.

So this can be the impact. So this can be the impact of earth air tunnels and you can see how much energy savings can happen because of using earth air tunnels. Because the load on the air conditioner will be completely cut sometimes and sometimes it can be dramatically reduced because the temperature that the air conditioner has to handle, the air temperature is much less. than the outside air temperature. So with this we will stop today's class and we will look at another advanced technique in the next class. Thank you.