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

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Lecture 04

Radiant Cooling System

Hello, dear students. Welcome to another lecture on an advanced passive strategy. Today we will look at an advanced passive strategy called radiant cooling. So let us look at the advanced passive design called radiant cooling system in today's lecture. Radiant cooling 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, or ceilings. This network of pipes can turn the floors, walls, and ceilings of a conditioned space into cooled surfaces that evenly absorb heat energy. So radiant cooling works best in tightly sealed buildings that integrate radiant with a downsized forced air system to meet the building's fresh air requirements. In this system, there are pipes embedded in either floors, roofs, or walls.

And the pipes are laid, changing the color so that there is clarity. And the pipes are laid as shown here. These pipes are embedded, which means further concrete is poured if it's a roof or a floor. So the radiant cooling system uses water as a medium to cool the occupied spaces of people, and the conventional air conditioning system uses air to create a cooling effect. There are three reasons why water is much more efficient than air as a heat transfer medium.

Compared to air, water is approximately 20 times higher in its thermal conductivity. Then the specific heat of water is 4 times that of air. And the density of water is much higher compared to air. So here you can see these figures. Where the specific heat of water, thermal conductivity of water, and density of water are much higher than those of air.

What is the principle of this radiant cooling? So the fundamental property of heat transfer is that heat flows from a hotter body to a cooler body. So these are two things that I have been reiterating for a long time. First is heat flows from hot to cold, and the second principle, though that is not used here really, but you must always remember the second principle also that warm air rises and cool air descends. So like in almost all of the advanced passive strategies, in this strategy also both of these principles will be used. So in any room, constant heat exchange happens between the human being and the surfaces around, say, the floor.

So between the floor either heat is radiated from the floor if the wall and the floor are warmer from the ceiling heat is radiated apart from the fact that there is conduction of the human being whenever he touches any particular object and that can also cause heat exchange through conduction. Again, if there is any apparatus here, like a computer or any machinery, that is likely to radiate heat. So there is constant exchange of heat inside a room because every system seeks to have equilibrium. So until all surfaces have the same temperature, there is a constant exchange of heat between the elements inside a room. The surface temperature of all objects in a room radiates, and this is the mean radiant temperature.

That is the basic principle of this system. So, in this system, suppose the ceiling has a temperature of 80 Fahrenheit and the temperature of the air in the room is 70 Fahrenheit. I have said that heat transfer happens from the hot part to the cold part, and therefore there is radiation of heat from the pipes that have warmer water. Therefore, by doing this, the person inside will not find it cold because he has heat getting radiated from whichever surface the pipes are embedded, whether they are walls, roofs, or ceilings. Similarly, if the roof has a lower temperature, if it is cool and the room temperature is warmer, then you have to make the room cooler.

What happens? When you have cold water running in these pipes, there is radiation from the floor and the wall, and that gets absorbed by the water, which becomes warm in its outlet. So, warm water comes out of the tube. So the principle of a radiant cooling system is the passive intelligent radiant cooling concept that is controlled and cooled by the water pressure and done by like city water or tap water. Even when the outside air temperature is over 36 degrees Celsius during the cooling period, natural city water has a temperature of approximately 28 to 30 degrees Celsius in principle because the city water is supplied at least 90 centimeters under the water. So this is the principle of earth air tunnels.

So in earth air tunnels, this principle is adopted where the subterranean temperature remains constant throughout the year, and at a depth of about 4 meters, it follows the average annual temperature of that place. Therefore, when the outside temperature in summer is 36 degrees Celsius, the average temperature at 4 meters depth would be the average of that place because in summer if it is 36, then we will assume in winter it is 20 degrees Celsius. Therefore this will be about 28 degree Celsius, and therefore when the summer temperature is 36 degree Celsius outside the water temperature through the pipe If it gets through municipal corporation, it will be about 28 degree Celsius. So, radiant cooling systems have been embedded in the ceilings of homes, taking advantage of the thermal mass to provide a steady cooling effect. Typically designed in conjunction with radiant heating, radiant cooling systems can circulate chilled fluid through the same network of embedded plastic tubing.

This network of tubes can turn floors, walls and ceilings into cold surfaces that evenly absorb sensible heat energy, including radiant energy from solar gang, people, lights, computers, any other heat-radiating gadgets, printers, etc. in addition to some convective heat transfer from the air. So in this principle, there are tubes that are embedded in the concrete floor, and in these tubes runs cool water, and because the water is cool and there is heat, the room is warm or heat radiated. What happens? This transfer of heat takes place, and in this process, the room becomes cooler. So heat transfer occurs whenever there is a temperature difference between two objects within a space and continues until both objects are in thermal equilibrium.

So this is the law of nature. According to a formulation of the second law of thermodynamics, known as the Clausius statement, heat cannot naturally flow from a colder temperature to a hotter temperature. In other words, heat will always naturally flow from hot to cold. So heat transfer will happen only between hot and cold. So this happens in three different ways: conduction, convection, and radiation.

A radiant cooling system uses all three modes of heat transfer, which are conduction, convection, and radiation. Let's look at what actually happens. Circulating water is more efficient than circulating air because of its physical and thermal properties. Water can carry 3400 times the energy that air can carry for the same volume. This property of water is used to achieve a maximum advantage in a radiant cooling system.

Also, the natural way the human body dissipates heat is mainly through radiation. So if you have a human being, he has heat transfer through- When a human being sits in a particular place, he has heat transfer through conduction due to his contact with surfaces through convection because of temperature difference of the air around him. through evaporation and through radiation. So there are different types of radiant cooling depending on the location of the piping. The first is chilled slabs.

So cooling through the building structure, which is usually a slab, is called chilled slabs.

Also known as thermally activated building systems, or TAPs. The second is ceiling panels. These deliver cooling through specialized panels. Third is depending on the position of the piping.

First is the location of piping. Second is position of piping. The radiant system is usually classified as slab on grade, suspended slab, and topping slab. So, based on where you place the pipe, you have these three classifications of radiant cooling systems. What is slab on grade? Slab-on-grade installation is the most popular technique used in commercial construction when the tubing is inserted straight into the structural slab.

So the tube is inserted into the structural slab, and it is advised to place a vapor barrier between the compacted base material and the radiant slab, such as high-density polythene sheeting. Insulation may be essential to the radiant floor system's correct and effective operation. The path of least resistance is where heat energy moves. When insulation is used properly, heat is directed towards the designated area. This is particularly crucial in regions with a high water table or wet soil.

Additionally, a well-insulated system has a faster response time. This system, which can be used for radiant heating and cooling, stores and exchanges thermal energy using the building's concrete mass. The second one is a suspended slab. So in multi-story buildings, structural slab on metal deck installations are typical for the higher stories. Radiant tubing installation is quite similar to slab-on-grade installation.

The major or primary distinction is the insulation, which is usually placed to the underside of the deck using either foam or wire mesh rebar to hold the foam in a rigid place. Then there is the topping slab. A tube can be inserted in a non-structural topping slab. For installations on existing slab or in situations where the structural engineer or local government does not permit installing tube within the structural slab. So this system can be a good alternative for a retrofit or when the local bylaws do not permit having a tube inserted in the slab. Slab-on-grade installations and this installation technique are extremely comparable because they do not offer any structural support.

The topping slab is usually thinner. It is only about 3 inches, and it is referred to as a low-mass structure. Because of the insulation layer's thermal break, it will respond faster and yet have less thermal mass. So this is how it basically works. This picture shows the schematic diagram of a radiant cooling system.

Pipes are embedded in concrete slabs or floors and during the hours when it is occupied. So for cooling, the radiant system uses both thermal mass and nocturnal cooling. Chilled water in the pipes is supplied through conventional chillers. So through the conventional chiller, you get the cold water, and this cold water keeps moving through the slabs. like this, and then what happens to the indoor equipment? Human beings, computers, they all generate heat.

This heat creates the air to become warm, and at the same time, the warm air adjacent to the ceiling becomes cool because of the presence of the chilled water in this tube and this air. This cool air tends to descend. So cool air tends to descend and warm air tends to move up and therefore people can feel. Now the same thing happens even at floor level. So even from the floor where you have chilled water, you can have cool air, which becomes cool because of contact with the slab, which is cool.

Besides the thermal mass of the slab, also absorbs the heat, and it becomes cool. It absorbs the heat from the room and becomes cool due to the chillness of the pipes, embedded pipes, and radiant pipes. Now, the pipes can be located in either roof, as you can see here. So, the roofs have pipes flowing across the ceiling, or you can have them on the floor.

So this picture can show that clearly. So you can have the radiant pipes on the floor. You can have the radiant pipes moving or embedded in the ceiling. And you can also have radiant pipes along the walls. These have to be designed well in advance at an early stage to be implemented. So how can we make the radiant cooling system more efficient? So cooling is more efficient.

Evenly distributed, drafts have to be eliminated, and these pipes are embedded in floors, walls, or ceilings depending upon the possibility and requirement. So this requires air movement and dehumidification equipment as part of the system. The temperature can be controlled by individual rooms. Here, this system can become more efficient if we are able to combine it with tapping geothermal energy. How is that possible? Now we have already seen that the temperature of subsurface soil is much less than the upper layer or ambient air temperature, and this temperature of the subsurface soil is the annual average temperature of that place.

If the annual average temperature in summer is 40 degrees Celsius and the annual average temperature in winter is 20 degrees Celsius, then the average temperature of that place's annual average is 30 degrees Celsius. Therefore, at a depth of about 4 feet or at a depth of about 4 meters, the temperature of the soil is 30 degrees centigrade. So, if the room temperature or the ambient temperature of a room is 40 degrees Celsius or 37 degrees Celsius, then if you are able to tap geothermal energy, then the water temperature can be 30 degrees Celsius, and this water can be used to run along the ceiling. So automatically, with absolutely zero effort in any way, you can get the room to become cool by tapping the geothermal energy as well as the radiant cooling system.

So, the pipes can be embedded in the slab. They can be designed for the spacing. They can be designed for the diameter of the pipe. You can also see the under part of the staircase having these pipes running. So you can embed this pipe in whichever surface you want, depending upon how much you want the room to be cooler. What are the advantages of radiant cooling? So the first advantage is that it reduces life cycle cost.

Compared to a traditional forced air system, radiant cooling has a lower operation cost due to the superior heat transfer properties of water. The installation of a radiant cooling system may also lead to a significant reduction in forced air system components and ductwork cost. Thanks to the high specific heat as compared with air, water is a much better conductor of heat energy. A nominal three-fourth water pipe can transfer the same heat energy as a 14 by 8-inch duct. A hydronic circulator moving warm fluid can typically deliver the same thermal energy as an air fan with a 75 to 90% reduction in electrical consumption.

The second advantage is that it improves energy efficiency. Compared to traditional systems, radiant cooling operates with a moderate water temperature, allowing you to raise your thermostat a few degrees. while still maintaining the same level of cooling. This can lead to a significant reduction in energy consumption as well as a reduction in carbon footprint. The efficiency of a radiant cooling system can be even further enhanced with the integration of water-to-water geothermal heat pump systems.

As we saw in the previous slide. The third advantage is that it increases thermal comfort. The human body feels at its best when it can regulate at least 50% of its heat emission via radiation. Radiant cooling optimizes the surface temperature of the occupant's surroundings, providing a comfortable environment while reducing draft and ventilation noise. The fourth advantage is that it has reduced fan power. With the ventilation air system, thermal mass can significantly reduce the need for airside systems, reducing the fan power of HVAC systems drastically.

Fifth is energy conservation. Additional savings due to lower supply temperatures of chilled air can cause a lot of energy to be conserved. Sixth, there is no energy compromise. There is no noise.

There are no drafts. And you can't see the pipe. You can't see the pipe. The pipes are embedded or hidden. And therefore, there is no compromise on aesthetics. Besides, it's a sustainable solution. The radiant cooling technique has zero ozone depletion potential and global warming potential, reflecting one of the best environmentally friendly cooling techniques.

Radiant cooling also provides better adaptive comfort to the occupants. In the coming years, where protecting the environment is of significant concern, radiant cooling can be a very good cooling system. Another key benefit of radiant system is the great architectural freedom afforded by a system that is hidden in the floor, slab, or wall. Radiant systems are safe gentle quiet steady and invisible and provide unmatched comfort through the use of warm surfaces it of course comes with its own set of limitations so their limitations can be first They can malfunction. Sections with leaking or blocked radiant pipes have to be closed, disrupting supply in the process.

This can also lead to condensation issues. Condensation reduces cooling capacity. Hence, an efficient envelope with non-operable windows is required. Condensate formation on the cold radiant surface can result in water damage and molds being formed. The third is maintenance issues. Complicated controls require skilled maintenance staff because it's not easy to maintain temperatures below 23 degrees Celsius with the help of only radiant cooling.

But that is also its advantage if we are able to maintain 23 degrees Celsius just with the help of radiant cooling. Although potentially suitable for arid climates, radiant cooling is problematic for homes in more humid climates because of condensation on the panels. When their temperature is below the dew point of the air in the room. So condensation can occur when the temperature is below the dew point of the air in the room.

The house must be kept dehumidified. In humid climates, simply opening the door could allow enough humidity into the home to allow condensation to occur. Besides, there is high capital in expenses for the system because you have to spend for the tube and the labor. Let us look at a few case studies. The first case study is the L&T Hazira at Surat, Gujarat.

It has a hot and humid climate with a high latent heat load. The design condition is that the indoor design temperature should be 25 degrees Celsius and relative humidity should be 60%. Here the radiant cooling was used for the ground floor. So the insulated ground floor slab mitigated the loss of cooling effect, and because they used a combination of radiant and conventional HVAC, they were able to reduce the AHU power from 65 kilowatts to 21 kilowatts.

Besides, the chiller power has reduced from 181.3 kilowatts to 56.5 kilowatts. Hence, there has been a total savings of 48% When a combination of radiant cooling pipes and a radiant cooling system with conventional HVAC is used to get the appropriate indoor thermal comfort condition. The next case study that we will see is the Infosys Pocharam campus in Hyderabad. In this campus, you can see that there are two symmetrical forms or two symmetrical blocks along the central core. So what they did was this Infosys Pocharam, which is in Hyderabad and has a hot, dry, or moderate climate.

It is an office building with an area of 11,600 square meters. So it has two symmetrical halves of the buildings, which are air-cooled with different technology. So in this part, as we saw in the previous slide, one part is through the conventional cooling system, whereas the other half is cooled through the radiant cooling system. A low-pressure piping and ducting distribution system is installed. The capital cost of the radiant system is 3302 INR per meter square. Whereas the conventional system was installed at a slightly higher rate of 3,327 rupees.

The energy index for a radiant system was, I will draw the comparison here so that we can visualize it easily. This is conventional, and this is, this block uses radiant cooling. Then, cost-wise, if you see, conventional cooling costs 3327 INR, whereas radiant cooling costs 3302 INR. The energy index for radiant cooling was 25.7 kilowatt hour per meter square, whereas for the conventional system it was 38.

7 kilowatt hour per meter square. Thus, the efficiency of the radiant system was 33% less than the conventional system. The average chiller plant efficiency for the radiant system was 0.

45 kilowatts per ton. Compared to 0.6 for the conventional system. The quantity of water required by the radiant system is one fifth. As compared to the water requirement of the conventional chiller of similar capacity. Air quality is also improved as there is no recirculation. So contamination is reduced. Comfort conditions measured inside the building are well within the permissible limits as given by ASHRAE 55, at least during most of the time.

This building has been operational for the last 3 years, and the radium system is functioning without any major complaint. So, this building is a clear example where the conventional air conditioning system is and radiant cooling is compared at every level on a routine basis. So today we saw the radiant cooling pipe system, which follows the natural process of heat transfer, that is, heat moves from hot to cold. And we also saw how these pipes can be embedded in floors, walls, and ceilings, and if it is combined with geothermal energy, how much more energy efficient it can be because the pipes that are embedded in the floor, wall, or ceiling will absorb the heat that is generated by human beings or the apparatus, and in that process they will cool the room in a very energy-efficient way. So today we saw this advanced passive system. We will stop this class with this and we will continue with another advanced system in the next class. Thank you.