Energy Efficient Architecture
Lecture 5

Evaporative Cooling

Passive cooling is a building design approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low or nil energy consumption. As you can see in this picture, passive cooling begins from the outside. There is a tree, a deciduous tree which means that it has leaves throughout the year and it is going to cut down the sun rays penetrating into the building. The major source of heat gain in the building has been cut down at the source and further penetration through the trees has been cut down by the overhangs, sunshades that have been projected. They have good ventilation opening systems to let out the used up hot air outside. This type of system uses various natural cooling elements such as vegetation ground cover, water, sunshades to cut down the solar radiation penetrating into the building to help maintain the thermal comfort for the occupants using the space. This eventually reduces your energy bills, energy consumption or the air conditioning of spaces.

Let us move on to the fundamentals of passive cooling; in fundamentals of passive cooling, heat flow from high temperature areas to low temperature areas. This is based on how you need to design your openings, windows and proportion of windows to doors, these are all based on the fundamentals we are going to look at. Reverse flow can only be induced by feeding additional energy into the thermal system. If you want to reverse the flow of heat, if it has to flow from a higher temperature to a lower temperature, you certainly need to use additional energy resources to reverse the physics of this whole mechanism and passive cooling seeks to use natural heat flows whenever possible.

Some of these strategies that can be used to have passive cooling is; reduce heat gains in internal and external. This is by having good vegetation ground cover, using water bodies around your site to reduce the heat gain at the source. This is what is known as 'Reduction of heat gains at the external factors'. By using thicker walls, making a design such that the harsh light doesn't hit your living room or spaces which occupants are going to use throughout the day. Open high-to-low temperature heat flow path to divert the excess heat (heat removal into a suitable heat sink). As we saw the fundamentals of passive cooking, the heat moves from lower temperature to higher temperature, you need to make your designs and the physics of the building have to arranged in such a way that the heat that is accumulated within the built environment can escape easily outside. You need to provide the hoardings and apertures according to it. As you can see in the third picture below, they have good window openings which means that the heat that enters and the heat that is created by the television and by the occupant using the space can be flushed out immediately through the other side of the opening that is present.

Let's move on to the next topic of this presentation which is called 'Evaporative Cooling'. Evaporative cooling is the oldest form of air conditioning ever used. The ancient Greeks used to fill terracotta pots full of water and leave them by doors and windows to benefit from evaporative cooling. As you can see in this picture, this is one of the oldest method in which the king sits here and these pots have been filled with cold water and as the air passes from this area, this cold water present in these pots have a heat transfer. The heat of the air reduces as it passes via these pots and the cool air reaches the king. This is the basic fundamental on how it began during the Greek Period. This is being developed over generations. Later the Arabs hung wet blankets over doors and windows to achieve the same effect. As you see, the Arabs developed it by hanging wet cloth or we blankets around their doors and windows so that the air that is passing through the opening has to come through these windows and doors which passes through the wet blanket and observes the water that's present in the blanket and as it passes inside, the air that comes inside is automatically cooler when compared to the air outside.

The Physics of Evaporative cooling - Evaporative cooling is a natural phenomenon that occurs when moving air passes over a wetted medium or water source i.e fountain, river, sea, shower, etc. The human body uses evaporative cooling through sweating to maintain a constant body temperature. As we might have observed, when we head towards places that are close to a river or a pond or pass by over a bridge or a water body, you will feel slightly colder or chiller when you are passing through such places, it is because of this evaporative process that has been happening which absorbs the heat present in the air and adds humidity to the air which cools the air temperature.

Human body also follows the same physics which by sweating, we lose the heat gained in our body which helps us maintain our thermal comfort. Warm dry air when passing over water liberates some of the water in the form of an evaporate. This adiabatic process converts sensible heat that which can be measured by a thermometer into latent heat. As dry air passes through a fountain or a water body, humidity is added onto it by the water body present here. Then this air that was initially dry, as it passes through a fountain or a water body, the evaporation happens causing the humidity to increase in the air. When it hits us, we feel slightly cooler. The net result is air which has measurably lower temperature than ambient air approximately 6 to 7 degree Celsius for a typical Irish summer temperature that has increased levels of relative humidity. As you can see in the picture, this hot dry air has been made to pass through this wet medium and then the air that is passed outside is called cool air. This process of evaporative cooling can reduce the ambient temperature from 6 to 7 degree celsius. But we should also be conscious that it can add the humidity levels too. This is most effective when your design is being made in hot and dry climatic conditions. When you are coming to warm and humid climatic conditions, you need to make certain alterations to keep your humidity also in controlled levels.

Types of Evaporative Cooling

Types of evaporative cooling; Direct Evaporative cooling in which the air is made to pass through the water body directly and Indirect evaporative cooling is through certain processes in which your humidity has to be maintained in regions with high humidity levels.

Direct Evaporative Cooling - with direct evaporative cooling, outside air is blown through a water-saturated medium (usually cellulose) and cooled by evaporation. The cooled air is circulated by a blower. In this picture, this warm air passes through a direct wet medium which can either be a cloth, a blanket, a fountain or a water body in which water passes and the warm air that passes through this body gets cold because of the humidity that is present in this direct source which adds to the warm air and makes it cool air.

Direct evaporative cooling adds moisture to the air stream until the air stream is close to saturation. This obviously adds higher relative humidity compared to the first primary air source which was coming. Then, the dry bulb temperature is reduced while the wet bulb temperature stays the same. The temperature we observe is slightly colder or chiller and is due to the reduction of dry bulb temperature, not due to wet bulb temperature. Dry bulb temperature is sensible air temperature, the one we measure with the thermometer. The wet bulb is the lowest air temperature achievable by evaporating water into the air to bring the air to saturation. This is the lowest temperature that can happen in the air. That cannot be reduced by this method of cooling system. Only the dry bulb can be reduced. Moving on to In-direct evaporative cooling system. With indirect evaporative cooling, a secondary (scavenger) air stream is cooled by water. The cooled secondary air stream goes through a heat exchanger where it cools the primary air stream. The cooled primary air stream is circulated by a blower. This method is mainly used in areas with higher humidity levels or colder regions that have prolonged summer season with higher humidity levels in which humidity has to be controlled. The relative humidity cannot be increased because it will cause discomfort for the human beings and occupants who are going to use this space. For this we are going to use primary air steam which has an indirect evaporative cooling. The secondary air stream has passed through it and the humidity level is being maintained, not added. Cooled air is made from primary to the outlet air due to the presence of Secondary air stream which is being blown to take out the excessive heat present in the primary air source. So, indirect evaporative cooling does not add moisture to the primary air stream. Both the dry bulb and wet bulb temperatures are reduced. In this method, we will be able to reduce both dry bulb temperature as well as the wet bulb temperature and it doesn't add any humidity to the already present primary air stream. This is because it is not passed directly into the wet medium.

Next is indirect/direct evaporative cooling - with indirect and direct evaporative cooling, the primary air stream is cooled first with indirect evaporative cooling and then cooled further with direct evaporative cooling. This system is a combination of what we have seen earlier, direct evaporative cooling system and indirect evaporative cooling system. At first the indirect evaporative cooling happens in which the primary air is made to pass through this indirect system, through which the secondary air stream is being blown and takes out the excessive humidity and heat that is present. This reduces the dry bulb temperature as well as the wet bulb temperature. Then, once again it is passed through the direct piece of cloth or a cellulose system in which the cool air has a further reduction in dry bulb temperature.

Indirect/ Indirect evaporative cooling system is using two different indirect cooling system to reduce the temperature of the first primary air source considerable and drastically. In the first stage, the primary air stream is cooled by indirect evaporative cooling. In the second stage, water is used in first-stage cooling passes through the wet side of a coil. Additional sensible heat is removed from the primary air stream, and no moisture is added to the primary air. When you consider the system that we saw earlier, the direct and indirect evaporative cooling, the relative humidity is maintained but the dry and wet bulb temperatures can be reduced. This system is the one in which you can completely maintain the relative humidity levels that is present earlier on the primary air stream, we can also achieve much cooler effect in the outlet air when compared to the primary air stream. As you might have observed, this is the Indirect cooling system. Again this cooled air that is coming out from the primary air stream through the indirect evaporative cooling system is again made to pass through this indirect cooling system to achieve much more cooler air in which the dry and wet bulb temperature is reduced.

Indirect Evaporative cooling or DX system

With indirect evaporative cooling with DX back-up, the primary air stream is cooled first with indirect evaporative cooling. Most of the time, this cools the primary air stream to the desired temperature. When more cooling is required, the supplemental DX module cools the air further to reach the desired temperature. This is for extreme cases, for climatic conditions where the temperature can rise upto 50 degree celsius also with higher humidity levels. We need to reduce the humidity as well as the temperature. Due to the extreme conditions of air temperature, we need much more effective systems to further reduce the air temperature to achieve the even thermal comfort. For this we are using this DX system, this is for extreme conditions which is comparatively more effective in overall evaporative cooling.

Indirect Evaporative Cooling with DX is also reduced cause we need to also the relative humidity from the primary air stream. The primary air stream passes and the secondary air stream is blown through this indirect system and the relative humidity is exhaustive or taken out by the process of evaporation and then this cooled air is made to pass through the DX, the supplement that we have to achieve much more colder air outlet compared to the primary air stream.

We are going to look at what are the advantages of using Evaporative cooling systems. Evaporative cooling is economical, effective, environmentally friendly and healthy. We are not going to use any additional gases or anything like that. This is the most ethical and economical. We can straight away do this in hot and dry climates by keeping huge water bodies outside your site which will add benefits to your design. Cuts mechanical cooling costs from 25% to 65%. Let's say you are using it during a hot and dry climate or a combination of climates in which rather using air conditioned spaced for 8 months, adopting these kind of strategies brings down the usage of air conditioning just to 1 month from 8 months. This can reduce energy bills from 25% to 65%. Increases existing equipment cooling capacities without adding mechanical cooling. Less greenhouse gas production typically 80% less. When you are using air conditioning, the air conditioner you are using is obviously eliminating chlorofluorocarbons and carbon monoxides that are causing ozone depletion. All this can be cut down by using evaporative cooling system when compared to mechanical cooling. This allows flow through ventilation with plenty of fresh air. As human beings need 80 litre of fresh air to maintain our thermal comfort, this system has benefits such as supply of fresh air constantly rather than leaving you dependent on any other mechanical system, a driver or a motor to flush in the fresh air that humans require. Effective - Evaporative cooling actually becomes more effective as the temperature increases, just when DX air conditioning becomes less effective. As the temperature increases, the usage of evaporative cooling is much more effective. For example when you look at palaces in Rajasthan you will find a moat or a water body around the palace. The water body that is present around the palace makes the air that enters the grounds of the palace much more colder when compared to the outside city. This is much more effective. Evaporative cooling works in all areas of the country, not just in hot dry climates. Although the Pacific Northwest is certainly damp in winter, it is dry in summer. In fact, humidity in this region of the country almost always decreases proportionally as the temperature increases. So the cooling power of evaporative systems increase as temperature increases. This is one example for Pacific Northwest in USA. How the colder regions have higher humidity levels but the summer is also extended. How we can use the evaporative methods effectively. It's the same how increase in temperature increases the effectiveness of evaporative cooling.

Environmentally Friendly because evaporative cooling does not use chlorofluorocarbons, it does not contribute to ozone depletion. As we saw it reduces the usage of air conditioning spaces and other air coolers and other mechanical cooling systems which we use in our day to day lives, this is reducing to the ozone depletion and contributing to CFCs. Evaporative cooling is healthy and comfortable because it brings in outside air and exhausts stale air, smoke, odors and germs. Helps maintain natural humidity levels which benefit both people and furniture and cuts static electricity. Does not need an air-tight structure for maximum efficiency, so building occupants can open doors and windows. This we observe because we usually observe in mechanical cool buildings, the building has to be completely shut all the time to maintain the air temperature that's present due to the mechanical systems that we have like air conditioning, air coolers etc but this system does not demand such type of closed spaces or air tight spaces. The windows and doors can be kept open, it invites a lot of fresh air and ventilation. To have a look at what temperatures this direct and indirect evaporative cooling systems can be adapted, let's have a look at the Psychrometric chart in which this green represents the comfort temperature referred by Ashrae 55 which refers to the comfort you do not need or any other external passive heating, passive cooling or any other additional mechanical systems you require to maintain the thermal comfort. This is good enough for human beings to survive without any additional systems and this system is when you need to have a temperature range, a humidity range you need to have for direct evaporative cooling systems. As you can see this relative humidity increases and because of the increase in the humidity levels present in the air, we cannot opt for direct evaporative cooling because it is going to contribute to additional relative humidity levels in the primary source after cooling. We have to adapt indirect evaporative cooling systems for these type of temperatures.Further after this temperature, it's effective when you are using indirect evaporative cooling, indirect DX system. As architects, we can make sensible choices in our cooling systems, passive cooling systems depending upon where your region comes and what prolonged period your climatic conditions fall according to the psychrometric chart.

Climatic applicability - Indirect evaporative cooling can be applied in regions where the summer average wet-bulb temperature is below approximately 20 degree Celsius. The ceiling acts as a radiant convective cooling panel for the space below, so that the indoor humidity level is not elevated. Effectively for indirect evaporative cooling, it can be applied when the wet bulb temperature is not more than 20 degree celsius usually. This is like a clue for you to choose which system you have to adapt. The ceiling acts as a radiant convective cooling panel for the space below, so that the indoor humidity level is not elevated because of the presence of a roof which reflects most of the solar radiation and flushes out most of the humidity levels due to the presence of aperture openings. Let's see what are the designs that are recommended to achieve good, evaporative cooling system. The pond should be effectively shaded from solar radiation. Considering the winter conditions, the shading should also have high insulation, and the ventilation openings between the shading and the water should be approximately 30 to 50 cm high.

When you are having a pond on the roof to cool your indoor spaces. You need to effectively shade it, so that it doesn't trap the solar radiation that has been falling on the water body that is very important. In winter the pond should be closed and the water drained off the roof. When you are designing this system for regions in which there is colder temperature for a prolonged periods as well. You need to have openings to drain of the water that you are going to store in your roof. This is important or else you are going to add much more colder temperature to the indoor during the winter season and it might make the occupants want to use the room heaters. The roof itself should be conductive as practical, as the insulation in winter is provided by the pond's cover.

Expected Performance - the pond's water average temperature follows the average ambient wet-bulb temperature (about 1 degree C above it) with swings depending on the pond's depth. If the roof is a good conductor, eg; reinforced concrete and the building itself is well-insulated, then the indoor average temperature in suitable climates will be below the average outdoor air temperature (dry-bulb temperature) by approximately 3 degree Celsius. This is for direct evaporative cooling in which you keep a pond above your roof, considering its being shaded. Usually the temperature of the pond will be more than the ambient temperature of the surrounding air. This effectively traps the solar radiation and it doesn't allow the heat to pass through the interior spaces and it effectively reduces up to 3 degree celsius compared to the actual air temperature, what you might expect indoors. The indoor temperature swing depends on the building's heat capacity as well. If you are having good thermal mass in which the specific capacity of the material is very high such that it can trap heat and dissipate it outside. When you are using such materials which can dissipate heat outside and absorb the cooling of indoor spaces, it will be much more effective since cool air does not escape outside immediately. Research has demonstrated the potential of shaded roof ponds to serve as a cooling system in air regions. In desserts this is much more effective.

Noturnal Radiation Cooling

Let us move to the next part of the presentation which is Nocturnal Radiation Cooling. This means cooling of a building by outgoing longwave radiation during the night can be achieved by two systems - Direct nocturnal cooling and subsequently protection of the upper surface from the sun and outdoor air during daytime by external insulation. The cooled ceiling services as a radiant convective cooling panel for the space below. This system is for places in which we have higher daily differences where the temperature in the morning can reach upto 40 degree celsius and the night temperatures can reach up to 10 degree celsius, so there is no clouds in the atmosphere. The heat can be dissipated outside. We have insulation in which it is closed during the morning hours and the interior space is being protected from the outside harsh temperatures and during the night, it can be opened up. The heat that is present within the interior space can escape outside and the cooling that is present in the night, outisde, can be trapped inside and then it can store the cool temperature that is present during the night for the entire day.

This is how it works. During winter, the insulation is left open since you need hot air to keep warm. This heats up the space and increases the temperature of the interior. During Winter night, you can close it so that you don't reduce the temperature that's present indoors furthermore. During summer, it is opposite of the winter. During the day, the insulation is closed to protect the interior spaces from additional solar radiation. During the night it's being opened to benefit from the cool outside air. Radiant cooling of a specialized radiator, usually made of metallic plate above the insulation with an air space in between. Outdoor air circulated at night under long-wave radiator is cooled by contact with the cold metal. This is also in one system where you are using additional cold metal plate to observe and trap the coolness rather than just using insulation, this is an additional layer that has been put up for the primary system that we just saw.

The cooled air can be blown into the building or through a gravel-bed, thus transferring the 'cold' to a mass which serves during the following day, as a cold heat sink, counteracting heat penetrating into or generated inside the building. This is the same system and the same physics that we just saw earlier. This is the same one but just with the additional usage of metal strips. This is how the metal radiator is being installed above your roof insulation and it traps the cold air during the summer season and it is being taken through the walls, it is used to cool the surfaces of your entire structure.

The final conclusion for the presentation on the last topic is 'Passive Desiccant Cooling Method'. Passive desiccant cooling method is effective in a warm and humid climate. Natural cooling of the human body through sweating does not occur in high humid conditions. In high humid conditions, already the relative humidity is very high and you cannot use simple evaporative cooling systems to achieve comfortable temperatures or comfortable humidity levels. For a passive desiccant cooling, it is additional system which uses one dehumidifier to take out the humidity that's present in the air and then it reduces the air temperature by normal evaporative cooling system. This uses combination of mechanical as well as your passive strategy. To decrease the humidity level of the surroundings, desiccant salts or mechanical de-humidifiers are used.