Climate and Built Environment
Lecture 3

Movement of the Sun

Passive solar design is based on utilizing the sun's heat energy and its predictable movement throughout the season. When we are looking at passive design strategies, major idea to achieve passive strategy, even if it is passive cooling or passive heating we need to know where the sun is located. And how much radiation it is going to give? Which determines all the other factors such as: Air temperature, Humidity levels, cloud cover etc? All these are correlated with the position of the sun.

Movement of the sun. As the Earth rotates around the sun on its annual cycle, it is tilted at an angle on its vertical axis. This impacts how the sun's rays strike various locations on Earth. The Earth is in its most extreme tilt at winter and summer solstices. The sun is something that is constantly located and earth rotates around the sun in its orbit. But it doesn't rotate on its straight orbit, it's slightly tilted. Because of this tilt we experience seasonal variation such as summer and winter conditions. The sun appears to rise in the east and sets in the west. In actuality, the earth is rotating on its axis and around the sun. So the earth rotates not only around the sun, but it also rotates within itself, that is why we experience day and night changes. Because it rotates around the sun we experience climatic variations.

Here is the diagram that compares the sun's path on the winter and summer solstices. If you observe this diagram, we can see June 21st which is usually summer solstices, which means the sun is at very high level, and it produces higher amount of solar radiation. The sun path is traced like this, in which sun is high. Whereas, during winter the sun path is at much lower level compared to the summer solstices. During winter solstices, the sun path is lower and it is much further away from the earth location, because of the tilt and elliptical orbit in which the earth is rotating around the sun, as a result of this we are experiencing difference in the sun path during summer solstices and winter solstices. This determines, in which you need to locate, what type of elements, this can tell you how much shading depth and shading elements you need to have to cut down the summer solar radiation but invite the winter solar radiation. This affects how low or high the sun appears in relation to the horizon. In the winter, the sun is relatively low in the sky with its lowest arc through the sky on the winter solstice, on December 21st. So, December 21st is classified as winter solstice because that is when the sun is at its lowest solar radiation levels. In the summer the sun travels a high path through the sky and is at its highest angle on the summer solstice, on June 21st. The June 21st the earth experiences the sun to be much more closer to it because of which it's classified into summer solstice. The equinox falls on the point between the solstices and indicates the arrival of spring or fall. The winter solstice falls when you are exactly in between extreme summers and extreme winters, it's when spring or fall is going to happen. That is when your equinox is being experienced.

This picture shows the sun's path throughout the year. The highest arc represents the sun

path on the summer solstice, while the shortest, lowest arc is the sun's path on the winter solstice. When the sun is very high here, it represents it is the summer solstice level in which the sun path is traced throughout the year. But when its lowest level, it means it's winter solstice level. And the average between these two is called Equinox, which happens in between both the extremes. On each equinox, the sun travels a path that is right in the middle of the path that is it travels on the solstices. So, March 21st- vernal Equinox; June 21st- summer solstice which is the highest path; September 21st- is Autumnal Equinox which means March 21st is going to be spring and September 21st is going to have fall. December 21st – is winter solstice, which means it the lowest path. This happens due to the presence of elliptical path in which the earth is rotating around the sun.

Earth's Rotation- The amount of daylight or night time is also determined by the amount of Earth's tilts. The earth's axis is tilted 23.5° from the plane of the Earth's orbit around the sun. As you observe, in this picture this is where sun is located; this is the orbit around which the earth is rotating. The earth is not rotating this elliptical orbit, it's not in a straight angle compared to the sun which is tilted 23.5° on the plane of earth's orbit around the sun.
Earth's Revolution- The motion of the Earth in its orbit around the sun is an ellipse, not a circle. That means at some points in the orbit the earth is closer to the sun than at others. The Earth's orbit is actually an ellipse and not a circle. If it's a circle we will experience all the season to be the same, but because we have elliptical orbit the earth is located further away from the sun, we are experience winter climates when the sun is located much closer; on the lower axis on the ellipse we are experiencing hotter seasons or summer seasons. When the earth is closest it is at perihelion. When it is farthest it at aphelion. It depends on elliptical path, if it's closer or longer. The difference in the distance is about 3.5% not enough to account for the seasonal changes. Not only has that contributed to seasonal changes, but rotation of the earth itself.

Earth's Curvature and its Tilt. What causes the daily and seasonal changes is due to the earth's curvature and its tilt. Here because of the Earth's tilts, how much amount of light is fallen on the earth is being explained. When sun is at higher level we are going to get lot of light, and during summer it's being tilted to almost tilted 73° because of which we are getting higher amount of sunlight. During the winter, sun is located at much more lower angle and is further away because of which we are experiencing lower sun rays or very deep and low sun angles which is almost 23°. If you are very close to the equator you might experience no shadow because the sun is just above the building and there might be no shadow around it; because there is no tilt or angle has been happening. When you are located further below almost 23.5° close to tropic of Capricorn or tropic of cancer, you might observe still direct solar radiation but you might have shorter shadows. When you are at much more higher altitudes, say if you are in Australia or if you are in places like Ireland you might experience less amount of solar radiation which means we have longer shadows.

Solar Position

The sun's movement through the day and through the year is one of the most crucial environmental factors to understand when designing high performance buildings. If you want your buildings to be highly performing, if you are conscious about reducing your energy bills and to save the environment you must understand where your solar or sun is being located during different months and different time in which the building is going to be occupied. If you design your building with careful consideration of the sun's path, you can take advantage of characteristics such as natural day lighting, passive heating, PV energy generation and even natural ventilation. So, if you are designing your building to respond to all other environmental factors such as day lighting, natural ventilation; if you know the position of the sun and type of activity for which you are going to design you might use external strategies to store thermal energy in the means of PV cells. You need to know where the sun is going to come and fall. How much heat it's going to be giving out? Only then you can decide how much amount of PV cells you might need to store your energy or convert into –to heat your hot water or make into electricity. For all this basic information you might want to know about the position of sun. Altitude is the vertical angle the sun makes with the ground plane. Altitude is how high sun is located in relevance to ground plane is called altitude. And Azimuth is the horizontal angle between the sun and true north, Positive in a clockwise direction from north. This means if you are located away from the north- from the north how much tilt your building is making, that path is being traced which is being called Azimuth angle. As you see this angle is called Azimuth in relevance to true north for this building.

Sun path and solar Position – The first thing to understand is the sun's path at your location. At any given point on the sun's path its height in the sky is called its altitude, which is this in relevance to the ground plane to the highest point of the sun and its horizontal angle relative to true north is called azimuth. This is your north you want to know the location of the Sun in relevance to this point; you are taking the azimuth in connection with the altitude.

Seasonal variations and important dates- the sun's path varies throughout the year. In summer the sun is high in the sky, and rises and sets north of east-west in the northern hemisphere (in the southern hemisphere, it's south of east-west). It depends on, from equator if you are located above the equator or if you are located below the equator, the seasonal variation changes. When we are experiencing summer months, if you are located above it is usually from march to may, whereas the same season is being experienced as winter for places which is located below the equator, places like Australia, Antarctica etc. It also rises much earlier and sets much later in summer than in winter. In the winter the sun is low in the sky, and rises and sets south of east-west in the northern hemisphere (in the southern hemisphere, it's north of east-west). It is the same; it depends on which position you are located in relevance to the equator.

Study particular days: a) the solstices, study of the extremes of the sun's position. The

Solstice's means during summer months the sun is at very high which is called summer solstice; during winter the sun is located at lower solstice which is called winter solstice. Which means the position of the sun at its extreme levels, either it might be high or low. b) The equinoxes- the study of average sun's position. The average of two extreme positions which is during summer and during the winter which makes the equinox. The equinox is when we have our spring or fall month.

Study different Seasons: a) winter studies- how to maximize sun to passively heat the buildings? b) Summer studies- how to minimize sun to passively cool the building? You need to know about both the conditions of both the solstice levels and how much heat it is going to gain in to your interior spaces? Because depending on that, if it's a winter solstice you might want to improve the solar radiation that is penetrating inside your space. If it's during summer months or summer solstice you need to cut down your ingress in solar radiations.

There are four important dates to remember when considering a suns position which is: 1) summer solstice – for southern hemisphere its 22nd December & for northern hemisphere its 22nd June. The sun is at its highest altitude during the noon. 2) Autumn Equinox- for southern hemisphere its 21st March & for northern hemisphere its 21st September. The sun rises due east and sets in due west. 3) Winter solstice- for southern hemisphere, it is just the reverse, it's 21st June & for northern hemisphere its 21st December. The sun is at its lowest noon altitude. As we in summer the sun is at its highest & during winter the sun is at its lowest. 4) The Spring Equinox- for southern hemisphere its 21st September & for northern hemisphere its 21st March. For Autumn Equinox and spring equinox it's just the reverse of the northern and southern hemisphere due to the location, if you are located above the equator or below the equator. The sun rises due east and sets due west. These are some of the important dates you need to know where your sun is being positioned, because the rest of the dates it's going to be average of all these four climatic conditions.

Look at specific times of day- a) Morning: you may want to captures sun's energy to warm up spaces when the sun is low in sky. But you'll also need to protect against glare. During early mornings you might need sun coming inside the space and for your other surfaces to observe and store the thermal energies. b) During the Noon: sun is the strongest and highest in the sky. You may want to avoid the hot midday sun to reduce cooling loads in some areas. But you may want to capture the sun in other cases for passive solar heating or energy generation. For example, if you are having PV cell on your roof, you might want sun to hit the PV cells during the noon even though it's very high. We want to take advantage of such high sun rays. But some spaces, say if you are in your office and if there is very hot sun rays that is coming inside your space you might end up using lot of air-conditioning or air coolers. To avoid that you might know which place, how much solar radiation you will need before designing. C) Afternoon: you may want to prevent overheating and glare. d) Occupancy hours: you may be particularly concerned about the time, when the building is most heavily occupied. If you are designing, for worst case scenario, when its completely occupied if you

are maintaining thermal comfort when it's completely occupied your building will automatically act much better, when it's less occupied the people will have much more control towards their openings and apertures so that they can have their own controls and variations to adjust to thermal comfort.

Sun Path- Stereographic sun path diagrams are used to read the solar azimuth and altitude throughout the day and year for a given position on the earth. They can be likened to a photograph of the sky, taken looking straight up towards the zenith, with a 180 ° fish-eye lens. The paths of the sun at different times of the year can then be projected onto this flattened hemisphere for any location on earth. The sun path is actually what happens on the hemisphere? And how the earth is revolving around the sun, the path is being traced which is called sun path. This is very similar to taking an image from the outside using a fish-eyed lens. Even though you have circular placed, in fisheye lens you will observe everything to be flat. This is how it's being correlated and given as an example for sun path.

Let's see the summer sun path- on the left is a 3D visualization of the stereographic diagram on the right, showing the movement of the sun throughout the day on June 21st summer solstice. This line is what happens during the summer solstice. As we observe this is the highest point in which the sun is going to come. Here, the lowest point is the winter solstice line and highest is the summer solstice line. As we can see there is numbers like 11, 12, 3 which means the hour of the day. During 11 o'clock the sun is at that particular hour and at 12 'o'clock the sun is going to move here. Depending on the hour in which you need your space to be fully occupied or how much time your building is going to be used you can trace how sun is going to move around your building using this summer sun path diagram.

The winter sun path is, as you see here, this is the winter sun path which is the lowest line. (Look at the shadows how it's moving around the visualization) as we can see the shadows are very long and every hour it moves. This is how the sun is going to go around your building and shadow is going to apply. So, during noon, on 3D visualization- you can see the position of the sun throughout the year at fixed 12'o' clock. Even during seasonal variation exactly at 12'o' clock, this is how the shadow and position of the sun is going to vary. as you observe, this is how it's going to vary exactly at 12'0' clock for all your seasons. During summer there is very less of shadow & during winter, as you see, there is higher amount of shadow. The spring and the equinox is going to experience average shadow links between summer & winter solstice.

How do you read the sun path diagram? Sun path diagrams can tell you a lot about how the sun will impact your site and building throughout the year. Stereographic sun path diagrams can be used to read the solar azimuth and altitude for a given how to read sun path diagrams- at 9am on April 1st. this is at 9 am, this is how your sun path on April 1st. This is where your intersection point is at the azimuth of 62° and then altitude of 30°. This is the azimuth in relevance to the true north which is 30°. This is exactly where your sun is located on April 1st at 9 'o'clock. This is how you can trace your sun path in relevance to different

dates & different time if you know your azimuth and altitude of your location. This is the focal point.

Reading the sun position (step-by-step): Locate the required hour line on the diagram. You need to locate for which hour you need, if your building is going to be occupied from 9-4 'o' clock. You need to know for each hour where the sun is located; we need to locate first the hour. 9 'o' clock has been located here. Locate the required date line, remembering that solid are used for January- June and dotted lines are usually for July- December. These are solid it means, This is how the sun moves from January to June, but when it's dotted it's like this for July- December. Find the intersection point of the hour and the date lines. The intersection of 9 'o' clock & this day has been traced, This is where your sun is located now and Remember to intersect solid with solid and dotted with dotted lines. If it's going to be solid line for 1st of April at 9 'o'clock, this is where your sun is located and you know now you're azimuth angles, so azimuth has been intersected from the focal point which gives your azimuth angle to be 62° & from here we can trace our altitude which is 30°. Draw a line from the very centre of the diagram, though the intersection point, out of the perimeter of the diagram. Read the azimuth as an angle taken clockwise from the north. In this case, the value is about 62°. We need to consider a clockwise angular mean distribution. this is considered as zero & from true north you are calculating 62° in this case, so the azimuth is 62°here. Trace a concentric circle around. This is the concentric circle which is being traced for this position on April 1st. Interpolate between the concentric circle lines to find the altitude. In this case the intersection point sits exactly on the 30° line. This gives the position of the sun, fully defined as an azimuth and altitude. This is how you need to calculate your azimuth and altitude how high your sun is located in relevance to your ground plain and what is the angle that is located in relevance to true north.

Sun charts illustrating the variation in the sun's movement in relation to latitude. This is our equator line which is running here, this is tropic of cancer which is 22.5° above the equator and tropic of Capricorn which 22.5° below the equator. these are two lines, between these two lines what we experience is called tropics and this is the Arctic Circle which is 66.6° north from the equator and below, this is the prime meridian depending on the where the side is located the sun path is going to change. As you observe , in the equator you are very close to the sun path, this is almost like just below the sun that is why you have sun path to be like this. As you go north the sun path varies, as you go further above the sun path becomes much lower, which means when you are at tropic of cancer the sun is tilted from your building but you are still going to have very less shadow and you are going to have direct solar radiation levels. But when you are at the equator the sun is very high there is almost no shadow. This consideration has to be made when you are designing shading elements. When you are much above the equator the sun path becomes very low which means the solar radiation is going to fall on your building is going to be very less. This type of climatic conditions may demand for passive heating strategies such as having huge windows on the southern direction to take in lot of sun rays and to have different materials which will

observe and store your thermal capacity. As you go lower you are going to experience same type of climatic condition on a colder region but it's just the reverse. So the summer months above the equator, it is going to be winter months below the equator which is the southern hemisphere.