Principles and Applications of Building Science

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Lecture - 01
Solar Geometry

Welcome to the course Principles and Applications of Building Science. This is the first module. Here we will start with solar geometry. Mainly we will talk about the Earth-Sun relationship, Sun-path diagrams and what is the consequence of it on the solar time and local time and how they are different.

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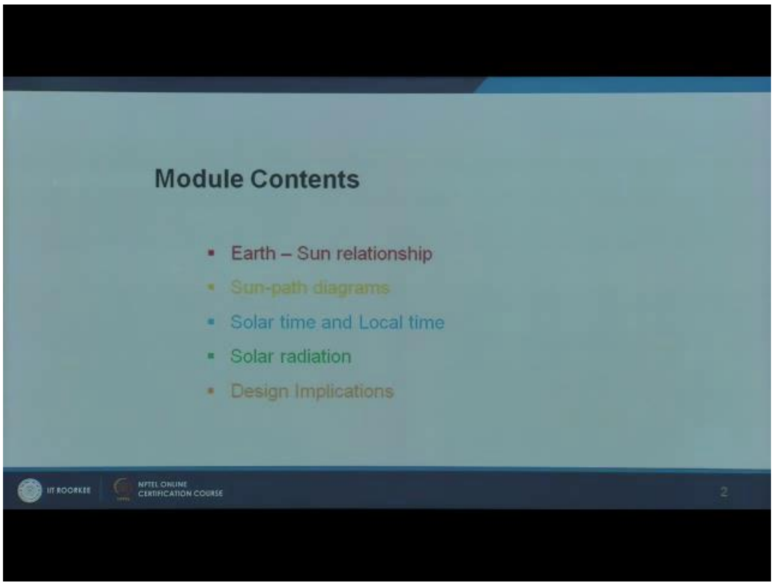

In Solar radiations, we will specifically look at how to measure and what are its implications. Finally, we will look at how that affects a building design, what are the design implications. To start with, we will look at the Earth-Sun relationship. We will relate it more with climatic building design. The climate of earth is driven by the energy input from the sun which is the source of energy. There are two essential aspects that person has to understand, one is the apparent movement of the sun or you know if you take a geocentric theory, it is apparent movement of the sun where the sun's position is that is the solar geometry we typically refer as and number 2 is the energy flow from the sun, be it heat energy or light energy.

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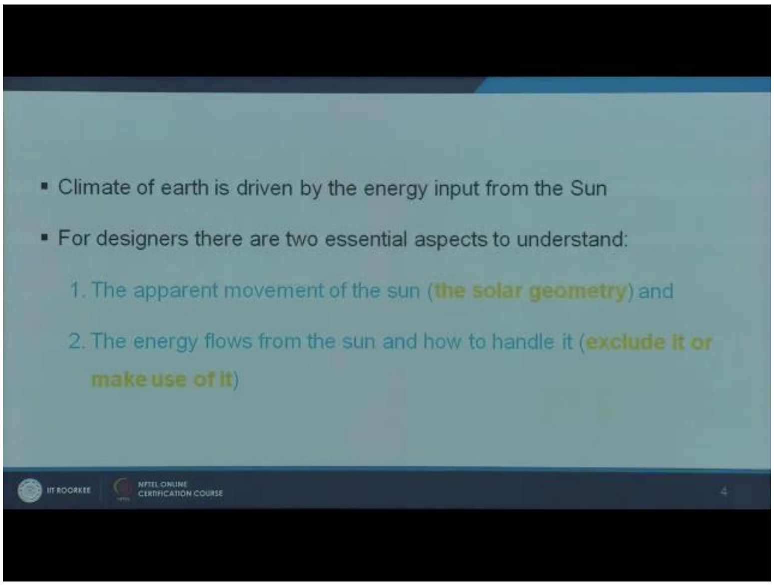

It is a energy flow from sun to the earth and how to handle it, whether you will include it in the building or exclude it in the building.

So, two primary things, one is the solar geometry, number 2 is the energy flows associated with it. Considering heliocentric view, you have sun in the centre. The earth is moving around it 365 days, the axis which is subtended with the equatorial plane and the sun. This particular angle, the tilt of earth is 23 and half degrees, this is constant tilt. As the earth moves around, you will start getting two typical extremes; one is called northern solstice that is when 23 and half degrees plus that are on June 21st and 22nd.

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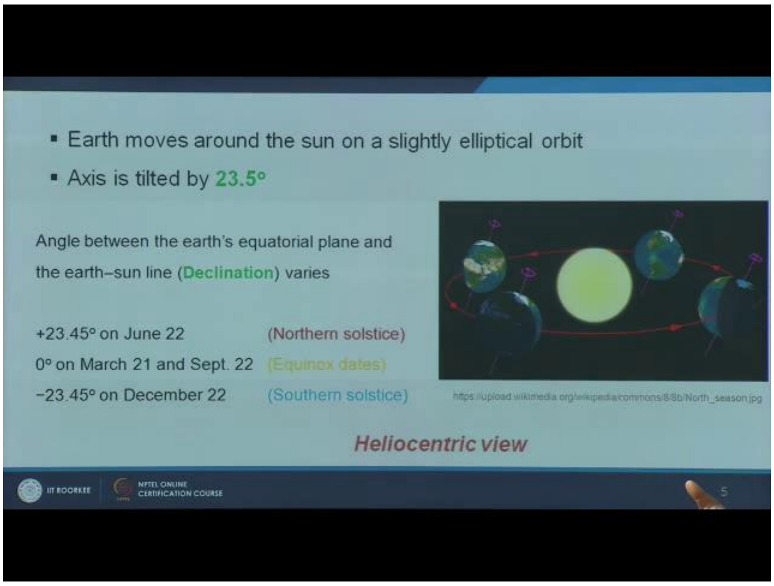

It happens that is, the day times are maximum and the night times are minimum in the northern hemisphere, typically we call northern solstice for countries or locations in northern hemisphere, this is called summer solstice and the other side winter solstice are the southern solstice for the earthen hemisphere which occurs on December 22nd that is minus 23 and half degree tilt. Typically, this is referred as southern solstice, for locations in northern hemisphere we refer to this as winter solstice. This is where you get the shortest day and longest night and typically we get minimum temperatures in this particular season.

Apart from this, when earth is typically you know there is a 0 degree tilt, you call it as equinox. It occurs twice that is 3rd week of March and 3rd week of September. So, there are four important dates which are critical, if you have to understand solar geometry first is northern solstice are summer solstice for the northern hemisphere, next is two equinoxes which occurs in March and September and the last one is Winter solstice or Southern solstice which typically is a minimum temperature associated with northern hemisphere. It is exactly the opposite for southern hemisphere.

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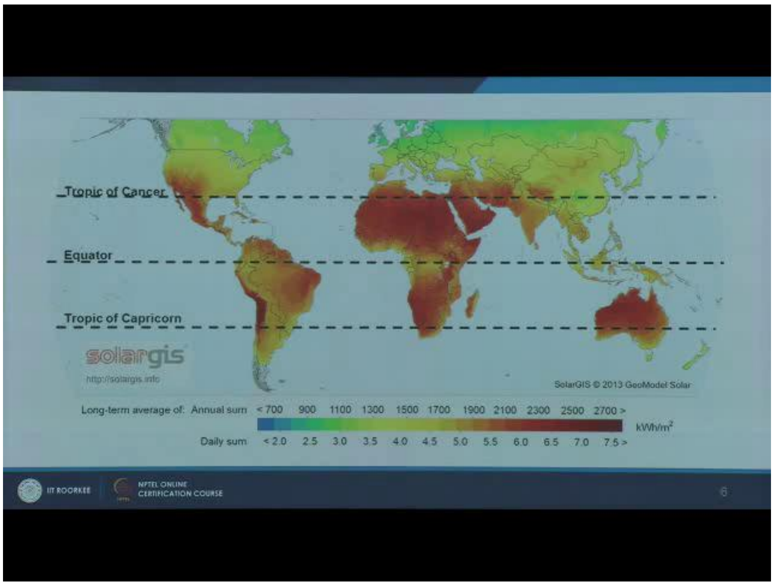

So, during northern solstice, they have winter and during southern solstice they have their summer, we have an equator here, Tropic of Cancer and Tropic of Capricorn 23 and half degrees north, 0 degrees and 23 and half degree south. So, we are talking primarily about the India or Asian part. Primarily, we will look at what happens around here and what is the impact of the solar geometry on our particular location. So, if you have to understand more or if you have to derive some implications of the solar geometry on our design, we have to start mapping the sun position. The first step is to get into a loco centric theory and get two typical angles to map the sun's position on a two dimensional plane, sun has 3D movement.

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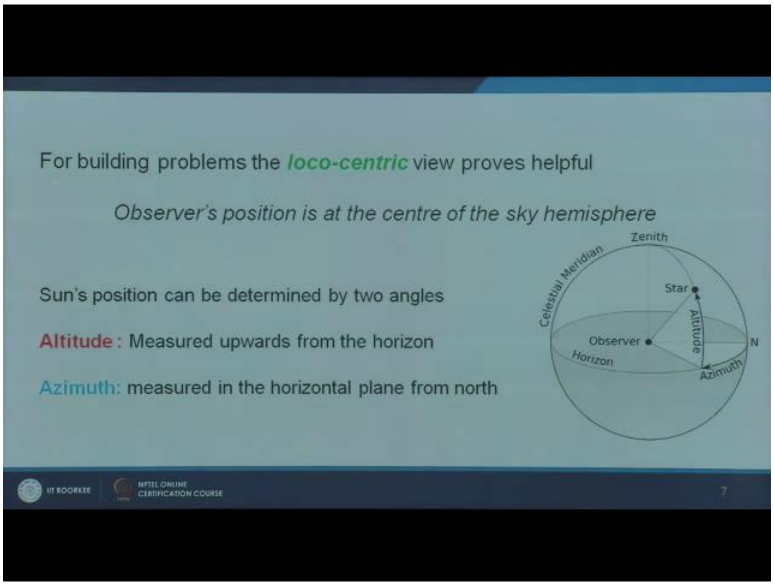

So, from that you are deriving two typical angles from which you can project, it is a trigonometric projection, first thing is that the altitude angle, wherever whichever orientation it is, you just typically take a horizontal plane and you mark the position of the sun, the angle which is subtended to the horizontal plane is called Altitude angle. Higher the altitude angle, sun is towards your head, that is 90 degree means sun is just above your head. Typically if you would say east and west, then you might get very low altitude angles.

Next is an Azimuth angle which you can take either north or south as reference. In many cases, you take north as a reference and wherever the sun's position, irrespective of its altitude angle where it is located, you typically project it down and take the angle difference between or the angle subtended from north.

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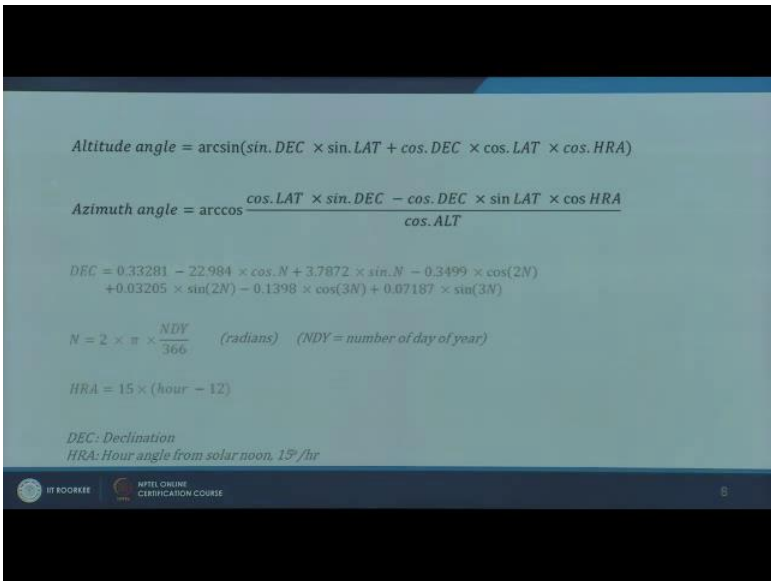

For example, when sun is right on the eastern side, you can say it is 90 degree or towards the west it will be 270 degrees if you are taking north as a reference point. If you have to really calculate altitude angle and azimuth angle, these are trigonometric calculations. So, you need few indicators like declination which we talked about earlier, you need the hour angle from solar noon, then you will need the number of day of year. With these things, there are some formulas which we are not going to work out as a part of this module, but if somebody is interested, if you know these 3 to 4 numbers, it is easier to locate the position of the sun and it is easy to calculate altitude and azimuth angles.

We will go more with a graphical representation given the shorten duration of this specific modules. Let us consider two specific examples to get a better picture of these solar movements.

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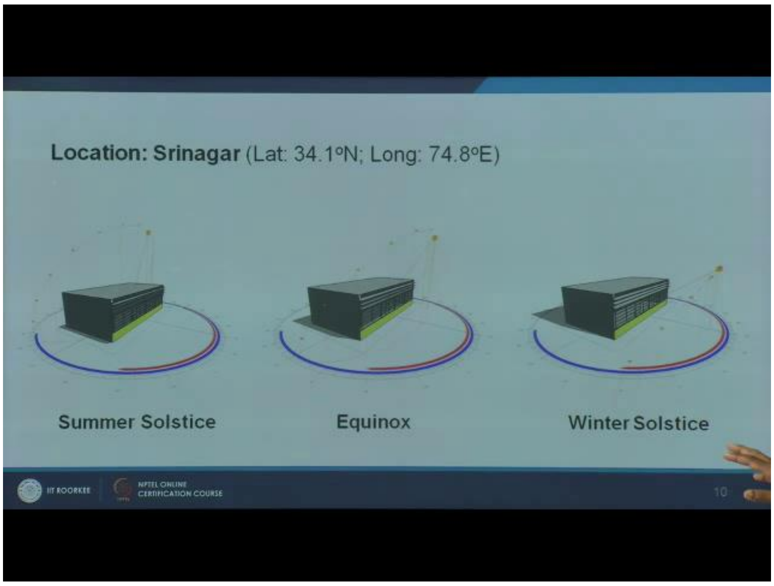

First let us take a location Srinagar, typically northern part of India. The latitude is 34.1 degree north and the longitude is 74.8 degree east. First let us look at what is the impact of change in latitudes. So, we will be considering Srinagar first, followed by Trivandrum which is in the southern tip of India, next we will look at longitude where we will talk about the solar time, also how to calculate local and derive local time from that. First let us take a look at the latitude of the place 34 degree north. There are three images. This is summer solstice where we are referring to the northern solstice or summer solstice here. Sun’s position, it rises somewhere, then at this point and then it moves traverses, sets here. Typically, you get sun right above the head, this is on summer solstice, it never crosses towards the northern side, it is slightly tilted towards south, but still you get sun from the north east and north western side during the morning and evening times. During equinox if you see, the sun rises here, moves along and then sets in this point.

So, typically you get sun rising exactly in the east, setting exactly in the west during equinox, but it traverses. It has a southern traverse and it rises in the east, traverses through south and sets in the west. Winter solstice, you have further lower altitude angle, here we are talking about three altitude angles, this altitude angle is high, slightly lesser and winter solstice December 21st here we have typically the least possible altitude angle. You do not get sun directly on the east or west, it is mostly somewhere close to south-east and south-west and it has a southern traverse, this is the case of 34 degree north latitude. Take a look at Trivandrum. This is 8.5 degrees north latitude which is much closer to the equator.

So, when we looked at Srinagar, it is further north of tropic of cancer. Here, we are talking about a location south of tropic of cancer much closer to the equator. If you look at the sun movement, it has you know the sun rise happens somewhere close to north-east and sets somewhere close to north-west. It traverses not directly through south and is somewhat half the center point, that is it has is slightly northern traverse during summer solstice, it is further half. So, this is a center point, this is south, this part is north. So, it has a typical northern traverse, what implication this has is if you have a northern wall which has large windows typically during summer especially in latitudes like this say 11 degrees, 10 degrees are even you know 15 degrees, 13 degrees north latitude.

You will have solar incidents on your northern facade and northern windows during summer months. The lower you go towards equator like typically the case of 8 degrees, 8 and half degrees north latitude, you will have up to 4 and half months, you will have solar incidence on your northern wall. So, when you are blindly following a code which says or a text book which says sun traverses from east to west through south, northern wall or northern facades are free of direct solar radiation. It might be misleading, you have to closely look at what latitude it is which decides because critical months like May, June and July where solar radiation is also more, temperatures are also more, you are going to get direct solar radiation on your northern facade here.

During equinox, east and west a slight southern traverse is noted, it is slightly half the center point, slightly traverses towards the south. Winter solstice, the altitude angle if you compare with Srinagar is not as slow as you looked at Srinagar, you do not get such a low steep penetration of solar radiation, it is slightly higher in terms of altitude angle. In all the three cases, the altitude angle is much higher compared to 34 degrees that is, the location Srinagar which we talked about. Now, let us look at something called Sun-path Diagram which is highly useful if you are designing a building specifically for shading devices or locating, orienting your building for anything to start with sun path diagram is a basic requirement. It is nothing but a two dimensional projection of a 3D movement, mostly we refer to stereo graphic projection, there are other types like orthographic. We will look at few of them in an example. Primarily, we are working with a stereo graphic projection.

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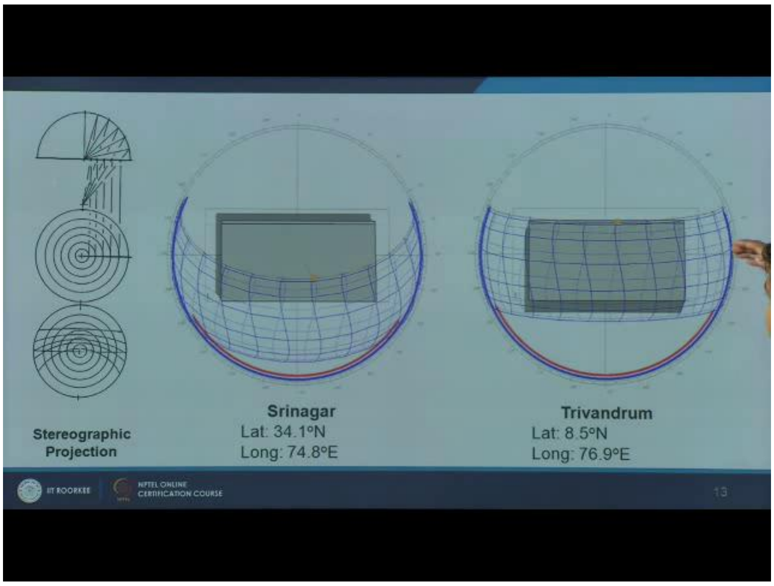

There are other things like spherical orthographic but mainly we are looking at a stereo graphic projection. You need two specific angles that is altitude angle and azimuth angle to locate our map to the position of the sun.

Now, coming back to our two example cities Srinagar and Trivandrum, the solar movement can be mapped like this. We looked at in the three dimensions, now, this is what we were talking about, this is your traverse of sun during your summer solstice, this is your traverse of sun during winter solstice, equinox occurs somewhere here. We will look at the components more in detail, this is for Trivandrum like I said, this is a center point and these are month lines. So, if you see up to four months easily, you will get direct solar radiation or solar incidence on northern façade.

If you have to access a northern façade, it will fall somewhere in this center line, again southern facade you have to take this as a center line and see how many months or how much duration you have solar incidence on your southern facade. So, typically in this case your northern facade is going to have solar incidence for more duration whereas, here it is only for 2-3 months that too slightly in the morning and evenings which can be prevented or up stretched to a vertical shading system.

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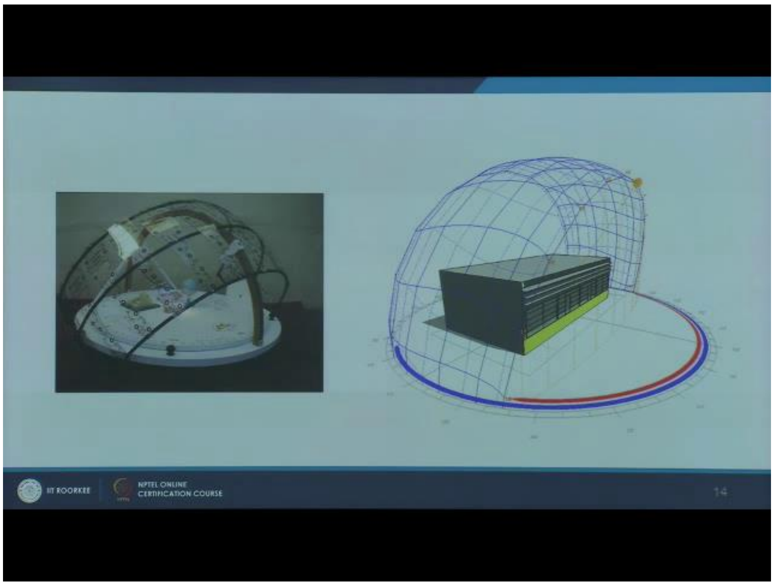

Here, you will also need a horizontal shade on your northern wall in order to avoid direct solar radiation during summer. In laboratories, this particular thing is studied using helloidol, you might have heard of this name, this is a device where you can set the solar position, everything is adjustable, you can set latitude, longitude, solar position and then I mean typically these are lights which cause shadows you can put your modal and you can assess what is a shadow penetration and what is a solar incidence? These things can be experimentally assessed. In this module, we are going to look at 3D graphic which is generated by a software called eco tech, we will be primarily using for demonstration, we will be using the models from eco tech as well as a associated tool called solar tool which helps us to graphically represent a three dimensional sun path.

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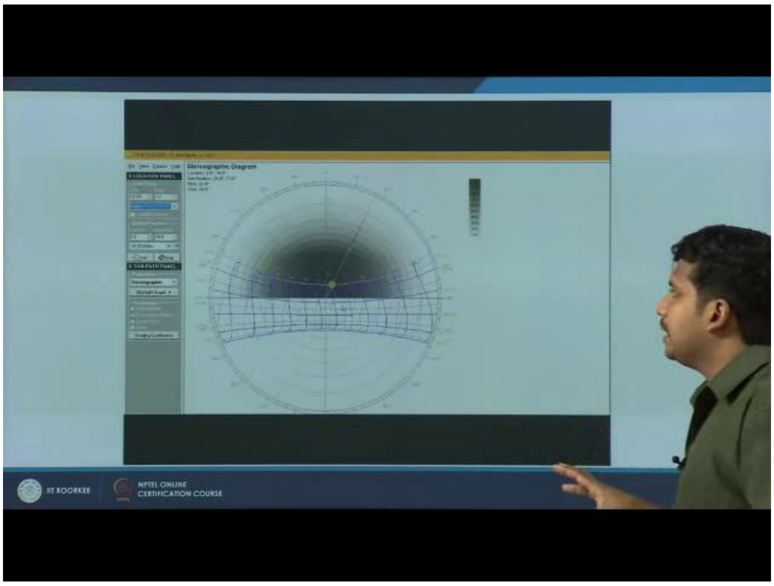

So, similar thing which we are going to look at, this is a solar tool which I was talking about, here we are talking about the solar path, this is a stereo graphic projection. There are different types of projections as I said Spherical, Equidistance, Stereographic, Orthographic, Wall drums, you can also look at tabular mapping of it. There are key components here, the peripheral line represents the azimuthal angle which we talked about and then the concentric line talks about altitude angle, these are the date lines, month lines for summer to winter solstice and these things are the hour lines. So, knowing this date and hour lines, you can locate the sun's position at a particular point. Other than this, this particular tool lets you set the date and time, say for example, if you are setting June 21st then you will have summer solstice here, for a particular time you will know where the sun's position is. When you will change it to winter that is December, sun position changes here.

You can also change the latitude of the place. Now, it is 34 degrees that is for Srinagar if I change it to Trivandrum's location, the solar path that is the total sun-path diagram varies, this is during December and this is during June. A simple representation of sun movement, we will look at the shadow and shadow assessments further in detail. So far we have been dealing with the latitude of a location and how it effects the sun's movement. Now, in this section we will talk about the impact of longitude and primary considerations which we have to give. So for this, one major thing you have to understand is the difference between solar time and the local time. The time used in the solar chart is a general solar time and it coincides with the local clock time only at a reference longitude for a particular time zone.

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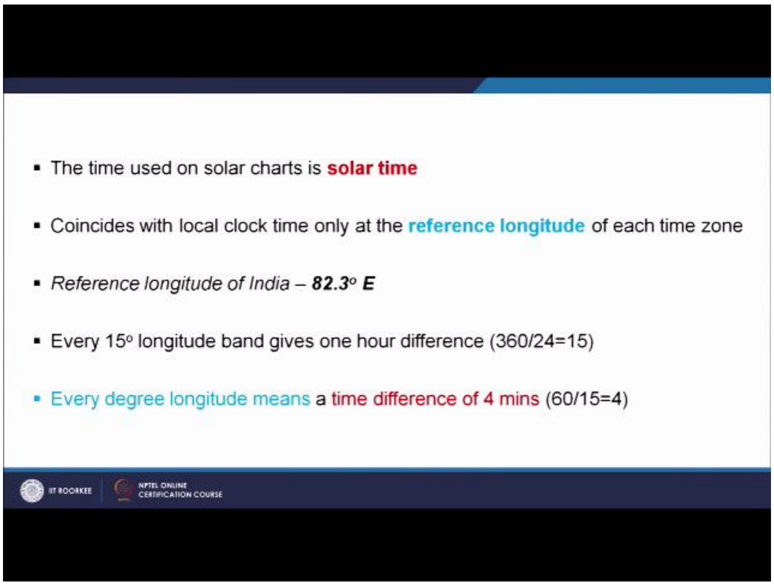

If you take the case of India, we do not have different time zones, there is one time zone across the country though we have a vast extend from west to the east, we have only single time zone and the reference longitude for India is 82.3 degrees east longitude. If you take a country like U.S, they have a different time zones as you go from east to west of united states the time zone varies for example, they have half an hour to 1 hour time adjustment every time zone as you move from east to west. For a basic understanding, every degree of longitude you move, it means a time difference of 4 minutes.

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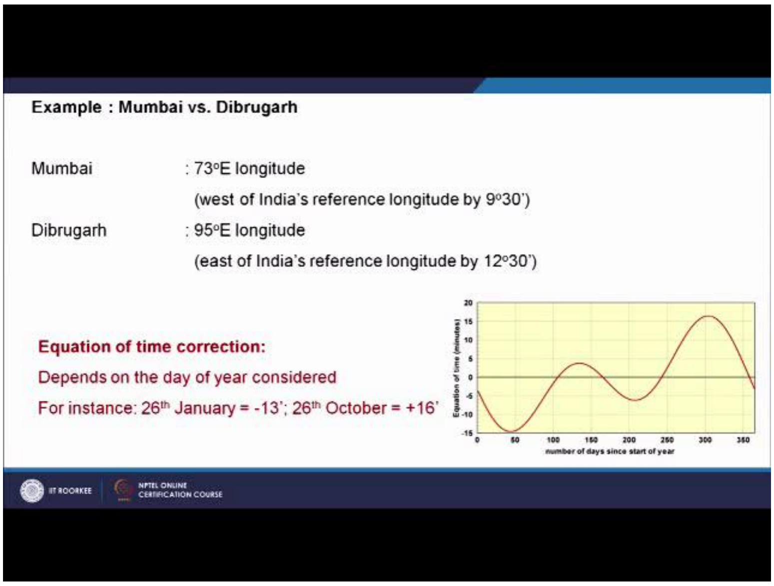

We will use this in further calculations. To understand this better, let us consider two locations, first is Mumbai which is 73 degrees east longitude on the western side of India, number two is Dibrugarh which is 95 degrees east longitude which is further east of India. Mumbai lies west of India's reference longitude that is 82 degrees reference line, it lies west of reference line by 9.5 or 9 degrees 30 minutes whereas Dibrugarh lies on the east of India's reference longitude by 12 degrees and 30 minutes.

Another thing which has to be factored in the calculation is the equation of time correction which can be done like I said earlier, it can be done numerically or I am showing you a graphic indicator, this simple graph which tells you how to find out the time correction. Along the x axis it has a number of days that is day of the year, starts from 0 goes to 366, then on the y axis we have the equation of time correction. This depends on the day of the year considered. For example, if you take 26th January, it comes somewhere here 26th day of the year, the time correction will be minus 13 minutes, if you take 26th October or 27th October which is somewhere around the 300th day of the year, the time correction will be plus 17 minutes. Using this, what we can do if you take the same case of Mumbai and Dibrugarh, the calculation goes like this.

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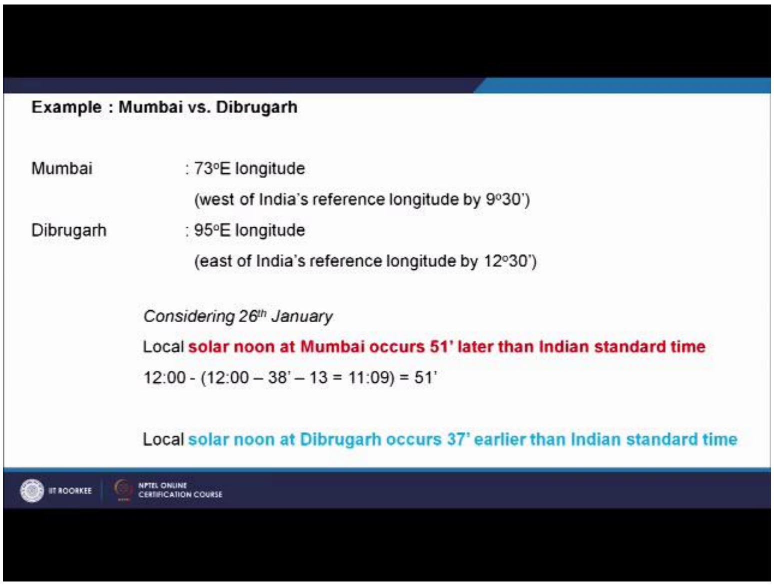

For example, if I have to establish what is a local solar noon, what time the local noon occurs in Mumbai, noon is 12 o'clock minus 38 minutes, this 38 comes from this 9 degree 30 minutes, if you multiply that for every longitude degree, it is 4 minutes. So, if you multiply you will get 38 minutes minus 13 because I am calculating it for 26th January, where is if I am calculating it for say as a example I stated 26th October or 27th October, the correction will be positive, it will be plus 17 minutes, here it is minus 13. So, this comes to 11:09. Subtract this from 12 then you will get 51 minutes. So, local solar noon at Mumbai occurs 51 minutes later than Indian standard time because it lies to the west of the reference longitude.

In the case of Dibrugarh, in the same way if we calculate, we find that the local solar noon occurs 37 minutes earlier than the Indian standard time. If India were to have different time zones from east to west, then the time zone adjustments will be something like half an hour to 45 minutes for each time zone if one were to divide the country into three different time zones.

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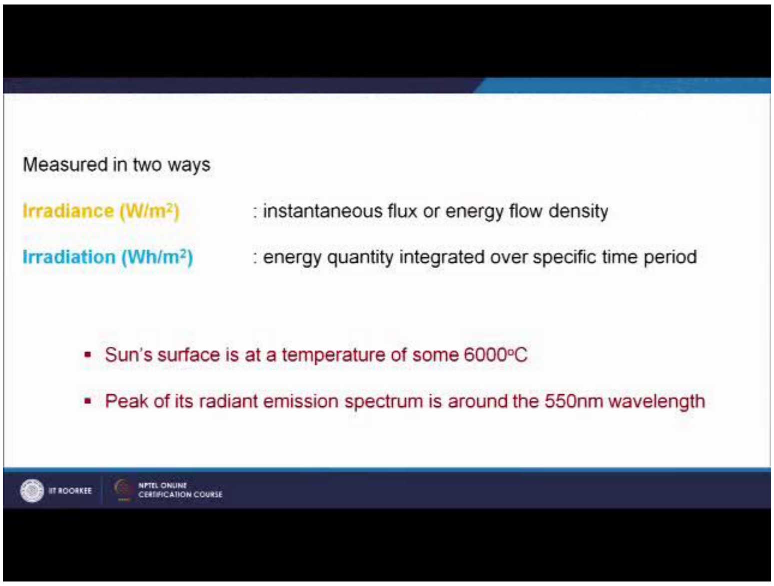

We will look little bit more in detail about solar radiation, two main measures are there, number one is Irradiance watts per meter square is most commonly used, it is a instantaneous flux or energy flow, earlier it used to be called solar intensity, now it is called irradiance watts per square meter, it can be horizontal or vertical. On Number two is irradiation which means the energy quantity integrated over a specific time, it can be per day, per hour or per year, total hour for a specific season. It is measured in watt hour per meter square. Looking little bit more into the details of the solar radiation itself, the sun's surface is around 6000 degrees centigrade, peak of its radiation emission occurs at 550 nanometer wave length.

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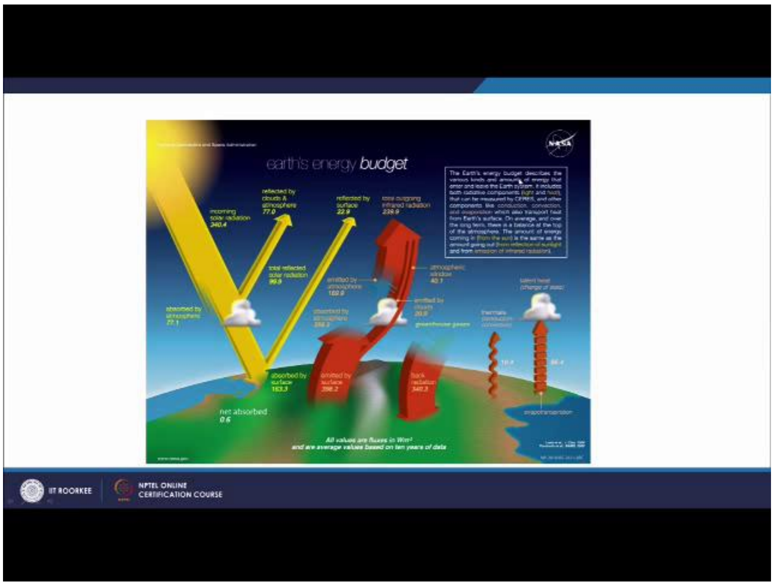

Now, this is a solar spectrum, we know three major things one is a visible spectrum, then you have ultra violet and infrared. Once the sun’s energy hits earth’s atmosphere, part of it is reflected back, absorbed and transmitted, whatever component is observed, it is re radiated, then after entering the earth’s atmosphere, the ground absorption or water bodies observe and reflect part of it, whatever is absorbed is re-emitted, what comes in a short wave radiation, once it is absorbed and then re-radiated, it goes back as long wave radiation. These long wave radiations are trapped by the cloud cover which we generally call green house effect where this re-radiator long wave radiation gets trapped in the earth’s atmosphere. There is a large variation in irradiation among different locations of the earth. This is for three main reasons; one is the angle of incidence.

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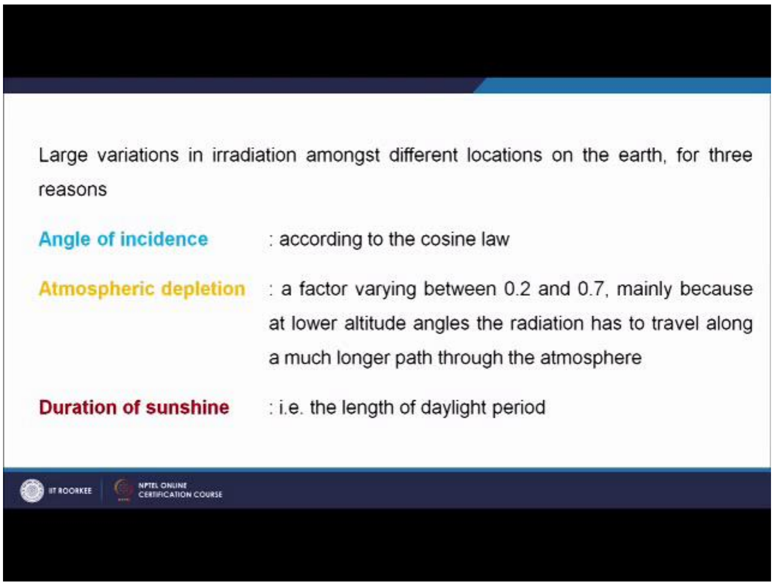

We know the cosine law which states that the steeper the angle of incidence, the difference will be more, number two is the atmospheric depletion and again it is a factor of the angle of incidence. For example, if it is in the polar region, the same sun's radiation has to traverse a long distance across the atmosphere cutting through. So, there is a factor which varies between 0.2 and 0.7 and then number three is the duration of sunshine. For example, earlier we said summer solstice versus winter solstice or the northern solstice versus southern solstice where the sun's duration of sunshine considerably varies between June 21st and December 22nd. So, this has a considerably impact on the irradiation.

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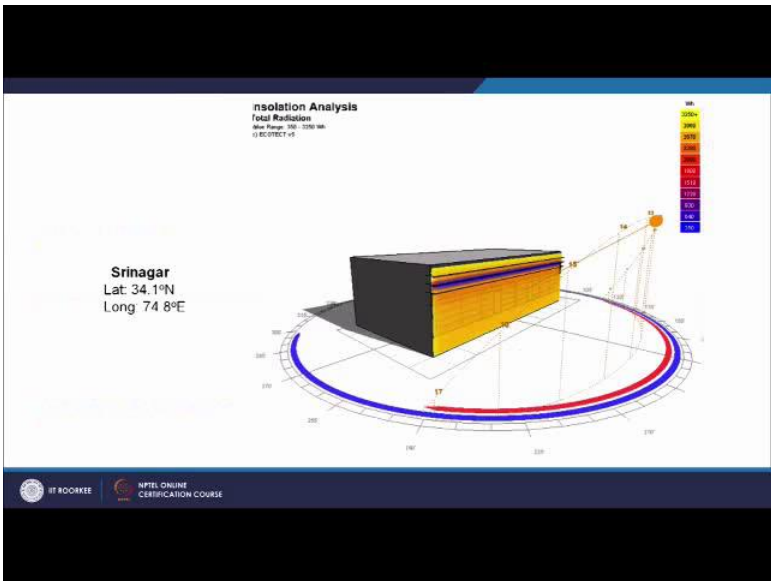

Let us come back to the example of Srinagar which is 34 degrees north and 74.8 degrees east longitude. You take the same southern wall surface, I have put some windows and some shading systems here, if you take the solar radiation incidence on a winter, this is winter solstice you have a steep southern sun, this is where the solar radiation incidence occurs if you see in this scale, this portion corresponds to somewhere around 3000 watt hours. This is for a particular day. On the instance of December 22nd this is the solar radiation which occurs on the southern surface, this is the total solar radiation. One more thing we have to remember is this total solar radiation has two components, one is a direct radiation and other is a diffuse radiation.

For example, consider this surface at this point of time, this is around noon, this particular surface is not getting any direct solar radiation, but still the radiation will be there because of diffuse components. Diffuse radiation will still have some impact on these surfaces, total radiation and net radiation will be minimum. Consider the case of Trivandrum which is 8 and half degrees north latitude.

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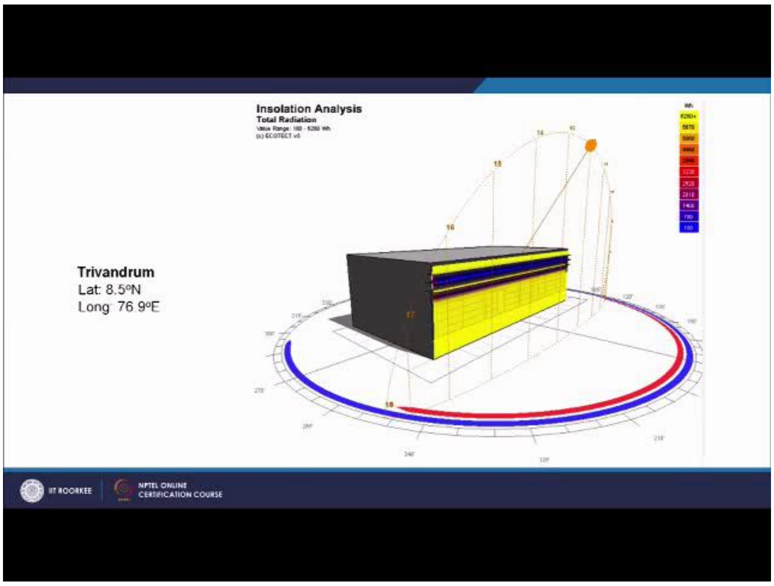

This is again winter solstice. This Northern sun is not as steep as you found in Srinagar and it is slightly with a higher altitude angle. Carefully look at this numbers, the total solar radiation incident on a southern facade which is somewhere around 6000 watt hours. So, the solar incidents you receive on the southern facade considerably vary between the northern parts of India that is a location like Srinagar versus Trivandrum.

Now, let us not worry about what climate condition it is, Srinagar has a colder climate versus Trivandrum has a warm and humid climate. We are not getting into the climate classification that is part of a different module, the subsequent module, but just the solar radiation intensity considerably varies on a given building façade and how do we account for this particular solar radiation in our building related calculation, the main parameter which is used this Sol-air temperature which is kind of a inclusive number.

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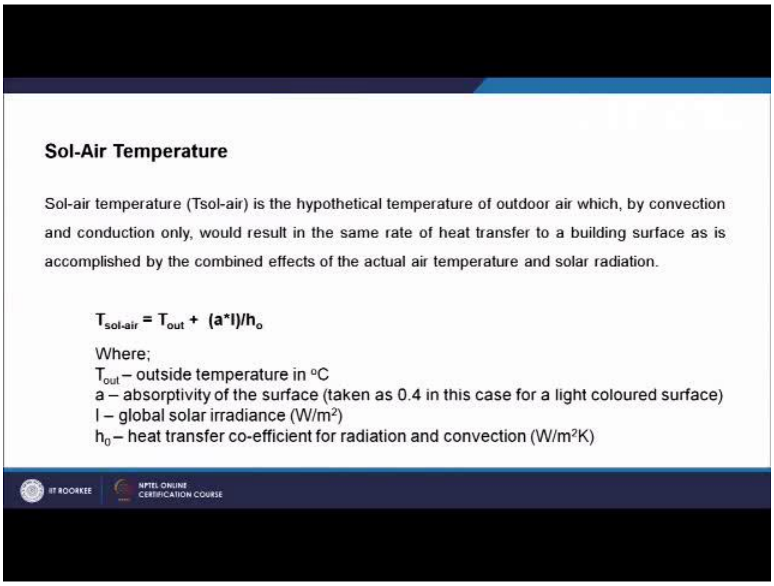

If you read this equation this is T out is a outside air temperature in degree centigrade, this is a drivel temperature of outside air, sol-air temperature actually includes the effect of air temperature and adds up a small component to it which is inclusive of the main thing global solar irradiance watts per meter square, absorptivity of a particular surface as I say imagine the same southern facade which I was talking about, if it were to be bright colored, say a white surface versus a black surface. This absorptivity of the surface considerably varies.

So in that case, this particular factor will vary. The 3rd part of this small factor is h naught or the heat transfer coefficient for radiation and convection, this is equivalent to the film coefficient on the outside surface of the wall. So, this particular factor is added to the outside air temperature. Sol-air temperature typically will be equal or more than the ambient air temperature in tropical climates, what happens is say imagine if you take a western facade somewhere around 4 o'clock in the evening, there will be an ambient temperature, take a case like Srinagar in June 21st say the ambient temperature is 30 degrees in the southern facade which we looked at. The solar radiation intensity will be x plus the absorptivity of a surface, imagine a white surface, there will be a heat transfer coefficient. So, a small magnitude say about 4 to 5 degrees will get added up which becomes the sol-air temperature. This is more or less equivalent to the surface temperature of a particular wall.

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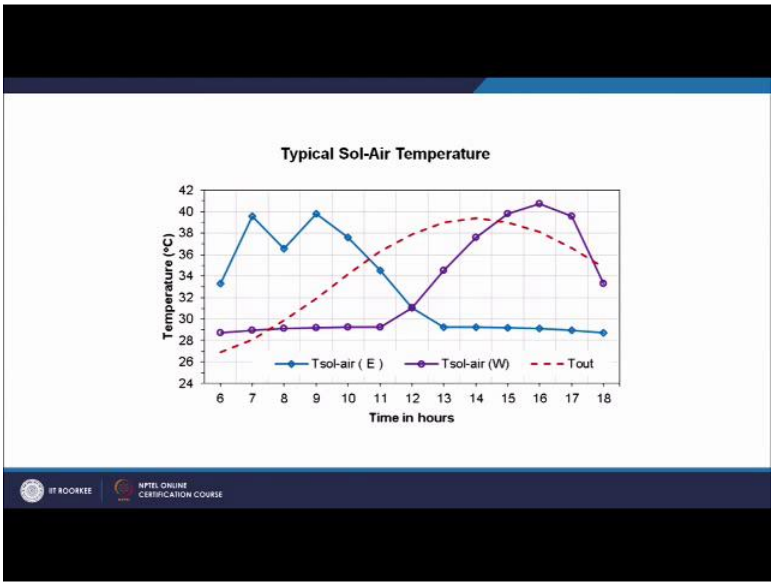

I have done some calculations using the same equation. Take this location, this dotted line represents the outside air temperature which starts from 6 o'clock, this is evening 6, this is a 12 hour graph. Morning, the temperatures are around 27 degree and goes up to 35 degree in the evening. There are two other lines in this graph, this is time in hours, this is temperature and there are two other lines, this is sol-air temperature on the eastern façade, this blue line versus this purple line, this is a sol-air temperature on the western façade. Interestingly, if you notice the eastern façade, the sol air temperature goes as high as 40 degrees. Early in the morning only around say 7 to 9 o'clock the peak occurs, then it cools down, comes back below the ambient air temperature whereas, on a western façade, this sol-air temperature rise much lower than the ambient temperature and then it peaks up in the evening and then its heat, now it gets heated up and what is the impact on building design. For example, if you were to have a wall which is part of a bedroom, your bedroom wall is exposed to eastern side.

The sol-air temperature will go as high as 40 degree in the morning and then it will cool down. So, when you want to occupy it somewhere around 9 o'clock in the night, the surface temperature is not that high and including the time lag which we will discuss later. The inside temperatures will be relatively cooler whereas, a west facing wall of a bedroom, the maximum temperature occurs somewhere around 4 o'clock to 5 o'clock in the evening, then this will be transmitted in. So, you will have relatively higher temperature inside surface temperature as well as heat gain through that particular wall.

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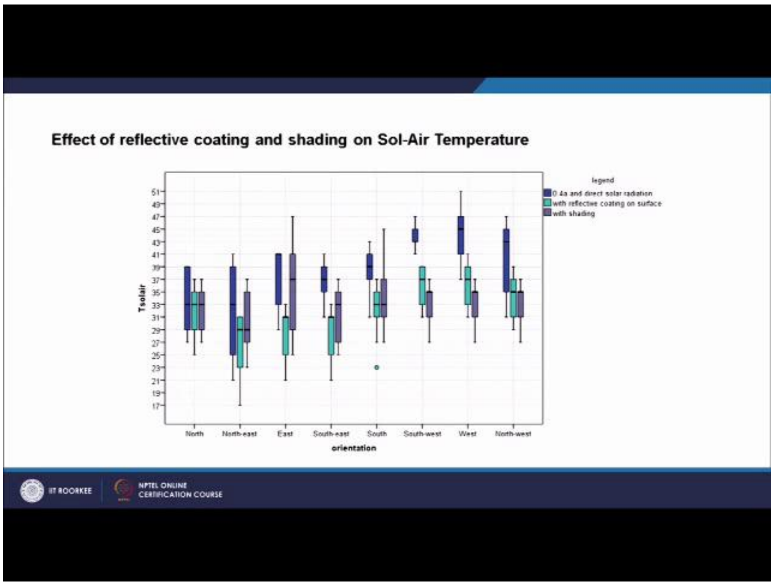

Here, we did a small calculation as such sol-air temperature is dependent on two main things, the one we have earlier saw the absorptivity of a surface that is represented by a brighter surface versus a reflective surface versus a darker surface. Number two is, it can be modified with the effect of shading, what happens in the case of shading, the moment you have a shading device or a balcony, the direct solar radiation is cut, but you have to keep in mind the defuse solar radiation still exist. So, it is not totally negated, but the direct component which is quite significant is totally negated if you have a full cover of shading. We have calculated the sol-air temperature ranges for 8 orientations.

There are three cases here, the first case, this is a dark blue, the absorption, the solar absorption of dark sun's of the surface is 0.4 which corresponds to a normal white painted or a ivory color painted external wall. There is direct solar radiation and it does not have any shading. Number two, this light blue where we painted the surface with a reflective coating. Today, we will get a lot of reflective commonly called low e coatings which are done on the wall, that is low emissive coating, mainly reflective coating has been done for the second case and the third, the same wall an additional shading system was added to the first case that is the absorptivity remains and there is no reflective coating, but additionally a shading system was provided that is the wall is completely shaded and you can imagine there is balcony present in front of the wall.

So, what happens in the first incidence is the sol-air temperature for example, in the eastern wall goes as high as 47 degrees, for a west facing wall it goes up to 51 degrees. This is in a tropical warm humid climate and goes as high as 51 degrees in a west facing wall whereas, when you paint it with a reflective coating it can be brought as low as 41 degree, you will find 10 degree difference on the external surface or sol air temperature. Instead of reflective coating, if you go for a proper shaded west facing wall, you can bring it down to as low as 37 degree and you have to notice that this is more or less equivalent to a north facing wall.

Imagine you have a balcony which has a west facing wall and you cannot avoid it, the better solution in today's context would be if you are in a design stage, you can provide a balcony or a deep over hang. So, as to shade the complete wall, it becomes more or less equivalent to a north facing wall forgetting about the wind and other components which we are discussing just with solar radiation and this can be made equivalent to the north facing wall or if you further do not have choice, you have crossed the design stage, then the next best alternate would be to look for a reflective coating, but this is temporary, the coating would last for around 2-3 years after which it loses its reflective property, it has to be recoated. There can be a slightly better improvement with reflective coating, but with permanent shading system, the whole sol-air temperature can be brought down.

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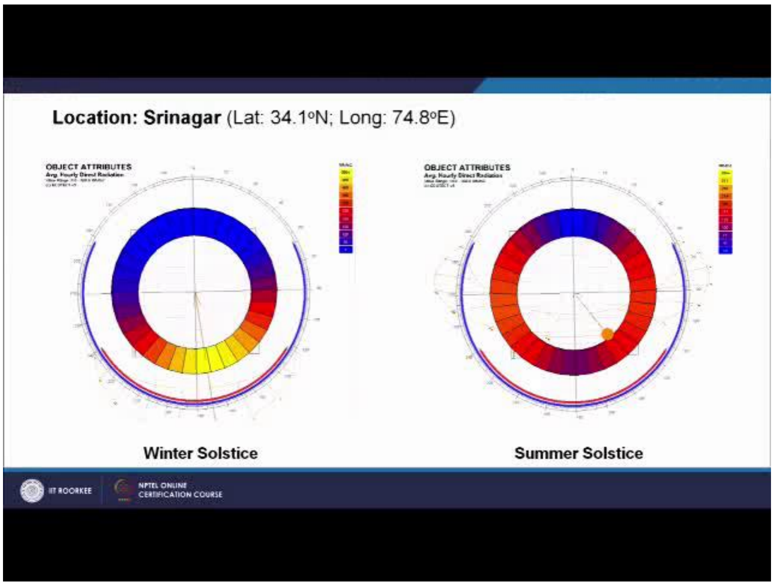

Let us discuss about few design implications, this particular graph, two things, this is again for Srinagar, this is winter solstice and this is summer solstice and this is the same solar radiation, but this is a direct solar radiation graph. I have split the whole thing, instead of drawing a square I have made a cylindrical structure which is segmented. So, each of this segment represents a specific orientation say if you want to take just four cardinal orientation east, west, north and south, you can refer watt hour per meter square, this is radiance at this particular instance of time, this is during winter solstice in Srinagar, this is a southern sun summer solstice, this is a condition.

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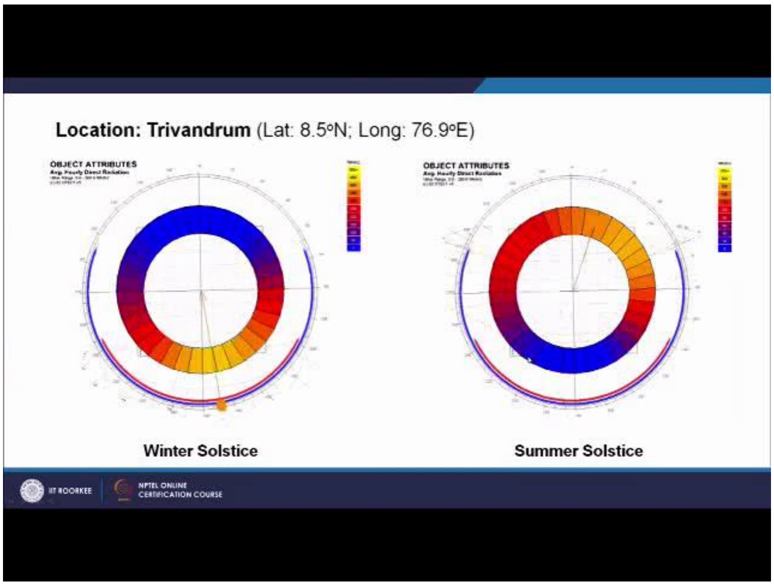

This is for Trivandrum, the numbers get higher during winter solstice and this is during summer solstice. Even northern surfaces and north eastern surfaces get more solar radiation. One important thing which we should not forget is the use of for example, northern windows or north lights as you go down the tropic of cancer towards equator, northern surfaces start receiving solar radiation, it is not that northern surfaces are totally divide of solar radiation and as you get closer to equator, what happens is suns starts traversing towards your northern wall as well.

This is considering a loco centric theory with sun as a moving body, you are located here and sun starts moving towards your north. If your building facade is this, you will still get solar radiation in your northern facade for at least four months for latitudes south of tropic of cancer. Further you go towards equator, it gets more. Especially, on an equator there will be equal distribution, half of the year sun will be to the northern side, half of the year sun will be to the southern side.

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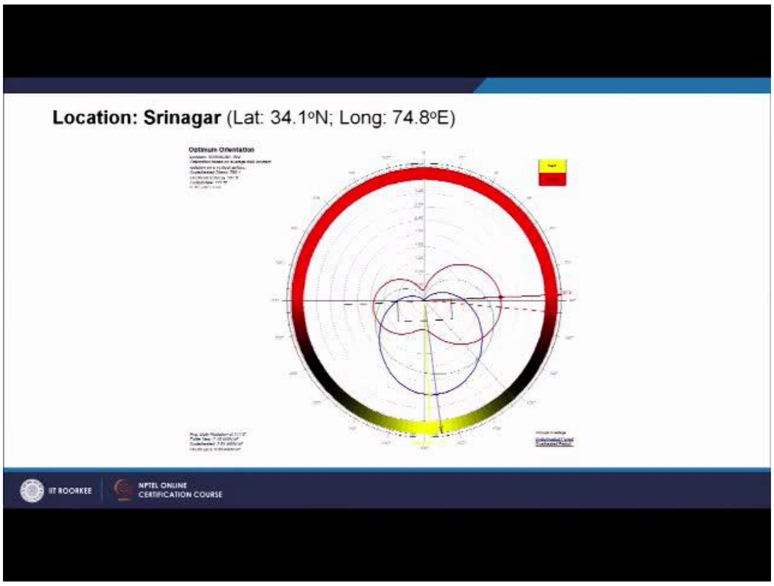

To get a better understanding, we have this graph. This small box rectangle here represents a building’s orientation, these lines here, the red one indicates the solar radiation during summer which is deputed as overheated period, the blue one which is shown here indicates the solar radiation during the under heated period or the winter season. This is an interesting graph which shows that which is a major direction from which higher solar intensity comes during summer, this is during winter and the green one is an a annual average.

Typically it is understood and agreed upon that, your longer surface of the building, longer facades of the building should not be facing east and west without enough solar protection. So, it is a better idea to orient it, the longer surface to orient it towards north and south, shatter towards east and west it is understood, but still you can go for minor directional changes depending on the location for example, in case of Srinagar the major solar incidence during summer occurs in this direction not exactly in the east, but it occurs slightly away from the east and during winter it is not directly on the south, but it is towards little bit towards east it is not south east, but slightly ahead of east.

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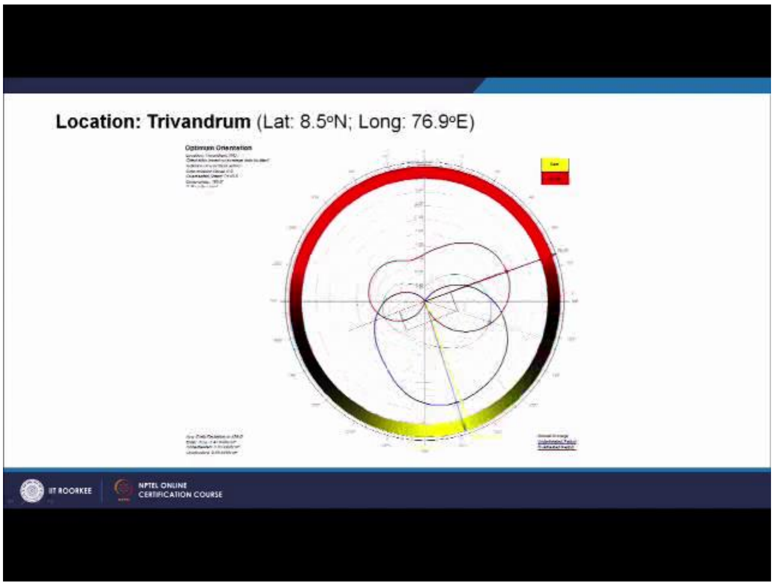

So, in this case the actual right orientation of the building will be a slight tilt rather than just on the plane. Considering the case of Trivandrum, the case changes the maximum solar radiation intensity during summer occurs at 70 degrees. So, this is where you get maximum solar radiation during summer and during winter you get somewhere around 160 degrees and this is where the maximum occurs. So, a trade of the best orientation would not be just south, the longer facing not just facing south, but it is somewhere around 160 degrees that is a perpendicular if you draw, this should be facing 160 degrees.

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This would be the best case in which the building can be oriented. We will close this session here, take a quick recap. We studied five important things, first thing is the Earth-Sun relationship, how it moves around and we studied about northern solstice equinox and southern solstice, the earth's tilt and then we talked about how this earth movement rather sun movement would be translated into diagrams for quick reference that is sun-path diagrams, the stereo graphic projection, how it is built and how it can be used.

Number 3, we talked about the effect of longitude and time zones, we calculated solar time and local time and then we talked about the impact of solar radiation, we took specific example of a building facade and were studying it for two different geo locations, then we studied about the design implications that is how to orient your building considering the solar radiation before positioning a building itself.

Thank you.