Sustainable Architecture
Prof. Avlokita Agrawal
Department of Architecture and Planning
Indian Institute of Technology, Roorkee

Lecture - 17
Climatic Considerations, Physiological Objectives of Design

Good morning, welcome to this new lecture on Climatic Considerations and Physiological Objectives of Design for the online course on Sustainable Architecture. And, I am your instructor Dr. Avlokita Agarwal, assistant professor at Department of Architecture and Planning IIT Roorkee. In the previous lecture, we have seen how to proceed with designing of sustainable buildings and we have seen the fundamentals of green buildings, what are the different components and how do we go about designing green buildings or synonymously sustainable buildings.

Today, we will be starting with the technical content, where the first step towards designing which we had already identified was to understand the climate of a place, the climatic context. Today, we will see how to understand how to define the climate of a place and then through design how do we respond to this climate.

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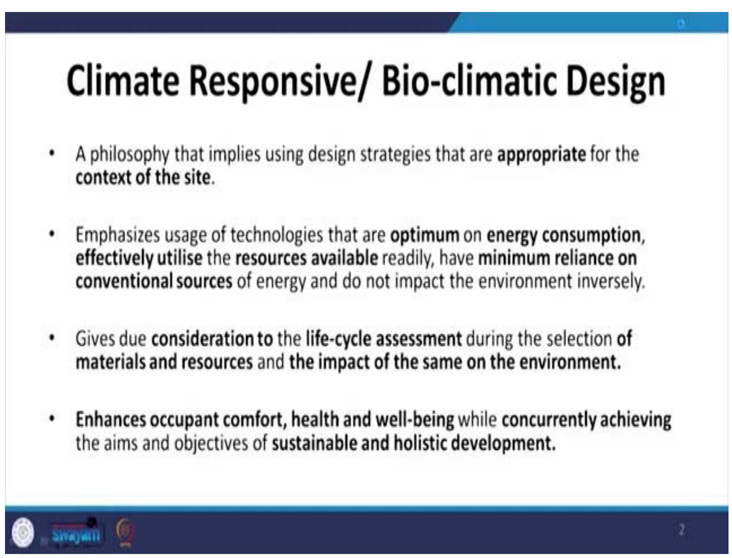

So, what is climate responsive design or bio climatic design? We have already seen the definitions. We know that these are the designs which employ design strategies that are appropriate for the context of site for the given climatic point of view. It mainly emphasizes on use of technologies that are optimum for energy consumption. We are mainly talking about the passive design strategies which help us reduce the demand and make the entire structure, the building envelope energy efficient.

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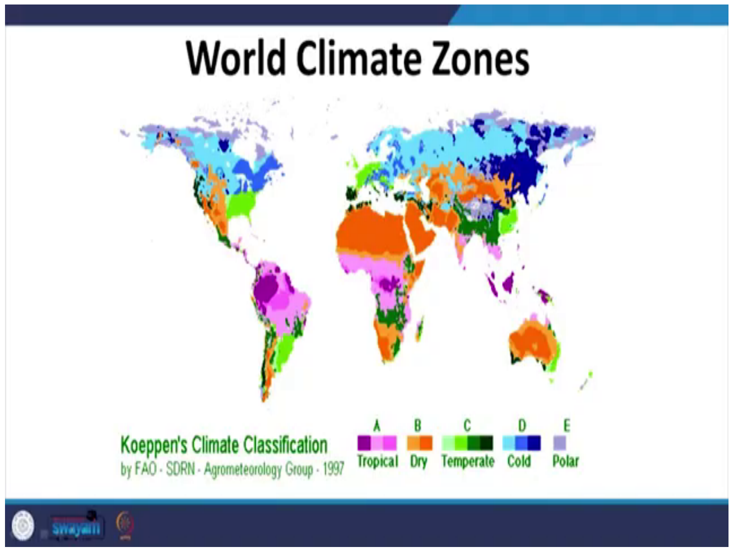

To start with we have to first identify and understand the climatic zones. Now, this world climatic zones are given as per Koeppen's climatic classification and as per Koeppen's climatic classification they are largely divided in 5 climatic zones of which 4 are present within our own country India.

So, it is tropical, dry, temperate, cold and polar. Polar climate classification is not there and we have in India all the 4, though for India as per ECBC we have different classification of climatic zones and we largely follow these climatic zones and the design considerations accordingly.

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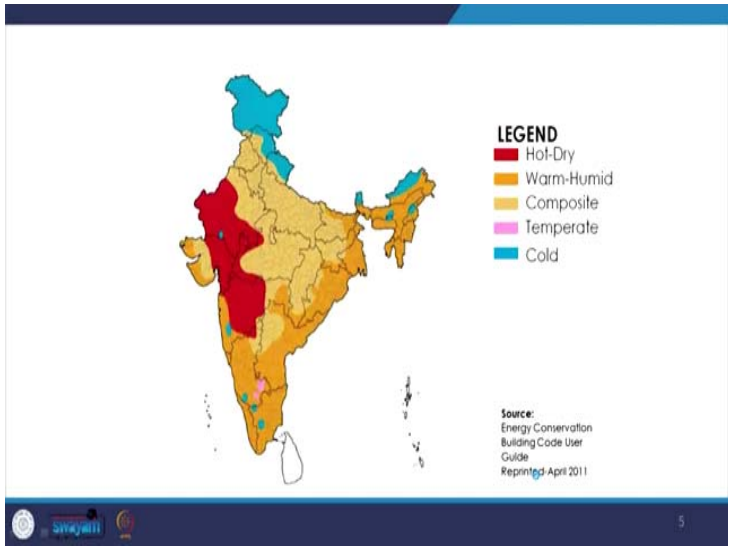

So, the 5 climatic zones which we take are hot dry which is largely the western part which is mainly the desert part and it extends slightly below. Then we have warm humid which is largely the coastal region of the country. We have composite which is mainly the north central region of the country.

We have temperate which is present in very limited pockets in the country this region is where Bangalore is so, Bangalore qualifies to be falling in the temperate climatic zone. And then we have north which is largely in the northern part of the country. So, these are the 5 climates which are defined in which our entire country has been divided.

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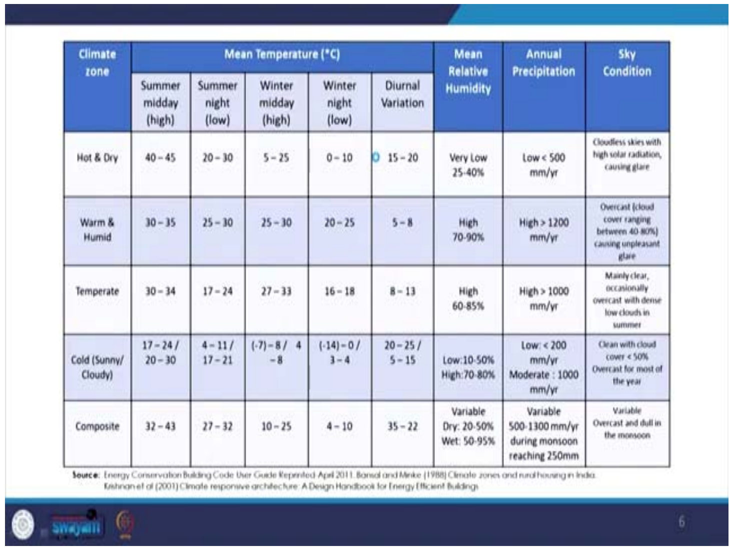

Climate zone	Mean Temperature (°C)					Mean Relative Humidity	Annual Precipitation	Sky Condition
	Summer midday (high)	Summer night (low)	Winter midday (high)	Winter night (low)	Diurnal Variation			
Hot & Dry	40 – 45	20 – 30	5 – 25	0 – 10	15 – 20	Very Low 25-40%	Low < 500 mm/yr	Cloudless skies with high solar radiation, causing glare
Warm & Humid	30 – 35	25 – 30	25 – 30	20 – 25	5 – 8	High 70-90%	High > 1200 mm/yr	Overcast (cloud cover ranging between 40-80%) causing unpleasant glare
Temperate	30 – 34	17 – 24	27 – 33	16 – 18	8 – 13	High 60-85%	High > 1000 mm/yr	Mainly clear, occasionally overcast with dense low clouds in summer
Cold (Sunny/ Cloudy)	17 – 24 / 20 – 30	4 – 11 / 17 – 21	(-7) – 8 / 4 – 8	(-14) – 0 / 3 – 4	20 – 25 / 5 – 15	Low:10-50% High:70-80%	Low: < 200 mm/yr Moderate : 1000 mm/yr	Clean with cloud cover < 50% Overcast for most of the year
Composite	32 – 43	27 – 32	10 – 25	4 – 10	35 – 22	Variable Dry: 20-50% Wet: 50-95%	Variable 500-1300 mm/yr during monsoon reaching 250mm	Variable Overcast and dull in the monsoon

Source: Energy Conservation Building Code User Guide Reprinted April 2011. Bansal and Minke (1988) Climate zones and rural housing in India. Krishnan et al (2001) Climate responsive architecture: A Design Handbook for Energy Efficient Buildings

Let us look at these climate classifications and how have they been classified to fall under each of these categories. So, what we are mainly looking at is, we are looking at the mean temperatures of summers as well as winters and the diurnal variation. Diurnal variation is the difference between the day and night. The maximum to minimum difference is the diurnal variation. We are looking at relative humidity which is also dependent upon precipitation.

So, what is the amount of precipitation that the place is receiving impacts how the relative humidity is going to behave, but it is not the only criteria, it is not the only reason why relative humidity of a place would vary. It may also vary because of the altitude, because of the altitude of the terrain. So, very high mountains may also be having deserts, while they might still be receiving some amount of rain. So, that is what we would be looking at and then sky condition which impacts the radiation which is being received.

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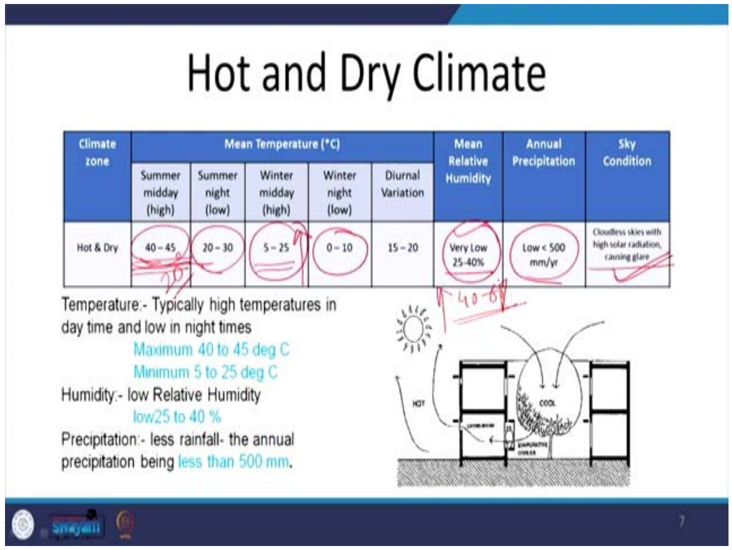

So, let us go over each of these climates which are in our country and look at how these parameters vary for each of these climates. So, first of all we are talking about hot dry climate. Now, this hot dry climate as we have already seen is found in the western part of our country which is desert like conditions. So, we are talking about cities like Jaipur, Jaisalmer, we are talking about the region of Kutch falling in hot dry climate. So, largely the west of Aravalis is what we are seeing as hot dry.

Now, in hot dry climate the temperatures summer temperatures are very high. So, summer midday temperatures the highest temperatures are within the range of 40 to 45 which is a very high temperature. In summer nights the temperatures fall down and there is a large diurnal range that we are looking at, but they are still within the range of 20 to 30 degree centigrade. So, the diurnal range is very high, we are looking at a diurnal range of 15 to 20 degree centigrade.

So, in the data in and when the temperatures are around 45 degree, in the night time we might still have a temperature falling around 25, 27 degree centigrade. So, that is a large diurnal range that, we usually look at in hot dry climates. If you look at winters, the midday temperatures may range from 5 to 25. So, in extreme winters the temperatures may fall to very close to 0.

So, 5 degrees and in moderate winters they may also go as high up as 25 degree centigrade. While in winter nights the temperatures may fall, they may come very close to 0. So, they may be varying between 0 to 10 which if you follow the weather news, you would see that the lowest temperatures in the plains are often in these cities of Churu, Jhunjhunu, Silchar which are predominantly hot dry regions.

So, this is what the temperature profile in a typical hot dry climate would look like. The mean relative humidity is very low 25 to 40 percent almost throughout the year. So, throughout the year, we have very low humidity and that is because the precipitation is also very low the annual precipitation is quite low which is less than 500 mm per year that is including the monsoon period.

So, which is very low, there is scarcity of water; underground water table is also very low going to this region. The vegetation is less and overall environment is quite dry. If you look at the sky condition; we see that it is cloudless sky with very high solar radiation which causes a lot of glare. So, there is intense solar radiation and clear sky. So, it makes the condition even worse. So, we have high temperature, low humidity, low precipitation and very high radiation; this usually classifies hot dry climate.

For the given environmental conditions of the hot dry climate which we have just discussed there are certain physiological objectives which can very clearly be identified. So, if you look at this summer temperatures which is very high 40 to 45 degrees. We automatically know that the physiological objective of design would be to bring down the ambient air temperatures, the dry bar temperatures.

So, we have to try to reduce this ambient air temperature down to approximately 25 to 30 degrees ~~centigrade.~~centigrade. Now t~~T~~hat is what we have seen when, we were talking about thermal comfort in the previous lecture and we were looking at the limits of thermal comfort, then this temperature needs to be brought down by at the approximately 20 degree centigrade. That is the difference that we are looking at.

In winters on the other hand we might need to increase this temperature slightly by around 15 degree centigrade. So, adding heat in winters or reducing. So, both of these aims can be achieved by reducing the heat transfer during the extreme weathers. So, in extremely hot summers, the heat transfer from outside to inside should be limited and vice versa in winters. And the thermal mass of the building will have a larger role to play in this. The other physiological objective here would be to reduce the amount of direct solar radiation which is received by the building.

So, how can we reduce the amount of direct solar radiation becomes a major concern, one of the physiological objectives. Another one, if we can handle it through design is ~~can~~can we do something about humidifying the environment. So, the relative humidity which is normally low has to be maintained between 40 to 60 percent. So, if we want to increase the humidity is there a way, is there a design measure through which we can increase the humidity slightly.

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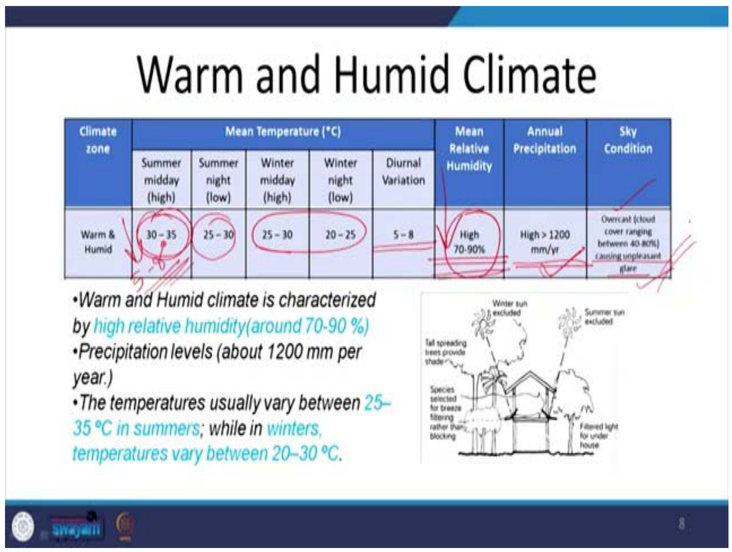

Let us look at the warm humid climate, if you look at the warm humid climate this summer temperatures are between a range of 30 to 35 and summer nights are 25 to 30. Where we can see that the diurnal variation is not very large and the temperatures are also not very high. They are slightly warm, warmer than the comfortable range, but they are not extreme as we have seen in case of hot dry climate. In winters also they do not fall too low.

So, they are between the comfortable range. So, 25 to 30 and the winter nights would be 20 to 25; so, hardly any diurnal variation. Now this is because of their proximity to the water body which is sea. So, these are all largely the coastal areas which we are talking about. So, they remain more or less at the same temperatures, but the problematic thing here is very high humidity.

Now, because of this very high humidity evaporative cooling is not possible. And, we are not, we cannot look at evaporative cooling as an option, as an alternative. Also the annual precipitation is very--very high, it is more than 1200 mm per year. So, almost throughout the year there would be a large number of days which would receive precipitation. If you look at sky conditions, it is most of the times overcast ranging between 40 to 80 percent of cloud cover and that causes extremely unpleasant glare that also limits; it also blocks the heat because of the cloud cover.

So, this is what the warm humid climate is and at times it becomes very difficult to handle the one humid climatic ~~conditions~~condition much more than the hot dry climatic conditions because of the high humidity. It is easier to humidify than to dehumidify a space. So, this humidity is a problematic feature here. For the given climatic conditions, if we look at the physiological objective, we might have to slightly reduce the temperatures by around 5 to 8 degree centigrade not much; not much not more than that, but the prime objective would be to bring down the humidity.

So, as to bring the environmental conditions within the comfort range; we would see how we can do that and if we are looking at the sky conditions, we would still want to shade because the temperatures are a little high and this glare, this unpleasant glare is often very tough to handle. So, the objective would be to cut down on the direct solar radiation. Composite climate is a climate which experiences the extremes of both the seasons, both the climates, all three climates rather.

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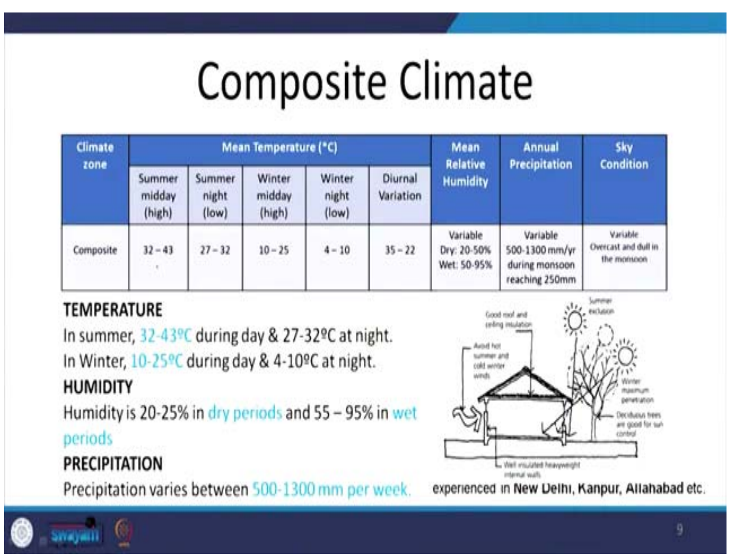

So, we have summer, midday high temperatures which range from 32 to 43. So, it is close to what the hot dry climates experience around 45. So, composite climates will also have temperature, summer maximum temperatures similar as hot dry climates and the winter minimum temperatures very close to what we would see in cold climates. We would come to cold climate, but the winter temperature is falling very low.

Unlike hot dry climate the humidity is varying, it is in such certain season, it is becoming extremely dry predominantly during the winter seasons and during monsoons it is quite high 50 to 95 percent of humidity is also present in composite climate. Along with that there is annual precipitation which is varying between 500 to 1300 mm per year, composite climate is a large area if we remember the map of India with climatic zones shown right in the initial slides of this presentation. So, there is a great variation in the precipitation which is received in the composite zone.

So, during the monsoons the precipitation goes very high. So, composite climate receives 3 distinct seasons, summers, monsoons and winters and the conditions vary in each of these seasons which is what the problematic causes. And, the sky conditions are again variable which because it experiences all the 3 seasons. Now, the physiological objective for composite climate becomes very difficult. The physiological objectives also vary with season to season in summers it is a hot dry climate, in winters it is a cold climate and in monsoon, during monsoons it is a warm humid climate. So, the physiological objectives for composite climate vary with season to season and they are the same as the respective climates as I have just talked about. So, it is one of the trickiest climates to deal with, when we are talking about composite climate.

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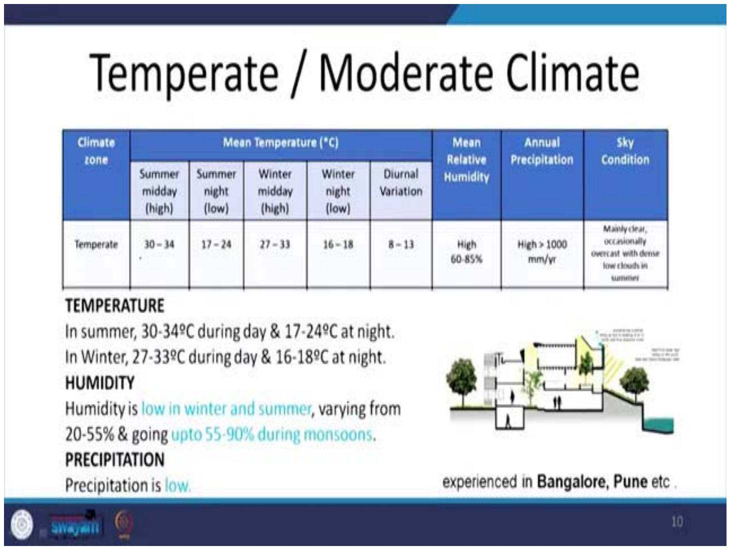

The temperate or moderate climate is by far the most comfortable climate because the temperatures range largely within the very close to the comfort range as we can see. So, the summer high temperatures are around 30 to 34 while summer nights are absolutely comfortable. If we look at winter day temperatures, they also fall within the comfort range. Now, this comfort range is not as per the ASHRAE 55 as defined by ASHRAE 55.

This is slightly higher than that, but falls within the comfort range as defined by tropical summer index which was developed based upon the responses of Indian subjects. The winter night temperatures are also very close to the comfort range, very low diurnal variation. Now, relative humidity is slightly high on a higher side 60 to 85 percent. And annual precipitation is higher than 1000 mm per year which is not too high as well.

And sky conditions are mainly clear, but in summers it is an overcast sky. Because, of this comfortable range of temperatures which we can see in temperate or moderate climate. The physiological objectives in a moderate climate are not aimed towards increasing or decreasing the ambient air temperature. The combination of temperature and humidity is also such that it remains largely comfortable.

So, the physiological objective is to avoid any heat gain or heat loss and maintain the indoors at the same ambient conditions as outdoors for large part of the year, almost throughout the year; except for few days in the year which are extremely hot or which are extremely hot only that. So, the intent is the physiological objective during some part of the year is to cut down on this direct solar radiation and to reduce the ambient air temperature indoors.

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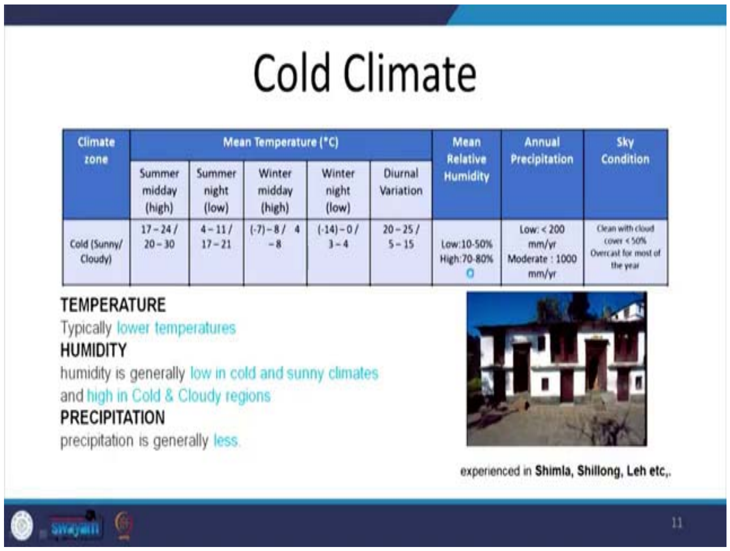

The cold climate is predominantly cold and the summer midday high temperatures fall within the comfortable range while the summer night temperatures may also get cold. So, we are looking at around 4 to 11 degrees centigrade which is cold. So, summer nights may also become extremely cold and that results in a very high diurnal variation. We are all looking at winter midday high temperatures which may be sub 0 which may be less than 0 and we are looking at winter night temperatures which are further low.

So, we are looking at an extremely cold climatic conditions, temperature conditions here and the relative humidity is extremely low. So, these are two types of cold climates we are looking at; we are looking at cold dry and we are looking at cold humid climates. So, there are certain parts of the country. For example, the Leh Ladakh area which is cold dry, while if we look at the northeast; if we look at the Arunachal Pradesh or Assam side. So, that is predominantly cold humid. So, a lot of precipitation is received in that area, but it still remains very cold.

So, these are two types of climates within cold that we are looking at, when we are talking about cold climate in our country. So, we have annual precipitation for cold dry, it is very low less than 200 mm per year which is the same as the hot dry. So, hot dry will have same precipitation and humidity while the temperatures go very high and in coldcold, they go very low, in cold humid the annual precipitation is moderate which around 1000 -mm per year is.

So, and the sky conditions are for dry, it is usually a clear sky while for the cold humid it is usually an overcast sky. Now, if you look at the physiological objectives for cold climate, we can very clearly see that because the temperatures are going so low; the intent is the objective is to bring in a lot of heat. So, increasing the solar radiation exposure, the exposure of the building envelope the solar radiation and bringing in a lot of direct heat, direct sunlight is what the physiological objective of cold climate is.

We have to increase the ambient air temperature of the indoors. Now, how do we do that? We have understood, what a hot dry climate is or what a cold climate is each one of these and we have also reasonably understood the climatic conditions. Now, how do we achieve thermal comfort inside the building? So, a lot of research has been carried out on this and there are a variety of tools which are available to us.

One such tool which we have looked at yesterday in the previous lecture was or that of psychometric chart. There we would plot the dry bulb temperature, wet bulb temperature, humidity all together and we would see where we are as far as the comfort, thermal comfort is concerned. We would look at an interactive psychometric chart here.

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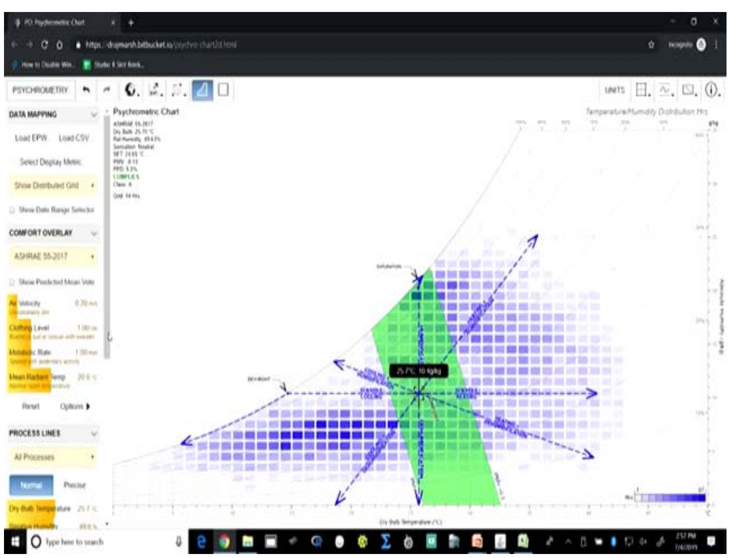

This is an interactive psychometric chart and you can find it at the address which is shown here in the address bar. If you look at this psychometric chart, you can load whatever file you want to check. So, load by the file, here I have used the weather data file of Jaipur to just show you an example, here we are looking at the ASHRAE 55 model of comfort.

So, this comfort zone which we can see here is, showing us the comfort zone where we have yesterday seen that it is varying from PMV minus 0.5 to PMV plus 0.5 and this is the comfort zone. So, and these grids actually show the number of hours as distributed on the psychometric chart. So, this is the total climate, this is the total weather data of Jaipur which is shown on the psychometric chart. Now, if I move this point this is the point which I want to understand.

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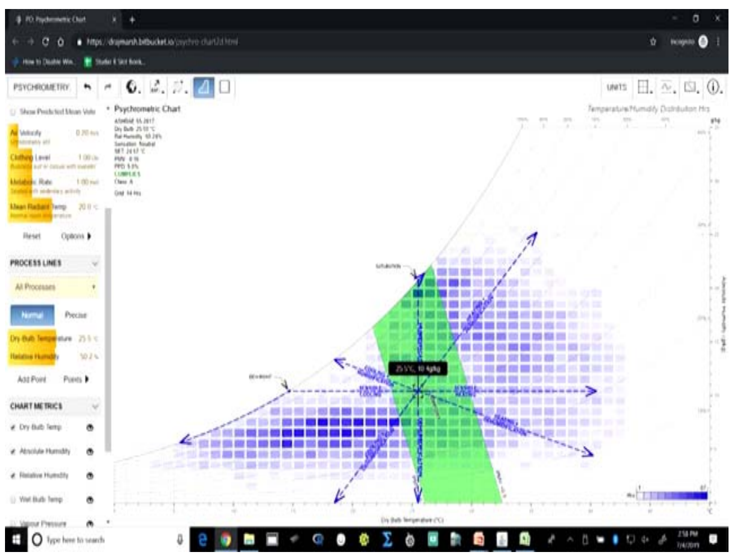

So, suppose I am in a point which has a dry bulb temperature of 25.7 degree centigrade and relative humidity of around 50 percent. I know that I am in the comfort range.

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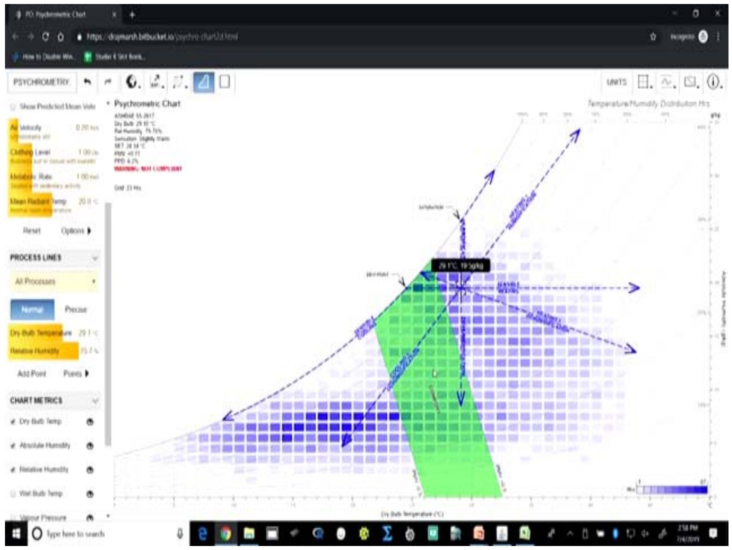

If I move this point up, if I go beyond comfort zone and if I am on a slightly higher side now, I have a dry bulb temperature of 29 degree centigrade and a relative humidity of around 75 percent. I know that I am out of comfort zone, but how do I create a comfortable environment.

So, this interactive psychometric chart clearly shows me that, if I cool along with dehumidification. I will be able to bring it down within the comfort zone or if I only dehumidify then ~~also~~also, I can bring it down to comfort zone. If I want to just cool then ~~also~~also, I can bring it down to comfort zone.

Now, if you see how much do, I have to dehumidify; we are looking at a relative humidity of around 80 percent here 70, 75, 76 percent and if I have to bring it to the comfort zone, I have to dehumidify by around 30 percent. So, I have to bring it down to around 50 percent to bring it within the comfort zone. On the other hand, if I go further high.

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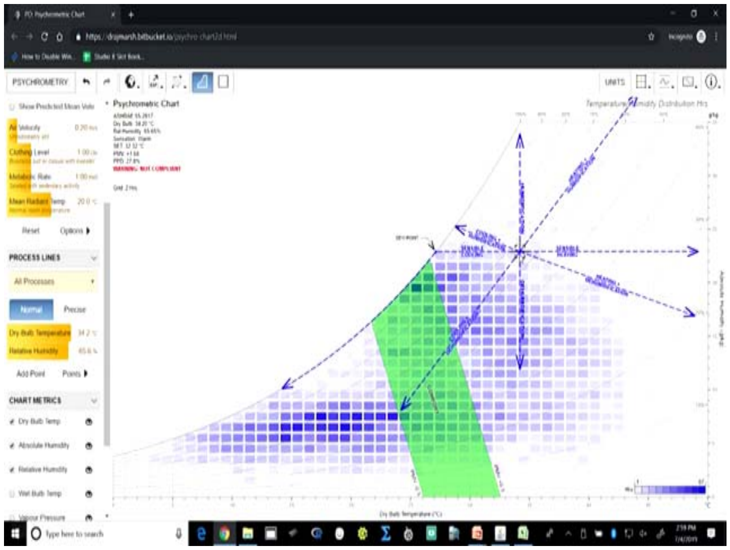

So, the temperature is further increased at that temperature and humidity of around 70 percent, we are looking at 65 percent humidity here. Even after you do dehumidification only dehumidification, I might not be able to bring it within the comfort zone. For bringing it within the comfort zone, I will have to look at the cooling plus dehumidification route here.

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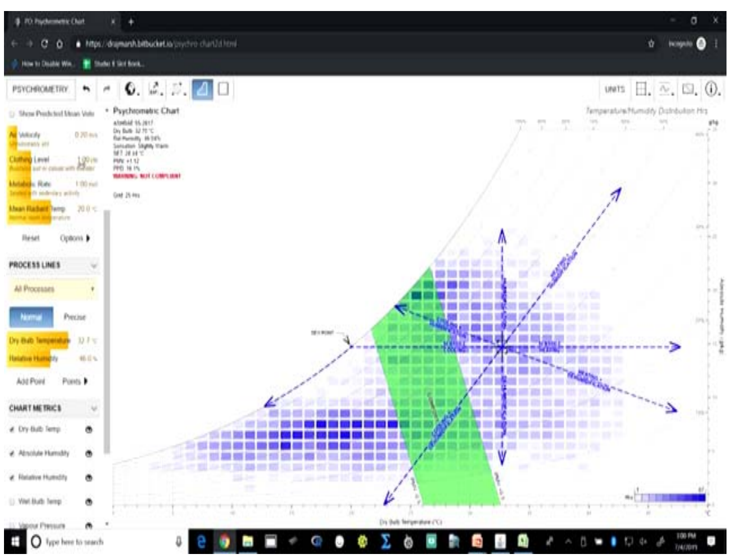

So, depending upon where this point is what is the environmental condition, we may look at the different strategies which are available to us. Now from psychometric chart, we can only look at the temperature and humidity changes which is what we can play with. Here it is also showing us the proposed clothing level and it is also showing us the metabolic rate it is assuming. So, it is assuming a clothing level of one ~~flow~~ clo and a metabolic rate which is for a sedentary activity.

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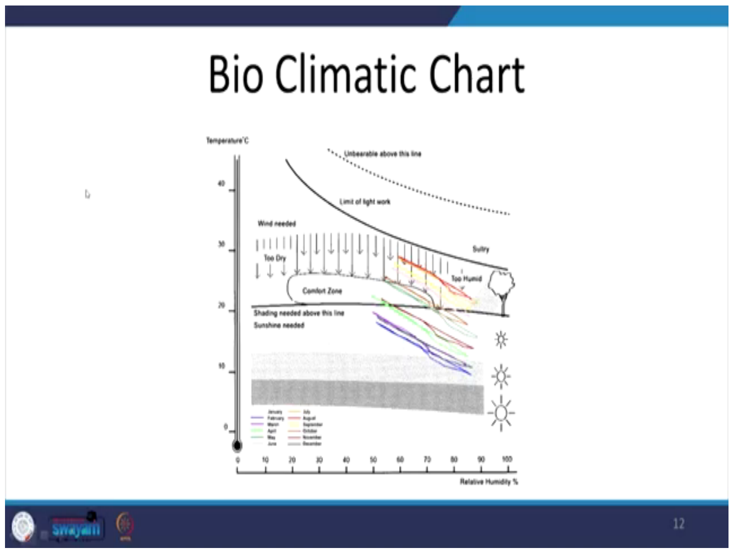

Now, if we go back to another tool which is taking it forward from psychometric chart, one we have is bio climatic chart. Now, if we look at this bio~~y~~ climatic chart, it very clearly ~~define~~defines, it very clearly tells us the comfort zone where on this axis, we have the temperature, dry bulb temperature and relative humidity. This comfort zone is very similar to what ASHRAE 55 defines and as per that what we have seen on psychometric chart. Now, if we are above this comfort zone, where the temperature is increased which is what we were seeing in psychometric chart just now.

There are different strategies which can be employed. Here, we are talking about the need for wind. So, if we are somewhere between this zone, we may be; we may be needing wind to bring it to the comfortable zone here. If we are somewhere here, we are quite humid here also we would be needing wind. If we look at a zone which is below this, where the temperatures are lower than 20 sunshine is needed. So, we need to add radiation further low we go we need more and more of radiation. Here, we need wind, here we need sun which is what so, the need for sun is increasing as we go here.

If we know; if we go towards this side where the relative humidity is less, this is where we would slightly need more wind and humidification. This is what comes from bioclimatic chart. Another very interesting tool that, we would find to not just know; what is needed from environmental point of view, but also tells us how to do that through building design, we can use Mahoney's table. Mahoney's table, they are a set of reference tables which are used in architecture and they help us in designing a climate responsive building.

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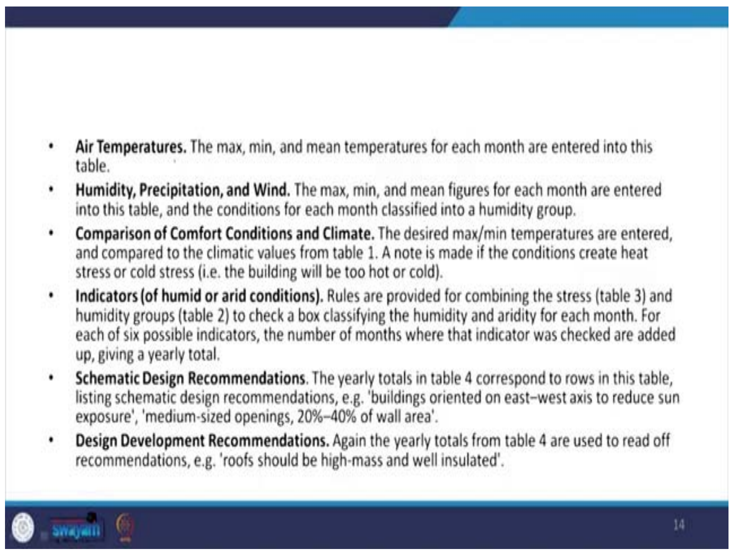

The parameters that we consider here are air temperature. Humidity, precipitation and wind and using these, we compare the comfort conditions and assess the climate. On the basis of this the indicators are decided and the climate is assessed as humid or arid and a schematic design recommendation is provided.

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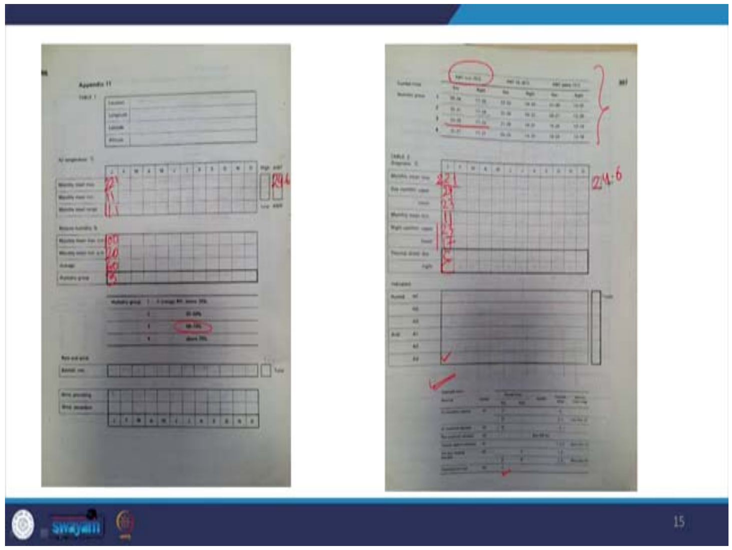

Let us look at these Mahoney’s table; you might have looked at these Mahoney’s table sometime during your early courses. For assessing any of the climate, we have to enter the values for the location, longitude, latitude, altitude. Along with that for air temperature, we need the monthly mean maximum and monthly mean minimum and from that we can calculate the range.

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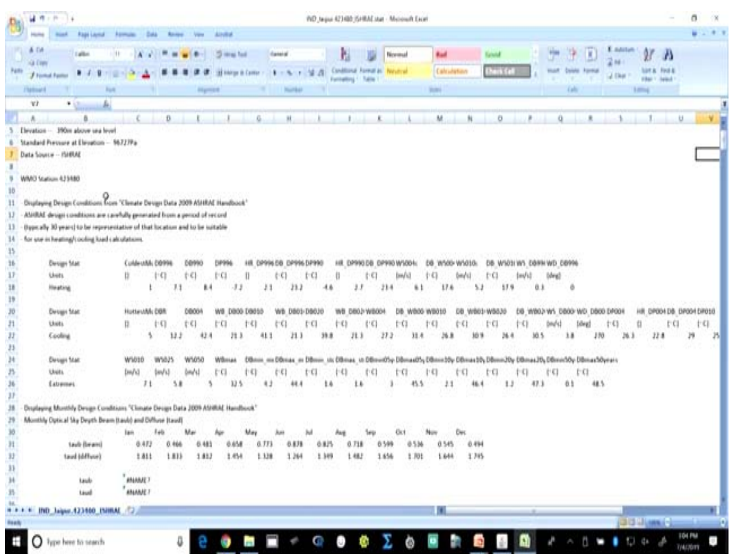

Let us look at the climatic data of Jaipur.

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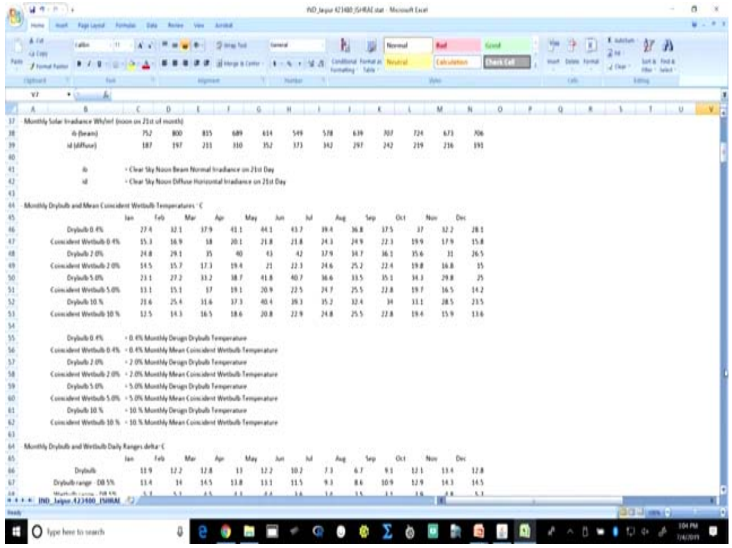

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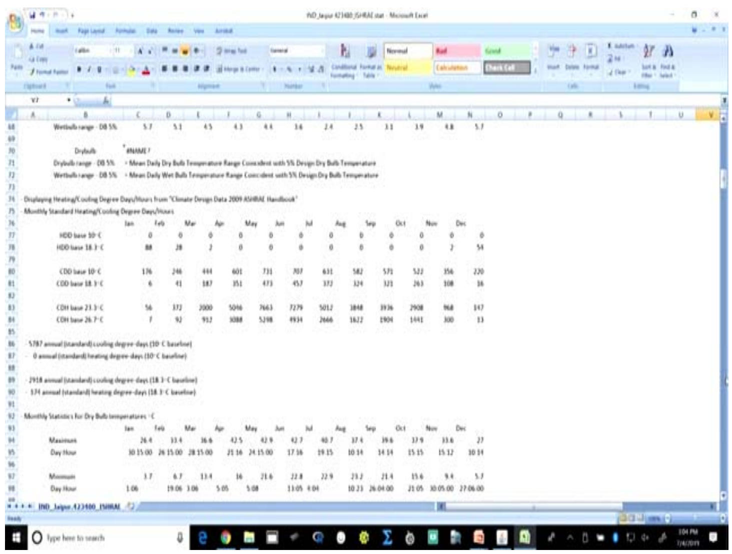

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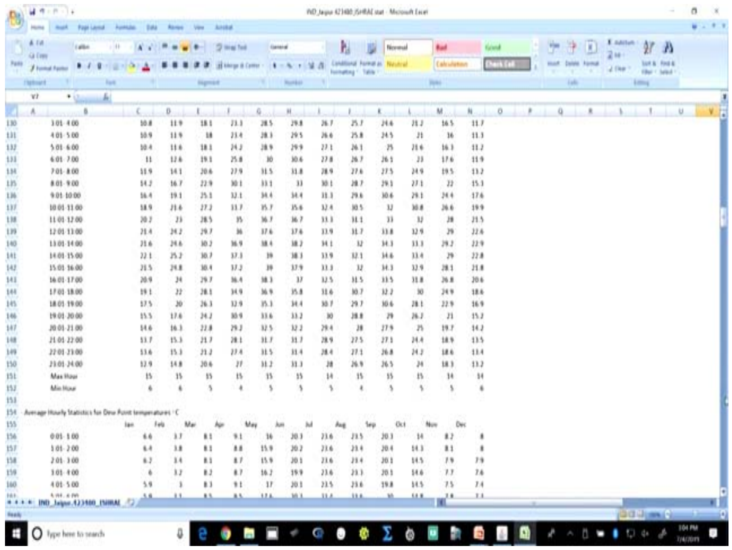

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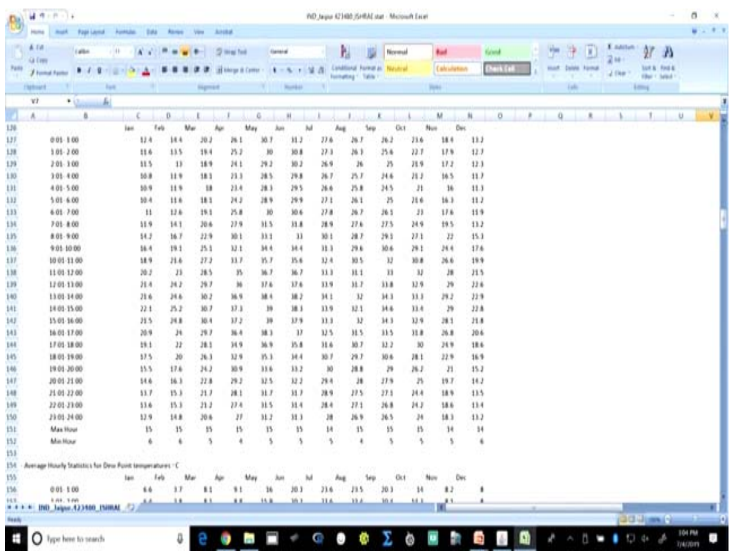

So, if you look at the climatic data of Jaipur, where the average hourly driver temperature for each month is given. We can find out the maximum temperatures which for January is 22.1 and the minimum is say 11 here. We can enter these values. So, monthly mean maximum was 22.1 and 11 here. So, for each month like that, we fill up these monthly mean maximum and monthly mean minimum.

We would know the monthly range which is the difference of these two. So, we would have 11.1 here which is the monthly mean range. We can have the highest temperatures and the lowest temperatures, the highest of all monthly mean maximums. So, it will come somewhere in May, June, July and monthly mean low. So, the lowest of all the monthly mean minimums which will be here, we will have an average annual mean temperature which will be the average of the averages of each month. And, there will be an average monthly range which will be the average of all the monthly mean ranges which we will get here.

This is how we will fill up the data for air temperature. The same thing we do for relative humidity. So, monthly mean maximum and monthly mean minimum for each month. The average and then on the basis of this average that we get here; so, say for Jaipur which we were looking at, we have a humidity which is around 100 percent and 20 percent. So, we have a monthly humidity of maximum of around 100 percent and minimum of around 20 percent, the average being 60. So, for this 60 average the humidity group is 50 to 70 which is the humidity group 3.

So, we fill up these two tables, this is the key to fill up the humidity group here. ~~Again~~Again, we have this data for rainfall and the total rainfall, the annual total rainfall prevailing wind which is the primary direction and these secondary directions for each of these months. That is table 1 for Mahoney's table. Once, we have done that there is a key to start with table 2. Now in table 2, we can write the monthly mean maximum as what we have in the table 1. And we can write the monthly mean minimum which we have in table 1 again.

Once we have that, we can write for the given humidity group. So, suppose and we also have the annual mean temperature. So, suppose the annual mean temperature in case of Jaipur comes out to be say, 24.6 degree centigrade. So, I have an annual mean temperature of 24.6 degrees which we will we can calculate if we have the entire years data. So, looking at the annual mean temperature 24.6 which is above 20 degree centigrade and we have the humidity group which we identified as group 3 here.

So, we can look at the day and night comfort range. So, in January the upper limit would be 29, the lower would be 23 for the day and for night it would be 23 and 17 here. So, from this table, we can actually fill up for each of the month. And, when~~ell~~ we have to calculate the thermal stress during the day; what we have to see is, if the mean monthly maximum which is 22.1, if it is we will compare it with the thermal stress of the day. If it is lying between the comfort limits for the day up between the upper and lower. If it is higher than that then we write H which is hot heat stress, if it is lower than this then we write cold. So, here we see that 22.1 is less than 23 so, we write cold

Same we do for monthly mean minimum which is 11 and we compare it with this range of night temperatures. So, if it lies between these two, it is O if it is higher than 23 which is the upper limit it is H and if it is lesser than this it is C. So, we see that for a place of hot dry climate like Jaipur also the January is actually a cold month. Then, we look at the indicators based upon this key. So, this key has to be used to fill up this one.

Now, we are looking at the January data, in January we have thermal stress of C we have humidity group of 3. So, if we look at this so, we have thermal stress during the day as C and which implies that, we have the indicator as A3. So, we tick the indicator which is given here. So, we have; if we have C it automatically comes to A 3. For other month suppose, we have H so, we place the groups. So, we have the rainfall, we have the thermal stress during day and night and we have the humidity group, we also have the monthly mean range. Together, we can find out which indicators are applicable.

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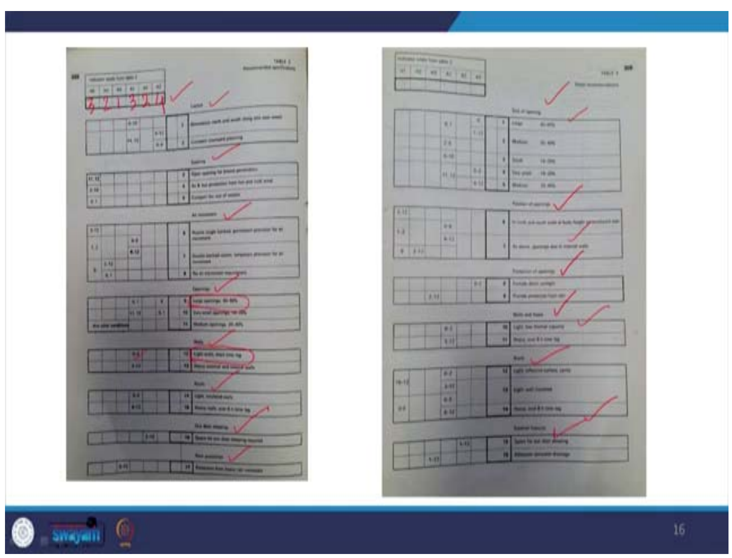

Once we have done that, we move on and we total up. How many H 1s are there, how many H 2s are there, H 3 and A 1, A 2 and A 3 and like that we will have these total number of indicators. Once, we have those indicators, we can go about finding out the strategy. So, these are given suppose so, it can be very conveniently read suppose, we have A1, 3 indicators are there; in case we have 3 indicators, we are looking at this.

So, if A 1 is 3 0 or 1, we are looking at large openings of around 40 to 80 percent. This is what is the proposed strategy, we are also looking at 0 to 2 for A 1 light walls short time lag is the strategy for walls. So, like that for each one this is I have just filled up these numbers, but you would get proper numbers, if you properly fill up the Mahoney's table. And, Mahoney's table are the first reference where you would actually get what kind of design strategy you can use for your buildings, envelope design.

So, they are talking about layout, the spacing between the buildings, air movement, openings, walls, roofs, outdoor sleeping whether it is advisable or not. Protection against rain, the size of opening, position of openings, protection of openings, walls and floors what should be the thermal capacity of walls and floors, the roofs what kind of reflective surfaces should there be and external features.

So, Mahoney's tables are the first reference, where on the basis of an initial analysis of very quick analysis of the weather data file. You can actually know; what kind of design strategies can be employed into your design. I will stop here for this lecture and we will continue with discussing some more tools for understanding the climate and deciding on the appropriate design strategies using some other tools in the following lecture.

Thank you, see you again tomorrow.