Climate and Built Environment
Lecture 2

ET and CET

Effective Temperature (ET) - Developed as a comfort scale, Combines effects of – air temperature, Humidity, & Air movement. Two Charts Produced- one for persons naked to waist that is called Basic Effective Temperature (ET), one for normally clothed which is called Normal Effective Temperatures.

The Effective Temperature, it's a combination which takes into account air temperature, Humidity, and also the Air movement. Usually when we look at Thermal Comfort we usually note about air temperature and humidity levels and we forget about the air movement which causes major physiological & psychological comfort levels and improves thermal comfort. This air movement aspect is also taken into account when you are looking at effective temperature levels. This has been developed as 2 basis in which there is one monogram, which has been developed for normally clothed person is called Normal Effective Temperatures; & one monogram for person who are dressed till waist, which means they are dressed only below their waist, so there effective temperature is slightly different from Normal Effective Temperatures, for persons who are normally dressed.

For example- if Dry bulb temperature is 30°C & wet bulb temperature is 20°C, Air speed of 2.0 m/sec. The basic effective temperature (BET) is 21°C. This means man naked to waist will sense environment of Dry bulb temperature 30°C, Wet bulb temperature of 20°C & Air velocity of 2.0 m/s as equivalent to 21°C, dry bulb temp of still and saturated air (i.e. BET).

(Pic) This is the dry bulb temperature the scale that is shown on the left hand side & the scales that is shown on the right hand side means the wet –bulb temperature. In this example it is 30°C of dry bulb temperature & wet bulb temperature of 20°C. So what we need to do is, you need to cross these two lines; and the Air speed of 2.0 m/sec which is being traced here has the intersection of all three points, which gives us the basic effective temperature which is 21°C. What we realize from this is even though the Dry bulb temperature is 30°C, due to the presence of air-velocity of 2.0 m/s the actual effective temperature that any person could feel would be 21°C.

(Pic) This is the next Monogram which is being developed for person who is normally dressed. The one we just previously saw was for persons who are dressed naked till waist. Monogram for normal effective temperature (NET). Let's consider the same example of Dry bulb temperature of 30°C, wet- bulb of 20°C, & Air velocity 2.0 m/sec. The normal effective temperature is 23°C. This means man normally clothed will sense environment of Dry-Bulb temperature 30°C, wet bulb temperature of 20°C & Air Velocity of 2.0 m/s as equivalent to 23°C dry bulb temp of still and saturated air. This is called Normal effective Temperature. As you look at this monogram, on your right you will notice there is dry bulb temperature, wet-bulb temperature scale which is being marked and then the air-velocity. As you cross these

three intersections which meets gives us the normal effective temperature which is equivalent to 23°C.

When you compare the previous example and this example, we can easily predict for persons who is being naked till their waist experience almost 21°C of effective temperature. Where as if the person is completely dressed for the same Dry bulb, wet- bulb & wind speed the effective temperature that they experience is 23°C. There is 2°C of difference; it is due to the clothing that the person is wearing and without it. Under occupant comfort also, clothing and their effective other thermal factors also becomes very much important.

Corrected Effective Temperature (CET)- the effective temperature was limited - did not take into account radiant heat. Modified to form corrective effective temperatures. As we saw in the previous example, effective temperature takes into account Dry bulb temperature, wet-bulb temperature & Air Velocity, but it doesn't take into effect of radiant heat, which means the heat that is being dissipated out by the surfaces that we are located in. For example, if you are inside the room there is constant heat released from the floor, roofing and the walls which acts to the environment or air temperature that is surrounding us. For example, let's say if you are in a warm & humid climate in which you are made to sit on the floor and the floor is made with material like concrete, and the concrete has usually good thermal mass which maintains the temperature, which is lower than the air temperature. Even though the air temperature might be little higher because you are constantly in contact with the cooler surface you will feel much more colder. This radiant heat that is being produced by different surfaces and body's skin are also very important in achieving thermal comfort. 150 mm diameter globe used to measure radiant heat in lieu of dry bulb. (Pic) This is the 150 mm diameter globe which is being used to measure the dry bulb temperature. This takes into account the radiant heat that is being dissipated by the globe.

Effective Temperature (ET) & Corrected Effective Temperature (CET) - Still used as a comfort index where humidity high and radiant temperature is low, Example Underground mines. Considering achieving thermal comfort for the areas buildings that is going to be located under-ground or underground mines you need to look into Effective Temperature & Corrected Effective Temperature because it takes into account the radiant heat that is being dissipated by the surrounding environment. Effective Temperature & Corrected Effective Temperature make limited allowance for effects of clothing and no allowance for levels of activity. The two monograms that are developed for Effective Temperature is: one for people who are completely dressed; and one for person who is naked till the waist. It doesn't given us how much clothing it can be added or reduced according to seasonal variation or weather condition on a daily basis. Also it doesn't take into account of activity pattern. So, if you are sitting still the amount of heat, or the work activity that you do which is being dissipated by watts/m2 is very less compared to, when your are performing your activities such as dancing, practicing some exercise, it produces lot of heat. That type of activity pattern is not taken into account, which is a drawback of effective temperatures.

Thermal Comfort

Thermal comfort is the comfortable temperatures for the human being to be without any usage of external heat source or cooling source. What is thermal comfort? Thermal comfort is a state of mind. That condition of mind which expresses satisfaction with thermal environment. Thermal comfort is state of mind; it might vary from person to person. If 5 people are made to sit in a inner room which has a temperature of 30°C; 30°C might be comfortable for one are two people, and for remaining 3 people it might be really hot. It depends on the place your are located & how you are being raised usually; and which temperature you are usually subjected to. If you are coming from a colder region 30°C will be very hot for you. But, if you are from hot & dry desert climatic conditions in which the temperature is usually 43°C. You might feel 30°C to be much more comfortable and you will feel there is no need for air conditioning the space or using air cooler or even electrical fans. This definition is according to ASHRAE.

Some of the Environmental Factors that contributes to Thermal comfort are – Dry bulb temperature, humidity, radiant temperature, Air movement, & solar radiation. Dry bulb temperature is the temperature that is present in our air. Next, comes relative humidity which means the amount of vapour content that is present in the air. Radiant temperature which we observe on different surfaces, for example metal is much more colder compared to wood that is due to difference in specific heat capacity of different materials. Different materials can have difference radiant temperature which has to be sensibly chosen for your climatic condition and the air movement. The air movement according to wind speed and wind direction thermal comfort can be articulated to make a person comfortable or less comfortable; this also becomes very important factor. It contributes majorly to psychological comfort. Solar radiation is the amount of radiation which is being observed by different surfaces of your building that is usually expressed in watts/m2.

Physiologically the human body's heat balance can be measured at steady state mind. It is usually in steady state mind is when you experience; it is not suddenly you are exposed under the sun you are bought inside the room and then you have to observe the Thermal comfort. Usually it has to be subjected for prolonged period to understand the thermal comfort and how your building is reacting to human means.

But human beings do adapt to their environment and their bodies. As we discussed in our earlier presentation how different ways body tend to adjust to human heat balance by evaporation, radiation, convulsion and conduction. All this even our body does even though if you're exposed to two different environments you might experience you are in a hot day on a road, and you suddenly step into the mall which is completely air-conditioned. You don't suddenly feel very cold because of the temperature difference because your body starts reacting & adjust to the environment to which it is subjected to, and do self- regulate to a certain extent. To certain extent it can self regulate by process like vaso- regulation, sweating or shivering all this process happens to regulate to our sudden change in

environmental conditions. Other environmental factors which gives benefit out of thermal comfort are- 1) Good health, 2) Productivity, 3) Comfort, 4) Energy Use, and 5) awareness about surroundings. These are some of the advantage that we gain by understanding about the environment in which we are living in. Having good amount of air changes will doesn't put your to risk rather it adds to good health condition and also it improves productivity in your work. You need good amount of natural ventilation to take out used up foul air; and also good amount daylight rendering quality at your work space. It improves comfort which reduces your energy bills, and your dependence of external air-conditioning or room heating space. It creates awareness about surroundings so that you're not contributing to ozone depletion or climate change we constantly know about.

Some of the other Physiological Factors are activity pattern. (Pic) As you observe in this image different activity pattern which has different metabolic rate. When you are sitting the body has 1 metabolic activity level, but when you are standing, exercise, running, working, or dancing the metabolic level changes from 1 to 7. Which means depending on your activity pattern, the envelop in which you are located has to be modified and changed. When you are designing you need to know which type of activities will go into which room and which space, according to that you might choose that design or envelop materials to be designed for. Human activity level measured in W/m2 or Metabolic activity. Depending on the activity pattern body is going to release heat which is going to add to your air temperatures. You need to be sensible to choose which amount of opening size, opening ratio; the window to wall ratio etc. It depends on clothing level as well. Clothing level can vary from being completely naked to wearing clothes like jackets and heavy pants. Also depends on colour of the clothing. (Pic) So as you look at this graph, lighter clothing observes lesser solar radiation and it contributes to lesser increase in temperature. When you are wearing dark clothes, obviously darker the colour sun is going to be observed more and the temperature is going to get elevated to match up to thermal comfort. Depending on the climatic condition and climatic variation you need to choose your clothing colours. During summer we usually prefer to wear much lighter or whiter colours. During winter we choose darker colours, black or grey shades. This thinking has to go into space design, envelop design as well, while choosing the paints, the colour of the material that you are going to choose has to be according to the climatic zones in which you are located. Insulation property of clothes is measured in Clo or m2 K/W.
This is the amount of clothing in which we have been measuring cloth insulation. If you are completely naked you have zero Clo. In winter season when you wear all your jackets clothes, sweaters and pull over's, your clothing level can go up to 3.5.

Other physiology factors we tend to adapt to our environment is adaptability, acclimatization, past experience, time of exposure and culture. These are some of the factors which contribute to our physiology factors. Adaptability is how much we can adapt to the environmental changes. So thermal comfort cannot be defined as from this temperature to this temperature is fixed for all the human beings! It varies person to person. Their

experience in the past is completely different and their culture in which they have been bought up will be completely different. For example, past experience if you are standing under shade for almost one hour and you suddenly come out of the shade & you are exposed to solar radiation, high after noon radiation levels you might feel really really hot even though the air temperature might be within the comfort levels. This is what past experience means. At the time of exposure is how long you have been exposed.

If you are designing something and it's going to be transition from one block to another block and the outside temperature is going to be unbearably harsh or cold; hot or cold at the time of exposure also becomes very vital. If you are going to design something which people will only use for 30-40 seconds, there is not much importance to be given for that type of space. How long the space will get used, how long the people are going to stay in that place becomes vital role to choose if you need to apply environmental factors or not. And culture means - where you have been raised? To which temperature ranges you are usually practiced with? All these factors come under culture.

Assessing comfort- to have a quicker realization, if the environment in which you are located currently is comfortable or no? There are lot of online accessing comfort tools which is very easy to understand. (Pic) 1) The first one is comfort calculator, as you see it takes in to account of air temperature, radiant temperature, relative humidity, air-velocity, activity rate & clothing levels. This can be adjusted according to what type of air-velocity the space is experiencing or humidity levels, radiant temperatures and air temperatures which will make the bunny that is present on the right (side of pic) to be hotter- it will make it red & sweating; if it's colder it will make it completely blue. Here its being adjusted in which it is just very close to neutral; but people who are dissatisfied percentage will be 18.5%. If it is less than 20-30% of people are dissatisfied, the majority of the people will be satisfied with in the space which is good enough for an environment to match to Thermal comfort levels. 2) This is CBE Thermal comfort tool- which takes into account of almost the comfort calculator tool factors. It also takes into account of mean-radiant temperature which is the addition of temperature from all the surfaces that is surrounding you. Then it also takes in to account clothing levels, activity pattern, and humidity levels which shows (Pic), as you see on this (graph) dark-blue is the comfortable range. This red spot is where your comfortable range is. The example that is shown here is, we are within the thermal comfort of factors which is given here. (pic) This is Psychrometric chart in which we usually use, Dry bulb temperature; wet-bulb temperature; air-speeds and relative humidity levels which locates whether we are within the thermal comfort or not? And what type of feeling we might have in the presence of effective temperature monograms. 3) This is LayMan tool- which is usually used for our studying thermal comfort for the outdoor activities. (Pic) So these are thermal comfort usually that takes place within the indoor or built environment. Whereas if you want to study a place or a garden or a street is comfortably located, you need to use layman tool which takes in to account the location of your place, and the amount of vapour pressure, relative humidity, air-velocity, cloud cover all the factors, which is environmental

factors, which determines the climate and the weather of that place is also taken into account; and metabolic activity which will tell if the place is comfortable or not? This is usually used for outdoors. CBE tool can be used with extended external thermal comfort adaptability levels; so far few people it might be thermal comfort levels might be extended for 1 or 2° above because depending upon their past experiences, exposures, culture and all that. That is taken in to account in one of these old method. Same applies to acceptable indoor operative, when you are measuring an operative temperature, which takes in to account air-temperature, relative humidity and Mean radiant temperatures. All these put together, the average what we get will be measure as operative temperature, which is = air-temperature + Mean radiant temperature / 2.

Use of Mahoney's Table

Next, we look at Use of Mahoney's Table - usually Mahoney's table is used for places such as warm & humid climate; or hot & humid climate, say mainly for tropical climate we use this Mahoney's table to determine what all are small passive design strategies that can be adopted? Let's see the task- The task of Mahoney's table is the element design stage has two major tasks: 1) to determine the form and dimensions of the elements which are not yet designed and for which only performances specification exist. When you are going to design a space and you have not thought about what is the proportion of the space has to be, but only you know what type of- task, type of activity pattern, type of climatic conditions is going to be located. For this type, to give you design instincts typically for tropical climate we use this Mahoney's table. 2) To re-examine elements which may have been agreed earlier, when design changes it cast doubt on their climatic performance. Even if you have finished your design completely and you are not sure if this design can actually work climatically, temperatures can be comfortable or not. You can recheck your design with the use of Mahoney's table. And it can tell you the design that you have done is correct or not; If you can articulate the design & create much better performance and all that. A general review may be facilitated by Mahoney's table. The last column of the table includes recommendation for six main features of building elements: a) size of openings, 2) Position of openings 3) protection of openings, 4) walls and floors roofs, 5) external features.

Let's see, how thermal comfort range is being calculated? (Pic) This is the typical month for place like Trichy, which has average mean temperature; maximum is usually above the thermal comfort and average monthly mean minimum temperature is just within the thermal comfort; and the overall men temperature is slightly above the upper limit of Thermal comfort. This is being calculated using the formula: Tn= 17.0 + 0.38 x To.av, (where To.av is the mean temperature of the month). It is based on this relationship, shows that the neutral temperature in relation to the mean monthly dry-bulb temperature. A comfort band is then plotted using a +/-3.0 K difference for 90 % acceptability of the occupants. This is the formula which is being developed usually to adapt places like India & Pakistan to find out the neutral temperature we use this formula. And from the neutral temperature we add +3 to achieve the maximum limit of thermal comfort; & -3 for the lower limit of thermal comfort.

(Pic) That is being traced in orange colour! The city experiences monsoon during November to January, and typical summers from April to July.

(Pic)According to ASHRAE-55, the thermal comfort for Trichy is plotted. This is the thermal comfort for Trichy, but we might use some of the passive design strategies to improve the comfort levels and to be less depended on Air- conditioning spaces. These lines show the monthly variation of maximum temperatures and minimum temperature. You might observe – the month like February & march are slightly within the comfort levels and all the other months are above the comfort levels; either due to the presence of high humidity or due to the presence of high air temperatures. To control these two factors we are going to increase the wind speed; by increasing the wind speed from 0.5m/s to 2 m/s the upper limit of the comfort band can be increased from this line to this line. This means almost 60% of the year is within comfort, if you are having 2m/s of air velocity in your buildings. You can improve the comfort for dryer months, say for during summer months, as we just saw, from April to August is completely dry which means the relative humidity is very low in the air. To improve that we can use direct evaporative cooling system keeping huge ponds or using wetted medium such as cloth; hanging wetted cloths in your walls and window openings, all this can improve your evaporative cooling effect which can contribute to 20-30% of further improving of thermal comfort levels.

(Pic) Let's calculate the same using Mahoney's table. So, location is Trichy, India. Longitude, latitude & altitude of the spaces is been defined so we know where it is located. What are different types of precipitation level; cloud cover which is being observed for this place? For each month we have plotted monthly mean maximum temperatures; Monthly mean minimum temperatures; highest temperature and lowest temperature levels. Also we have done same for (Pic) Relative Humidity- average relative humidity and we have classified into relative humidity groups based on if the relative humidity is below 30% it is numbered as one; and if it is 30-50% it is 2; 50-70% is 3; and above 70% is numbered as 4. According to which can observe almost during summer months which is from February very close to October / September it experience 50 -70% of relative humidity; and from October to January it experience high relative humidity which coincides with the monsoon months. The same is being done for Rainfall and wind moments- the wind direction has been plotted for each month and also the rainfall on the rainy days is Total no of days in which it's going to rain. This gives the comfortable limits: upper limits & lower limits which is being calculating the neutral temperature using the formula we just saw. (Pic) These are some of the essential indicators that is being developed by Mahoney for tropical climate, basically. This can be used to check if your humidity indicator- how much humidity indicator you have? What type of humidity classification the climate falls in? And the monthly mean temperature depending on all this you need to give protection for cold or outdoor sleeping is necessary; Thermal Capacity; and if you want to protect your spaces by rain or air movement is desirable. All these can be classified. (Pic) A humidity indicator is being plotted for each month separately by H1, H2 & H3. Finally what we understand by learning from this Mahoney's table- for climate like Trichy- we need to orient our building towards east-west axis, the long elevation

facing north-south. The air movement- rooms should be single banked with windows in the north & south walls. The spacing –broadly spaced breeze penetration; Openings- Not fully glazed and protected from the sun, sky glare and rain; Walls- light weight walls with low thermal capacity; Roof- light well insulated roofs with low thermal capacity. These are some of the design instincts which we can write down before starting to design, so we don't deviate from this type of environmental factors which is going to contribute to achieving thermal comfort.