Principles and Applications of Building Science
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Lecture – 03
Thermal Comfort Built Environment – 1

In this module, we will be looking at Thermal Comfort and Built Environment. To give you a quick overview thermal comfort is something for which the whole you know effort is being made, you talk about climate responsive building, and you are making a climatically responsive in order that in thermally environments are thermally comfortable. It includes provision of proper temperatures, appropriate temperatures curtailing excess heat gains, minimizing heat losses, enhancing ventilation. So, it involves a series of phenomena by virtual of which you call something like overall thermal comfort inside the built environment. The contents would be and introduction for thermal comfort, when we will look at what are the factors actually contributing to thermal comfort. Then we will go for comfort zone and thermal comfort models.

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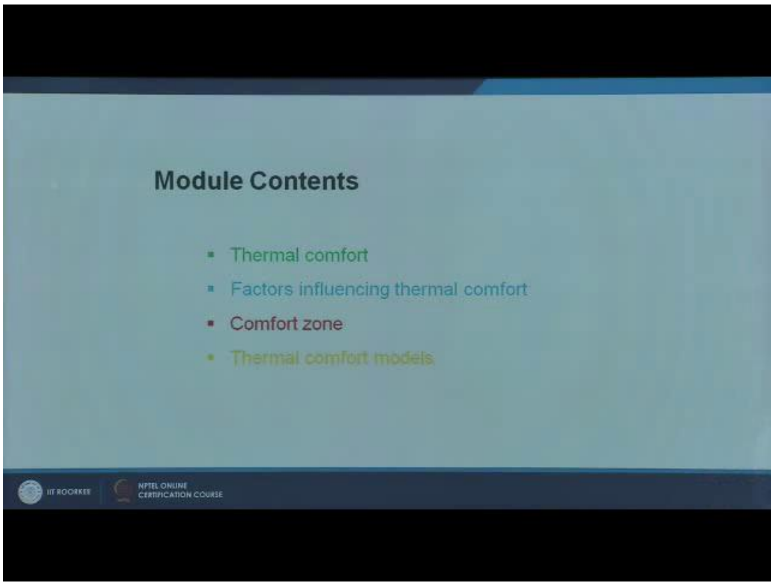

Human body produces heat continuously it is like a machine we call it metabolic process, as a part of this process, there is a continuous heat generation which happens because of which heat emission dissipation happens. We heat output varies somewhere between seventy watts during sleep and if you are involved in heavy physical activity it may go up to 700 watts

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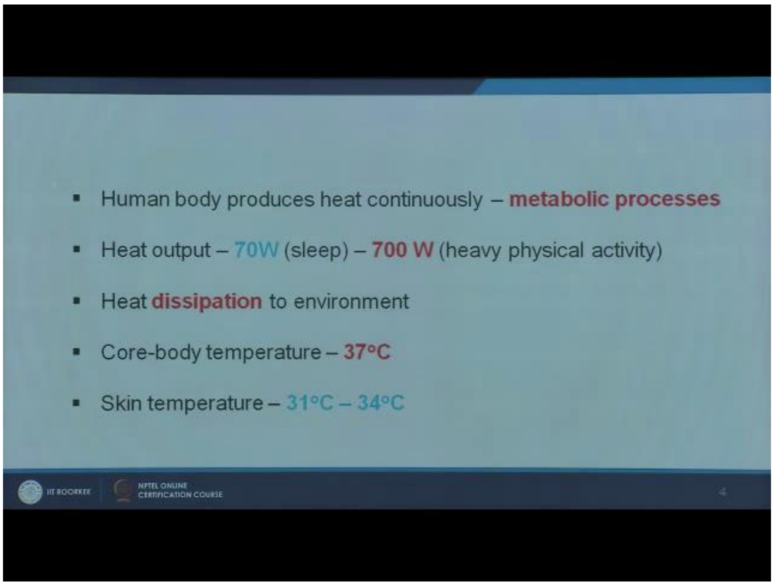

So, it depends primarily on what kind of activity you do. So, if you are in the class sitting and listening, versus faculty who is taking a class you are working in an office, versus you are on this street doing some physical activity or you are going for a jog. The amount of heat dissipation considerably varies from 1 to the other. So, if the environment you know ambient conditions indoor or outdoor. If it is amicable then proper heat dissipation would happen, whatever excess heat is generated will be dissipated to the environment.

Moment the ambient conditions are not in terms where it can get these heat or it can observed it can become a heat sink. Then the human body starts sweating, which means the excess heat is being given out in the form of sweat and because of this you proper transpiration then you know because of these evaporation heat dissipation happens. So, this is something we will look at further in detail we have two body temperatures; one is a core body temperature which is somewhere around 37 degrees and the skin temperature that is a surface skin temperature, which may range from 31 to 34 degree centigrade. When these two things are in place we are physically fit and these go up or come down then the bodies starts to adjust itself by either by sweating or by swearing in terms of heat or in terms of cold this comfort that is what we mean.

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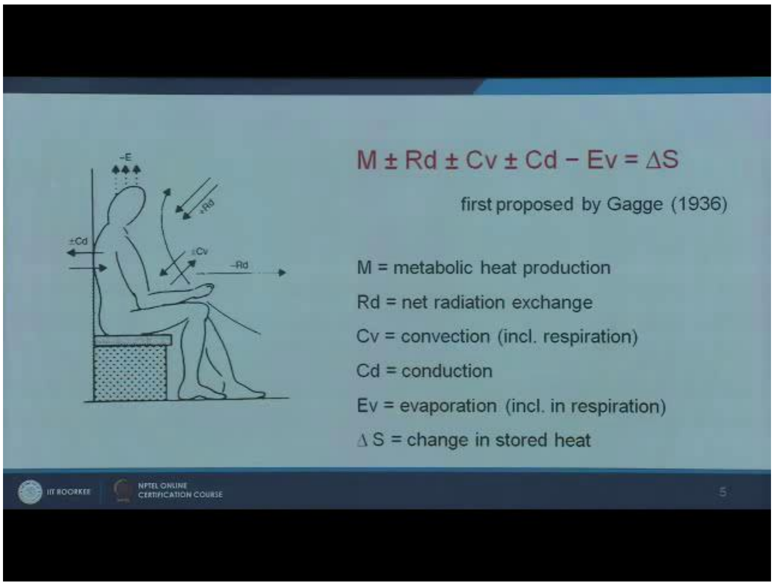

So, beyond that we get into the health related troubles, it can go up to a heat shocker first bite in the other side this is a metabolic heat balance or heat balance equation commonly termed as it is quiet old you know derivation which is there, you know very generally accepted you know broad outline of understanding how heat exchanges happen, here there are different terms first is the metabolic heat production that we talked about in the previous slide the next is net radiation exchange which happens between person and the environment. Then you have convection exchange which includes the respiration. So, whatever you breath you are also loosing heat or gaining heat then, you have the conduction exchange again you can gain heat or loose heat. If you are in touch it can be the floor surface or if you are reclaiming, if you are sitting then there could be some amount of heat exchange then you have evaporation which again includes respiration.

Then if you have this on the left hand side and the right, you will have the change in stored heat if these things are not equating or negating each other those, there will be some reminder which is delta s that is change in the stored heat if these things cancel each other then this will be 0. If you look more closely into this metabolic heat production is always possible you know positive you keep producing heat that is no negative term here. So, it is always heat gain, heat production, net radiation can be positive or negative. You can gain heat through radiation or you can lose heat through radiation convection again plus or minus you can gain heat through convection or you can also loose heat through convection conduction. Similarly is plus or minus minimum amount of conduction happens mainly it is radiation and convection. Wherever you are in touch physically with objects then you will have conductive heat losses or gains then evaporation finally, it is a delta s that is a net stored change in the net stored heat.

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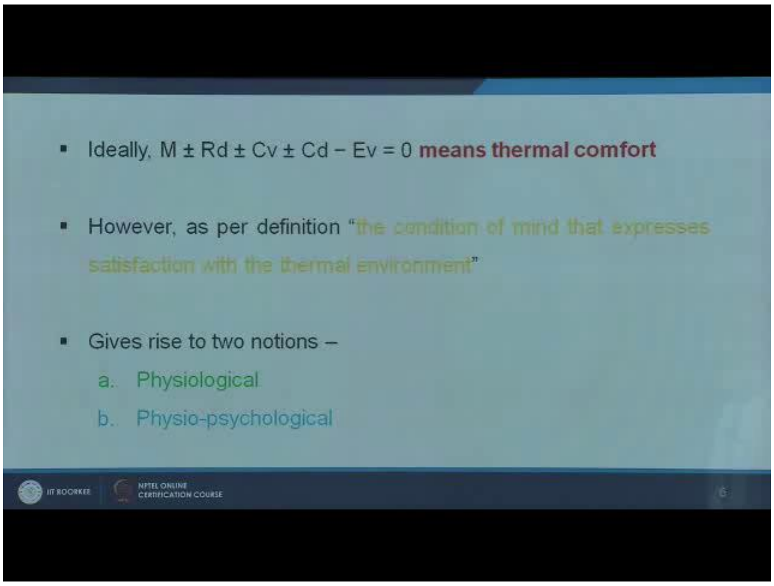

If you take an ideal scenario even all these things negative each other they cancel out you get 0 which means there is thermal comfort ideally, we should not be calling this as thermal comfort, but we must be using a term called Thermal Equilibrium.

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Our body is said to be in a state of thermal equilibrium, with a ambient condition indoor or outdoor conditions, but then what we talk about here is only the cognitive part. Cognitive thermal sensation this is what is primarily refer using this heat balanced equation, if you read the definitions of thermal comfort in any standard it is defined as the condition of mind which expresses satisfaction with the thermal environment here, we are using two terms expression and expression of satisfaction and it is the condition of mind. So, when you talk about the condition of mind and expression of satisfaction to the thermal environment apart from this thermal equilibrium and cognitive thermal sensation we have another term called thermal perception.

So, you have certain cues you are body is sensing it cognitively, it is sensing certain thermal condition and you are responding to it and beyond this response you start perceiving thermal comfort here, we come into two terms or two notions of thermal comfort one is the physiological approach to thermal comfort next is physio-psychological approach to thermal comfort. If you look purely at the heat balanced model thermally equilibrium and cognitive thermal sensation then you can deal with it in terms of physiological approach that is you are talking about the core body temperature skin temperature ambient temperature and how heat exchange happens between these three nodes or if you are talking about the second approach or the second notion you come to terms with the thermal perception.

The same environment you may be feeling may be warm I may be feeling it as comfortable somebody may be feeling it as slightly more warmer, then you feel, so it varies from person to person there is a psychology I may feel the same environment today as warm eventually say after week after two weeks, I may feel it is comfortable. So, when is a thermal comfort apart from physiological you also get physio-psychological, we will look about this physio-psychological approach in the next you know one of the future modules first, we will take close look at what is thermal comfort and physiologically how do you define heat balance and how do you define comfort by itself. What are the parameters that are what we will you know look more closely into what are the factors influencing thermal comfort there are three different sets of factors in fact, which contribute to thermal comfort.

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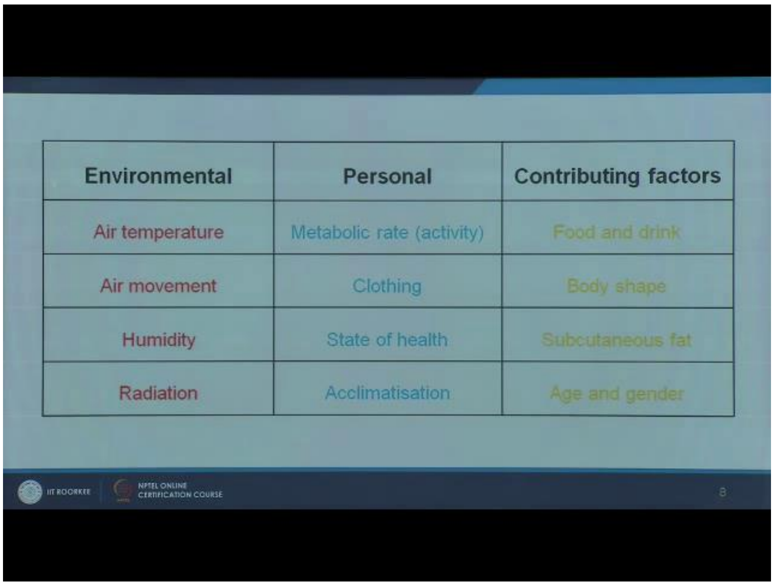

First is the environmental parameter set of environmental parameters basic is air temperature referred as dry bulb temperature technically, air movement includes air velocity and the direction humidity relative give humidity, indirectly it refers to the amount of moisture or moisture content in the air.

Then you have the radiation that is the radiant exchanges or controlled by this. So, four environmental variables it can be outdoor or indoor then, you have four personal variables first is a metabolic rate like we talked about earlier depending an activity you perform your heat generation varies. So, the excess heat which needs to be dissipated considerably varies from one activity to the other activity. So, based on this metabolic rate is a primary you know determinant of the personal variables then, next is the type of clothing you we wear what type of clothing is it a light summer clothing cotton wear or is set like a thermal wear which, you would put in the winter a woolen cloth next is the state of health. We will look at these parameters more closely then the state of health it varies from person to person if you are physically, if you are you know plot seek then your thermal perception differs where as if you are with some element you may perceive the same environment slightly in a different manner.

Then comes acclimatization which means adjusting to thermal conditions set of thermal condition it may be short term adjustment or long term adjustment say; for example, within winter there is a sudden raise in temperature among the winter months suddenly, there is a temperature increase and then it again drops down the winter is really chill. For example, you are dealing with say you know 8 degree, 10 degree temperature average temperature during winter suddenly there is a increase you get 25, 26 degrees and then it drops back. So, the perception of the chillness considerably gets effected, but over a period of time say within a short duration say three to four days or maximum week you will get across system 2.

Similarly, a short spell of rain during summer to bounce back to the regular adjustment you will need 3 to 4 days, you may feel slightly more hotter or warmer, you know cooler then you actually would have then there is a long term acclimatization. Imagine you are moving from a colder climate a city in a colder climate like Srinagar, you are located in Srinagar you are moving for a job to some other hotter location like Jaisalmer for the first year, second year you will eventually get acclimatized or adjusted you are psychology will get adjusted to this place and after to say 1 or 2 years it varies from again person to person a gender lot of variations are there because of that you will eventually get adjusted to particular thermal environment then your complaints of dis comfort will eventually come down.

Other factors which are contributing to it apart from these 2 depends on the food habits the drink you take body shape the fat content we call you know b m I another height weight things which are taken into consideration during thermal comfort assessment age and gender. Of course, as a great contribution now as a part of this particular module and the next module we will primarily look at the environmental variables and 2 personal variables which are primarily contributing to it immediately, we are not discussing this, but in of the later modules where, we talk about thermal adaptation adoptive thermal comfort we will talk about little bit acclimatization age and gender etcetera first about air temperature it determines the convective heat dissipation. How much effective the convective heat losses or gains happen is determined by the air temperature that is one of the primary you know determinant of it next is air movement it accelerates convection it alters skin and clothing surface heat transfer coefficient.

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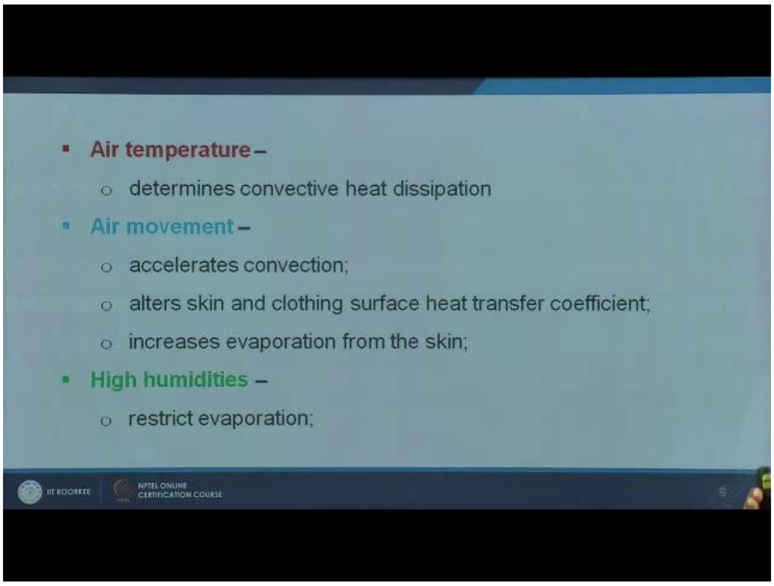

You know if each surface as something called film coefficient or surface heat transfer coefficient it is a total you know integrated factor of convective and radiative exchanges as well. So, we will study more about heat transfer coefficient in one of the other modules it alters the skin and clothing surface heat transfer, coefficient it as an impact of heat transfer through the clothing also it increases the evaporation from skin. So, these are the effects of air movement higher the velocity better the heat losses happened during summer humidity. When the humanity is really high it is sultry the air is getting saturated 90-95 percent humidity or even more it restricts the amount of evaporation that can happen. So, because of which you will start feeling more uncomfortable this is typically where happening which you know takes place in coastal areas or humidity climate specifically.

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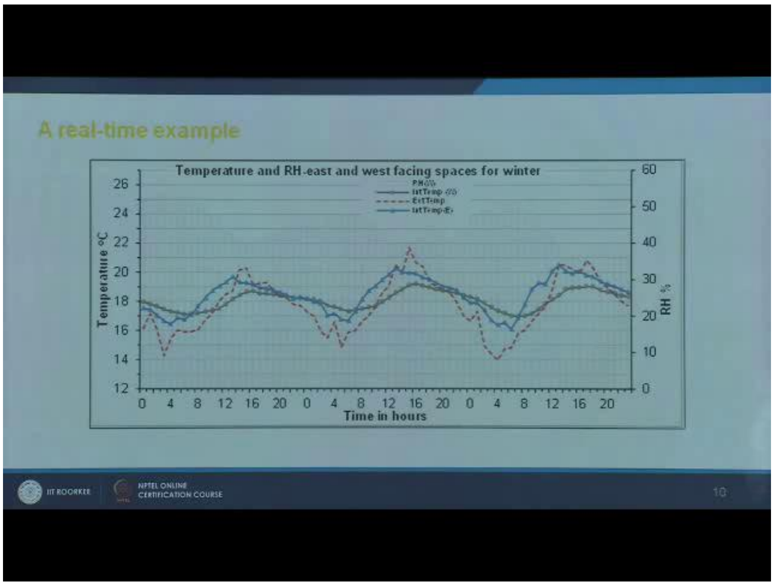

We will we will look at some examples and showing you few measured examples, which we are taking in residential environments climate conditions, may vary. But in this case this is a hot and dry climate typically the measurements were taken in winter I am just trying to present what happens, with the indoor air temperature air you know humidity and air velocity. How these things vary with respect the outdoor conditions just to give you have a perception of what do we you know what are we talking about, what kind of comfort or dis comfort we are dealing with or talking about here in this axis you will find the hour this is 3 day recording 0, this is a second this is the first day 24 hours then second day start this is the 30 day outdoor temperature variation is a cyclic phenomena the red dotted line indicates the ambient temperature. Then this is there are 2 rooms here; one is the east exposed room that is the blue color line and the grey one is a west exposed room.

So, there are two lines which closely follow the ambient condition the cycle of variation in the maxima, minima as well as the time of occurrence whose there is a delay there is a slight amount of damping slide damping. Which is available, but apart from this the trend is similar because this is a naturally ventilated residential space two, you know residences have been presented here and the thing grey bars which you see in the background we have to refer to the right hand axis that is the r h this y axis is temperature. That is what I was talking about the right hand y axis here it is a relative humidity in percentage. So, this also varies somewhere between 50-55 percent and minimum you can get around 35 to 40 percentage this is a hot and dry region of peak winter, it is not peak winter it is just half peak winter more or less is a moderate variations were observed this is typically what you will see when you are looking at naturally ventilated residential conditions.

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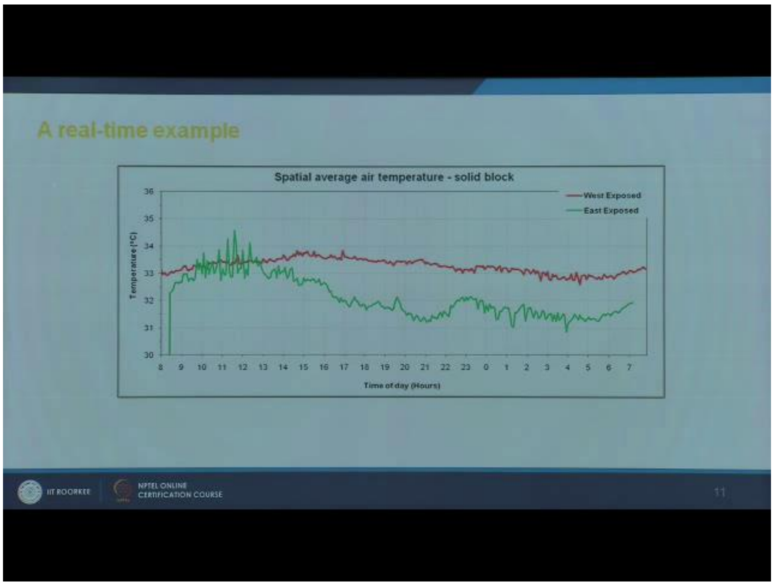

Indoor air temperature considerably varies as I said with respect to east and west exposed faces here. This is another example which we look in a hot and humid climate where the green is an east-east exposed space red is a west exposed space it may vary again you know it is one such example, it may vary from case to case there are other factors. So, this is a effect of orientation same material everything is same just the space type everything is more or less the same.

But by virtual of orientation there is a slight difference in the temperature you get about one and half to two degrees temperature difference because of orientation in a nicely cross ventilated space where, two opposite you know facades have walls have windows which is well ventilated you may be able to expect somewhere, around 0.2 to 0.3 or sometimes when, it is really well ventilated you will get around 0.6, 0.7 meter per second air velocity through natural ventilation again it is not a consistent air flow, that you can expect. So, it may vary with time this is a sea shore, so coastal area. So, you get you know sometimes there is a good breeze again it drops down then again it increases apart from the window modulations are door balcony door modulations that, you do typically you can expect somewhere around 0.5 to 0.8 meter per second air velocity in a cross ventilated space.

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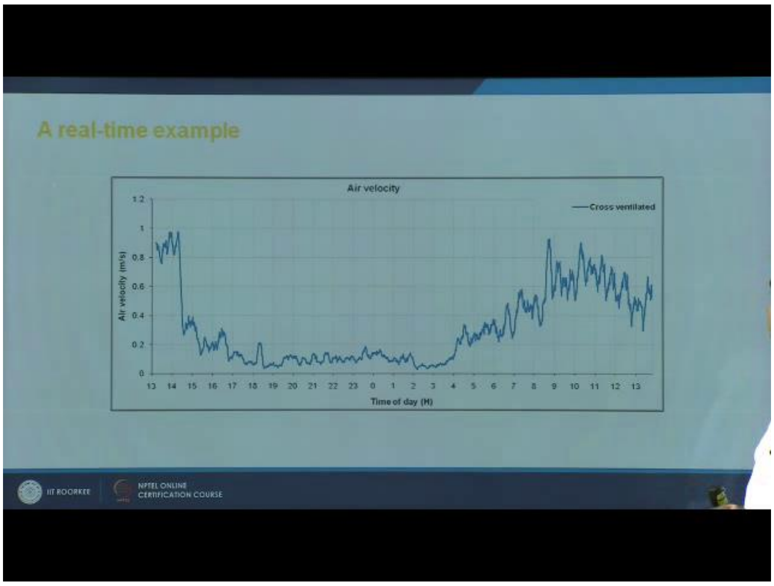

We talked about temperature humidity and air velocity the next important parameter which contributes us the radiation exchange.

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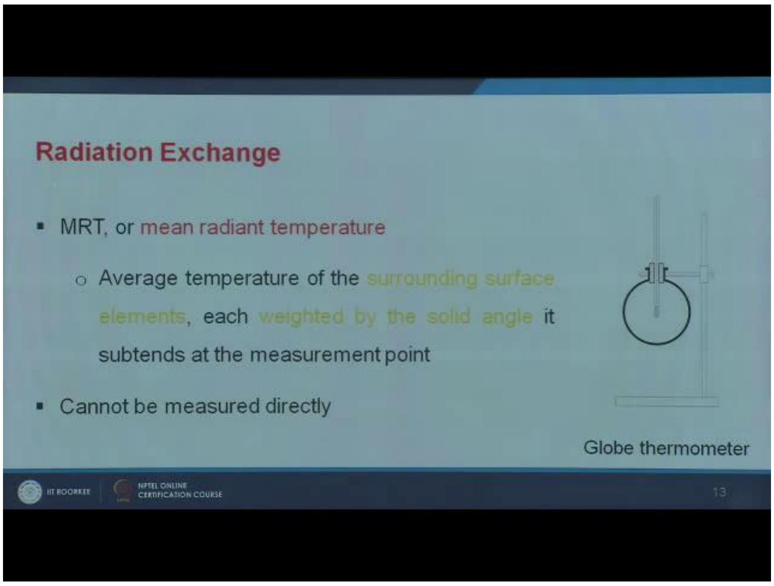

This is a very crucial factor and determining how comfortable or uncomfortable, you are in a given space we commonly refer the term called MRT or mean radiant temperature which is one of the most commonly used indicator for the radiant environment or radiant thermal environment radiation exchanges can be said using this is nothing but, average temperature of surrounding surface elements weighted by the solid angle and the area it subtends. So, it is like how much areas you know exposed to me or as a person if I am put in the center of the room how many surfaces are there and that what temperature they are and what angle they subtend.

So, this is primarily determining the radiant exchange between these surfaces and myself where I am sitting in a particular room as I move away from a surface or as I move close to the surface. You know tilt angle varies, but then the radiant temperature is considerably going to vary continuing we must understand MRT as a parameter it is not directly measurable mostly you actually determined it or derive it using another term called glow temperature. We measure it using glow thermometer we studies this in school as well the you know convectional way of measuring is keeping a thermometer mercury thermometer inside a copper glow, it is a mat black mat black painted it is like a perfect black body it is like a heat sink it absorbs all the radiation from various surfaces you put those thermometer inside the copper glow. There is a air temperature first this is measuring air temperature apart from this, it is also sensing the increase in temperature due to radiation exchanges.

So, the mercury gets heated up you gets slightly increased temperature, if it is a warm environment and the other hand if you put the same glow in a really cold chamber there is going to be heat loss this is going to lose heat this particular black surface will start losing heat and you will find a slide drop in the globe temperature by using globe temperature you will be able to determine mean radiant temperature, we will look at it how.

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A simple set up that we typically use for our measurements you have a data logger here this is a globe thermometer I was talking to about instead of a plain thermometer it as a sensor temperature senor inside this, but the principle of working remains the same the white one thin white one here is the temperature in humidity probe this one is the hot wire minimum meter for indoor measurements typically, if your air velocities are less than 0.5 meter per second vane anemometer which is commonly used in laboratories vane anemometer is may not be much useful because their sensitivities might not be that low.

Because you know they do well for velocities around 1, 1.5 meter per second or sometimes as low as 0.3 or 0.5 meter per second, but indoor air velocities when you are trying to measure something like 0.1, 0.15 hot wire anemometers are more sensitive they will be able to give you as low as low 0.05 meter per second air velocity again it depends on the instrument sensitivity there are few other probes. This particular one captures the radiation from this side and this side it determines, what is the radiant difference between these two radiant asymmetry we call we will look at this shortly.

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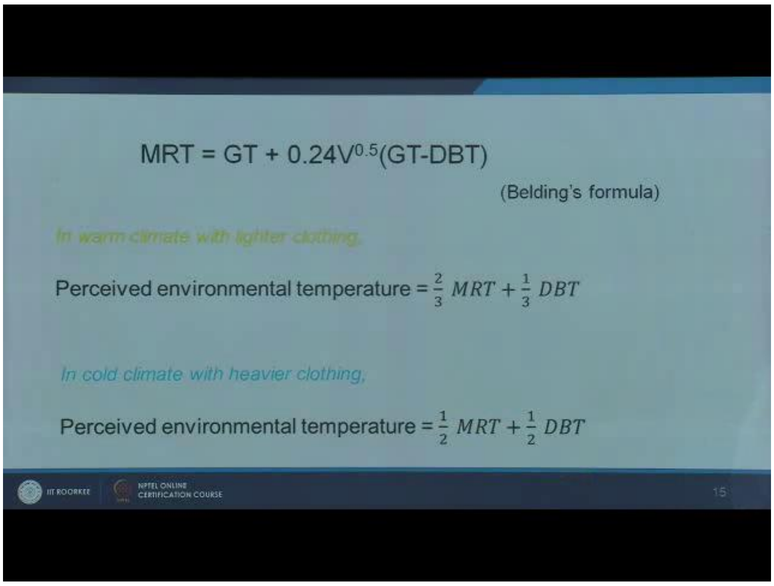

Now, our measured globe temperature using that this is simply equation, if you know formula which has been in used for quiet some years with globe temperature you add the air velocity components this is square root of air velocity and the difference between the globe temperature and dry bulb temperature. So, effectively as I said when, the surfaces around you are cold then the ambient temperature the globe temperature or MRT is going to come down then the average air temperature. Where as if the surfaces are hot then your mean radiant temperature would probably be higher than your air temperature classic example of this imagine, you are traveling in a car you are in the front seat you have the windshield you are driving towards west in the evening.

You have sun in front of you sun is heating up the glass you get radiant heat from the windshield side, where as you are trying to cool your car down through your air conditioner which is actually throwing cold air on you. So, you have a convective heat glass and the radiant heat gain this will never tally with each other even if you put your a c in full blast if the sun is really, harsh then you are still going to field the heat of it unless you have a very well conditioned system. Where you know you have throw from three to four directions then you are kind of getting neutral with it otherwise the radiant heat exchange heat gain will be more prominent and you will be still feeling uncomfortable.

Typically in warm me another thing to note it varies with respective air velocity as the where velocity increases or decreases MRT is going to go upward down regardingly in warm climate. When your with lighter clothing the contribution of mean radiant temperature say if, you are perceiving some temperature you are not going to actually perceive the air temperature, but in a warm climate when you have with light cotton wear then what you actually perceive is only one-third of dry bulb temperature and two-third of mean radiant temperature imagine. You are and then dry bulb temperature is 30 degrees, but your mean radiant temperature is 40 degrees then, you will still be uncomfortable because even 80 degrees as such 30 is, but when the radiant temperature is increasing two-third of contribution is made by this. So, you are going to feel uncomfortable.

Similarly, in cold climate when you are with heavier clothing say woolen wear the perceived environmental temperature is half of mean radiant temperature and half of dry bulb temperature this is also partly due to the amount of surface. Body surface which is expose to ambient here what happens, with lighter clothing much of the body is exposed to the ambient surfaces around you. So, there is more probability of heat gains from these surfaces. So, MRT takes the front seat whereas here you have more or less covered yourself as well as the surface properties are different you are in heavier clothing as well as this is a colder season then it is half contribution.

But still you will have half of the contribution made by mean radiant temperature, if the surface is really cold you will still be feeling uncomfortable.

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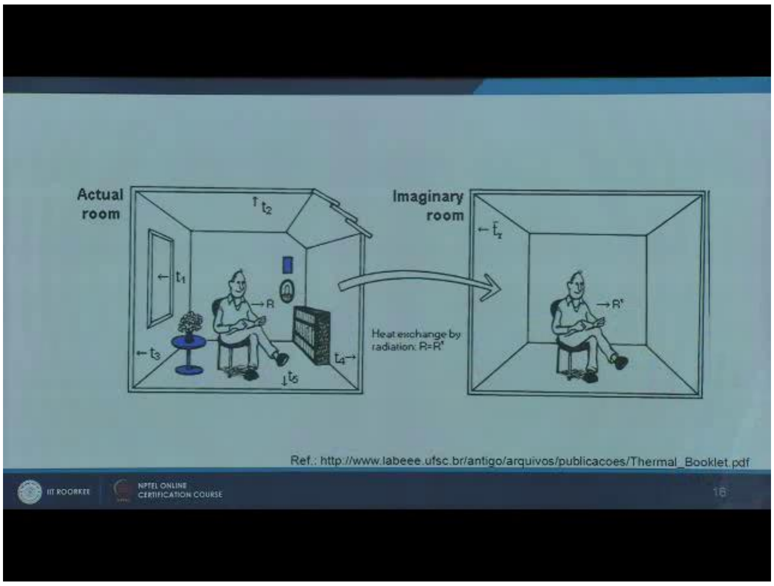

We have been always talking about an ideal imaginary room place yourself in the center you have 6 surfaces. You know exchanging heat with your body it either contributes to heat gain or heat losses through radiation, but ideally you know in an actual condition what happens, there are many number of surfaces you have tilted different angles different you know amount of surfaces say, even a book shelf you have the solid wooden or metals surface then you have books you have you know window, frame glass lot of other things are there everything is getting involved in the total heat exchange.

So, effectively determining mean radiant temperature in actual case is really a challenging activity and giving you similar examples of few mean radiant temperature measurements this is from our unexposed roof condition this is a top most floor in an apartment.

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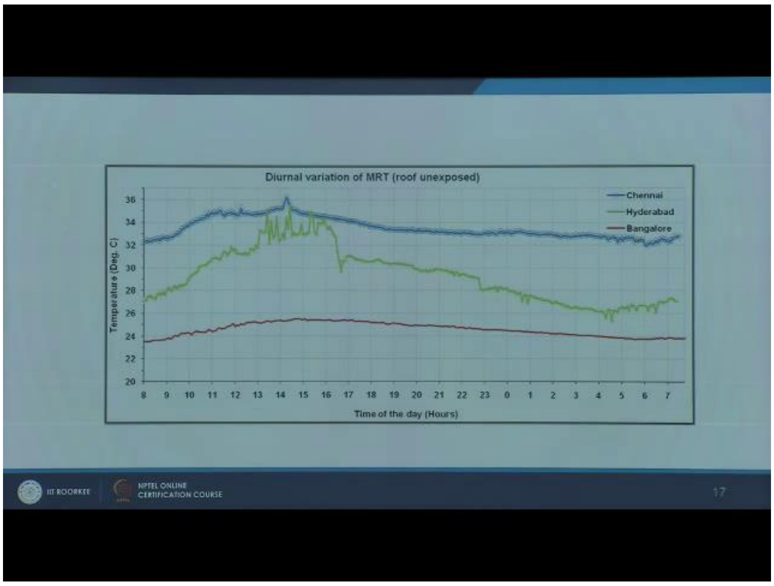

Three cities we measured more or less the indoor conditions that is the spatial typologies were similar then, you know floor area plus the orientation where more or less kept similar three different cities just to given an example of how mean radiant temperature varies this is the case of Bangalore, Hyderabad the peak comes close to this is the Chennai line to this comes close to this it may vary from case to case. Of course, orientation lot of other parameters are there, but typically variation and this is how it relates to the indoor air temperature it more or less revolves around indoor air temperature.

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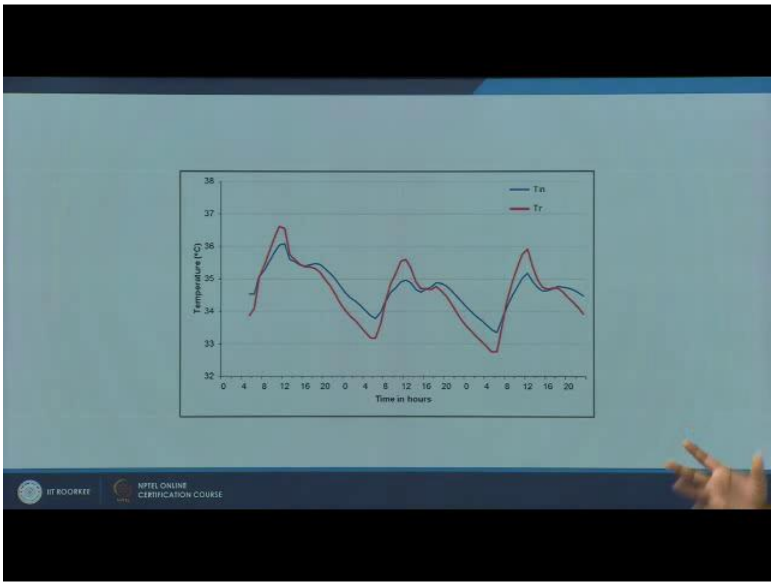

You will also observe similar pattern of variation, but in other conditions other climate it might slightly go up above then you know air temperature during the peak time when there is a good radiant exchange.

Say if you are in a room with large glazed window surfaces or balcony doors then, your m r p is going to really shoot up, but then it will also drop eventually in the night, it will get really cold then, you know it more or less follows the pattern, but the magnitude of difference might depend on various aspects like including orientation depending on the glazing glass surface area radiant property of surfaces the magnitude of variation might differ from one another similarly the variation in globe temperature or mean radiant temperature you have a good amount of variation in terms of roof exposed versus roof unexposed condition. Lot of us have you know an apprehension that the top most floor in a flat as more amount of thermal dis comfort you would generate down preferred buying a flat just on the top most floor for one reason that you get a lot of heat.

We know that we get a lot of heat, but it is not just the heat gain through the surface, but it is also raises the mean radiant temperature probably, if you are putting air temperature sensor in two flats; one in the top most floor and somewhere, in the lower floor air temperature is more or less going to be similar may be half a degree difference. You may be able to find, but moment you put a globe thermometer you start measuring globe temperature and calculate MRT with it you are going to find a considerable amount of difference 2 to 3 degrees easily you can find even with a properly treated roof.

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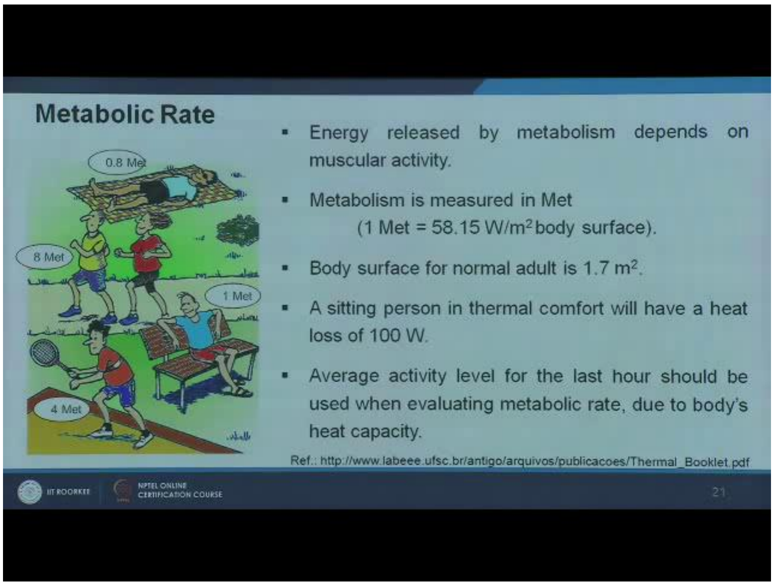

Let us talk about personal factors first is a metabolic rate, we talked about watt or watts per meter square of body surface this is typically a scientific measure, but as for thermal calculation we are trying to simplify it we are trying to use a term called Met. Met 1, Met is equal to 58.15 or 58, 0.2 watts per meter square of heat dimension.

Now, this is like equivalent to body surface of a normal adult is around 1.7 meter per square. If you take a sitting person doing sedentary activities say you are in office or you are in a classroom you are listening to something or doing typical office work computer based work you will have a heat loss of around 100 watts. So, effectively the met value will be around 1.51, 0.6 again it will increase say, if you are sleeping it would be 0.8 Met if you are sitting little be close to 1 Met playing jogging each one as a different metabolic activities. So, the average activity level varies for each of these activity just the quick him. If you are really training to estimate the thermal comfort of a person it is not the momentary activity that you have to be taking care of, for example, if you have to ask this guy who is sitting here how comfortable you are feeling or how uncomfortable you are feeling he might be missing a critical link he might have just completed a jog and he might have been sitting here.

So, the perception is different for this guy versus this guy. So, ideally what we general you know what we do for our comfort surveys or comfort assessment is we take into account what this guy or this lady did for the last one hour. What kind of activity they were performing and what is the amount of heat dimension. What is a Met value during the last 1 hour is always accounted in thermal comfort calculation? The next factor is the clothing insulation what kind of clothing you wear and what is the thermal resistance the clothing offers.

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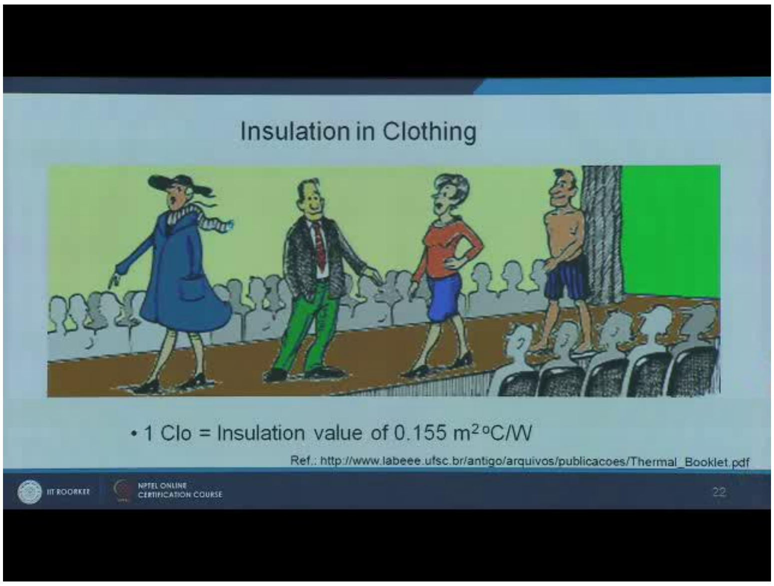

So, actually the clothing is one kind of capsule that protects you from the outdoor environment this is this is one line of protection the thicker are the more isolative your clothing is the lesser the heat exchanges that would happen. This is typically what happens during winter you have a thermal wear you have a woolen which prevents heat exchange from rather heat loss from the body to the ambient.

Similarly, during summer you have a thin cotton wear, which you know enhances the convective heat flow to happen between the ambient and the body. So, the clothing insulation typically it is a resistance value meter square degrees centigrade per watt, but here again to simply this we will refer to it as a term called Clo. clo 1, clo is equal to 0.155 meter square degree centigrade per watt. Typically, we can refer it as 1 Clo it depends from clothing type to clothing type. For example, this would be around 0.3 or 0.4 whereas a typically office where could around 1.5 Clo value it depends form the type of insulation the material used there is lot of research happening around and different type of ethnic wears and what is there clothing insulation which we did not have our repository.

The last few years there has been lot of interest where people are trying to find out different type of clothing and what is there actual insulation? This as a good amount of role being played in terms of the perceived thermal comfort, so we will start this module here, we looked at basics of thermal comfort and we looked at environmental and personal factors influencing thermal comfort. We talked about four environmental parameters air temperature, humidity, air velocity and radiation and two personal factors metabolic activity and clothing insulation and how they influence thermal comfort.

Thank you.