Principles and Applications of Building Science

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Lecture – 05
Thermal Adaptation

In the previous module, we talked about thermal comfort and the physiological processes behind this thermal comfort. This module talks about thermal adaptation in the context of thermal adaptation, and what is the idea behind this adaptive comfort model and the studies. Primarily this would talk about the physiological dimension of psychological as well as physiological. It is physiological dimension of thermal comfort.

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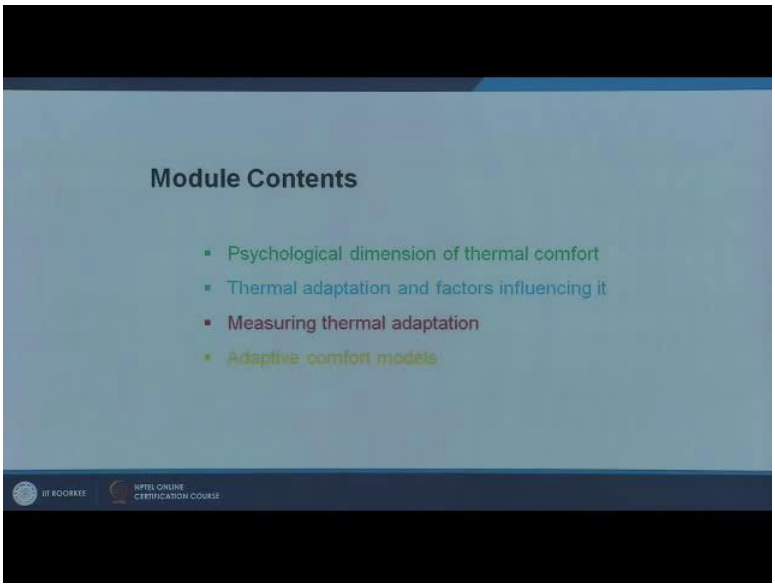

Then we will talk about thermal adaptation and what the factors behind thermal adaptation. We will talk about how do we assess or measure thermal adaptation lot of field studies are being conducted. So, we will take a look at how to go about these field studies, and then we will take a look at a few adaptive comfort models which may be relevant to design of buildings.

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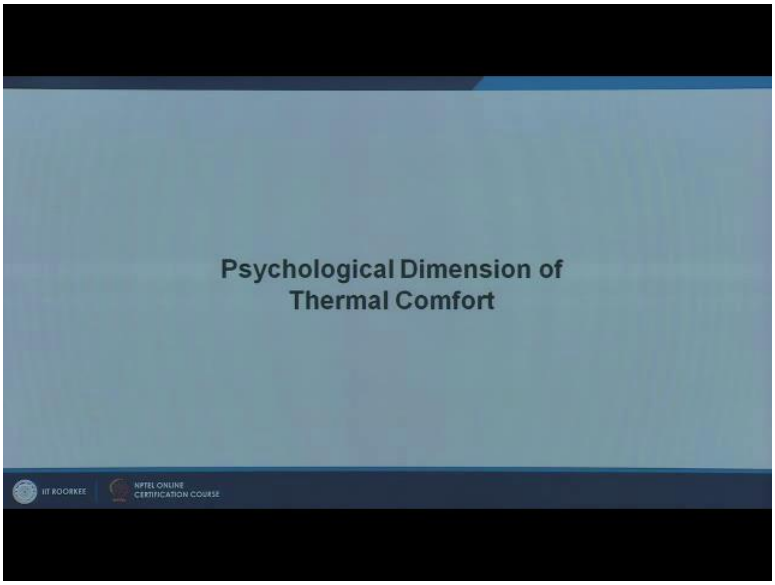

The psychological dimension of thermal comfort in the last module, we looked at comfort as a perception or an expression of satisfaction to the thermal environment around a person. But today in this session we would look at comfort as a negotiable socio cultural construct.

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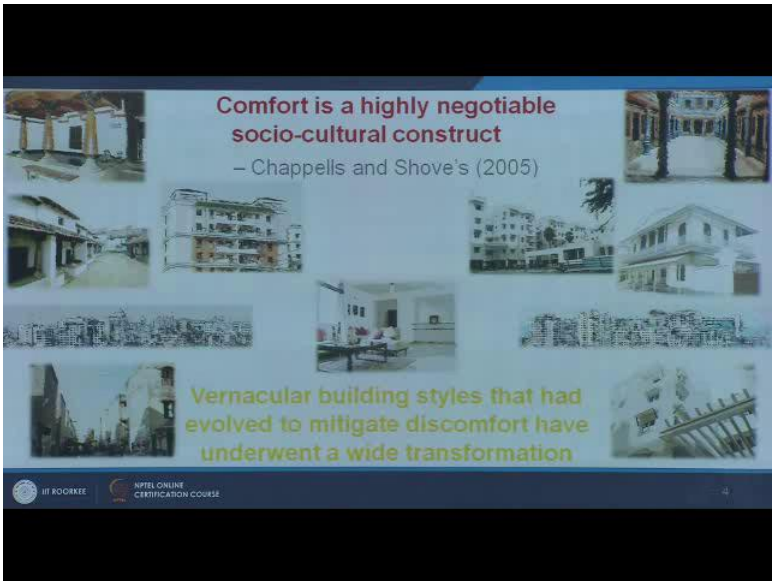

What happens? Comfort is not just physiological it is not a thermal regulation, but how we perceive and react to the thermal environment. We are under constant interaction with the environment, we will look at it in more detail, but with this practice comfort becomes a negotiable socio cultural phenomenon, which society we belong to what culture we grow up in this determines what our expectation to a particular thermal environment. What do we need what do we want and how do we perceive a given thermal environment. If we look at the building design vernacular building styles were more responsive, they were meant to be a limit responsive, but due to space constraints demand for spaces, the type of construction as underwent wide transformation. That is why you know we are re looking at how comfort can be assessed and how to design buildings for comfort itself.

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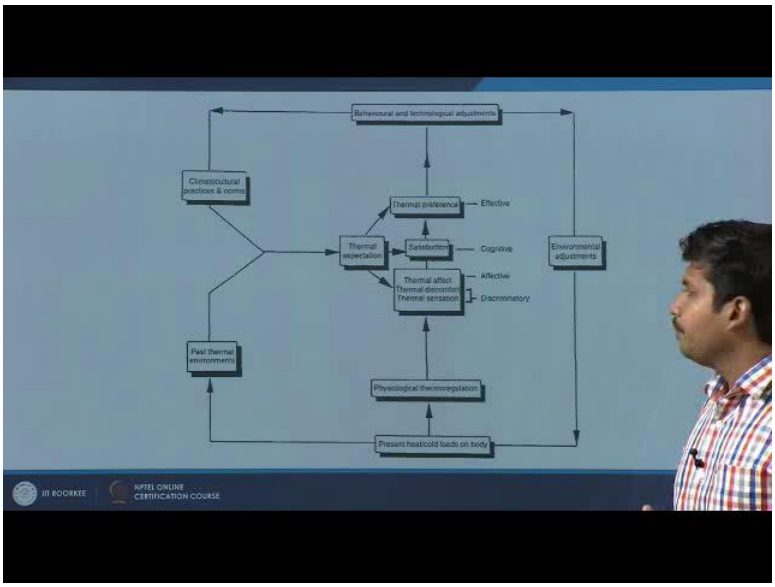

In the last modules what we saw is a person's body physiologically regulates itself to the thermal environment. Say for example, let us start in this chart let us start from this point present heat cold loads of on a body what happens there is a physiological thermo regulation process which the body, undergoes because of this we start perceiving or experiencing a particular environment. Here there are 3 different things first is the thermal effect, how do the environment affects you then we start talking about comfort discomfort and then we start sensing the thermal environment, this is the first part of it.

Now, what do we do? What else connects to thermal comfort? There is a huge setup parameter which is connecting to thermal comfort; the first thing is the past thermal environment says for example, you are moving from a place like Srinagar to work in Delhi. During summer you cannot stand it for the first year, for the second year and eventually third fourth year you get used to it. So, it is a long term thermal experience which is needed to get adjusted to a place similarly you move from a hotter zone to a colder area. You need a, you know quite a longer duration to adapt this is long term, but then suddenly it rains in summer. The first day you are happy the second day it is raining, but the third day it starts getting sunny again it is a short term thermal disturbance. So, your body gets acclimatized to the heat, suddenly it rains. So, there is a thermal readjustment and then when you get sun again you cannot tolerate it for the first day, the second day, but in 2 to 3 days time, you get used to it again this is a short term adjustment. So, this is the short and long term past thermal environment.

Then comes the Clemocultural practices and norms there are certain cultural practices it starts from the dressing code it starts from our food habit's, you know people living especially in composite climatic regions have a specific way of food habit's during summer, during winter, during monsoon, times this is quite well you know adapted food practices. Clemocultural practices and norms then you have environmental adjustments which a person does it can be active or passive leads to behavioral or technological adjustments. So, these things totally come, back first you had the thermal effect thermal affect comfort discomfort and sensation.

Now, we get another component called thermal expectation these thermal history, as well as your clemocultural practices and norms, together lead to something called thermal expectation. I am expecting something in this summer in this particular city. So, this leads to an expectation which has a lateral impact on the perceived comfort discomfort as well as the thermal sensation. This together leads to something the term called satisfaction. I may be comfortable, but I may not be satisfied there is a small difference between having a sense of comfort, having perception of comfort and expressing a thermal satisfaction. We will look at it little more in detail for better clarity.

Then this also affects the thermal preference say for example, like the earlier example I

said I am moving from Srinagar all the way to Delhi to work, my thermal preference because of these practices is something, but what I sense and I what I experience as comfort is different, because of this my satisfaction of the thermal environment is varying. Because of these things I go for behavioral or technological adjustments. Behavioral can be in terms of changing a dress, changing your activity pattern, doing or not doing certain activities, changing food habit's.

If these things do not permit or you are not willing to do these things you go in for technological adjustments, simple thing you buy an air conditioner, you condition your room, 1, 2 numbers of unit's technological adjustment happens which again comes back and affects your environmental adjustments. So, from a naturally ventilated or a free running environment you are moving towards a technologically controlled, mechanical controlled, and environment. This again determines your heat or cold loads on the body. So, this total thing becomes a loop.

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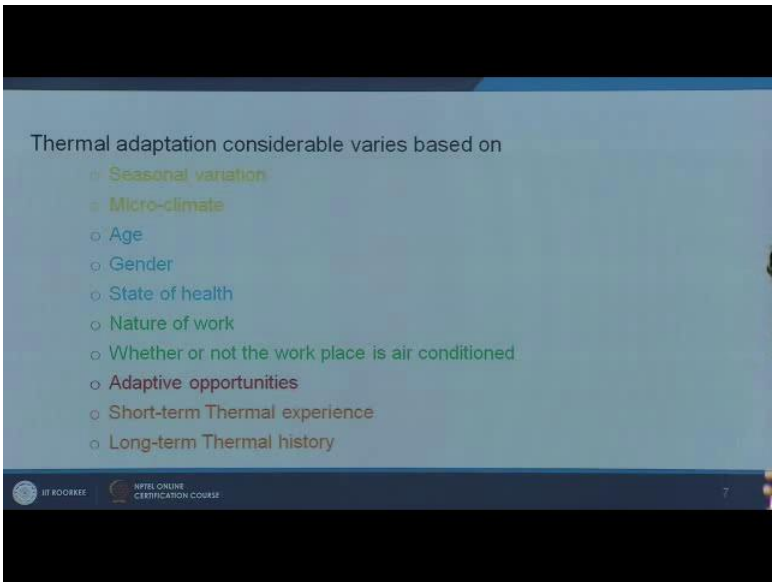

What is the factors primarily influencing this? I have indicated specific clusters with color codes. For example, the first thing is seasonal variation from summer to winter to monsoon to spring to autumn, there is a considerably variation between the seasons which significantly effects thermal adaptation. Number 2 is a micro climate moving from

suburban area or a rural area to the city, you have a significantly distinct micro climate I am going to show you some specific evidence or documentation which we made in this regard, these are environmental variables.

Then the next set is personal variables where age gender and state of health. For example, during field studies we found a considerable difference is adaptation, thermal adaptation with respect to age as well as gender. For examples older peoples did not complain about heat discomfort during summer, but they had more comforts you know more complaints about cold discomfort during winter.

Similarly, when we talk about age another critical example, which came up was the younger you know set of people less than 20 for example, had a preference for lower temperature, compared to people who were say above 50 years of age, mid age and old age people.

State of health has a clear impact, we will talk about this little bit know in a little by then the nature of work you do both the metabolic activity, which determines the net values which we talked about it depends on how much you know metabolic activity or heat production your body is undergoing. On the other side, it also depends on what kind of position and place you are stuck to. For example, if you are a I t professional, you are a student sitting in a classroom, you are bound to a seat, you do not keep moving around, you do not have a flexibility to switch on switch off your air conditioner or your fan, it is not your personalized control. Whereas, you have a single cabin you are sitting in this cabin then you have more flexibility, over the light fan opening or closing the windows set temperature lot of controls are available. So, the nature of work you do whether the work place is air conditioned or naturally ventilated has a lot of impact on thermal adaptation.

Apart from this you have the availability of thermo you know adaptive opportunities, Whether I have a access to controlling the fan speed, whether I have access to controlling the air conditioning set point temperature, whether I have open able widows which will facilitate better ventilation. So, presence or absence of adaptive opportunities this is where the role of designers comes into picture. For example, you design a building to

have an office space whether you are taking care of providing an adaptive opportunity. So, that this person sitting in this cabin is going to use that opportunity some time or the other to make himself comfortable for a few more hours. Rather than opting to switch on an air conditioning system.

Then we talked about these two phenomena, these are like more psychological short term thermal experience like you know, a sudden change of weather during a particular season; say you know a typical sunny days in rainy season, monsoon season or a few rainy days in the summer season changes your thermal experience, your body gets you know needs a few more days to acclimatize back to the summer condition after the rain.

Long term thermal history, it depends on where you grow up what you know about the particular season, your summers may not be as harsh as you know where you grow up would not be as probably may not as harsh as what you experience in the place where you work or where you study. So, there is a lot of difference or it takes a lot of time for you at least a few years to get to this acclimatization. So, this is short term and long term, this is not an exhaustive list, but these are some major parameters which influence the thermal adaptation processes.

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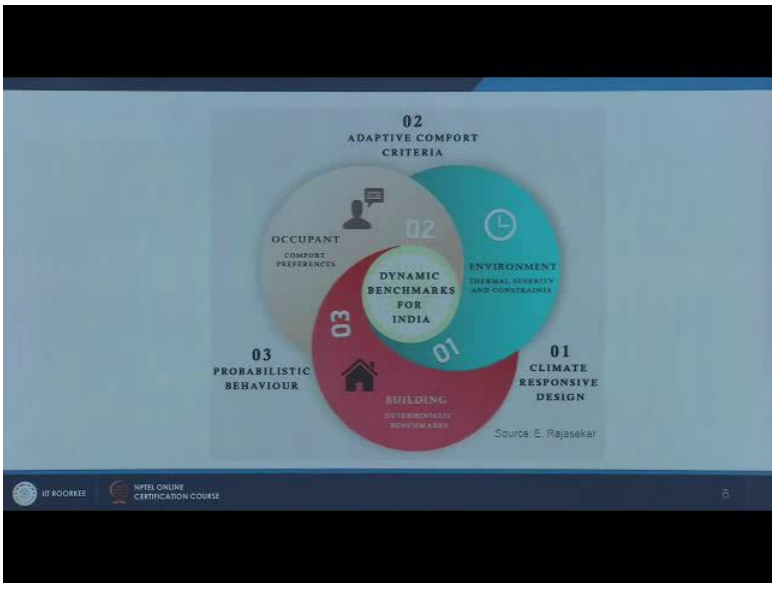

In short I would like to present this as you know graphic for your understanding and info graphic for your understanding. This is more or less covering the themes of what we have been discussing, so far and few other modules that we will discuss after this as well.

Let us start this from here there are 3 main components the first is the environment say outdoor environment. This is a major component; the thermal severity of this particular environment affects comfort. Influences comfort, then you have occupants people who are perceiving comfort or perceiving the environment, so about the people by them self like we discuss the age, gender, body mass index lot of things and their own their physic effects the perception of comfort.

Then number 3 comes the building, how we design a building actually this is where we are going to we started the module somewhere from environment, now we are moving towards comfort and occupant, next we will be talking more about building then we will go to you know comfort and energy efficiency in building this is where we are moving along.

First is a environment how the environment itself is severe we talked about climate, now we are talking about occupant the physiological as well as physio-psychological part of occupant comfort. The next would come the building how building impacts the comfort, but now, what we need to understand these 3 entities are not acting by themselves independently; they are partly independent partly they are dependent on each other. Environment is an independent variable, but then occupant interacts with environment this particular interaction how he perceives the environment we talk about thermal comfort thermal perception then we talk about thermal history, thermal adaptation. So, his experience of the environment determines adaptive thermal comfortable. So, how the environment by itself is how his body reacts, what is his thermo regulatory phenomena plus how in long term or short term he adapts to the thermal environment? So this interaction builds us the adaptive comfort criteria.

Next part is how building interacts with environment, we will look at this interaction more in detail, but to look at it short we talk about climate responsive design we did look at some vernacular principles which were being adapted to be more climates responsive.

So, there is a thermal severity in the environment for most of the climates then, we design our buildings and this building starts reacting with the environment this is more or less a deterministic way of reaction or eventually you know it is a cyclic phenomenon

It keeps happening and like this interaction which is more you know probable and eventually it is a matured phenomena where it keeps changing season to season, it is not like a long term prediction I cannot say what I would be experiencing next summer compared to this summer. So if I have a data of say a person x has experienced the past 5 or 6 summers, and this being his thermal experience was this I may not be able to say hundred percent surely that the next summer with this given temperature he is going to stay comfortable or uncomfortable.

Whereas, the building versus environment response is more or less cyclic then comes how occupant interacts with the building. The interaction has two dimension one is more design oriented how we use the space what we do move around this comes more into the design side, but what we are talking about more relevant to what we are talking about is how we use the adaptive features provided in the building. As a designer it bothers you in order to give proper adaptive mechanisms in the building. Building proper adaptive mechanism, which will facilitate the occupant to improve this level of comfort rather than opting for mechanical systems, this is more of a probabilistic behavior I can open the building probably I can open the window, probably I may open the window to what percentage people are willing to use it. So, this is more of a probabilistic you know interaction occupant using the building rather more focused using it is adaptive features then the comfort perceptions considerably changes.

So, these 3 things together how harsh is the environment say typically take a suburb the building is behaving in some manner in summer then the people are using the building in some way they are closing the windows in the daytime opening it in the night time for proper night ventilation. So, this totally determines overall indoor thermal perception, this whole phenomena can be combined together and say what is the overall adaptive thermal comfort available for the person. We saw this particular no comfort boundary in the last class.

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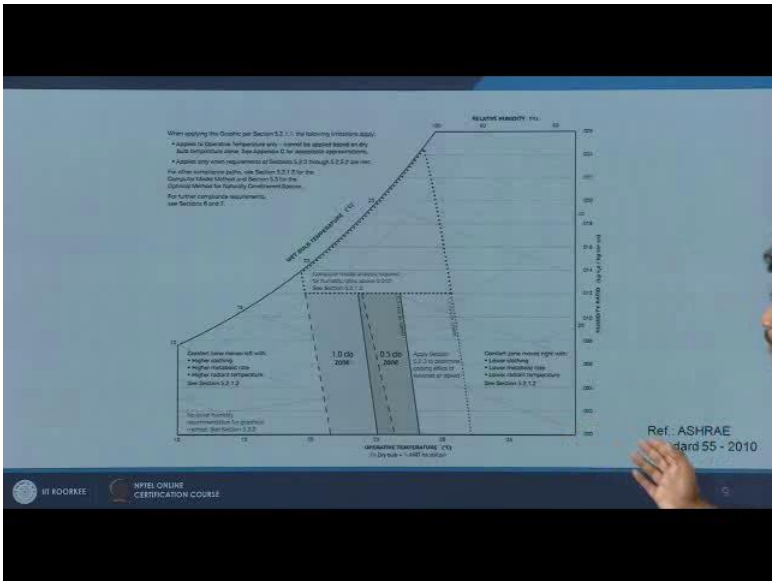

On a psychrometric chart this ASHRAE model they are superimposed the comfort zone for summer and winter where this set this particular boundary the you know area lying within this boundary the temperature humidity combinations would provide comfort for a set of people, and we also saw moving towards the right or left how it affects being comfortable or uncomfortable.

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But to simplify this the adaptive model gets you a comfort boundary something like this, what you have in x axis is the mean outdoor air temperature, this could be daily mean or this could be monthly mean here we have indoor operative temperature and simply this particular band is said to be a comfort zone. I give you the history of how this particular thing itself is developed, but before getting there you will see 4 lines here, the first two the inner set this makes the shaded portion this is 90 percent acceptability limits.

So, when the prevailing mean temperature is like this, this particular operative temperature set is set to be acceptable for 90 percent acceptability limit then, the next broader one is 80 percent acceptable. Acceptable by 80 percent of people, Another interesting thing that you need to notice here, the comfort boundary is not a straight line like you see in your conventional model we always say you know 24 and half degree plus or minus 1 and half, 2 degrees is comfortable, but this particular model says that the indoor operative temperature or the comfort temperature rather the comfort band increases proportionally with respect to the prevailing outdoor air temperature. For example, what is comfortable to you at 10 degree ambient temperature is not comfortable to you at 30 degrees ambient temperature. When the prevailing mean temperature for example, the daily mean temperature is 20 degrees then, 10 degrees then your probable indoor operative temperature comfort could be between 20 and 22 somewhere in this area.

But then when the prevailing outdoor mean temperature gets higher, for example you are going towards summer somewhere between 30, 32 degrees then this particular limit the same you know 20 to 22 degrees, you will perceive us being cool or cold. Whereas, you would prefer being in a temperature of something like 28 degrees, where you would express comfort. Similarly in winters the same 28 degree you will express it as being warm probably not hot, but you would probably say that this is a warm condition rather than saying that it is comfortable.

This particular graph has been developed as a part of, what you know what it is referred as research project 80, 84 this is one of the you know common or standard reference there is a interesting report available an exhaustive report. This particular report sequentially analyzed different components of thermal comfort, it took into consideration

numerous field studies which were conducted, we will talk more about the procedures for field studies, but lot of field studies which are you know where people ask about thermal perception with different group of people performing the actual activities rather than a control laboratory setting this is where there is a starking difference between the adaptive model and the standard thermal comfort model.

As we said for example, the Fangers comfort model or the tropical summer index model the Indian model, these particular models were developed in controlled laboratory setting like you get some hundred people to the lab, you control the environment indoor environment you modify the temperature, radiation, humidity, air velocity and for each of these modification you make them respond as to how they feel. But one major difference which happens from this comfort to what we actually experience is, in field we are not bound to this you know third party controlled temperature or any environmental settings, we are free to adapt to certain extent of course, to certain extent we all are also bound to do certain things say if I am working in a office I am bound to follow dress code, I am bound to do or not do certain things, but still I have certain amount of flexibility to adapt myself to a thermal environment. So, in this case people found there is a lot of difference between the laboratories controlled results of comfort versus the field results of comfort thermal comfort.

So, taking that into account as a thermal theme thing, particular report looked at different field studies and evidence from field where there was a difference between the lab controlled comfort you know perceptions, versus what actually people experience in the field putting all these data together this database is also available online for you, if somebody wants to explore this is from different countries. You know prominently from South-East Asian countries. If you are interested to take a re look at the data derive something out of it, you can feel free you can search for RP 80 84; lot of data the whole setup data is sequentially stored and it is freely available for assessment. Taking those data this particular analysis was made and this is a fit which was brought in and people found that 90 percent acceptable limit lies somewhere here, we will look at few more you know examples specific field studies and how these things are developed in the following things.

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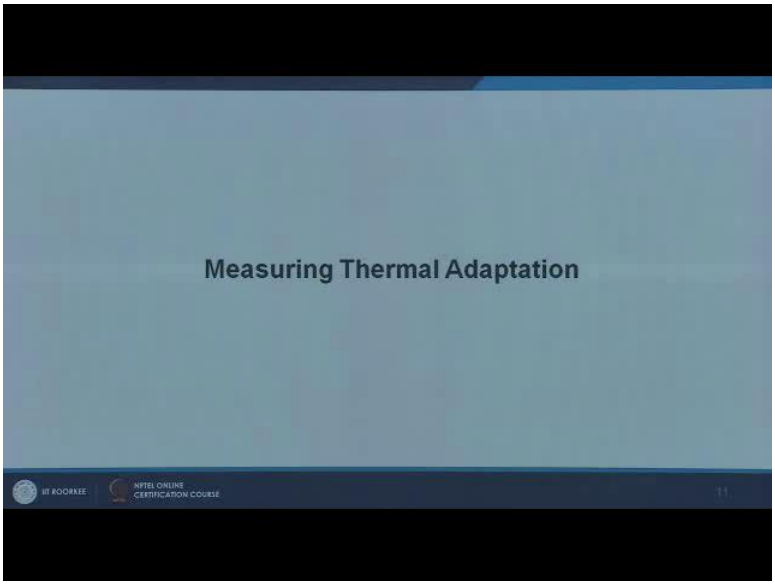

How do you measure thermal adaptation, if we say measuring comfort there are lot of you know indices we also looked at few of them like Fanger PMV or for example, the effective temperature of TSI you basically assess the thermo regulatory phenomena we saw the low pierces 2 node model, where you know you study the thermo regulation phenomena of the body itself, but when you say thermal adaptation, you are talking about set of dynamic people or people doing dynamic mechanisms to keep themselves comfortable people are under you know movement they are not idle.

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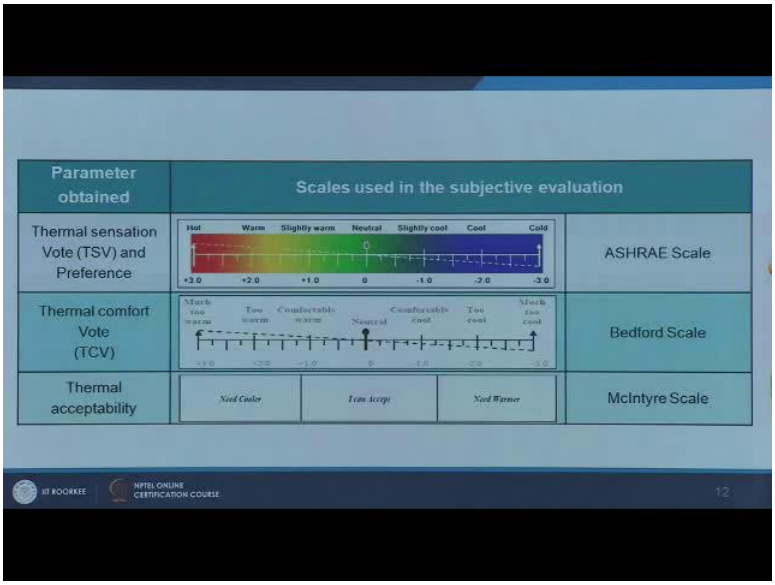

So, primarily these adaptive studies revolve around conducting field measurements of comfort it has two components, one is physical measurement accompanied by subjective assessment. It is like you have a set of sensors you go to the field you measure the condition parallel you also ask people, how do they feel? So, how do we ask how do they feel and what do you measure this is what you are going to look at this section.

There are 3 important scales, which we have to keep in mind in order to do thermal comfort studies on field today you find lot of studies such studies are being reported. So, if one is interested to conduct these studies we need a lot of more studies for India specifically because, the climate is diverse cultural variations are really huge we have lot of psychological differences. So, with these things we need a lot of field evidence. If one is interested you have to have in mind 3 important scale; the first is the ASHRAE scale all these things are double liked scale this is 7 point scale, you have 0, which is thermal neutrality in the center towards the right you have slightly cool, cool and cold minus 1, minus 2 and minus 3; here you have plus 1, plus 2, plus 3 representing slightly warm, warm and hot, this typically we call thermal sensation mode, but you know it is depends certain authors refer it as the actual sensation vote s v there is a different terminology, but the scale remains the same. Ideally what you ask is what do you perceive, when you have to ask this question you need to ask them what is your thermal perception? Or what is

your thermal sensation right now?

The next particular scale which is interesting is the Bedford scale, this looks alike in terms of the number, in terms of the balance it is also seven point scale starting from 0 minus 3, one side and plus 3 in the other side, but there is small difference. In fact, you know it is a major difference when people answer for this small difference in terms of the verbal variations which is you know put in here, 0 is neutral here, but when you go to minus one or plus one you find the term comfortably cool or comfortably warm. We refer this commonly as a comfort scale rather than a simple sensation scale, this is like a thermal sensation scale, what do you sense the thermal environment like, but this is like are you comfortable with it? I am going to show you some field evidences how the answers the same person answering in these two scales there is a lot of difference in the way he answers, this rather asks you whether you are comfortable when you say, if am feeling slightly cool it means that the environment is slightly cool, when you say I am feeling comfortably cool it is cool, but you are comfortable with it.

The next important scale is the 3 point scale which is McIntyre scale commonly referred as McIntyre scale this is very crucial information which you know you get from the field, just 3 simple things I need cooler, I need warmer or I can accept. For instance a person might say I am slightly warm, but he may say it is comfortably warm and he can also say I can accept this, which means this particular setup thermal environment if you go with the sensation scale you may say that no this is slightly warm you need to bring it to neutrality, which means that people always do not need neutrality, but they can also be feeling comfortably warm. For example, a slightly increased temperature or a radiant heating will give you or will keep you comfortably warm in winter, and you can still accept that particular thermal condition.

A sample comfort questionnaire, you know just to show you that there are lot of dimensions in which you can assess thermal comfort a standard like you know ASHRAE 55 thermal comfort standard would give you an appendix what all basic conditions you need to ask how to ask and what to do, basically these comfort questionnaires will have their date time stamp plus age, gender.

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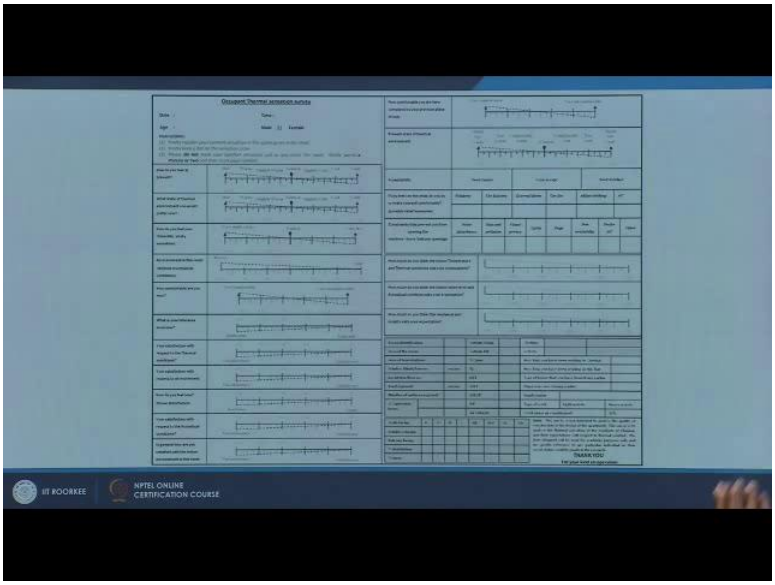

You will be noting it, but other than that you will also have some place where you will have to note the environment criteria, what does the here you know we had room dimension and you know basic features of the room about the whether the windows are open, fan is on off, what type of thermal environment is prevailing in the room plus the design configuration, apart from clothing and activity level, when I say activity level it is not the momentary activity the person is doing, you have to also record what activity this person was doing for the past 1 hour at least. So, that you get a fair idea about what thermo regulation is happening in a particular person.

Apart from these environment criteria, you ask a set of questions it can be short questionnaire, it can be a long questionnaire this one I am showing you is a little exhaustive one. Apart from basic 3 scales you also can ask them about how do you feel about the air moment whether it is breezy, whether it is windy what about the sultriness whether it is humid you know sultry or whether you feel it like dry you can also ask about the health conditions, you know as you ask more questions in a systematic way the better information or inference can be made out of this.

There are two types of surveys which are typically done, one is the transfer survey which is called right here right. Now you go with the questionnaire go with the setup

instruments, Let the instruments settle down with it is no sensitivity. So, it may take a minute to 5 minutes depending on the instrument sensitivity. Then you also let the person sit settle down you explain him what you are trying to do and then you ask the question saying you know it can be exhaustive, it may take about 5 minutes he will be answering you about each of these questions and what he was doing for the past 1 hour, where he comes from like that plus your measurements will be going on. Say you know 10 to 15 minutes of this interaction will give you a set of answers from a particular respondent this is one type you know right here right now or a transfer survey.

It is like a door step survey you have to get in of course, but it is like you know knock the door get it do the survey, but other type of survey which is you know even more informative is the longitudinal survey, where you keep asking the same person set of questions multiple times say it can be 3 or 4 times a day to it can go all through the season. He may be answering it daily he may be answering it 3 times daily over the year you know as you have provision the more stable and more informative the data is, but one small constraint is you cannot ask exhaustive questions again and again to the same person. The number of questions have to be limited, and the number of measurement parameters also might be you know might have to be limited because, if you have to install such a, you know set of specific instrumentation for each person it may be really a costly affair.

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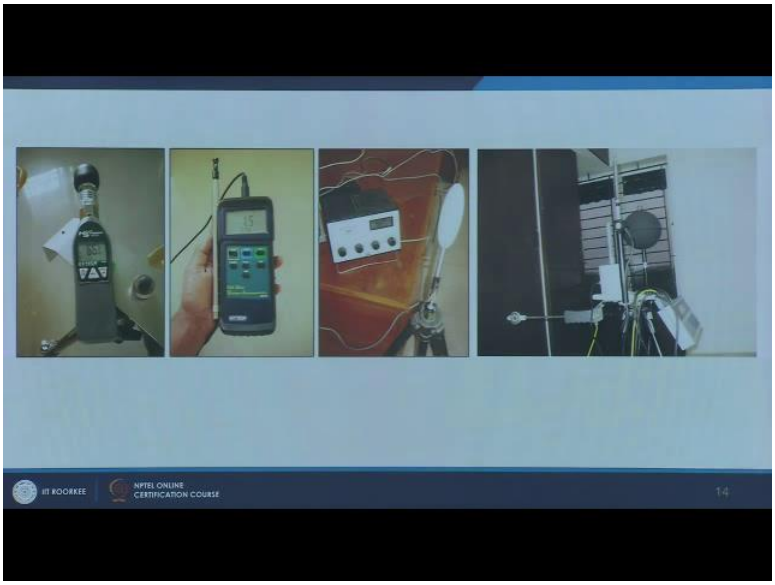

Typical set of instrumentation, before we talk about instrumentation there are 3 classes of survey, level 3 surveys for instances there are 3 levels; level 3 is like you have minimum instruments you measure temperature humidity probably air velocity, again sensitivity vary varies I am giving you a very basic information about this, say you have temperature humidity and you are measuring air velocity you also ask the person a few questions about the thermal environment it does not cost you much, but still you manage to get some amount of data, but the accuracy of the data considerably varies, as you go to level two service, level two you need to measure at least 4 environmental parameters temperature, humidity air velocity as well as radiation in terms of globe temperature you would have to measure apart from noting down their activity in metabolic, you know metabolic activity and the clothing insulation.

Then comes level one survey, where the temperature humidity as well as the thermal environments are recorded at 3 different levels, say if a person is seated you take in his foot level his waist level, as well as his head level, for the same with the standing person apart from this it also needs continuous recording for at least a duration. So, that you measure the thermal environment surrounding for a particular duration. It is not like a momentary survey. So, there are 3 levels of course, level one gives you more standard and stable information, but it is eventually it is costly for example, these are you know

this is a very small device we used to have for measuring temperature humidity as well as globe temperature, along with a hardware anemometer which measures air velocity. Hardware anemometer has better sensitivity for indoor measurements this give you much better results than vent anemometer, this is a comfort meter which directly measures the Fangers predicted mean vote.

I am not talking much in detail about the construction of this instrument, but later versions are available this is a very useful instrument it directly gives you plus 3 to minus 3, it you set metabolic activity and the clothing insulation this is the one of the you know very fine instruments, which even you know it has been in news for the past 30 years it is still being updated.

Apart from this if you have to do level one survey, you have to have at least two sets of instruments like this, measuring into different levels you can measure temperature humidity, air velocity, then the radiant asymmetry globe temperature air you know at, at least two different heights plus you need a data rather which needs to continuously be recording at specific frequencies. I will show you few results. So, as to touch space some what we were actually talking about, we did a subjective evaluation or adaptive comfort survey for a set of people in a warm humid climatic condition, I am going to show you some results and relate to what we have been talking about. What we did we did a survey of about 300 plus about 330 you know people were surveyed, there were short term surveys like transfer surveys, they were longitudinal survey the overall data set was something like 1500 around 1500 numbers data sets were there because longitudinal about 100 people were answering again and again and for specific duration during summer during winter.

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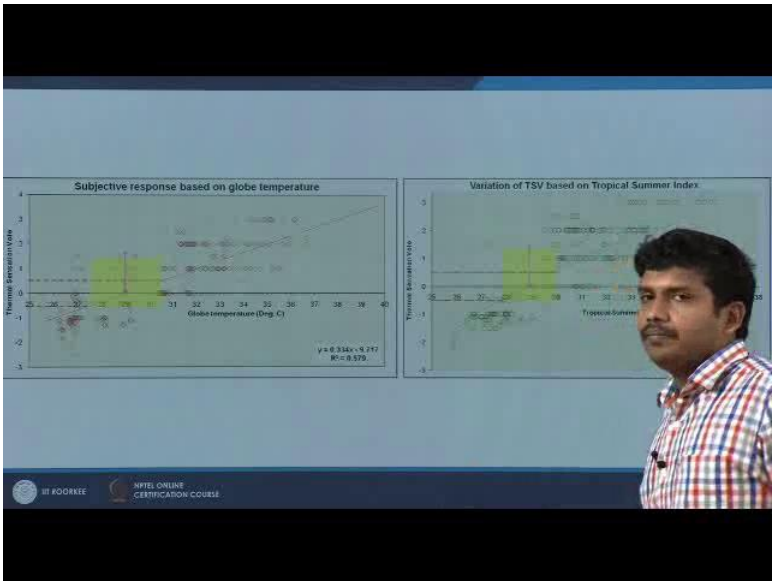

So, the data set was about you know measurements were taken what you see here is the indoor globe temperature and what you see here is a thermal sensation vote. This is the first in the 3 scale that I was talking about this is the ASHRAE scale thermal sensation people were answering on how they actually sense the thermal environment the temperature is recorded were something like 25 degrees all the way up to 40 degrees of indoor globe temperature the measurements were taken and this is the response given by people.

There are 2, 3 interesting things which we need to note. See whenever you do adaptive comfort survey that is what you will get you will get a graph like this, when you plot you will get a graph like this, what it means say take a temperature of say 36 degree, you have set of points dots across the y axis it does not, of course, come down which means this is cold this is cold, this is cold, cold and very cold. This is you know on the hotter side, you do not get the colder responses during this particular temperature of course, 36 degrees nobody tells I am feeling cool which means there is an anomaly in the measurement, but still what we found there were set of people who were also saying they are with it that is you know they say it is thermally neutral I will tell you who said those things.

Then there a set of people who were responding somewhere between one and two, and there were a good amount of people responding between two and 3 you get more data of course, on in the higher side as the temperature go up. Whereas, if you see temperature like 26 degree you still have some people saying I am thermally neutral, but still you find more number of votes coming towards the colder side as I said this is like one humid more specifically it is a hard and humid region, this was recorded in Chennai where winters are not that prominent. As it gets lesser than 25 degrees people start saying that you know it is a cold condition, on the contrary if you go to a colder climate or a composite region you are used to 25 degrees, 26 degrees, because your temperature drops you know drop as low as 5, 6 degrees. So, 25 is comfortable you may get further lower temperatures, you may get this response you may not get this response. So, one important thing we need to note this particular dispersion is very location specific very you know specific to the socio cultural group which we were talking about.

Coming back to this particular response, some people had responded that they were neutral feeling neutral they are with it this actually corresponded to a set of people from different socio cultural segments of the people, you know society we recorded with a set of fisherman for example, was one group of people from with whom response was taken, of course, it was a indoor measurement not outdoor measurement.

Fisherman's colony we covered the other measurements were taken in HIG homes like you like people already are using minimum two air conditioners and their thermal responses. So, this is a total response. So, you have a wider dispersion. Similar thing yeah one more important thing is when you fit a curve here this particular line is a simple linear fit, it crosses 29 degrees at thermal sensation vote of 0, which means the thermal neutrality for this total set of people is around 29 degree. If you take plus you know 0.5 or minus 0.5 say 90 percent acceptability then their limit would be somewhere between 27 and up to 30.5. So, this would be range which is thermally acceptable if you go with the thermal sensation vote.

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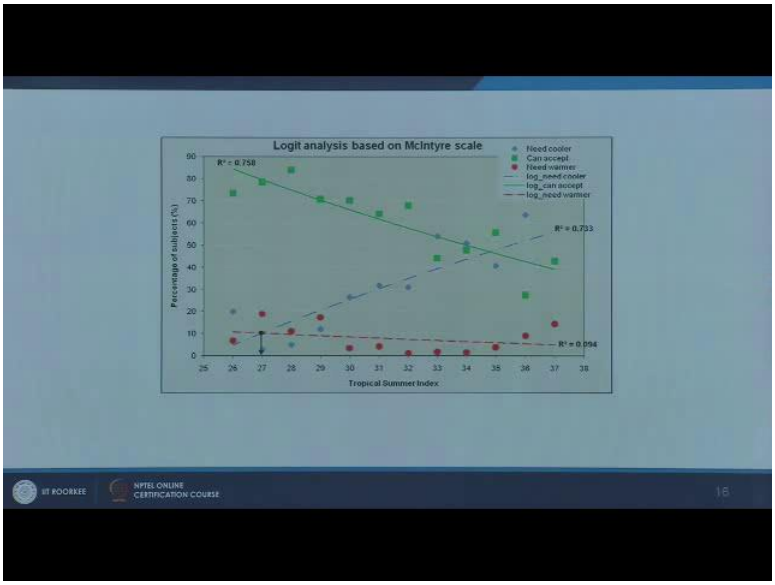

A similar assessment done with tropical summer index, because this is only temperature you know globe temperature response if you include humidity and air velocity you can do the same thing with TSI. This is the third scale, which I was talking about the McIntyre scale you ask them whether you can accept you need warmer or you need a cooler environment. You have tropical summer index here and percent of subjects here this is a logic analysis you see this green line this is like I can accept, as the temperature t s I increases I can accept votes come down, the percentage of people saying I can accept comes down percentage of people saying I need cooler goes up and need warmer naturally comes down, we did not go much on the colder side of the recording. So, this you know particular line fit did not really come well, because most of it was taken in the warm nobody is going to say I need warmer, had we been doing the this you know surveys on the other side say 0 to 25 degree this line would fit much better.

Taking this clue, if you see the need cooler and need warmer line meet, this particular thing is probably the thermal preference of people. Getting back to the previous slide, what actually they were saying they were you know feeling thermo neutral about they were saying I am feeling thermo neutral at 29 degrees. Whereas, when you ask them whether you can accept it or what you prefer, it comes to around 27 degrees. This says that 27 degree is the thermal preference, but they can sensation wise they are with 29

degrees. These 2 degree differences will probably induce people to adopt for more air conditioning system or getting into more cooler environment.

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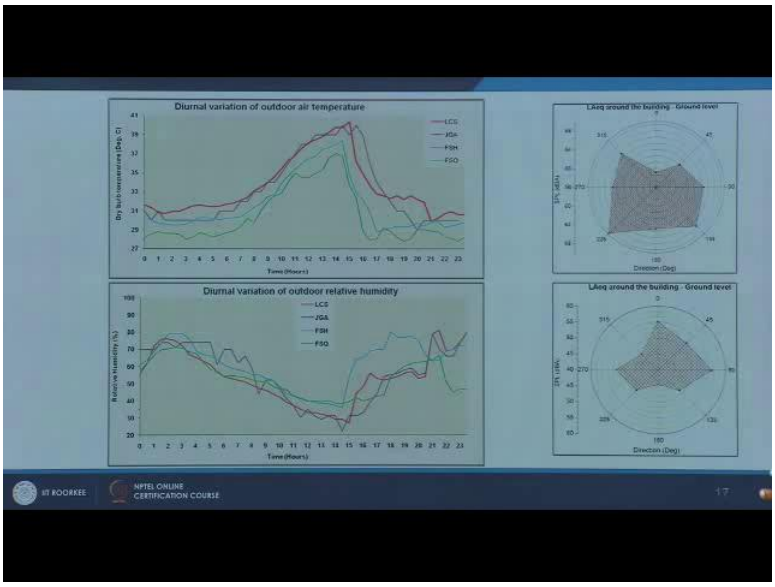

There are also other parameters like micro climate, but getting much into the details of it you have obligations based on this you can refer to.

But just to give you a simple example taking two different housing colonies, this is like you know micro climate recording of that particular thing temperature humidity and the ambient noise level. Why I have put noise level is, one was in a major traffic intersection people were not able to use their balconies or windows because it was too noisy as well as air pollution was pretty high. The other one was in a quieter environment temperatures were also considerably different this particular one the maximum temperature during summer went up to 40. Whereas, here it was around 37, 38 under similarity this were taken from my department stations in these two locations in the same city humidity levels are also different.

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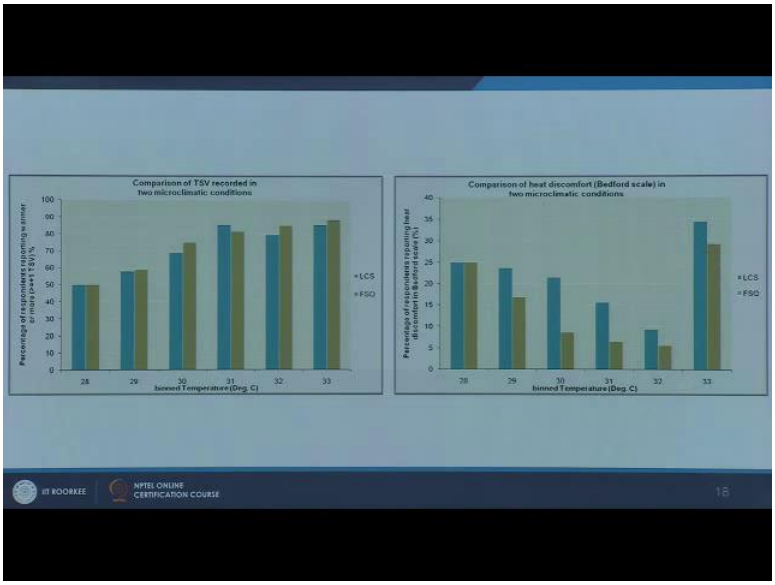

If you know carefully assess this particular thing is on the ASHRAE scale this is the TSV on the ASHRAE scale and the responses are more or less same between these two housing you know colonies. Whereas, if you ask them on Bedford scale how comfortable you are people located in this particular thing the expression of comfort considerably changes this is heat discomfort. So, it is on the other side of it heat discomfort the higher the number is the more people are saying I am feeling more heat discomfort.

Say take a temperature like 31 degree this particular thing is located in a better setting people had the flexibility to use their windows, balconies they can open windows they can you know get more ventilation compared to this people who were bound to keep their windows balconies closed. At same temperature say a temperature of 31 degrees almost you know double the percentage of people said they were feeling uncomfortable, or they were experiencing heat discomfort compared to this particular thing. This happened at almost all the temperatures. So, as a designer what this means to you micro climate or setting up the micro climate is very crucial, not just you know ambient pollution alone is a major thing. Visual privacy especially in apartments when you have two adjacent blocks looking at each other people do not open the windows it affects the ventilation, but it affects.

Thermal adaptation, in the context we are talking about as a result of which people are going to express more heat discomfort and this would lead to usage of more energy in terms of mechanical systems. Let us take a look at some adaptive comfort models, there are lots of studies and each study is reporting about a different setup. So, more or less overlapping, but a different range of temperature humidity condition or environmental condition which it people are able to adopt.

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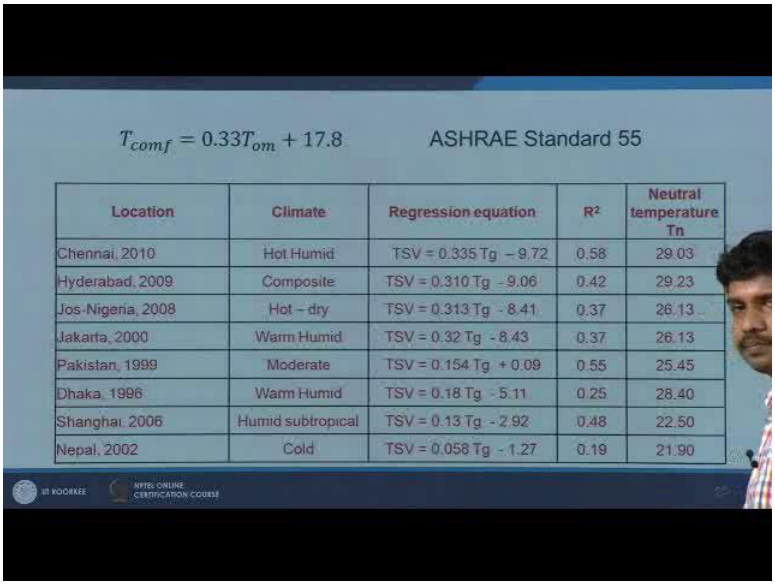

One standard reference is the ASHRAE standard model where comfort temperature are T comf can be expressed as you know 0.33 into T om, om means monthly outdoor mean temperature for a particular month you take the outdoor mean temperature, 0.33 of it plus 17.8 this is the standard reference, but as you see there are lot of studies in India as well as you know South-East Asia plus across the globe there are more studies is not a you know total list of the whole thing. And each one of it more or less if you see it is like 0.3, 0.15or close to 0.2 of globe temperature most of these studies I have collected were based on globe temperature. A plus or minus some variable and the neutral temperature also we find that it is considerably different. For example, if you take a colder climate like Nepal the mean you know the neutral temperature was around 22 degrees as a contrary if you see a composite climate or a hot humid climate, you find neutral temperature as high as close to 30 degrees 29 degrees present.

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So, there are lots of more comfort models, but more or less they are like you know regression models developed based on field evidences. If you compare two cities in India, I have taken the standard comfort model the ASHRAE model and I have plotted two different cities based on the monthly mean temperature. So, this particular thing is month here this is outdoor air temperature this thin line show the monthly maximum mean, maximum and mean minimum the dots represent the mean maximum and mean minimum.

Then the center one is the monthly mean and the red line shows the T comf calculated based on this particular equation. So, this is for Ahmadabad where you find the comfort temperature, varies somewhere from 24 degrees and it can go as high as 31 degrees during summer. Whereas, if you take a city like Bangalore the comfort temperature is close to 25 degrees during winter and it can go up to say around 28 degrees during summer. There is not much of a difference keeping this in mind Fanger revised his comfort model or rather provide you know proposed the addition or add on to his own comfort model the PMVDPD model he introduced a factor called expectancy factor, which is nothing, but to scale down the actual prediction of the PMV for example, if your PMV is 2.

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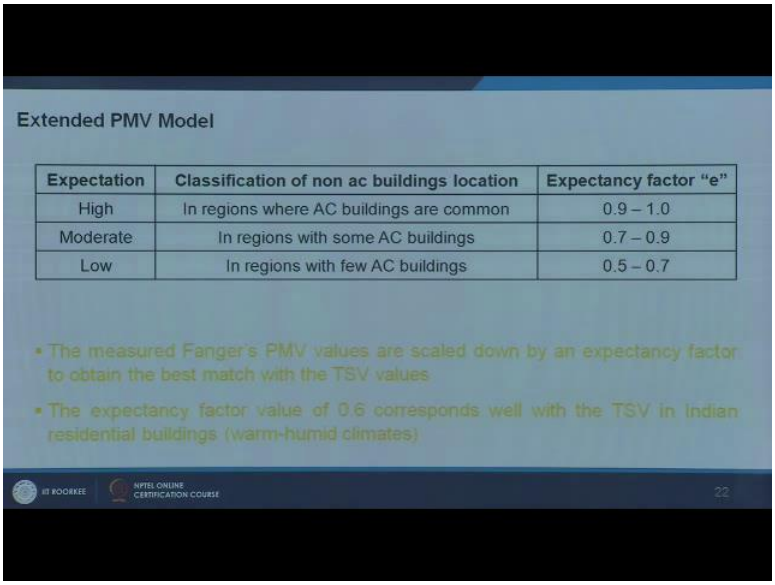

Which means you are feeling hot, then he says that in region where a c buildings are common you can retain that particular vote by itself it can be just two, whereas if there is a region where there are few very few a c buildings or you take a socio economic strata where people are not able to afford for more air conditioners. Then he is saying that the p m v value can be scaled down as low as 0.5, that is half of it instead of being hot it would be warm. So, the same model he is saying can be extended using this.

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We did try to compare the actual you know predicted model the same graph I showed you with the PMVs prediction always you know the standard PMV model tends to over predict if it is like neutral it says it is really warm and it goes up high, but introducing a weightage of 0.6 it comes closer, but it cannot directly align of course, you know this particular trend line changes from location to location, but more or less around 0.5 to 0.6 in Indian you know condition PMV comes much closer to the predicted or sorry the actual perceived thermal comfort.

One of the reason additions to the model that not so, recent, but about 6 to 8 years back this was implemented in the European codes as well; here this is the concept of running mean outdoor temperature instead of taking daily mean or monthly mean temperature, monthly mean outdoor temperature.

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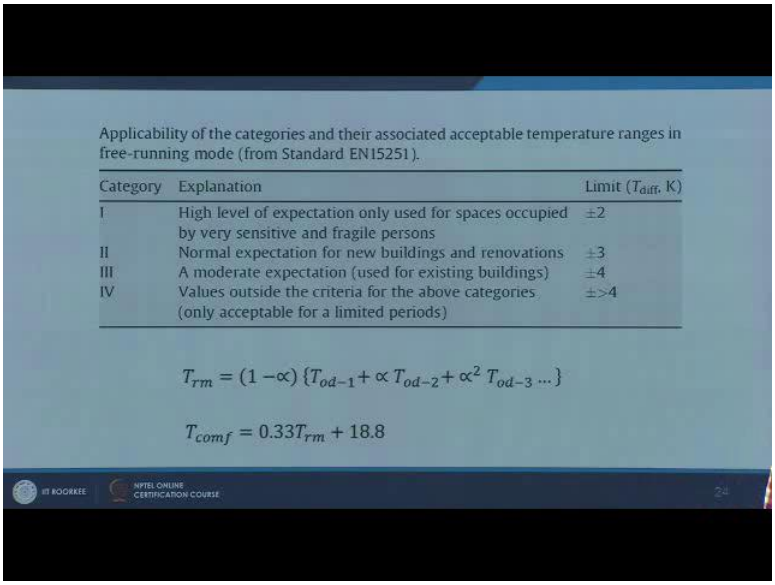

The concept of using running mean temperature like you know you say short term thermal history that you are accounting for, take the mean temperature of the past 7 days and then like you do a decay calculation kind of you know you give more weightage for yesterdays mean temperature slightly lesser weightage for previous day and it goes on for the past 7 or 8 days. It can go longer also, but typically five to seven days is taken then instead of a particular daily mean you get something called running mean temperature and compare temperature typically co relates much better with the running mean temperature rather than the actual ambient mean. We have also verified the same thing it has a better coincidence with the running mean temperature compared to the actual daily mean temperature or monthly mean temperature.

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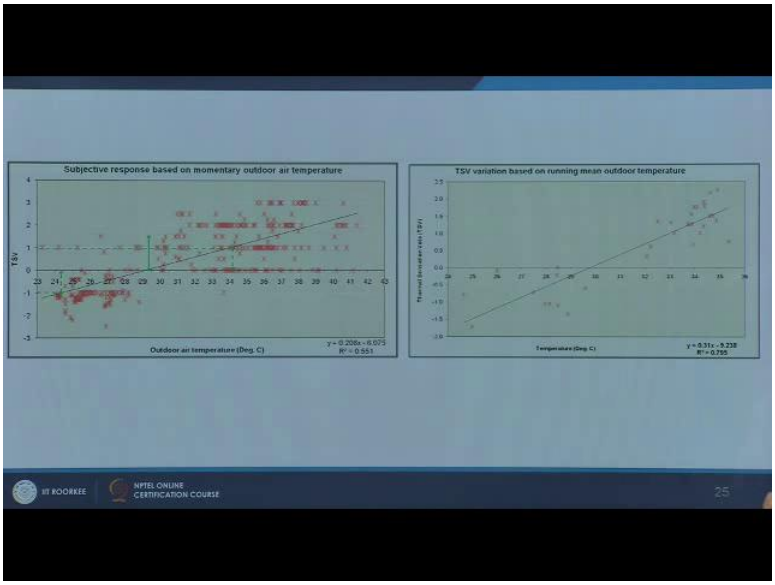

This is a thing; this is like typical outdoor air temperature mean temperature of a particular day versus this is a running mean outdoor temperature. The carnations were much closer now you had a better m value plus the r square values are also slightly higher here.

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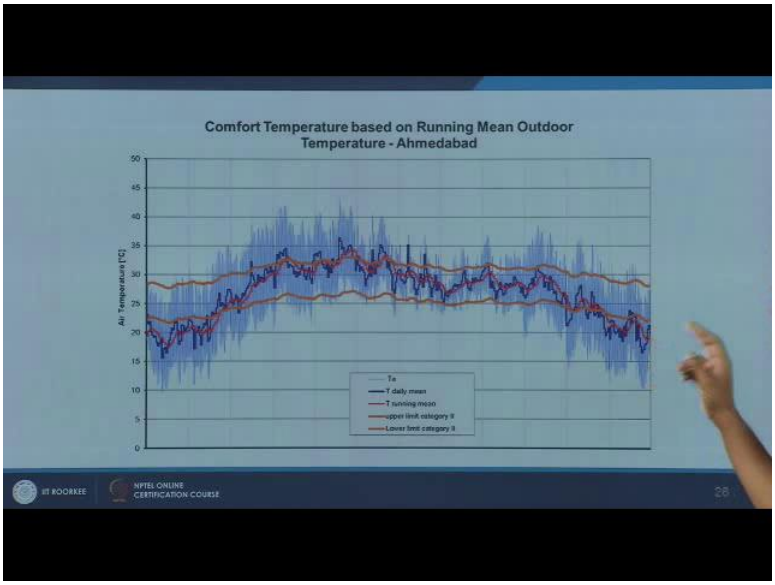

Similarly, this is how the band, the comfort band using the previous equation I showed you this is for Ahmadabad the light blue line represents the actual hourly temperature variation, the blue one is the mean daily mean temperature. The red one is the running mean temperature this band here tells you what is the adaptive boundary based on the running mean temperatures. So, it continuously varies all through the year it goes up to around 33 degrees maximum and as low as around 20 to 23 degrees during winter. And this is the case of Bangalore the boundary more or less lies similar, but the fluctuations and the spread is different. Why do you have to know all this we will start more about this particular graph elaborately in further modules, but this particular thermal adaptation has a significant impact on the actual monthly energy consumption of a building?

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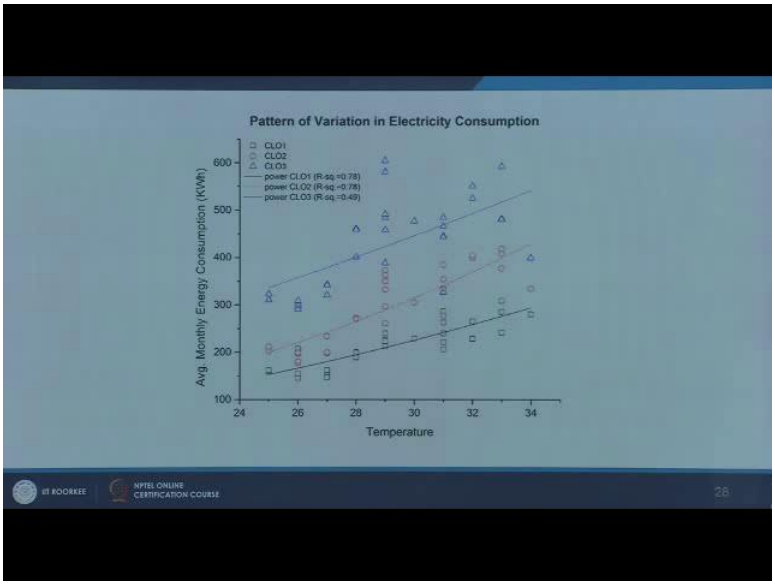

We will talk about energy efficiency in those modules we will touch upon these things, but to connect these two modules, one of the studies which we found you know which we did we found that there is a considerable amount of difference for the same user group. People are similar the houses they live in are similar orientation you know floor configuration design configuration are all similar, but due to personal variables and adaptive phenomena, which they are you know getting into, there is a considerable difference between their monthly energy consumption monthly bills seem to be quite different from each other, we stop this particular module here.

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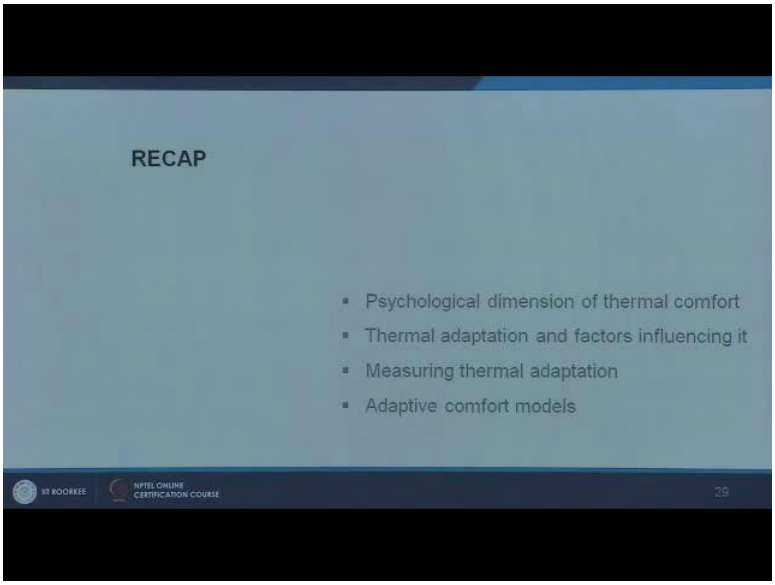

We looked at the psychological and physiological dimensions of thermal comfort. Then we talked about thermal adaptation and major factors influencing it, which you know looked at how to conduct an adaptive comfort survey and how do you measure this parameters in field and we also looked at few adaptive comfort models in this video.

Thank you.