Science of Clothing Comfort
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Lecture - 24
Clothing Comfort Related to Thermal Transmission (contd.)

So, hello everyone. Now we will continue with the transient heat flow.

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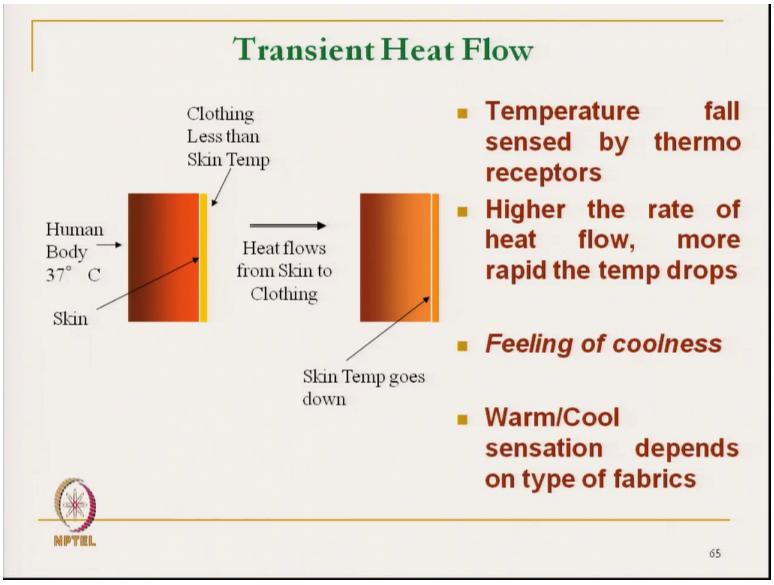

So, we must have observed that when we wear clothing or we touch any object, we immediately feel either it is cold or it is warm. So that the warm cool sensation, it is depends on the transient heat flow behavior of heat from our body, ok. Maybe it we received heat or it we may lose heat.

But this warm cool feeling, it comes for immediate transient heat, it is a sensation of within a fraction of second; that that is called transient heat. Suppose we are we are touching an object, and immediately we were feeling warm or cool, but after certain time it may fed slowly. So, that is how it is called warm cool sensation, ok.

Now, our human body is core temperature is kept it is a normally it is a 37 degree Celsius, and when the clothing we are wearing, it is a normally it is a temperature is say less than the body temperature outs skin temperature. And it does not mean that you will feel cool of that; it depends on the various factors, that these things we will discuss. And if it heat flows from the body to the, from skin to the clothing immediately, then we will feel cool feeling.

So, the temperature fall sensed by the thermo receptors, and higher the rate of the heat flow, more rapid the temperature will drop. And if the temperature drops rapidly, then we will feel cool. Otherwise we may not feel cool if the temperature is actually it is a heat flow is at slower rate. So, the instantaneous heat flow rate it is basically it gives the warm or coolness. So, if the heat flow instantaneous heat flow is there, then we feel cool because the temperature of our skin goes down.

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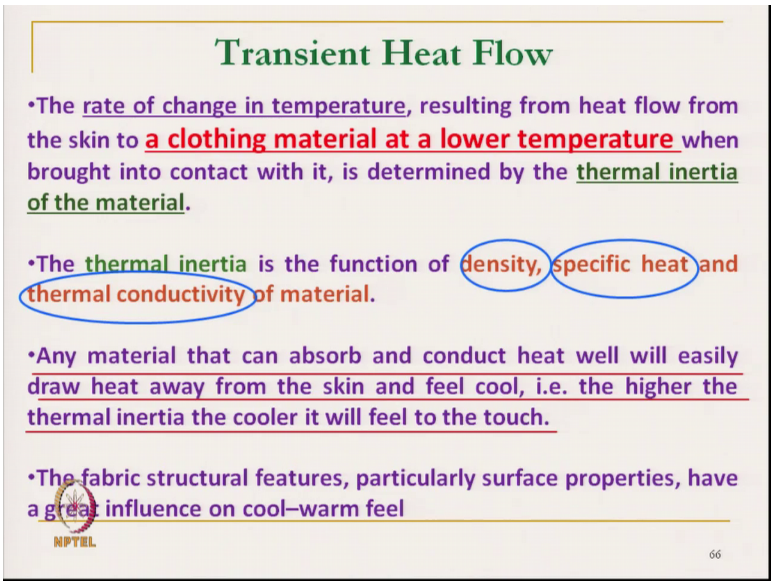

So, the rate of change in temperature resulting from flow of heat, from skin to a clothing material at low temperature; so, clothing material has to be at low temperature, otherwise we will receive heat when brought into contact with it is determined by the thermal inertia of the material. So, if the thermal inertia is low, then we will not feel cool feeling ok.

So, it is the material characteristics, there are many other characteristics. So, the thermal inertia is the function of density of the material, specific heat of the material, thermal conductivity of the material. So, all these things if we if your thermal inertia is high, then we will feel cool, if the temperature with the materials temperature is lower than the skin temperature.

If the thermal inertia is not high, then we will not feel cooler; like, it is a thermal inertia is a function of density specific heat and thermal conductivity of a material which is not conductive in nature. So, we will not feel cool; like if we touch iron piece or one some insulated wood; so, that is why that the we know that it is a, we feel cooler feeling when we touch iron because of the it is a thermal in a thermal inertia; which is related to with the thermal conductivity.

Similar is a case of the clothing. And we will see that that various factors which actually affect the thermal inertia; so, the density, specific heat and thermal conductivity of the material. So, any material that can absorb and conduct heat well is easily draw away the heat from the skin and we feel cooler. So, the higher the thermal inertia the cooler is the feel of touch. So, feel of touches extremely important, because that that material may not be cool. So, the one we can see the 2 material, one is the cool touch material if and another is the warm touch material, they are kept in the same environment, they the effective temperature of this 2 materials are same. But the cool touch material gives the cool sensation; the warm touch material gives warm sensation because of the thermal inertia.

And this thermal inertia it is a material characteristics, that is the, if the it is a textile material it is a fiber polymeric characteristics; like a specific heat, density, thermal conductivity. And the fabric structure also in addition to this material characteristics the polymer characteristics, the structure of material, like structure of fabric, particularly surface property of fabric have a great influence on warm cool feeling.

One very classical example we can give, suppose if we touch one fabric made of say twill structure. So, cotton cloth or twill cotton fabric, another fabric is made of cotton, the cotton satin fabric. So, if we touch the both the fabrics so, we will feel the satin fabric gives better cool effect cool touch effect, then the twill and this is due to the fabric structural feature.

So, fabric structure if the fabric structure smooth. So, why satin keeps the higher cool effect because satin has got high float a length. So, large number of areas a contact area with the skin is more; that is why satin gives cool touch, and the on the other hand twill has due to it is projected structure ok, that it the contact area with the body it is a less. So, it does not actually it is a draw heat from the, our body at higher rate.

So, we can control though warm and cool touch of fabric by controlling the surface structure of cloth. So, the bed sheet it is our daily experience, we can feel that of a simple example of same 2 bed sheets are made. One is made of a the made from the same yarn same say cotton yarn made of same say cotton yarn, but one bed sheet is made of a say plane of a plane view one by one plane view another is made of say satin. So, we our experiences that it is a satin fabric gives a higher cool touch, because of the higher contact area with the body, and they can draw that fabric can draw heat at higher rate gives cool feeling.

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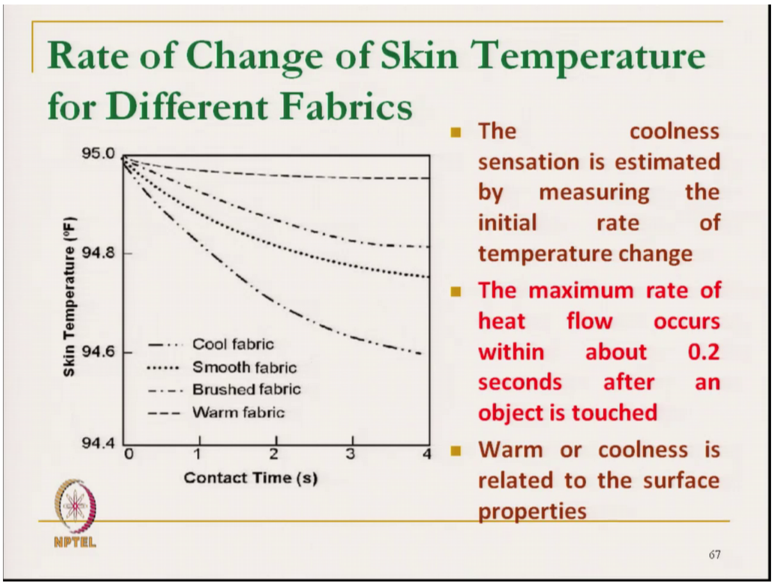

So, let us see this is the curve; where the x axis gives a contact time and y axis gives the skin temperature. Now this is of the fabric warm fabric, warm fabric this is warm fabric, brushed fabric, this is the smooth fabric and this one is cool fabric.

Now, these 2 fabrics are there, warm fabric means if we the sensation of coolness is estimated by measure of initial rate of change in temperature. So, initial rate of change in temperature. So, this is the temperature say at 95 degree Fahrenheit. And here it becomes out say 94.6 degree Fahrenheit so, this rate of change initially. It may be within say 2 seconds one or 2 seconds, what is the rate of change in skin temperature it is a against the skin temperature. So, that gives us the, whatever the fabric will be cool or warm. So, this is the, for this is the temperature does not change much ok, skin temp.

So, this will give one feeling. And whereas, this fabric for this fabric it is a cool fabric the temperature changes is very high. So, it gives one feeling. Among this 2 the smooth fabric and this is the smooth fabric and this one is the brushed fabric. They are made of the same material, same structural construction, but one is a normal smooth fabric another is the same fabric is brushed. So, what is the difference? Here one can see the smooth fabrics the temperature drop is skin temperature drop is higher than the brushed may be because of the feel smooth fabric the contact area is high. So, maximum rate of heat flow occur within 0.2 seconds after an object is touched ok. And warm or coolness is related to the subject surface properties. So, that if we change the surface, warm and coolness is there changes.

So now the question is that it takes away heat and the sensation of coolness is within 0.2 seconds, 0.2 to 0.3 seconds. But what happened, the if we after that? So, after that it is not that it will keep on a it will keep on a drawing heat, because the environmental temperature is same. So, it cannot draw the draw heat it is at that rate, because it is a instantaneous heat change.

That means a fabric which is cool in touch, if we wear that fabric for certain time say for 5 minutes 10 minutes, that cool sensation we will go. So, that that instantaneous cool sensation is within a second ok. And after that what will happen? That same fabric may not be cool in touch. But if we keep moving, our body is normally it is not in stationary condition. So, if when our body moves; that means, that that, but same fabric will keep make different contact points, keep changing the contact point. So, every new contact point, it will give again the cool sensation. So, every when we keep on moving, the it a new contact point is generated and old contact point earlier contact point is released. So, overall we will feel keep on feeling the cool sensation.

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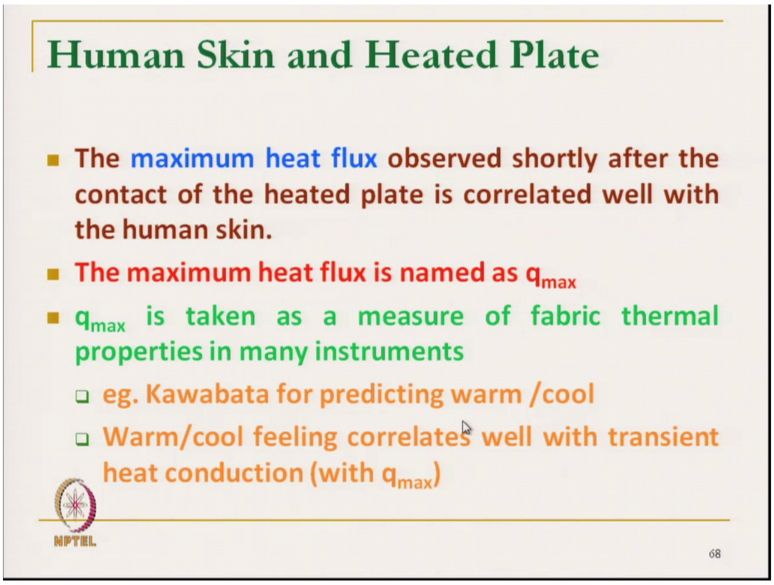

So now it is actually measured by maximum heat flux. So, which is observed shortly after the content of the heated plate is correlated with the human skin. So, that any, how to measure this now heat flux? So, heated plate is kept. So, that heated plate is that the temperature of the heated plate is a exactly kept in the around the 35 degree Celsius; which is human skin temperature, and when the fabric is touched with that, and immediate instantaneous heat flow heat absorbed by the fabric is measured, by the sensor. The instantaneous heat flow is measured. So, that is called the q max. So, maximum heat flux is named as q max. So, that is plotted against time. So, immediately the what is the maximum heat flux it is a the heat is drawn from the plate; which is equivalent to skin that is measured, q max is taken as a measure of fabric thermal property in many instruments. So, kawabata instruments which predicts the warm cool feeling.

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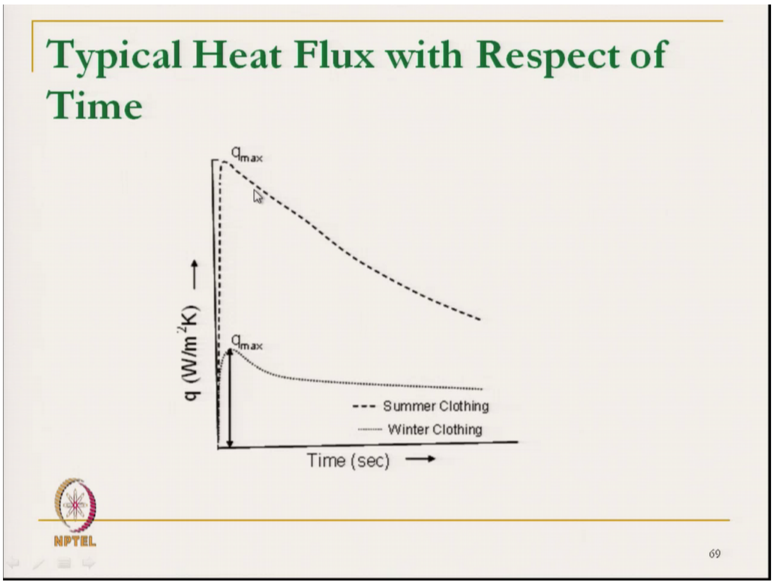

And if we see this is the diagram; where the quantity of heat transmitted from the plate heated plate with respect to time with reference to time is plotted here. So, 2 fabrics are there, this is fabric one and this is fabric 2. So, fabric one is actually it immediately it draws maximum, it very high. So, this value it is a q max. So, what does it show? This fabric which is actually summer clothing which is actually taking maximum heat immediately from the body.

So, that is why for summer clothing we have to use a fabric which has got higher q max value. Similarly, for winter if we use the same fabric, we may feel uncomfortable. So, to keep us comfortable, we have to use a fabric with higher lower q max. So, transient heat flow should be as low as possible for warm clothing.

So the, we have seen that how to design then so, for if we see if we want to have a fabric from same type of same yarn. In that case, we have to design a clothing for winter which we will give us higher surface contact area. And if we have to design a clothing for winter, we have to have lower surface contact area. May that you we can reduce the lower surface contact area by brushing by some other surface treatment.

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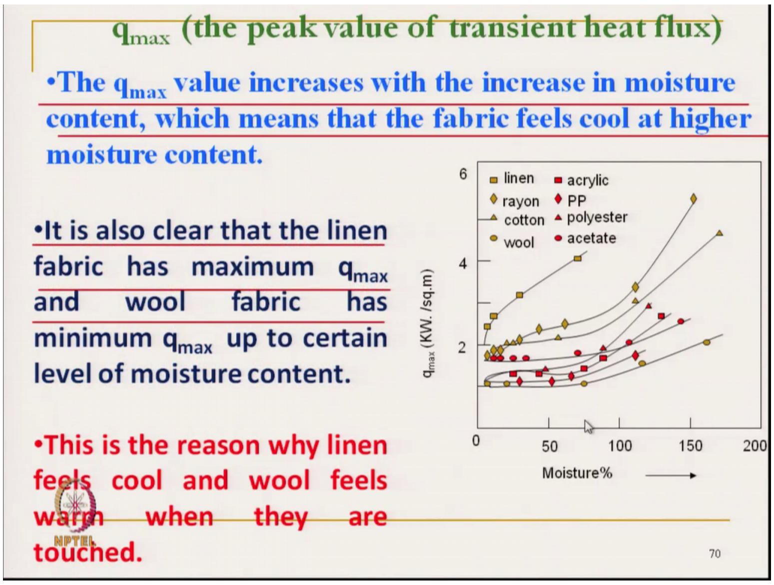

Now, this is an experiment carried out with different types of fabrics made from different types of fiber, and act q max value has been measured at different level of moisture, ok. This is the q max value for a particular for different fabric.

So, q max it has been observed that q max value increases with the increase in moisture level. So, what does it mean? A fabric your fabric has got higher moisture; that means, it will draw heat at higher rate from the skin. So, at if we draws higher rate the heat at higher rate from the skin; that means, we will feel cooler. So, the q max value increases with the increasing moisture content, which means that the fabric feels cool at higher moisture content.

So, we will feel cool at higher moisture content, but among the fiber if we see, this is the linen, linen gives the linen which results a higher q max value. That is why linen is called cool fabric; so, because linen has got higher q max. On the other hand, if we see the wool has got lower q max value. So, wool that is why wool gives the warmth. So, the warmth due it for wool is due to 2 reasons.

One is a one is that wool has got the lower q max value, and also wool due it is specifics morphological structure that is the, it is a basically it gives some crimpy structure. So, its contact area is less. So, lower contact area gives the lower that warm touch. So, that is we are not talking about here the thermal insulation. Here we are talking about the warm and cool touch.

And another aspect of wool is that wool while absorbing moisture. When it wool absorb moisture it, releases heat. It is a exothermic absorption. So, that is again it is a one of the reasons, why wool is actually warm in even in the humid condition, it gives it releases heat. So, it is also clear that linen fabric has maximum q max and wool has got minimum q max, up to certain level of moisture content. This is the reason why linen feels cool and wool feels warm when they are in they are we touch them, ok. That is why this is mainly due to the q max value.

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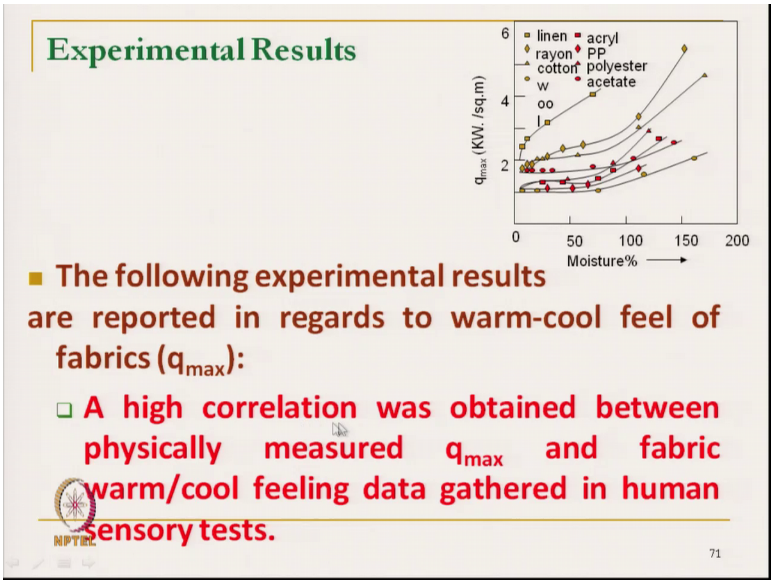

So, higher correlation was observed between the physically measured w max value and the fabric warm cool feeling by subjective assessment. There is a good correlation has been observed with the q max value. So, that is why q max is a basically it is a indication of the warm cool feel.

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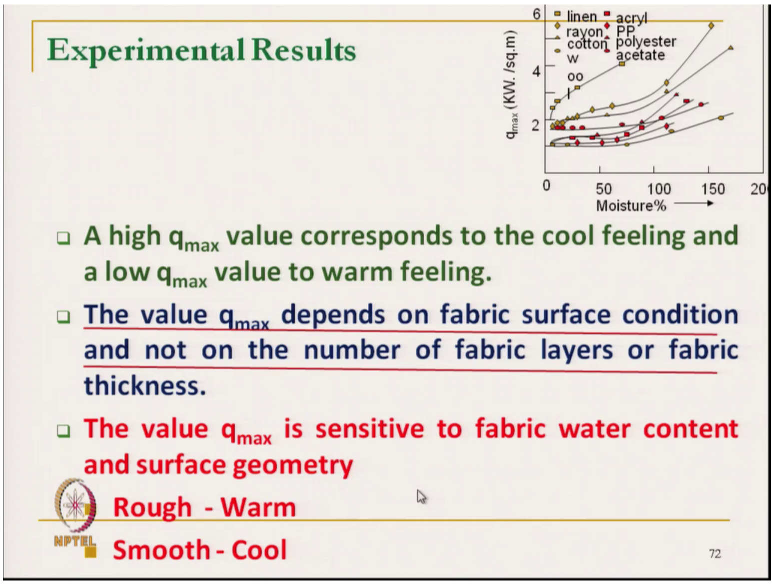

A high q max value corresponding to cool feeling and low q max value warm feeling, the value of q max depend on the fabric surface condition and not in the number of layers of fabric.

So, if we even it is a single layer wool, thin single layer wool fabric will keep warm touch, then multilayer linen fabric. It is it is not the thermal transmission, it is the it is that a instantaneous transmission. The value of q max is sensitive to water content, ok. And surface geometry so, that we have discussed.

So, rough surface gives warm cool and smooth surface give cool touch. So, that fabric which is warm; if we press through the calendar and then touch, it will give cool feeling; so, that is a due to the surface contact area.

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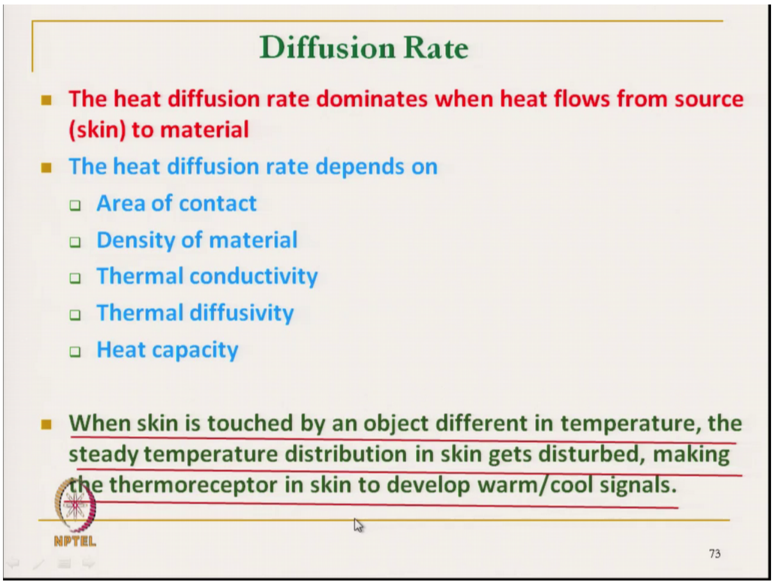

And another way of releasing heat is a it is a diffusion, ok. So, the heat diffusion rate dominates when heat flows from source that is skin to material. That is a through the through heat diffusion. And it is a depending on the area of contact, density of the material, thermal conductivity of the material, thermal diffusivity of the material and heat capacity. It is a similar to that of q max transient heat.

When skin is in touch with an object, different in temperature, the stead temperature distribution of the skin get disturbed ok and making the thermo receptor of the skin to develop warm cool touch. So, that is basically, this is mainly due to the diffusion of heat. So, you have discuss the steady state heat flow and transient heat flow. Now we will discuss that how to measure this thermal transmission characteristics of clothing.

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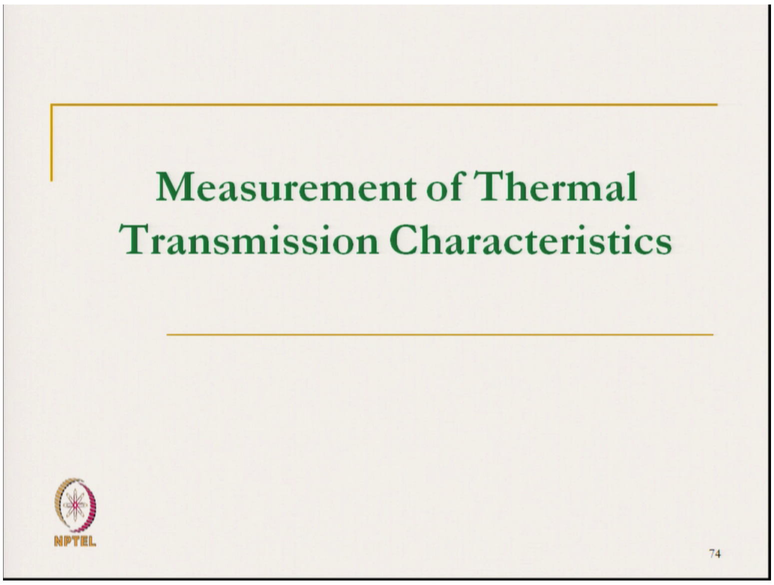

So, it is very important to understand measure the thermal characteristics, thermal transmission characteristics of clothing to evaluate that suitability of a particular fabric ok for a particular application. So, thermal transmission is measured by the one is the insulation value is measured by it is thermal resistance.

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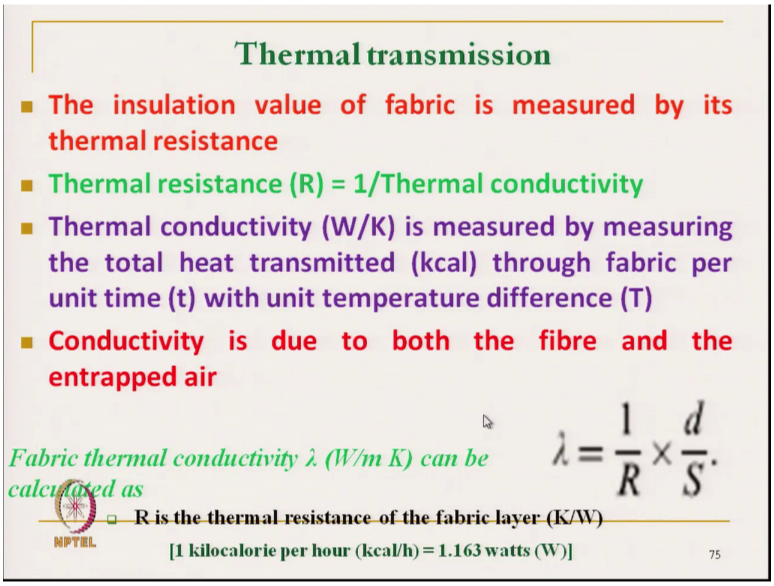

So, if we want to know the thermal insulation. so, we have to measure the thermal resistance and which is reciprocal to the thermal conductivity. We can either measure the thermal resistance or we can measure the thermal resistance or we can measure the thermal conductivity. And thermal conductivity which is watt per Kelvin is measured by measuring the total heat transmitted ok. The total heat transmitted it may be through conduction, convection, radiation through fabric per unit time with unit temperature difference.

That is the way we can measure. So, we will discuss in detail, conductivity is due to both fiber and entrapped air. So, that it is a combination of fiber and air, and fabric thermal conductivity we have we know this with this formula we can measure.

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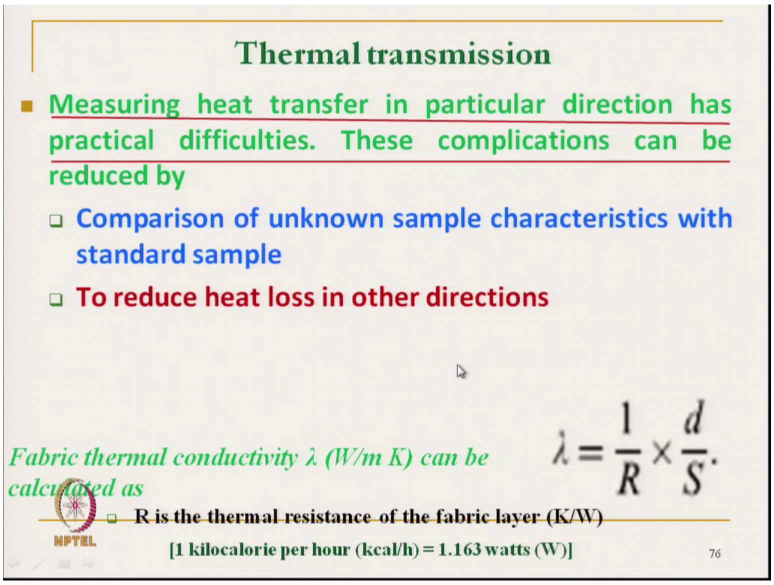

And actually measuring the thermal transmission of through a material is a it is a it is very difficult, practical difficult is there. So, measuring air flow is very easy. So, we can take a channel then take a pipe, and we can measure the quantity of air is flowing in a fluid flowing. Like, measurement of water flow through a pipe quantity of water flow it is a very easy. Because we can measure the quantity of water flow per unit time that is it ok.

But measurement of heat flow is very difficult, because the heat flow heat flows in multiple directions. So, controlling heat flow in unidirectionally so far; suppose, I have a fabric sample.

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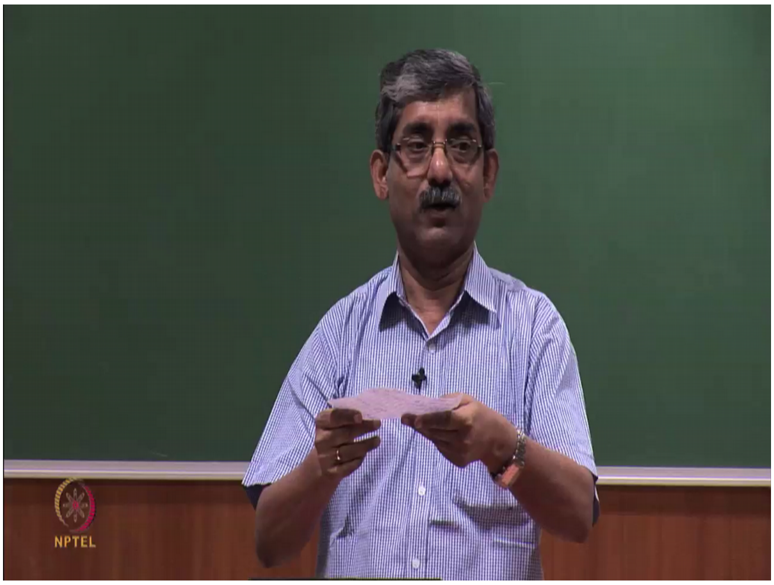

So, if I want to know the conductivity of the fabric. So, through this fabric the heat source is there. So, through heat if we want that heat to be flown through only through this fabric, it is very difficult. Because a source when heat is related. So, it will transmits heat in multiple direction it ok. So, that only directing the heat through the fabric is very difficult.

But directing any other fluid air or liquid or any other fluid it is very easy. So, that measurement it is a it has got practical difficulties. So, this complication can be reduced by 2 methods. One is we can compare with the standard non material. So, if we know thermal insulation of any material, thermal resistance of any material, and if we place our test sample in series, then by comparison by using the standard equation, standard formula we can calculate the thermal resistance of the unknown fabric, unknown sample. So, that is a, it is a comparison with the standard a sample, and this technique is known as the it is used in that tog meter; which is very popular in measurement of thermal resistance of fabric. And another is to reduce the heat loss to the other direction. So, if we can direct, if we can control the heat loss; then we can calculate directly. Suppose heat source is there, this is the heat source.

Now, if we can control the heat flow only through this, only through the fabric, we can control we can restrict the heat flow in other direction. Then we can directly measure the heat flow rate per unit area per unit time. So, that these are the 2 approaches we can measure. So, first approach by using the known sample, we can measure the characteristics of unknown sample which is used in tog meter, and by reducing the loss of heat in other directions, and this principle is used in guarded hot plate. So, these 2 principles we will discuss, and along with that we will discuss other techniques. So, this is the standard formula as we know.

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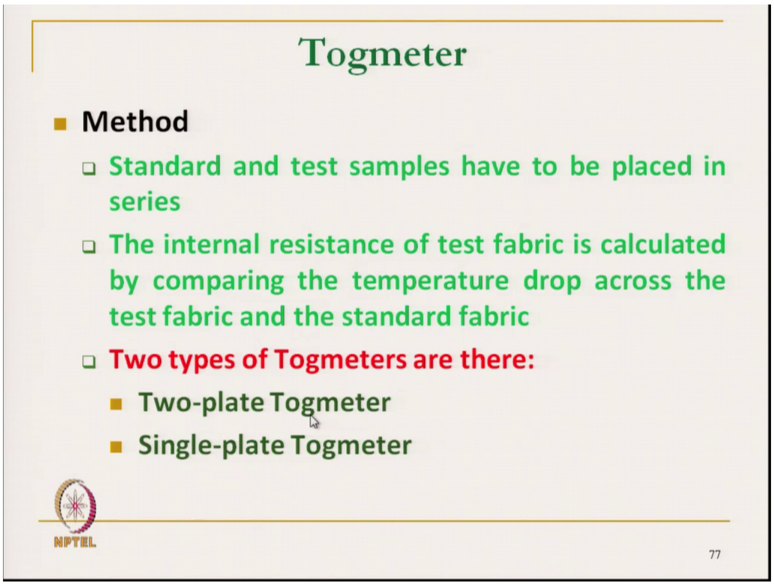

Now, tog meter; tog meter there are 2 types of tog meters are there. So, one is called double-plate togmeter, another is single plate togmeter. So, it is a 2 plate double plates 2 plates. So, the method is the standard and test sample have to be placed on in series. So, they have to be placed in series, and the internal resistance of the test fabric is calculated by comparing the temperature drop across the test fabric and the standard plate, or standard fabric we can, whatever we can use. But here we normally use the plate, known plate.

So, two types of tog meters are there. One is two-plate tog meter; another is single plate tog meter. In 2 plate tog meter we use 2 plates; one is the standard plate of a known thermal insulation thermal resistance. Another plate here is that it is a just to one insulating plate we just to cover that.

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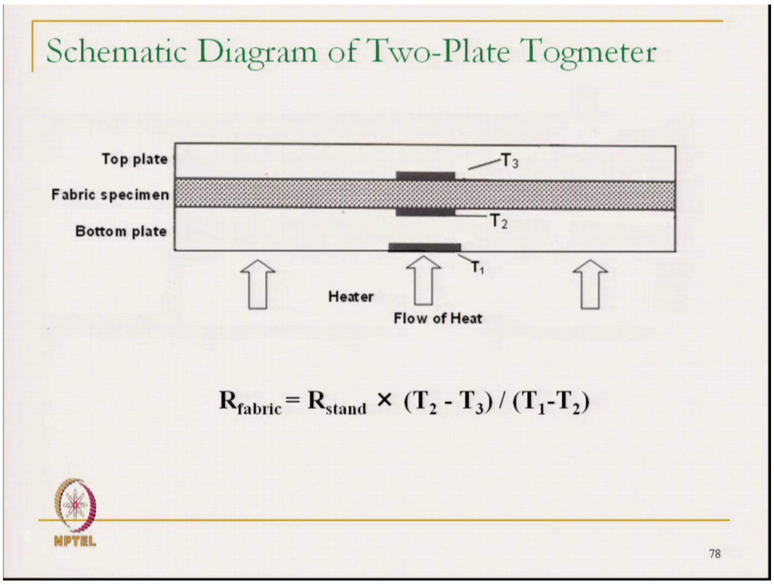

So, this is the 2 plate it is a top plate. Top plate is used just to actually control any external disturbance ok, in case effect of air temperature is actually eliminated here.

But the problem with this 2 plate top plate is that, it has got it is own mass. And the mass due to it is mass, the fabric which is compressible in nature get compressed. And sometimes it gives the, it is a wrong result. So, that is a and this, and fabrics with different compressibility, we will give different this thermal resistance value. So, that if we assume the compressibility of the fabric section, then it is it gives the better result, but if the compressibility of the fabrics are different, then it gives some wrong result.

So, that is a limitation here, and here and the advantages that here the problem of air disturbance is not there. And this is the bottom plate which is a standard plate here, and with a known thermal resistance value and our fabric sample fabric specimen with or which we are we want to measure know the thermal resistance here. And T 1, T 2, T 3 are the temperature drop temperature at across the display this is a surfaces. So, this T 2 minus T 1 is the temperature drop across the known surface, known a plate and T 3 minus T 2 is the temperature drop across the fabric specimen.

Now, the standard formula is that resistance of the fabric is actually by the temperature difference. It is basically it is a constant value. So, resistance actually the pure is that, the resistance if the materials are in series, then the resistance of one plate is proportional to the difference in the temperature ok. So, that means, this is proportional to the this the resistance of fabric, divided by the resistance of the temperature difference across the fabric. So, it is constant. So, that means, R fab R fabric divided by T 2 minus T 3, this constant equal to R standard divided by T 1 minus T 2. T 1 minus sorry T 2 minus it is it will be T 1, T 2 minus T 1. So, T 1 minus T 2 temperature difference is there. So, this T 1 minus T 2 is the temperature difference between the bottom plate.

So, that is how it works, and we can get the thermal resistance value of the fabric by knowing the resistance of the bottom plate, knowing the T 1 T 2 and T 3 value. So, this is the principle of two-plate tog meter.

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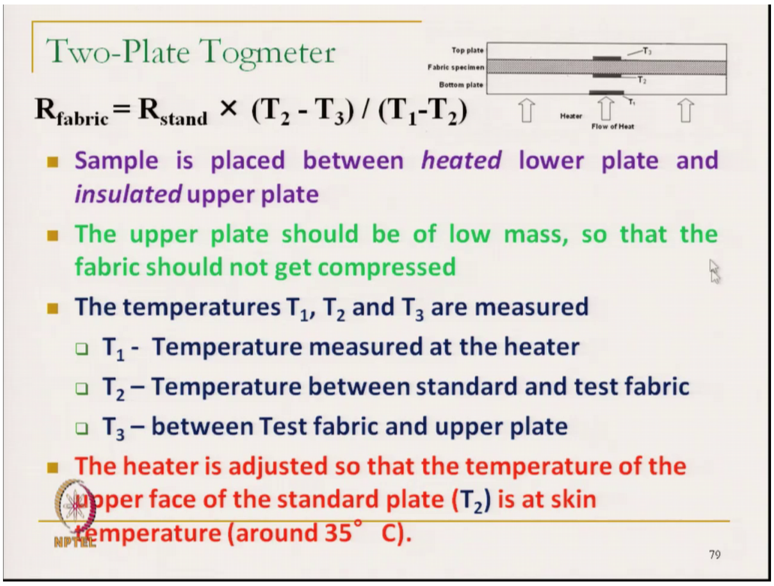

And sample is place between the heated lower plate, and the insulated upper plate. This plate, upper plate is insulated plate. The upper plate should be as low as possible. The mass should be as low as possible just to avoid any undue compression. So, these are the temperature at different point. And the heater which is important the heater is adjusted here at the bottom, there is a heater arrangement the heater temperature is adjusted in such a way, that the temperature T 2. That is the temperature at the upper surface of the bottom plate should be around the skin temperature. So, it should be around 35 degree Celsius. That is how you have to measure the keep the temperature of the heater.

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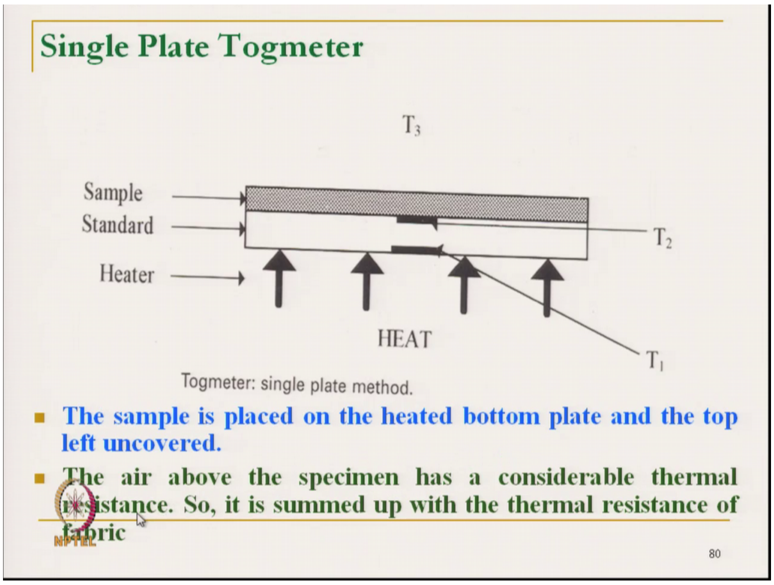

Now, coming to the single plate tog meter; so, single plate tog meter, the problem of the compression it is eliminated here. Here we use the single plate here. And the temperature I mean both side other bottom side is the higher temperature is T 1, and other side of the surface it is a T 2. And the T 3 which we take it is not at the surface of the fabric; which is some distance above the fabric area, that is it is a it takes the ambient temperature.

So, that means, here the problem is that, we have solved one problem by compression of compression, but we have added another complexity. Here it is a we are this temperature T 2, it is it takes care of the insulation of fabric as well as the air. The air insulation is incorporated here. So, that we have to take care when calculating the installation of the sample.

So, the sample is placed on the heated bottom plate. And the top plate is left uncovered. So, the air above the specimen has the considerable thermal resistance. So, initially in this technique in this method, we measure that the, it is called bare plate test. We measure the thermal transmission of thermal resistance without the fabric. Just to know the thermal resistance of the air. So, it is a bare plate test, the air above the specimen has a considerable thermal resistance. So, it is the sum up of the thermal resistance of the fabric, ok.

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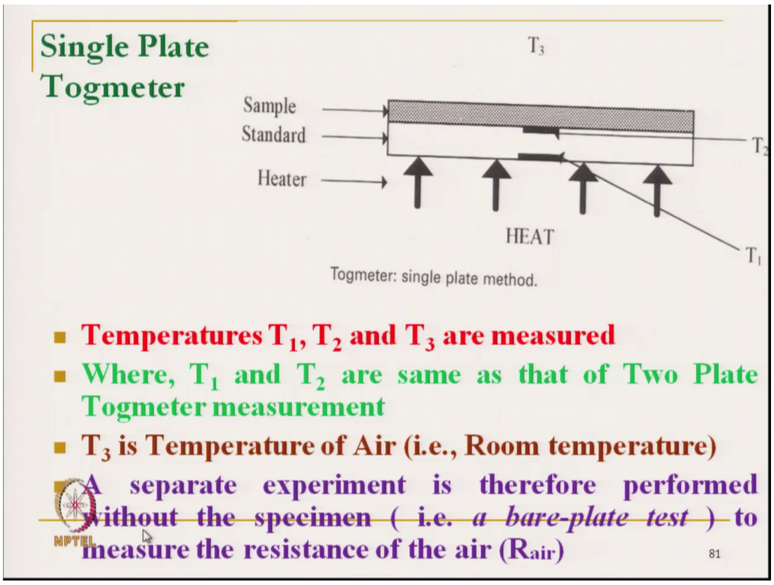

So, this total, it will be air plus fabric; so, temperature T 1, T 2, T 3. So, at T 1 and T 2 are the same as that of the 2 plate tog meter. And T 3 is the temperature of air, which is a room temperature. So, that T 3 you have to ambient temperature, a separate experiment is therefore, performed without the specimen which is called bare plate test to measure the resistance of the air, as we have mentioned.

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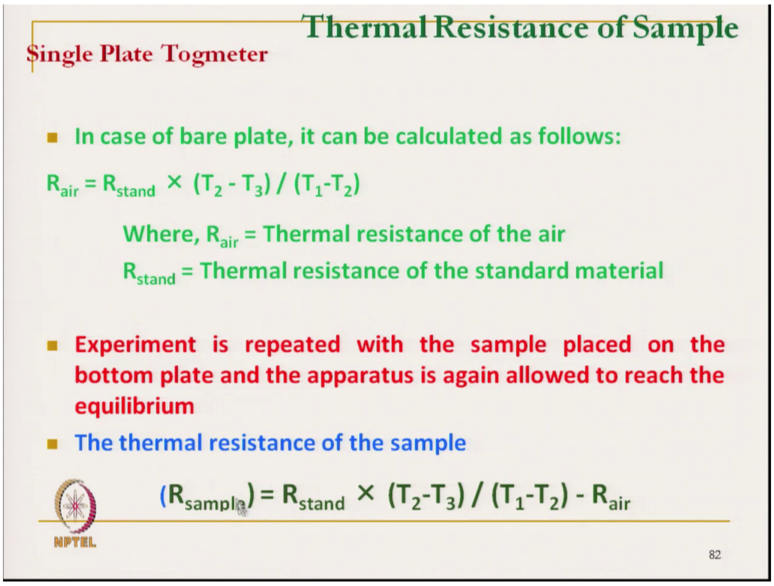

In case of base plate, it can be calculated the bare plate. So, it can be calculated the R air equal to similarly way, R standard multiplied by T 2 minus T 3 by T 1 minus T 2. So, what is this? This is actually the insulation of air; when we are measuring the thermal insulation without any fabric sample. So, thermal resistance of air and this is the standard plate.

So, the experiment is again repeated after placing the fabric sample. And the apparatus is again allowed to reach to it is equilibrium. So, that it is important that you have to allow the experiment up to the equilibrium problem. Initially, the temperature will keep on changing. So, after it reaches the equilibrium point; that means, the heat flow is stabilized. So, at after that only we have to measure the take the reading of T 1, T 2, T 3.

So, the thermal resistance of the sample is we can measure. So, this is the thermal resistance of the sample. This is the standard and if we will take this value and after that the earlier measured air resistance of air we have to subtract from that; so, that we can get the total thermal resistance of the sample. Technique here in tog meter, it is used as that that the comparing the thermal resistance of the fabric with the standard known sample and this samples are kept in series. And next technique as we have mentioned it is a guarded hot plate.

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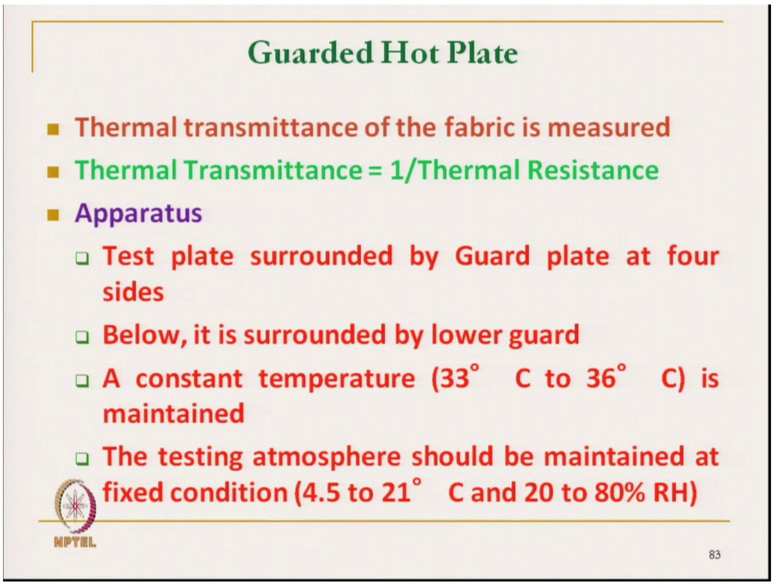

Guarded hot plate it is in this technique, we actually control the direct the heat flow direction through the fabric only, through the specimen. Not and we try to stop the heat flow from other direction. So, here in a tog meter another difference is the tog meter, it measures the heat flow indirectly by comparing the in tog meter we measure the thermal resistance. And which with which is indirect in nature, which gives an indication. But in guarded hot plate, we measure the direct, direct heat transmission. Here we do not measure the heat resistance; here we measure the heat transmission. The amount of heat amount of heat transmitted through the fabric.

So, which is actually reciprocal of heat resistance, thermal resistance; so, heat transmission is measured which is reciprocal to the thermal resistance. And this apparatus the, it has got different subcomponents. First is that it is a test plate, ok. Test plate is the plate where the actual heat transmission, the actual power drawn by the heat plate is measured. And above the heat plate the fabric specimen is placed.

So, this is the actual the main the component of the, this instrument through which the heat is transmitted through fabric. And to restrict the heat flow from the test plate to other direction, side way direction, the lateral heat flow is restricted by using the guard plate. It is covered with the, it is a basic typical it is a square in size shape. So, the guarded ring guard plate is actually placed around the, this test plate to restrict the heat flow side way.

And another plate which is the bottom plate, it is a called lower guard plate; which is placed below the test plate. So, and the temperature the all these plates test plate guard plate and the bottom plate that temperatures are kept exactly same. So, between say 30 3 to 36 degree Celsius; so, at constant temperature is maintained. If it is 33 degree Celsius, so, 30 16 degree Celsius will be maintained for all the plates. So, what does it mean? So, that if we maintain the same temperature; that means, there is no temperature gradient. So, heat will not flow to that direction. So, heat will only flow to the direction of lower temperature.

So, that is why this total system is placed at a temperature which is lower than that temperature. The standard is you can we can keep around say 4.5 to 20 degree Celsius and around 20 to 80 percent relative humidity. This is the standard atmospheric condition; where we want to keep the atmospheric temperature lower than the skin temperature so that the heat flows through the, that surface through the test plate and heat cannot flow in other direction. So, we will we will continue with this measurement techniques in the next class till then good bye.

Thank you.