Science of Clothing Comfort
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Lecture – 25
Clothing Comfort Related to Thermal Transmission (contd.)

Hello everyone. So, we will continue with the measurement of Thermal Characteristics and we are discussing the technique Guarded Hot Plate.

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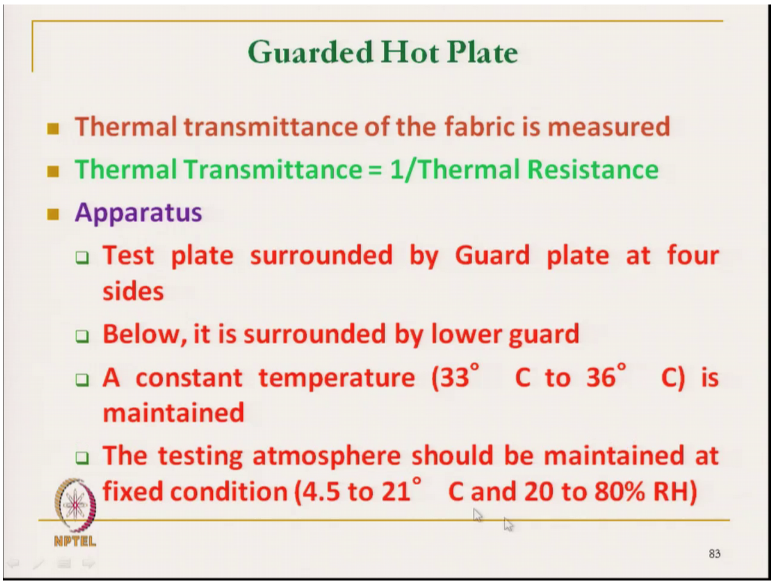

Guarded Hot Plate, here we use the technique of directly the Thermal Transmission measurement by controlling the heat flow from other directions. And thermal transmission is a reciprocal of thermal resistance. And also we have discussed that the test plate is the main component of this instrument which is covered by the guarded plate.

And, the surrounding temperature is kept 36 degree Celsius that all the plates are kept 3 to 36 degree Celsius. And the surrounding temperature is kept much lower than that and typically it is around 20 degree Celsius, it is kept one can keep between 4.5 degree Celsius to 21 degree Celsius depending on the requirement and the standard relative humidity depending on the requirement it can vary from 20 percent to 80 percent relative humidity.

And, during the test one has to keep this conditions atmospheric condition fixed. And one thing one has to take care this atmospheric temperature should be lower than this skin temperature so that heat flows out.

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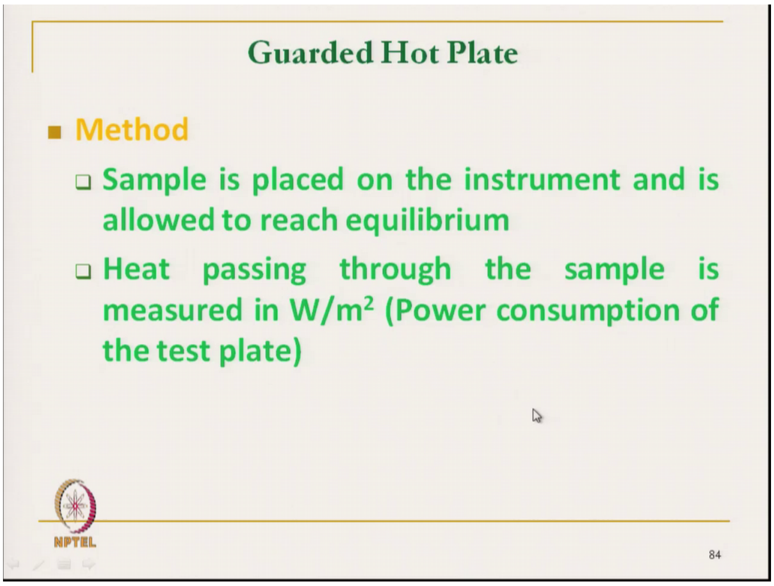

So, the method is that it is sample is placed on the instrument that is the test plate and the temperature is allowed to reach it is equilibrium. And heat passing through the sample, the specimen is measured in watt per square meter, that is a power consumption by the test plate. And as we know that we have to direct the heat flow through the fabric only; heat whatever power is consumed by the test plate that heat has to pass through the fabric only, for that the arrangement is made.

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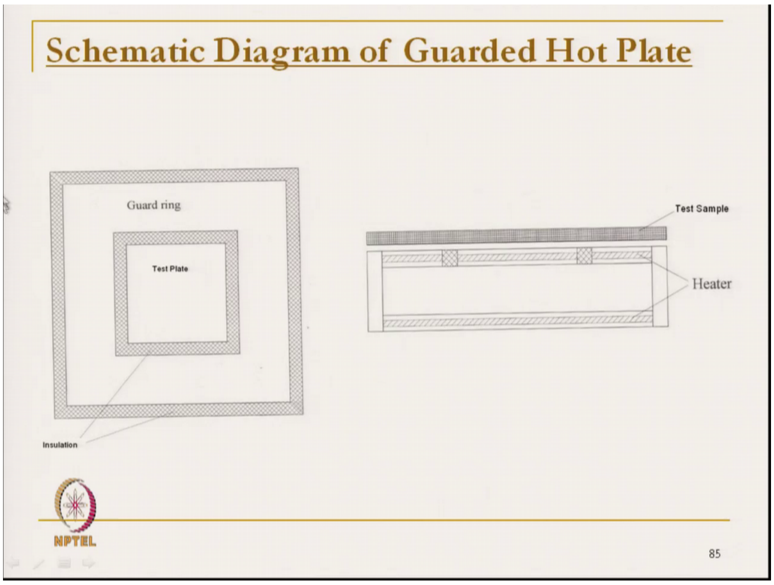

So, here this central plate it is a test plate and this one the edge which is around this test plate it is guard ring. So, they are both of both test place and test plate and guard ring are made of metal, metallic plate and there heated in exactly same temperature. So, if you see if this is the top view, if we see the side view, the central one it is a test plate. And the guard plate these are the guard plate. So, the use of guard plate is that and if we use 2 separate heater for this, another plate which is a bottom plate which is at the bottom of this test plate and guard plate and 3 separate heaters are there to heat these plates. One heater is the for test plate, another heater will be for guard plate and third heater is for the bottom plate. And the heaters the power consumption by all the heaters can be noted down.

But, actual power consumption by the heater the test plate; the heater which is say heating the test plate is used to calculate the thermal transmission characteristics of fabric. And this heaters are this plates are heated by the power source and the temperatures are kept exactly same. So, that the heat flux is not; the heat is it cannot flow sideway because the guard ring is of the same temperature there is no temperature gradient. And it cannot come at the flow to the bottom side because here the bottom plate is of exactly the same temperature.

To restrict the further heat flow between the guard ring and the test plate there is another insulation is placed which is actually scorch insulation. Some insulation material is placed around the test plate. So, that it is totally insulated and the guard ring is also some insulation is placed so, that there is no heat flow. Now if we heat the material here, so if we heat the test plate so that heat will flow only upper direction only through the top and that and test fabric sample is placed just above the test plate. The heater which is heating the test plate the power drawn by that heater is used for that heat transmission through the fabric.

So, we can directly measure the amount of heat flow through the fabric per unit area if we know the area of the test plate and per unit time also.

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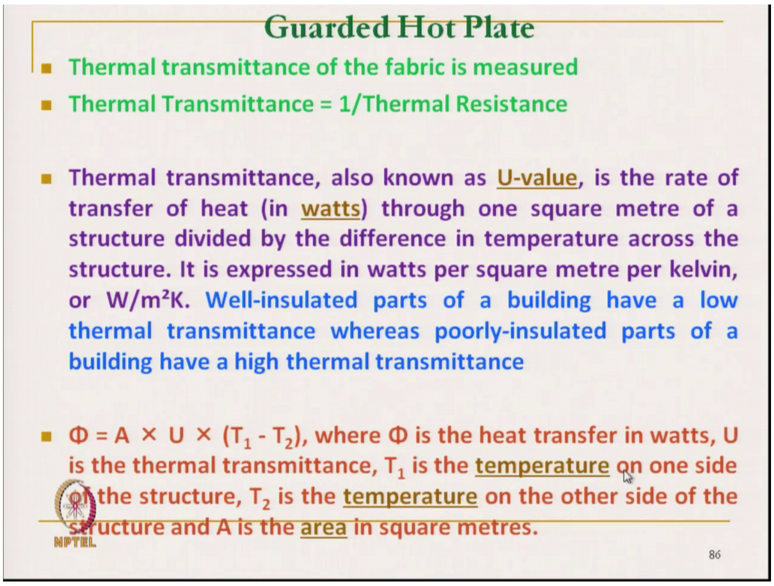

So, thermal transmission is measured here which is a reciprocal of thermal resistance. Now, how do you measure? So, thermal transmittance so, this is the thermal transmittance is also known as U- value. In general it is not only used in textile material it with this U- value it is used for any other place any other place where thermal transmission is important like building.

So, if we know the thermal transmission of insulating wall or maybe glass window this U- value is used. It is the rate of transfer of heat in watt: through 1 square meter of the structure, it may be any structure may be textile fabric a structure divided by the difference in temperature across the structure ok. So, in case of fabric, if we know the temperature between the 2 surfaces so that the temperature difference is so; which is nothing but watts per square meter per Kelvin per diff unit difference of temperature.

So, if we compare the well insulated parts of a building have lower thermal transmittance, like a thick insulating cloth will have lower thermal transmittance then a thin fabric. So, that is why the thermal transmittance is measured, the physical significance of thermal transmittance is this. Now phi is the heat transmission in watt, A is the area, U is the thermal transmittance and T is the temperature difference.

So, we can measure the heat transmission if we know the thermal transmittance of the material. Here we are doing in reverse way. In normally, we want if we want to measure the heat transmission in watt, if we know the thermal transmittance of material like glass window, one insulating wall. With a known thermal transmittance and if we know the area of that wall or if we know the temperature difference between the 2 surfaces of the wall we can measure the heat transfer in terms of wattage.

But in guarded hot plate we use the same formula, but here we want to know thermal transmittance of an unknown fabric sample. In that case we should know the heat that heat transmission in watt. So, here heat transmission in watt by measuring the heat required by this test plate.

So now, let us see the animation.

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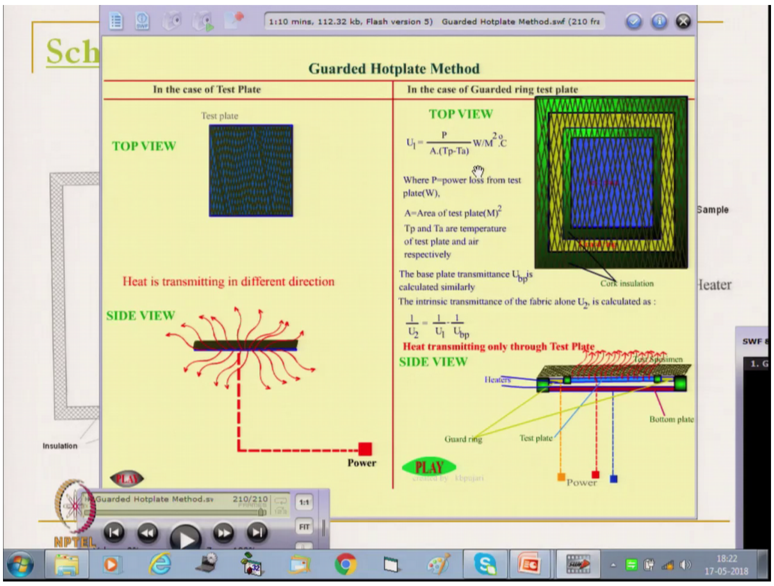

This is a beautiful animation you can see here. Now this is in case of test plate. Suppose test plate, where we do not have any fabric only test plate, there is no guard plate, there is no bottom plate, there is no fabric. So, what happened to the test plate, if we connect the test plate with the heater. Now let us see this is the top view and this is side view, and where we are putting only fabric on the test plate and nothing no guard plate. Heater is attached with that that is power source is there and this is the basic nothing but heater, the test plate is nothing but heater ok. And power source is there. And here as there is no guard plate, so heat is being transmitted to all the directions; it gets transmitted through side way, through bottom way, as well as it is transmitted through the fabric also.

Now, if we know the power required for this heater then we cannot say that this power is utilized to transmit heat through only through the fabric. It is the portion of the fraction of this heat is getting transmitted through the fabric. Suppose it is a x quantity of heat is drawn power is drawn by this heater; that means, a fraction of x will be required through the fabric, but we do not know the what is the fraction, that is the problem. That means, this system has to be modified. So, this system is modified in guarded hot plate.

So, in guarded hot plate let us see the animation. So, this is the test plate, this is the front top view, side view, this is the guard ring ok, guard ring and here it is a bottom plate, it is placed fabric is placed here. And, now these 3 plates are connected with the different power source. Red one is connected with this test plate, this blue one is a bottom plate and yellow one is a with the guard ring. And now we can see the from red one, red power source the heat is flowing only though the fabric and it is not going to any other direction. So that means, whatever heat is flowing through the it is a drawn the power is drawn by the test plate that if it is known, if it is P the power drawn by the test plate at if we know the area of the test plate A and the temperature difference between the test plate 2 sides of the test plate and then that case we can calculate the U- value. That is the thermal transmittance it is P by A multiplied by Tp minus Ta. So, that is how we can measure the thermal transmittance of the fabric.

Now, so thermal transmittance of the fabric is we can measure by. So now, coming back to this measurement again so, this temperature difference if we know we can calculate the value of U.

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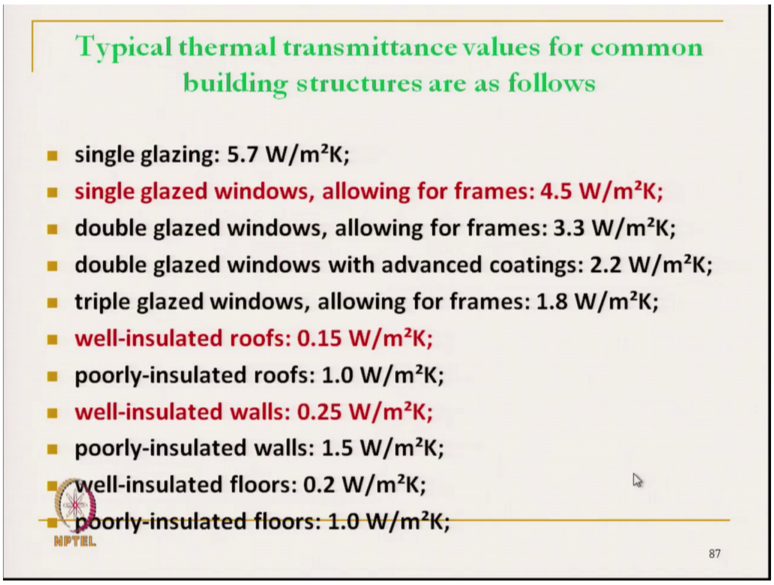

So, we can see the typical values; typical values of some known material, because it is a single glazing type glass so it is a 5.7 watt per square meter per Kelvin. So, these are the different; so well insulated wall it is a 0.25 watt per square meter per Kelvin.

Well insulated floor these are the typical value. So, why are we using this value, why do we want to know this value? Just to get an idea about the standard insulation of standard material which we regularly come in to contact with this type of material. So, triple glazed window allowing for frame it is 1.8 watt per square meter per Kelvin.

Now, if we compare these values with our textile material we can just see the insulation of this thermal transmittance of this material. So, there thermal transmittance value are very low. So, insulated wall poorly insulated wall it is 1.5. So, well insulated to one it is 0.25.

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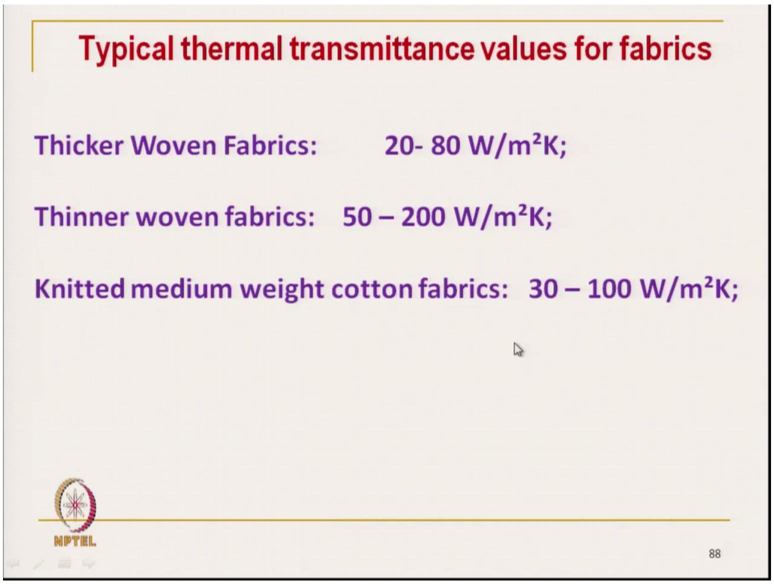

So, if we see as compared to this with the same unit the fabric material it is a say thick woven fabric it gives 20 to 30 watt per square. So, if we have thick woven fabric, the type of insulation we are getting it is much less so, very high thermal transmittance.

So, we must know this value then only we can try to develop clothing for some insulation purpose, thinner woven fabrics it is a 50 to 200 watt per square meter per Kelvin. So, these are the different values.

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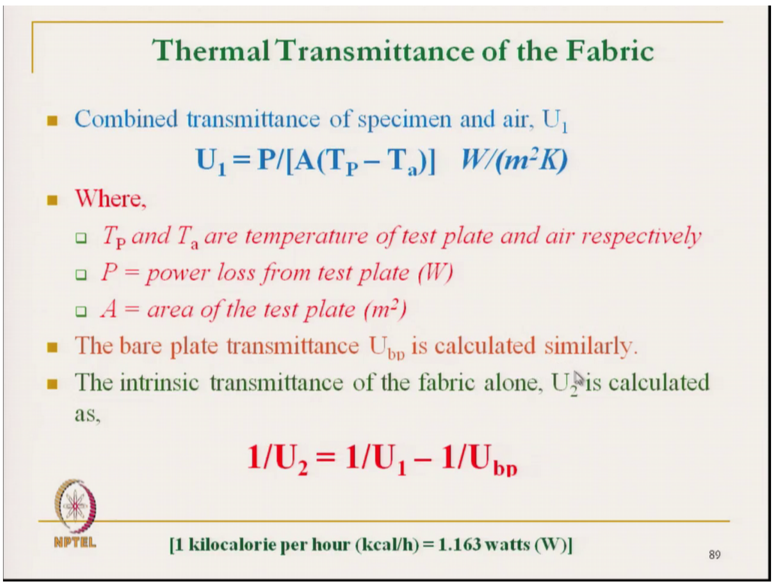

And, now what we have got. So, combined thermal transmittance is what we get, it is a combined means it is a including the layer. So, it is U 1 is the combined insulation; P is the power loss from the test plate, which that means, the power drawn amount of quantity of power drawn by the test plate. A is the area of the test plate and T a T p and T a are the temperature of test plate and ambient air.

And then, what we have to do? To know the transmittance of air again we have to perform the bare plate test. So, the bare plate test is that it is a; and there for bare plate test we will get the value U 2, U 2 this calculated the transmittance of fabric. So, U bp is the bare plate which shows the air the thermal transmittance of air. So, effectively finally, if we want to may know the thermal transmittance of fabric. So, this is the formula 1 by U 2 equal U 2 is the thermal transmittance of fabric equal to 1 by U 1 minus 1 by U bp.

So, using this formula we can measure the, calculate the thermal transmittance of fabric itself.

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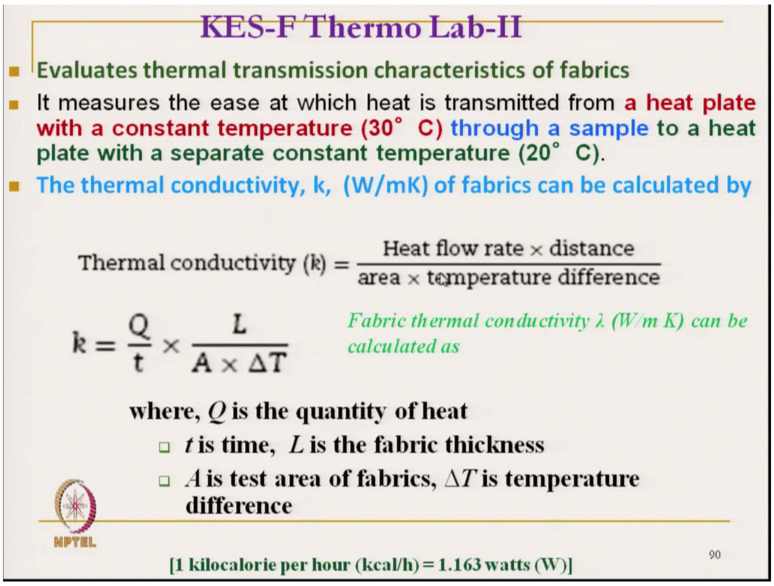

Now, another method measurement of thermal transmission characteristics is the KES-F Thermo Lab ok. It evaluates the thermal transmittance characteristics of fabric where 2 plates are used and in between the 2 plates fabric sample is used.

So, the heat plate with a constant temperature of 30 degree Celsius and cold plate it is a separate plate with a lower temperature which is standard 20 degree Celsius in between there fabric is sandwiched. And then the amount of heat flow is measured the thermal conductivity is measured in terms of heat flow rate and distance by area and temperature difference. What is the distance? This is the formula: the heat flow rate Q by t and that heat flow rate from the heated plate ok, L is the is the fabric thickness that this distance between the 2 plates, A is the area and delta T is the temperature difference which is constraint here it is a 10 degree Celsius.

So, this using this thing this equation we can calculate the thermal conductivity. So, thermo lab it is measure the thermal conductivity, Tog meter measures the thermal resistance and the cardioid hot plate measures the thermal transmittance.

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Then coming to another method of measurement of thermal transmission characteristics it is using the Thermal Manikin. Thermal Manikin it gives the idea of total thermal transmission of clothing it is not in the fabric form it gives in the clothing form and it measures the 3 dimensional measurement technique, 3 dimensional it a heat flows at different direction at different dimensions.

It is used for testing and product development by building and automobile industries. So, that in there it is used extensively, also in textile industry it is used for developing clothing with improved thermal properties and performance testing of protective textile. So, for protective textile performance testing's thermal manikin is extremely important. Particularly for those applications where its a hazardous environment where extremely heat, extreme hot, extreme cold, temperature where normally we cannot perform the subjective assessment ok.

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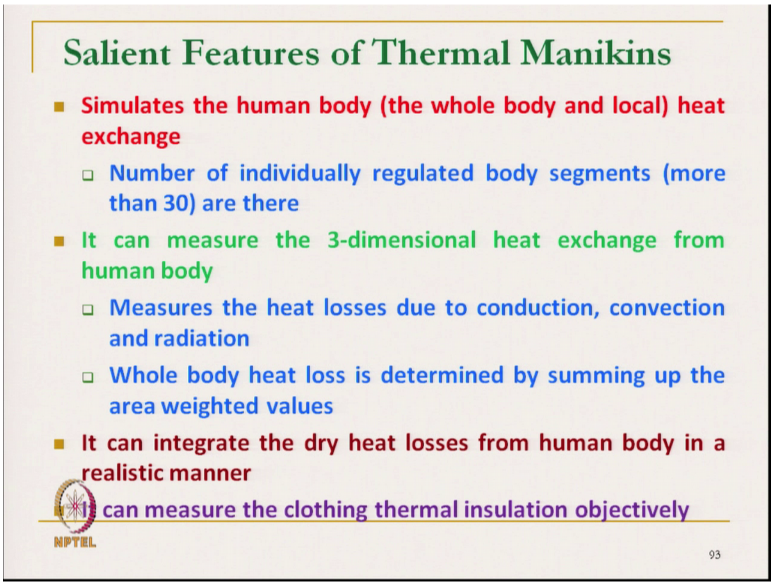

It is basically it simulates the total human body and it is divided into many segments, typically 20 to 30 different segments it is divided and different sensors are placed.

So, number of individually regulated body segments it is a more than 30 now. So, at different body segments the sensors are placed where it measures the temperature and heat flow. It can measure the 3 dimensional heat exchange from human body, measures the heat loss due to conduction convection and radiation. So, the whole body heat loss is determined by summing up the weighted average.

So, it at different location we measure the heat loss and then we measures the total heat loss by weighted average at different like or depending on the area of that particular zone. So, we can measure. So, here it gives the total heat loss, it can integrate the dry heat loss from the body in a realistic manner. So, it actually that in dry heat loss and also there is another type of magnetic manikin it is a sweating manikin. So, there it actually simulates the sweat and measures the heat flow.

So, here it is a actually realistic manner means, the actual heat flow at different direction different level it can simulate and clothing thermal in solution it can measures objectively. So, actual clothing it is not the fabric sample here actual clothing it can be measured.

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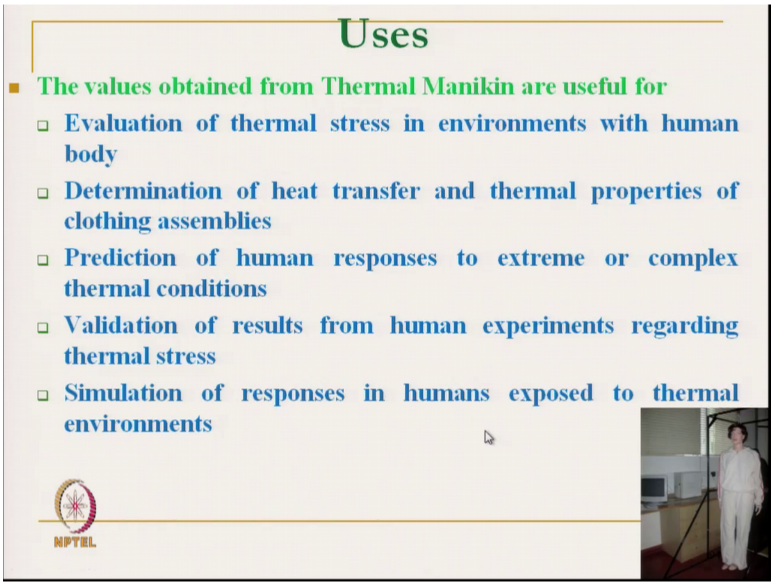

So, it is used to evaluate the thermal stress in environment with human body, determine the heat transfer and thermal properties of clothing assembly. So, it is total clothing assembly it is thermal transmission it can measure means a number of clothing. So, it is not only the outer clothing or a single layer it is a different types of clothing including the gloves and shoes also.

So, total clothing it measures inner garment everything. Prediction of human response to extreme or complex thermal condition, where we normally we cannot go, we cannot perform test in those condition thermal manikin is used like extreme heat or flame in that those condition and it gives realistic value, and it validates the results from human experiments. So, even it can validate the subjective assessment.

So, that a manikin test we have seen so it gives the realistic picture. So, after now we will discuss the other techniques to measure the thermal protective clothing for extreme heat.

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So, it extreme heat and it also measures the flame protection.

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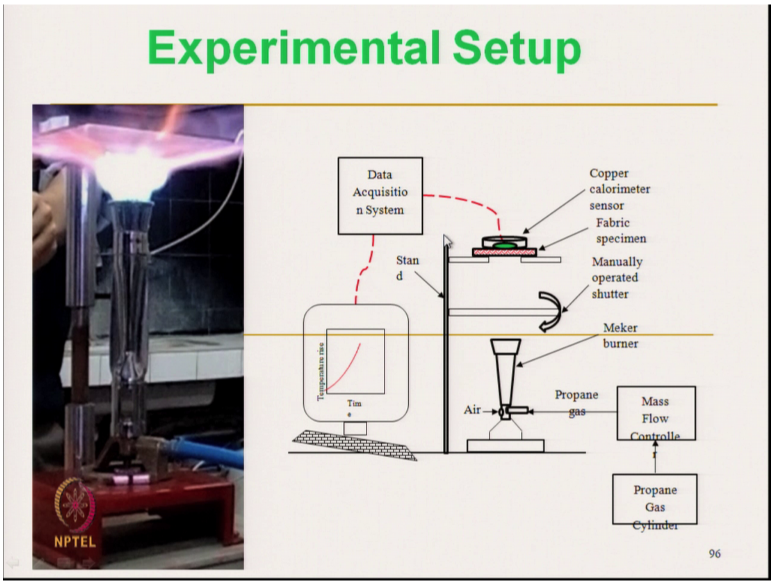

This is one technique, its the instrument has been developed here in our lab. So, where the fabric is kept in the test sample is kept in horizontal position and here it is a sensor where it is a copper calorimeter sensor and fabric sensor specimen is there and this is a burner where direct flame is actually place generated. And there is a fabric, this a blocker, the shutter is there and shutter is removed manually, but way one can do automatic removal also.

When shutter is removed the direct flame is the fabric is exposed to the direct flame and the heat flown through the fabric is measured for certain time. And this instrument we are not interested in the barn characteristics of fabric. We are interested here in the thermal transmission heat transmission due to the flame and this calorimeter the sensor measures the heat transmission. And the temperature increase, temperature increase in that which is sensed by this calorimeter it is plotted against the time and which by knowing the rate of increase in time one can predict the time required for second degree burn ok, if we compare with the stoles card.

So, that way this instrument will give the idea of exposure time of second degree one. Now why is it important? So, suppose person of firefighter or some any anyone who is actually exposed to heat, the particular fabric how long will it actually be protect the will be able to protect the person from any burn injury. So, there are 3 types of burn injury I will discuss here.

So, this is the experimental setup.

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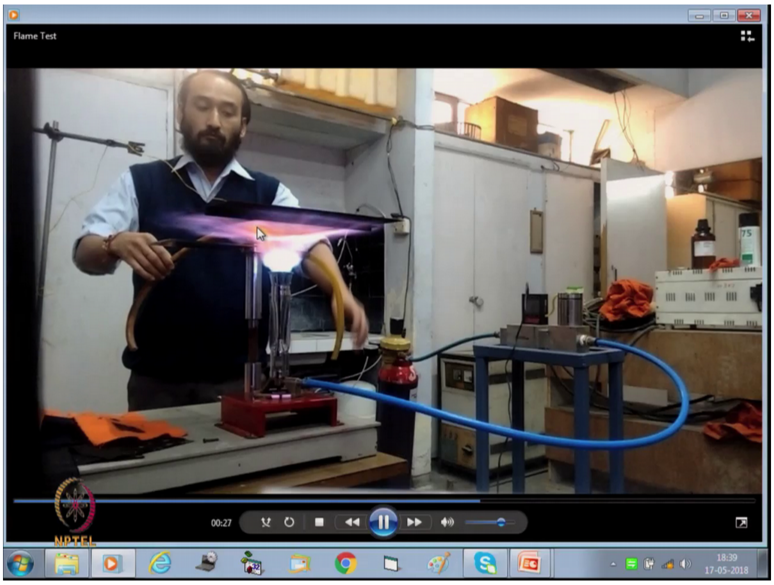

Now, let us see the experiment real experiment. Now it is adjusting the flame rate we can adjust the rate of flame that can be automated also, now this is now forming now the blocker that is way that is if and it is remove this blocker. Now with the time the temperature is recorded and after said 10 second standard time or maybe we can have a 15 second 20 second after certain time it is removed that is the burden stopped. And we know the temperature rise with the time. And that, if we know that with the time and knowing the time so we can now predict that particular sample how long one can actually survive in case of fire without any burn injury.

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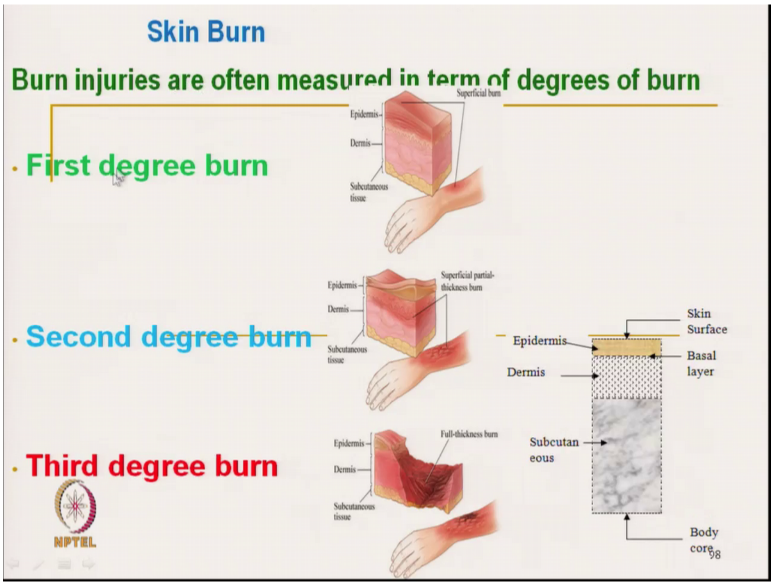

So, there are mainly 3 types of burn injuries: one is first degree burn injury which is very the low intensity; where it can get recovered quickly. Second degree burn injury is a severe one, but one can actual recover it is but. Third degree burn injury we cannot do anything. So, our is this instruments idea here is to predict the second degree burn injury because, then third degree burn injury means that there is skin total a skin structure is destroyed.

Now, let us see.

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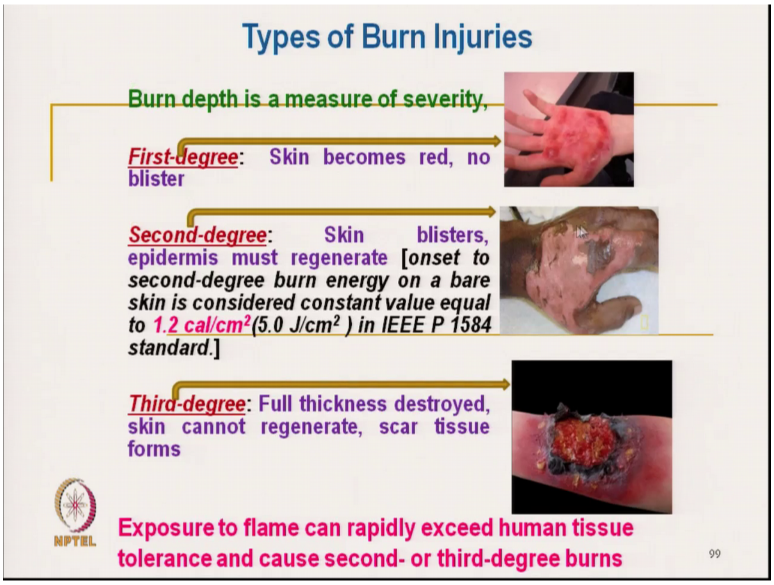

The burn depth is measured by it is severity. So, first degree burn injury is the skin becomes red no blister so that means, that is normally you can get it covered quickly. But second degree burn injury means; that means, it can be recovered, but it after a long time and the person can survive skin blisters, epidermis must be regenerated; so epidermis what is our surface that should be regenerated. So, that is a type of burn injury and third degree burn injury means it is totally it is destroyed. So, our idea here is to know the time required for second degree burn injury.

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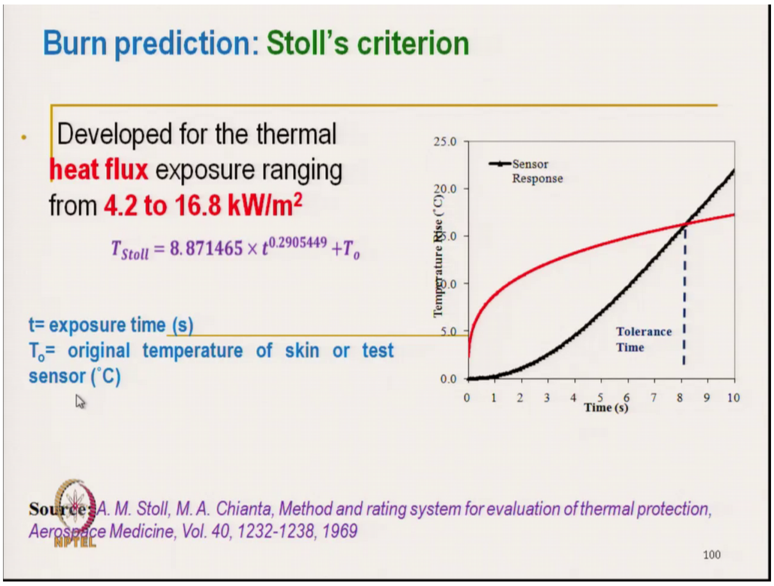

And this is the actually this is the Stoll’s curve here. And this is the curve which we have actually got from the instrument this black one and the point where it is actually intersect with this standard curve that is the tolerance time. So, that time if it goes beyond that; that means, then yours third degree burn injuries will start.

And in this instrument heat flux is actually 4.22 16.8 there is a heat flux. And this Stoll’s equation. So, this is the Stoll’s equation where T 0 is the original temperature of the skin or test sensor.

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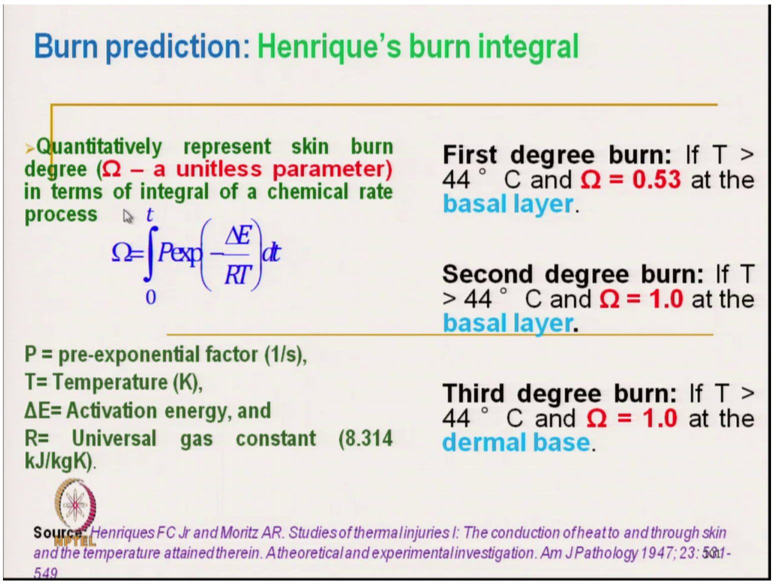

So, these are the 1 ttt a representation of the skin that the omega is the quantitative value. And with this value this is the integral, this value this is the term integral of this omega value it if it is 0.53 it is a first degree burn ok. And if it is 1 that is second degree burn in if it is express in the basal layer and if it is dermal layer then it is third degree burn. So, that way one can get it is a thermal integral.

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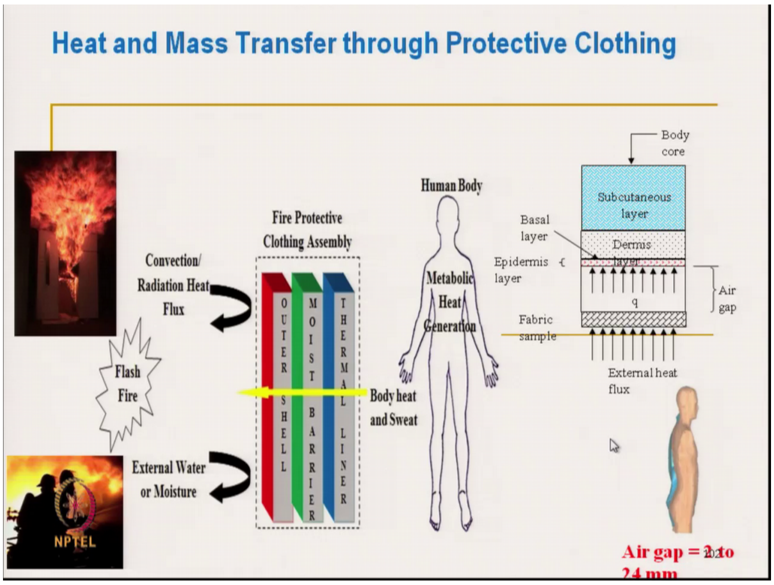

And, earlier instrument what we have observed it is we have seen that the fabric is in the horizontal direction. But most of the condition if we talk about our clothing, the fabric layer is in vertical condition. So, it is important to know what is actually happening in the vertical condition.

When the heat source; heat source may be radiant heat source or maybe flash fire comes from the side. So, this is the fabric layer, fabric layer typically it is a 3 layer, one is outer layer, that is a middle layer and the inner layer. So, the outer layer which is basically it is a protective layer thermal protective layer middle layer it is insulating layer and this inner layer which is basically absorbent layer. In case of any sweat and anything it comes out from the skin so, it should be absorbed.

And middle layer will actually it is insulating, it will not allow the heat to flow through that through that layer and outer layer which will actually prevent it from the burning. And also it will act as a reflective layer. So, in outer layer we can have some reflecting layer. So, that the maximum radiative heat at least it should get reflected.

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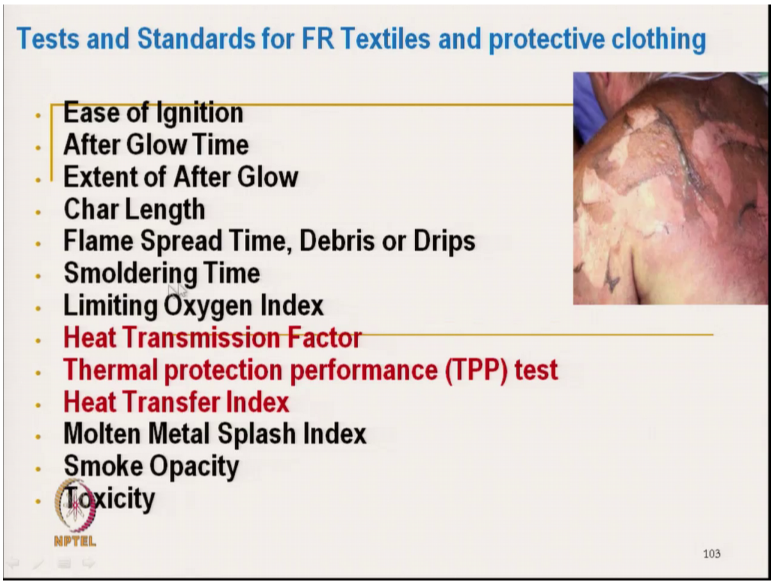

And the type of measurement for fire retardant textile or protective clothing there are different types of parameters one can measure, like ease of ignition. What is that mean say the way that how quick it get ignited, so that depending on the type of fiber, type of finished material, if we can actually use different types of finishing treatment to change this parameter.

After Glow Time is one of the parameters, Extent of After Glow, Char Length is another parameter, Flames Spread Time is another parameter, Smoldering Time, limited LOI Limited Oxygen Index ok. Heat Transmission Factor, Thermal Protective Protection Performance TPP Test, Heat Transferred Index ok. These are the different ways of expression of the fire rated in textiles, but here in this instrument these 3 parameters will be measuring: Heat Transfer Transmission Factor, Thermal Protection Performance and Heat Transferred Index.

These 3 parameters quantities can be measured using this new equipment.

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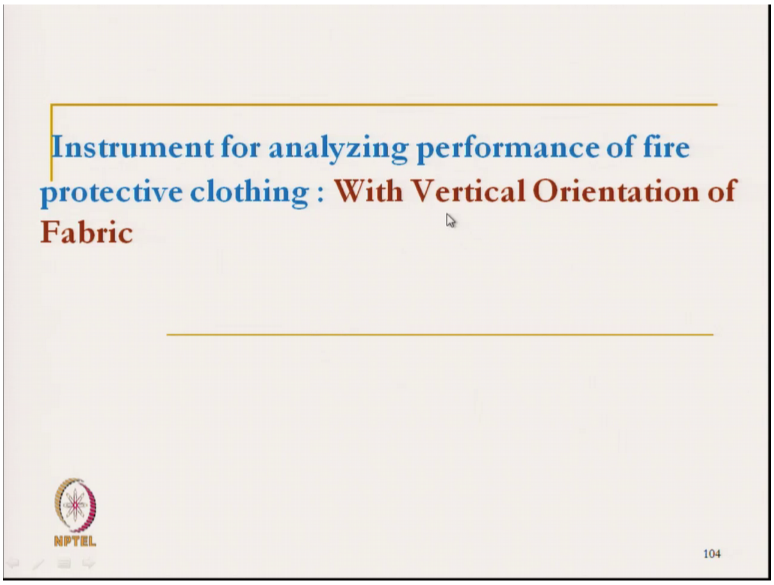

So, the instrument for a here it is a vertical orientation of fabric.

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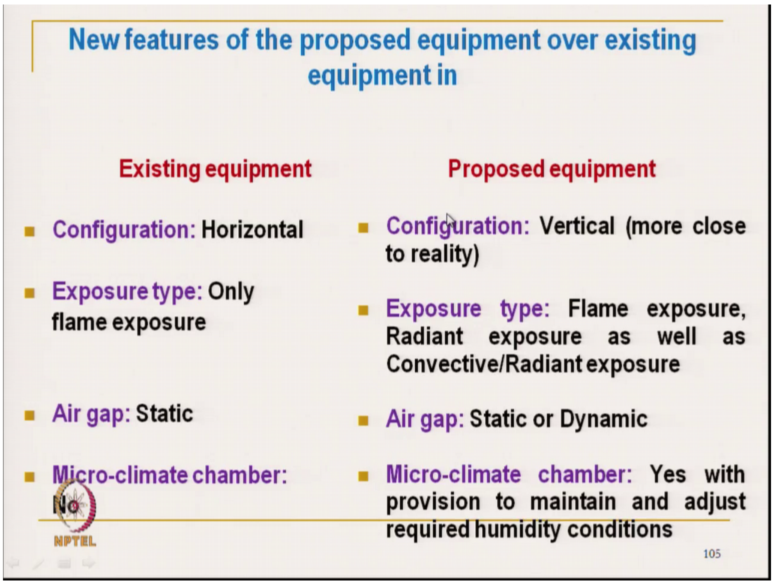

Now, that existing earlier instrument is that it is a horizontal orientation the other most of the other instrument like sweating guarded, hot plate, Tog meter. So, all this instruments are horizontal orientation, but the thermal mannikin is the vertical and it is a 3 dimensional, but this instrument it is a only vertical orientation which is more realistic. The exposure type earlier we have seen in the video it is only flame type exposure, but this vertical instrument it is a both flame and radiative heat flow and it can work both at a time.

Air gap was stationary air gap there is and in this instrument we can change the air gap because that to simulate the air climb that air gap between the skin and the fabric that is the microclimate thickness. And microclimate is not there that earlier instrument we cannot chase the microclimate, but here we can chase the microclimate; the humidity of the microclimate we can change.

So, at different humidity level the thermal transmission behavior and the exposure which we get, the comfort which we get will be totally different. So, this instrument gives all these advantages; who are the existing instrument.

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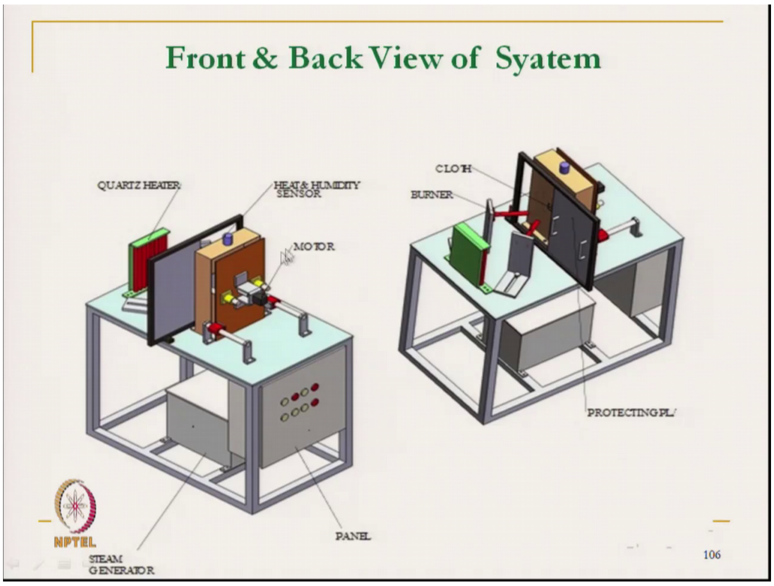

This is typical view of the instrument; here this is the source of heat. So, this is the radiative heat source and along with the burner to give the flame, this is fabric holder fabric sample is there. And this one is the chamber, the climatic chamber where we can control the humidity.

So, humidity of this is control just to simulate our microclimate humidity. And at the back of this here it is a the sensor though which will measure sense the temperature and heat flow we can measure. And this is connected with the motor; this is connected with the motor just to control the change the air gapped, air gapped is controllable. At different air gap this can be this that the thermal transmission can be measured ok. At different level of heat so, we know it is a radiative heat by flame walls. Now try to see.

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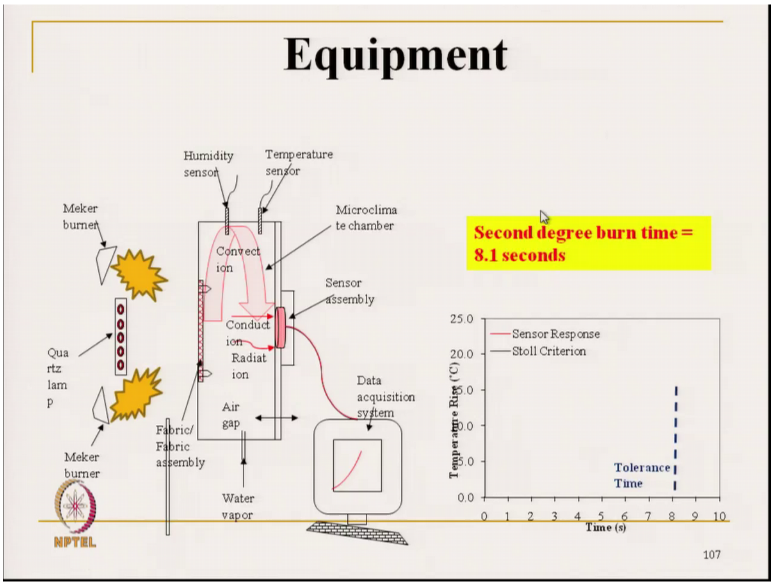

This is the flame, it is a flame and here it is a radiative heat source, it is the flame source, this is the radiative heat source. The burner is there for flame and it is a quartz a lamp is for radiative it. We can change the number of lamps to increase or decrease the rate of radiation radiative heat and this is the chamber where the fabric is placed here and fabric holder, these are fabric assembly. And this is the chamber where we can actually change the humidity of this chamber. And also the depth of this say change that this distance of this chamber is can be changed to change the air gap.

Now, this is the air gap it which is changeable as we have seen by motor we can change this distance and here is the sensor; sensor assembly. And sensor assembly is connected with the computer which directly gets the temperature value. And this is the microclimate chamber, where we can actually inject the water vapor or we can draw the water vapor to maintain the humidity level and humidity level is maintained by actually measured by the humidity some sensor.

So, at different relative humidity we can get the heat how much temperature how much heat is flowing, what is the temperature of the skin at the other surface of the fabric, what is the temperature of the microclimate that we can measure here, temperature sensor is there, this is the equipment and this is the shutter.

So, when we want to measure start thus experiment you just remove the shutter and we immediately start the experiment. This is the showing the flame, shutter is removed the heat is flowing it is flowing through the fabric and ultimately the sensor is receiving the sensor temperature and temperature is increasing and we are getting the plot ok. And here we can circulate the humidity, we can inject the humidity at different humidity level.

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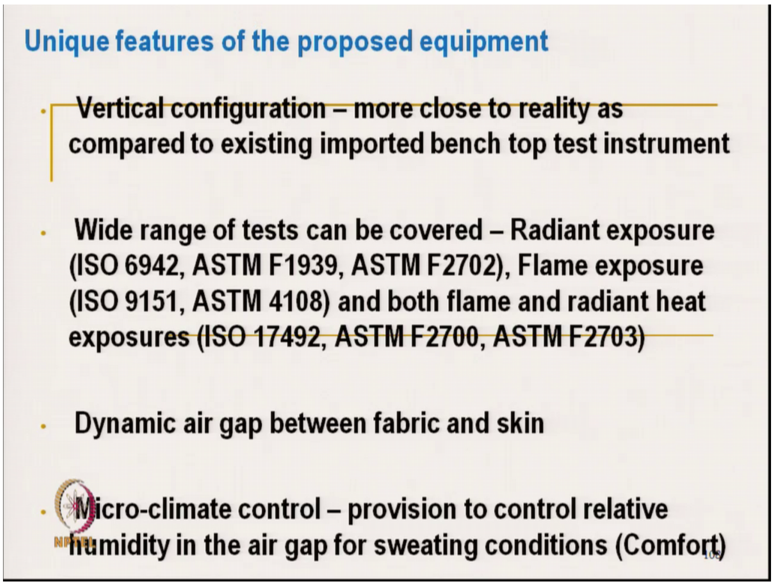

So, this is the vertical configuration more closely to the reality ok, it is as compared to the bench top instrument, wide range of test can be covered by Radiant exposure using ISO 6942, ASTM for ASTM F 1939, ASTM F 2702 this all this standards can be followed, Flame exposure by ISO 9151, ASTM 4108. So, this standards can be followed and both flame and radiant heat exposure by this standard.

So, this is a total, so widely it can be used dynamic air gap between fabric and skin, micro climate control it is to control the microclimate humidity to simulate the sweating.

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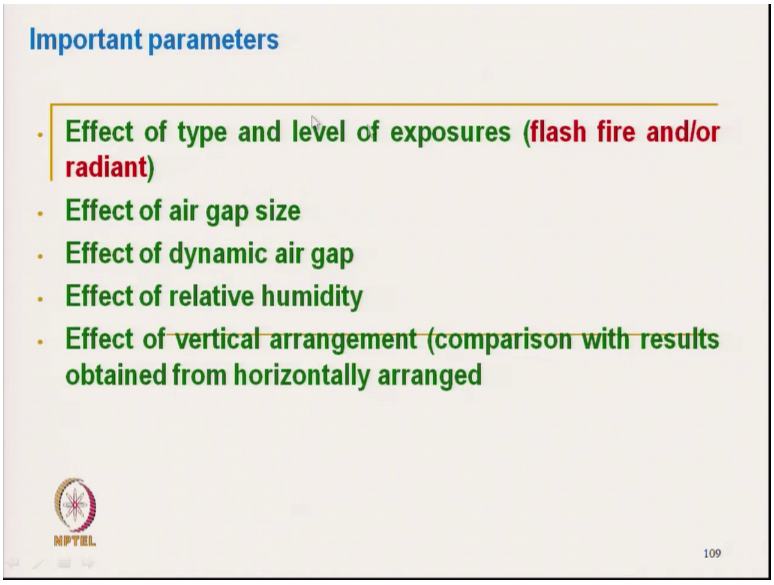

So, the important parameters are effect of type and level of exposure can be measured. So, different level of exposure we can measure, effect of air gap size, effect of dynamic air gap. So, if normally it is very important as far as clothing comfort is concerned when we are in motion.

So, at when we move that air gap keeps on changing; air gap keeps on changing so, that also it simulates. So, effect of relative humidity whether we sweat or not whether we generate humidity, so that also it can measure; and vertical arrangement. So, that way this instrument gives complete information about the fire protective clothing.

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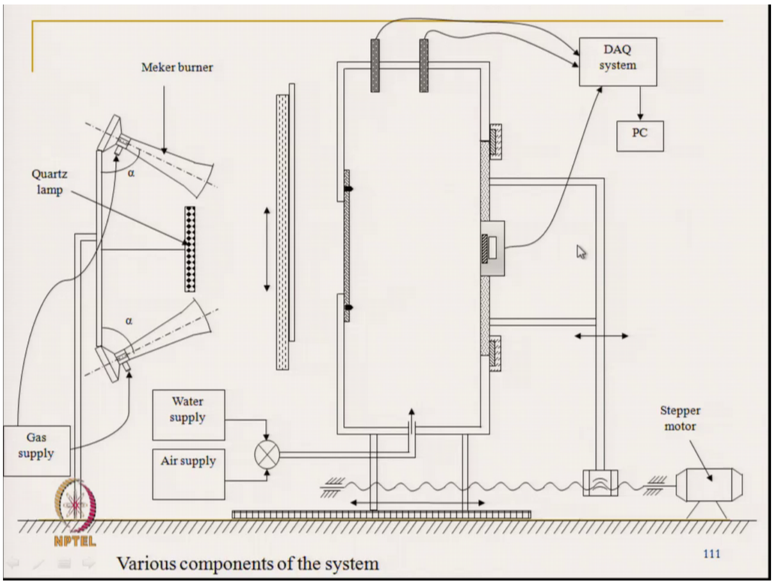

And this is actual picture in. Now we will discuss the various thermal transmission parameters. Till now what we have measure we have discussed the different-different measurement technique. Now we will discuss the different thermal transmission parameters which are practical in nature, and how to correlate with this practical units with the units which we have got from the instrument.

So, the practical unit is like Clo. So, that is used for any clothing. So, this all these parameters we will see.

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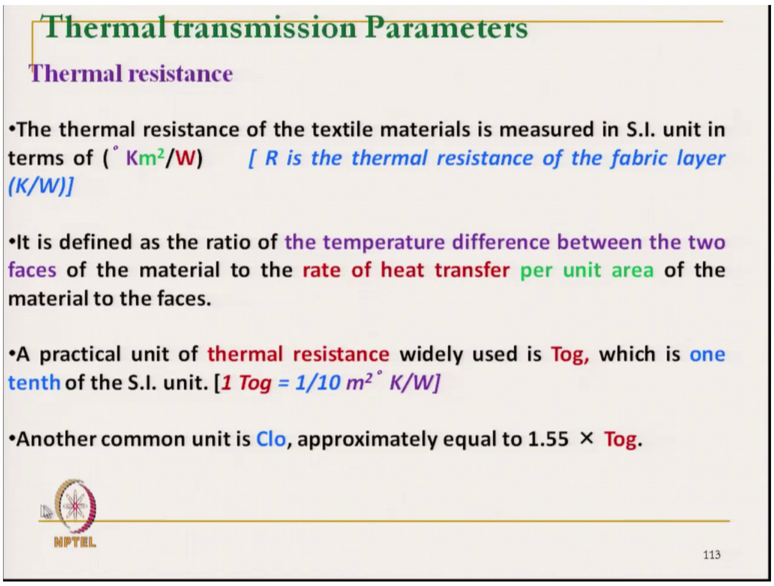

So, what is thermal resistance that we know?Thermal resistance of textile material is a measure in S.I. unit in terms of degree Kelvin square meter by Watt. It is a basically it is a reciprocal of thermal transmittance and which we measured in said sweating I had guarded hot plate we have seen there we measured watt per square meter per degree Kelvin. Here it is just reciprocal of that and R is the thermal resistance of fabric layer.

It is actually defined as the ratio of the temperature difference between 2 phases of the material to the rate of that is difference between the 2 phase of the material temperature difference and to the rate of heat transfer per unit area of the material, that is the rate of heat transfer per unit area of the material to the phase surface.

The practical unit is that it is a Tog, practical unit of thermal resistance is widely used as a Tog which is actually 1 tenth of the S.I. unit. So, 1 Tog is one-tenth of square meter degree Kelvin per watt ok. And one another unit is a Clo, which is approximately equal to 1.55 into Tog.

So, this all this Clo, Tog will discuss in next session. So, here thermal transmission different parameters will continue. So till then goodbye.

Thank you.