Science of Clothing Comfort
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Lecture - 37
Combined Heat and Mass Transmission & Clothing Comfort (contd...)

Hello everyone welcome back. So, we are discussing the Combined Heat and Moisture Transmission phenomena related to Clothing on Comfort. So, we are discussing now the clamminess sensation. So, here we are comparing with two types of fibers. So, one is hygroscopic fiber like wool and hydrophobic fiber like a polyester.

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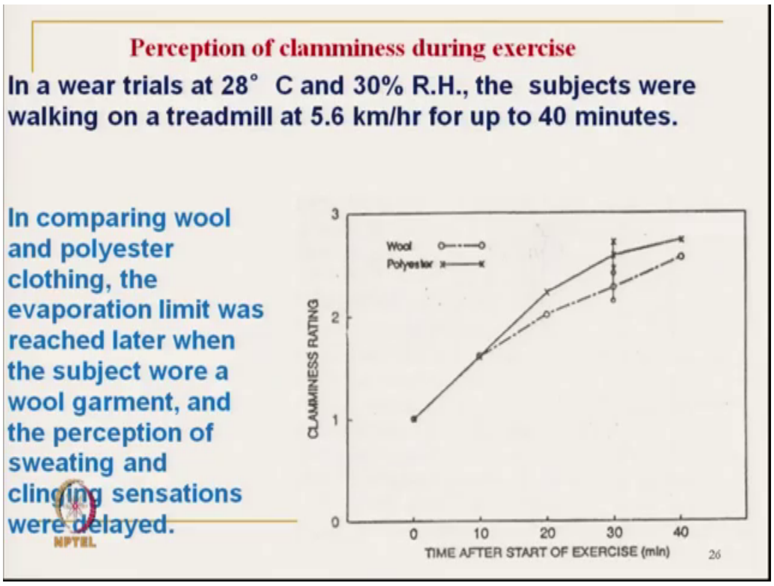

So, in case of wool we have seen that wool actually delays the clamminess sensation because it absorb moisture from the micro climate and it delays the clamminess sensation of wear.

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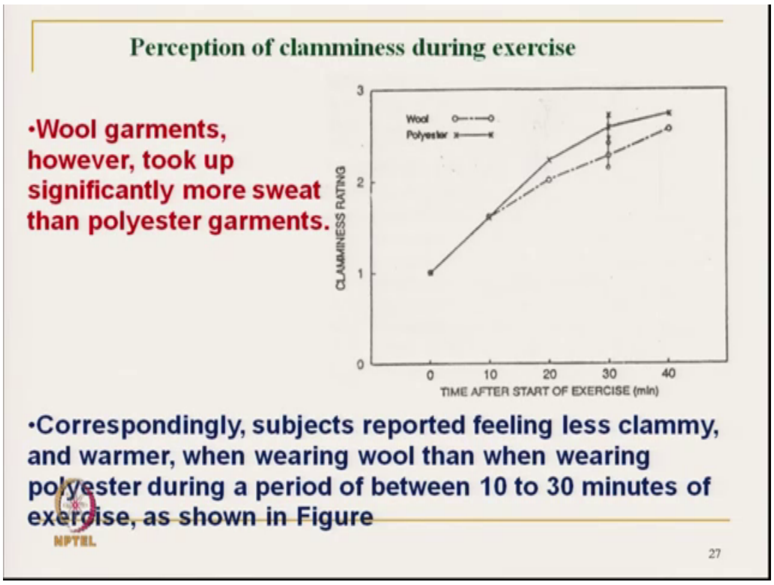

That is wool garment took up significant moisture, significant sweat from our skin as compared to polyester and correspondingly subjects reported feeling less clamminess and warmer when wearing wool because warmer due to the heat of sorption. Then, when wearing polyester during a period between 10 to 30 minutes, warmer wool one is due to the heat of sorption and another is due to that it is not totally wet, but polyester clothing it does not absorb. It gets wet and the total conductivity of heat also reduces.

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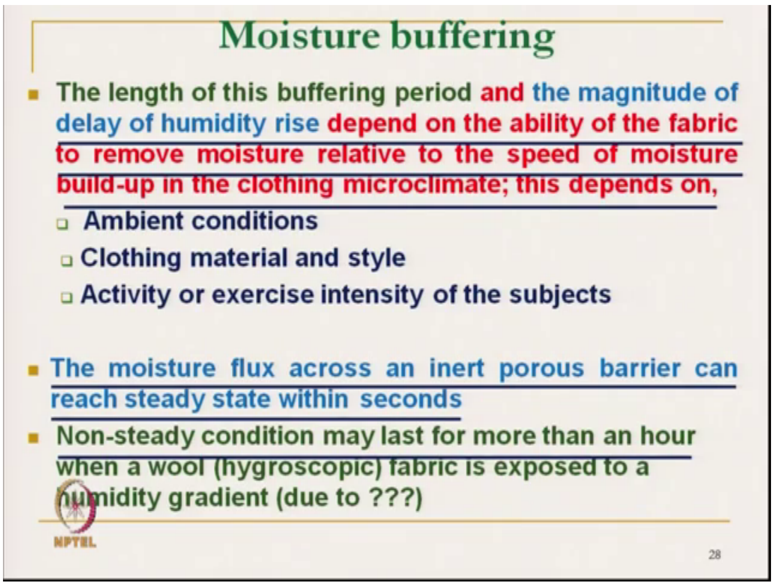

The length of the buffering period by the wool fabric and the magnitude of delay in humidity rise in the inside the wool fabric depend on the ability of the fabric to remove moisture relative to the speed of moisture development.

So, if a person develop moisture at certain rate due to certain activity, if the clothing if he is able to remove, absorb that moisture quickly, quicker than the generation of the moisture, you will feel actually dry. You will not feel clamminess, and this depends on the ambient condition that this if ambient humidity is less. That means, you will the cloth will try to absorb, take out the moisture from the micro climate at faster rate. If the ambient condition is wet, it is saturated condition. That means, the fabric that the fiber has already absorbed moisture from the environment.

So, it will not be able to absorb the sweat from the skin or from the microclimate in that way. So, it will delay clothing material and style. That obviously depends on the fiber type and the types style means the style of the fabric. That means, it is a design of fabric style of the clothing whether proper ventilation is there, whether it is a loose fit or tight fit. So, all these factors determine the buffering period and activity or intensity of exercise. So, if it isvery active, its rate of sweat generation is very high. So, then in that case the moisture development will be different.

So, the moisture flux across and inert porous media, it is basically is a, it is instantaneous because porous and inert when it does not absorb moisture, that means it works in as we have discussed it is Fick's law, it is Fickian. It flows through the only force through the diffusion. It goes, it is instantaneous and it goes immediately, but in non-steady condition. It may happen in case of say hygroscopic fiber, what it happen it actually it allows the moisture to transmit it through the force as well as it absorb the fabric, absorbs moisture and gradually it gets transmitted.

So, that is we have already discussed this issue, steady state and most of the cases in hygroscopic material it is non-steady case, because it in two way for Fickian diffusion, non-fickian diffusion take place.

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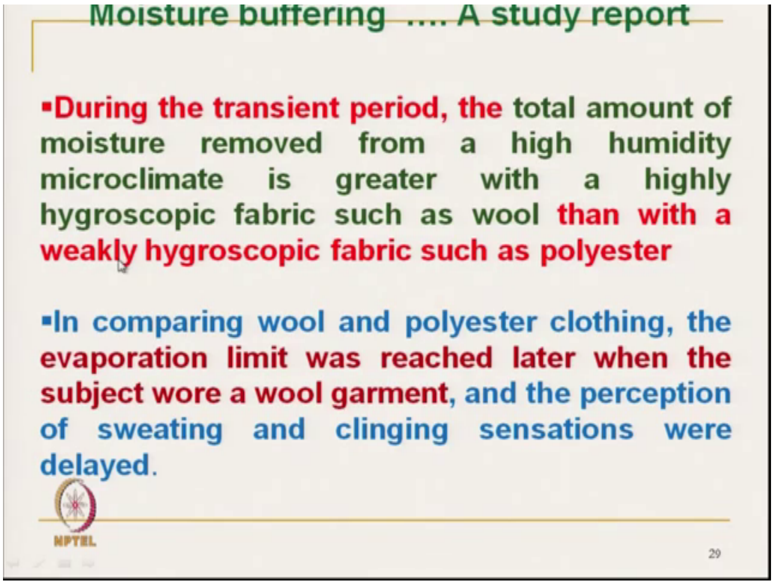

During the transient period, that means initially when it keeps absorbing, it has not keep to the steady state condition. The total amount of moisture removed from high humidity microclimate. That means, within from the skin and clothing that microclimate is greater with highly hygroscopic fabric, such as wool that is the amount of moisture removed will be very high. In case of hygroscopic wool material will like wool then the hygro weakly hygroscopic fabric when hydrophobic fiber like polyester.

In comparing wool and polyester clothing, the evaporation limit was reached later when the subject wore wool garment that we have already discussed because wool absorb moisture. So, that means the limit will reach later, and the perception of sweating and clinging sensation were delayed. That means, it will sense the clinginess or sweating in, it will delay it will after certain time. It is not immediate. That means, clamminess feeling you will feel at later delayed time.

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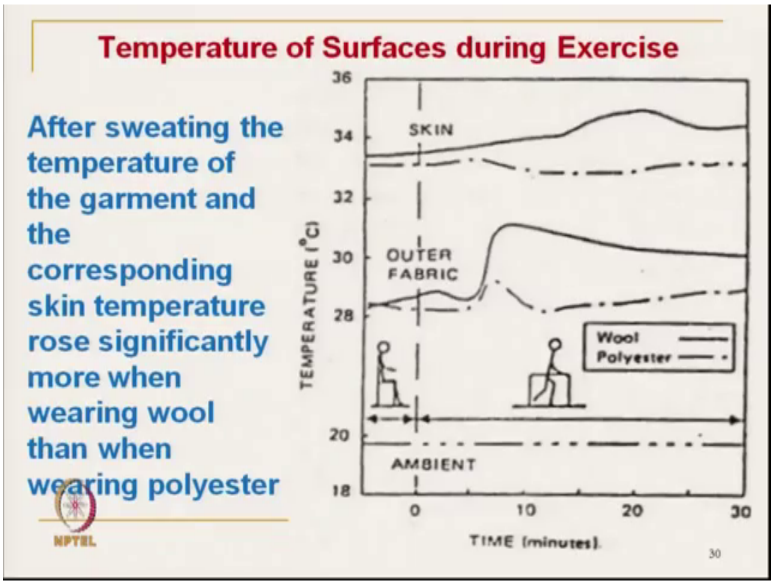

So, if we see this picture shows where the surface temperature or skin temperature of a person who is doing exercise, who is doing say thread mill working. What is happening here after certain time when he when he starts his exercise, after certain time he will start sweating. In x axis this is the time, and y axis it is a temperature, a temperature of the outer fabric surface and temperature of skin.

So, after sweating the temperature of the garment and the corresponding skin was taken and when it start sweating, it has been absorbed. That is when the temperature at the cloth surface has been taken. It has increased suddenly and that is for wool fabric the person, the wool fabric its temperature start suddenly shoots up and that is due to the that heat of sorption, but in case of polyester it is almost flat. There is no significant change in that and the same change is absorbed in case of the skin temperature.

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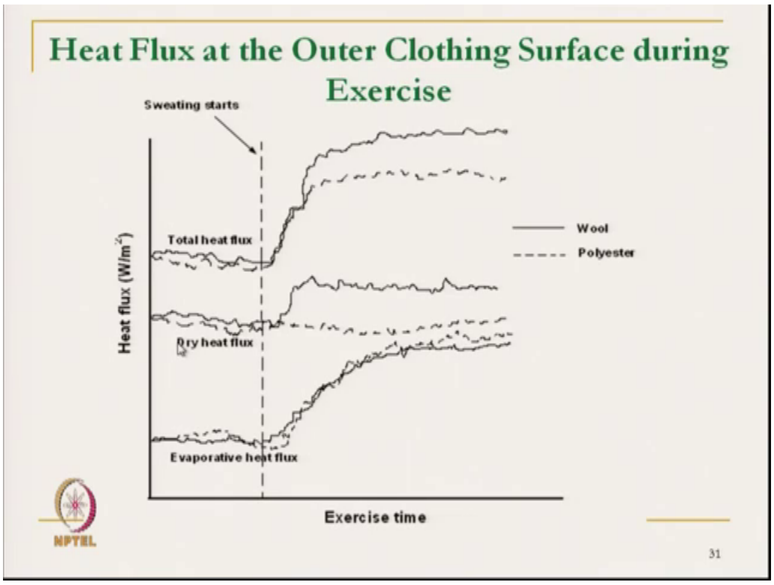

So, this we can see here the dry heat transmission. So, skin temperature is also increasing that is basically due to the increase in the fabric temperature. So, it is linked, and when we see that in when is wearing a polyester, it is not increasing. That we have already discussed earlier that exercise normally if a person do exercise, it does not change the skin temperature.

Skin temperature only changes with the environmental temperature, but in this case during exercise, the skin temperature increases and that is due to the increase in fabric surface temperature and from that study it if you see the dry heat flux and this is the total heat flux and at bottom it is an evaporative heat flux. If we see, the evaporative heat flux is almost same for wool and polyester

So, wool and polyester fabric, it is almost same because the heat, evaporative heat flux taking place because he is doing the exercise in particular environment, environmental condition, particular humidity condition. That is why it is giving the same evaporative heat flux condition, but if we see it is interesting. The dry heat loss is high in case of wool and in case of polyester, it is almost same. It is whatever heat flux was there initially before the exercise and after exercise even after sweating, sweating starts at this point.

Now, when sweating starts, the evaporating heat loss is increasing. It is obvious, but why suit the dry heat flux increase because as we have seen in the last picture, the dry heat, the temperature surface, temperature of wool fabric increases as the surface temperature of wool fabric increases, the heat, actual temperature gradient increases. So, that will that is a driving force for dry heat loss. So, dry heat loss increases for the fabric with hygroscopic in nature and also, more the heat of sorption, more will be the dry heat loss, and that effectively if you see the total with the, this is the total heat loss for wool fabric, the total heat loss will be more.

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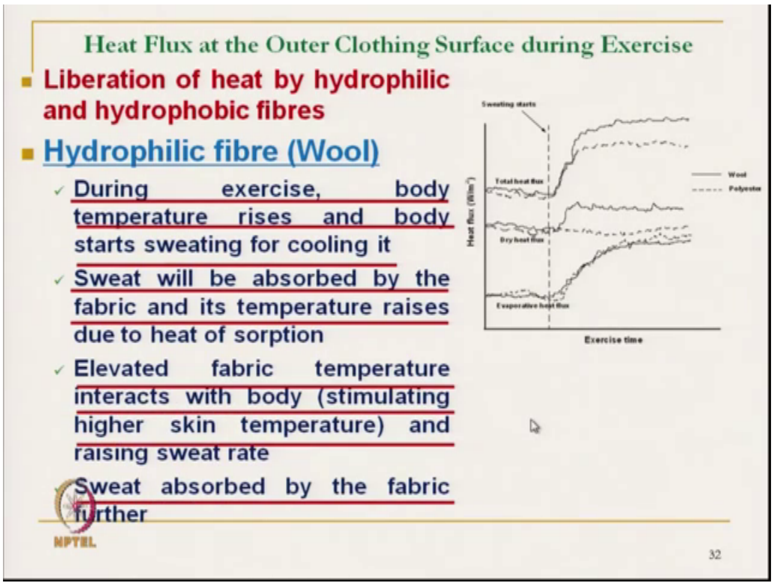

So, this is explained here, the liberation of heat by hydrophilic and hydrophobic fiber for hydrophilic fiber. During exercise, body temperature rises and the body starts sweating for cooling it. Sweat will absorb by the fabric like hygroscopic wool fabric and the temperature will rise due to heat of sorption. Elevated fabric temperature increases the body, increases with the body stimulating higher skin temperature and raising the sweat level. That is why sweat level as increased and that is why evaporative wetness is increasing. Sweat absorbed by the fabric further, further sweat will be absorbed and dry heat loss we have already discussed.

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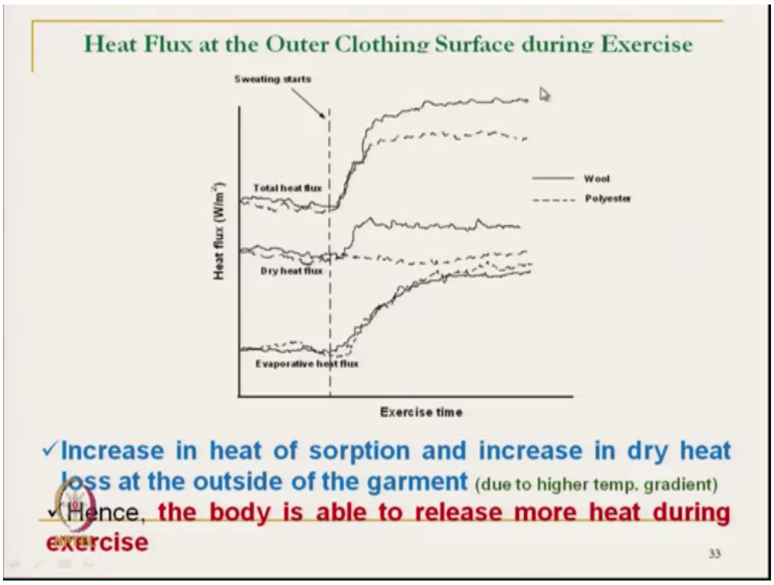

So, increase in heat of sorption increases the dry heat loss as at the outside of the garment due to the heat flux, temperature gradient. Hence, the body is able to release more heat during exercise.

So, it is able to release a cost that is why wool garment is used in sports textile just to actually release the more heat, dry heat.

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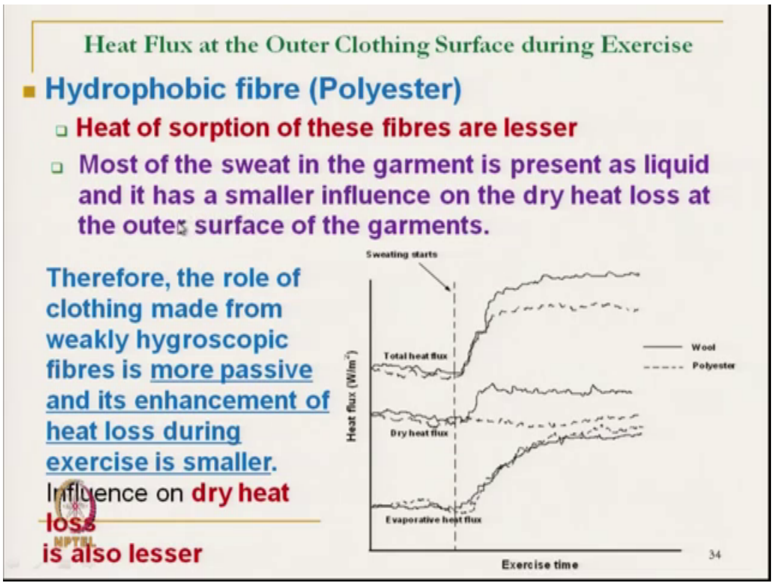

Now, if you see the hydrophobic fiber like polyester, the just opposite things happening it is not able to absorb moisture. So, its dry heat loss is less and its total heat loss is also less, although the evaporative heat loss is almost same. The most of the sweat in the garment is present liquid and it is a smaller, it has a smaller influence on dry heat loss. Therefore, the role of the clothing made from weekly hygroscopic fiber hydro phobic fiber is more passive and its enhancement of heat loss during exercise is small. So, heat loss is particularly dry heat loss is small.

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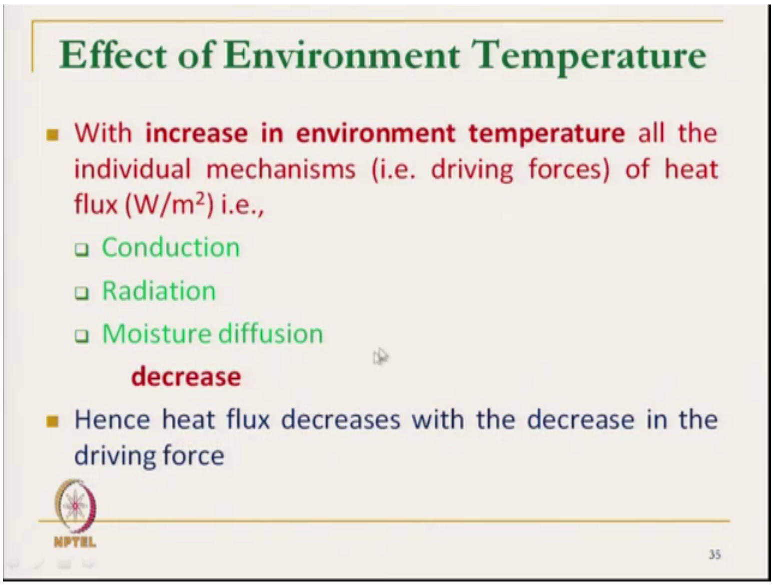

Now, if you see the effect of environmental temperature, with the increasing environmental temperature, all the individual mechanism as we have discussed driving force of heat like conduction, convection, radiation decreases. Hence, the heat flux decreases with the decrease in driving force. Total heat flux decreases and only phenomena is that evaporative heat loss at high environment.

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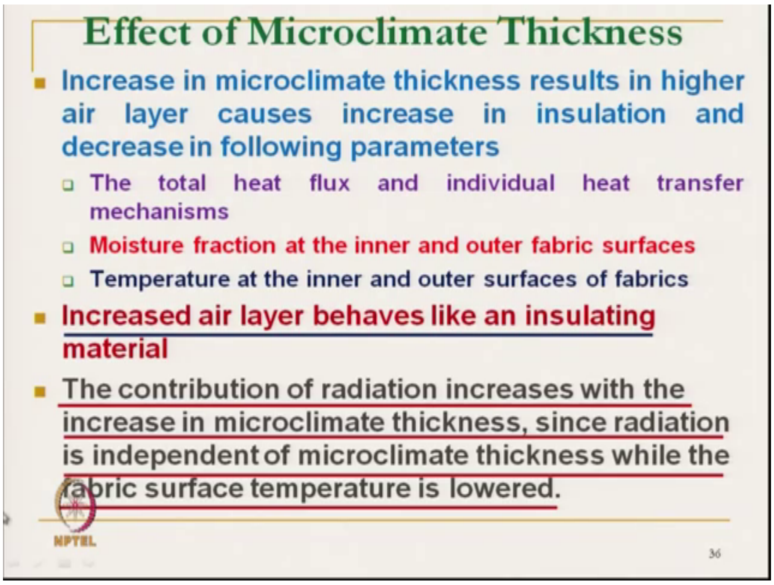

Now, if we see the effect of Microclimate thickness, so increase in microclimate thickness that means a person is wearing loose fit clothing results in higher air layer causing increasing insulation and decreasing the following parameter. What are the parameters? The total heat flux and individual heat transfer mechanism. The total heat flux will reduce moisture fraction at inner and outer fabric will decrease, and temperature at the inner and outer surface will decrease because why temperature should decrease? It is because of the thickness.

The total fabric temperature is higher. If the microclimate thickness is less because the insulating air its insulating because our its assumptions is our skin temperature is high, and increase in air layer behave like an insulating material. Only thing is that the contribution of radiative heat loss, the radiation increases with the increase in microclimate thickness. That means, if for microclimate thickness is more, we are wearing loose fit garment.

The air layer in a thickness of air layer increases, that means air being insulating that means, thermal conductivity will be less or if it is still air that means thermal convective heat loss will be less, but the radiative heat loss is not dependent on the thickness of the air layer. That is why at higher microclimate thickness, the majority of heat loss takes place through the radiation. Radiative heat loss is prominent and it is independent of microclimate thickness while the fabric surface temperature is lower.

So, that means radiative heat loss is more. In that case it is going in the waveform. So, fabric surface temperature is lower because of the thicker insulation. So, that is why its outer layer or inner layer it is less.

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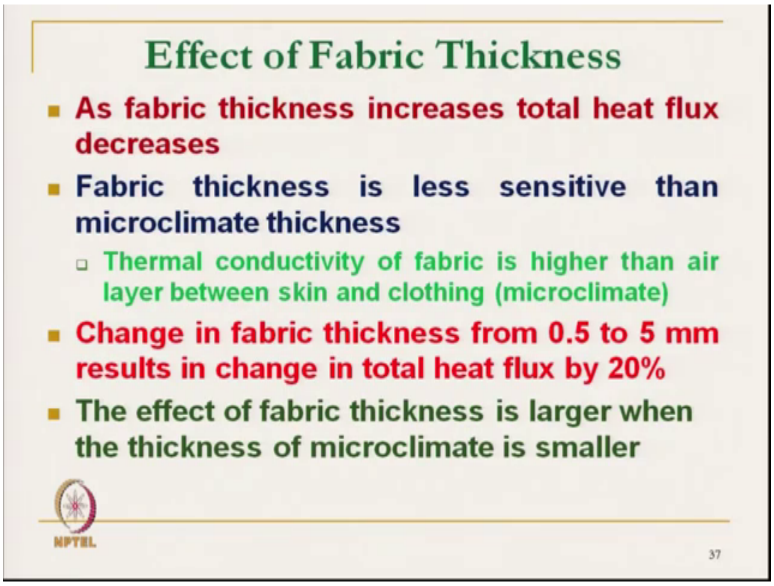

So, after microclimate thickness, let us see the effect. How is it related with the fabric thickness? So, as we know the fabric thickness increases if it is increasing, then its heat flux is decreasing, but it is less sensitive than the microclimate. As microclimate thickness in fabric, there is a air layer and also the material is there, but in microclimate only air layer. That is why it is less sensitive than microclimate and at thicker microclimate thermal conductive of fabric is higher than air layer between skin and clothing.

That is microclimate change in fabric thickness from 0.5 to 5 millimeter results in change in total heat flux by 20 percent. That is the study report shows and the effect which is important. The effect of thickness is large. That is why if the microclimate is smaller, so that means microclimate insulation is actually dominating factor.

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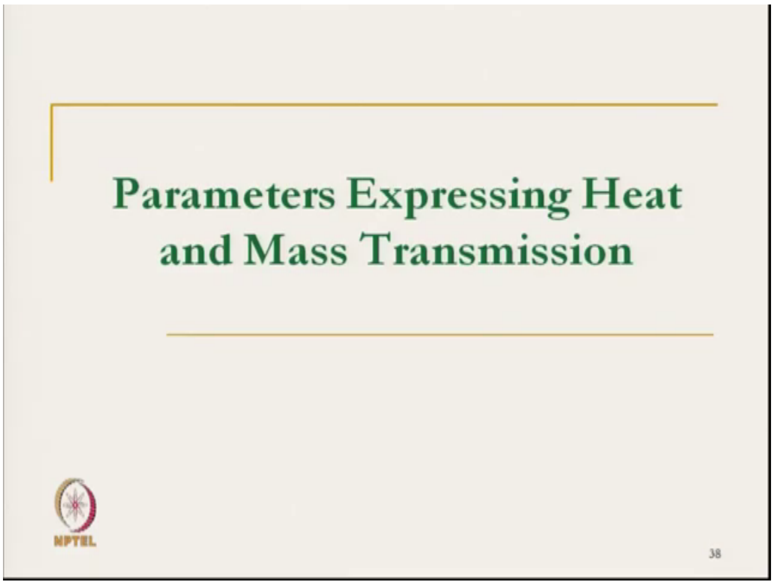

Now, we will discuss few parameters which are interlinked of heat and mass transmission. So, heat transmission we have seen there are various parameters like clo and the various parameters tog, thermal conductivity thermal insulation. These are the parameters and similarly for moisture transmission, we have seen there are various parameters, but there are few parameters which are actually very important, which are related with the combined effect. The most important is the evaporative transmissibility.

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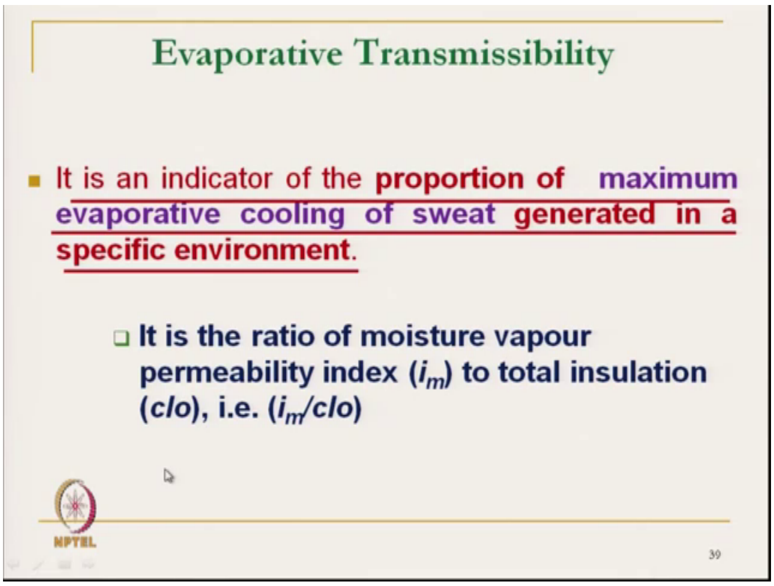

So, the understanding is very important here. It is the indicator of the proportion of maximum evaporative cooling of sweat generated in a specific environment. So, maximum evaporative cooling means it consists of heat transmission and also, mass transmission, quantity of mass. Quantity of moisture vapour transmission means it is proportional to the how much heat it will take.

That is why evaporative transmissibility is very important and it is expressed by the ratio of moisture vapour permeability i m to the dry insulation clo. That means, if we take the ratio i m by clo which is actual which will give the parameter which is evaporative transmissibility at two fabrics of same clo value will give different evaporative transmissibility and that will actually give you, give us the actual comfort. A fabric with high evaporative have dry insulation like clo value.

If it can evaporate high higher moisture, if its moisture i m is high, that means the evaporative transmissibility will will be high, so that the ratio is a very good indicator of the comfort sensation. We can see suppose two fabrics, one is a clo 1, another is a clo 2. Normally we will see that clo 2 will give us very high insulation, but on the other hand if we see evaporative that is permeably moisture vapour permeability index i m, if it is say 1 is 2 4, if it is changing, then we will see the fabric 2, second fabric which was very high insulating at apparently it was looking at very high insulating, but due to higher permeability index it will give us very good evaporative transmission. So, that is why the ratio is very important.

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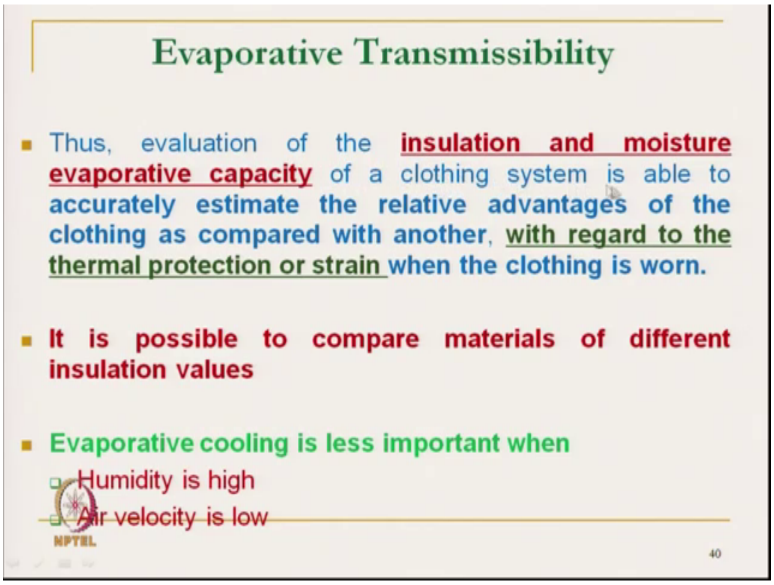

Thus evaluation of the insulation and moisture evaporative capacity of clothing system is able to accurately estimate the relative advantages of clothing as compared to other with regards to which fabric will give us actual sensation of comfort, ok. If we assume the clothing like for extreme cold climate, it is different because there if we assume person is not sweating, so in that case clo may help directly will clo will help, but when the person will starts sweating, in that case only clo will not give the correct picture.

There in that case evaporative transmissibility is important. That means, insulation the evaluation of the clothing of the insulation and moisture evaporative capacity of clothing system is able to accurately estimate the relative advantages of clothing as compared to another with regard to thermal protection or strain when clothing is worn. That means, thermal protective value it is possible to compare material of different insulation value. We can actually compare, ok. Evaporative cooling is less important when humidity is high and air velocity is low.

Now, it is very important here. Now, if we use evaporative transmissibility as an indicator of comfort in very high humidity condition, then we may feel sometime something is wrong misleading result, because in that case evaporative cooling is not there. So, in that case we will see the clo value is giving indication, ok.

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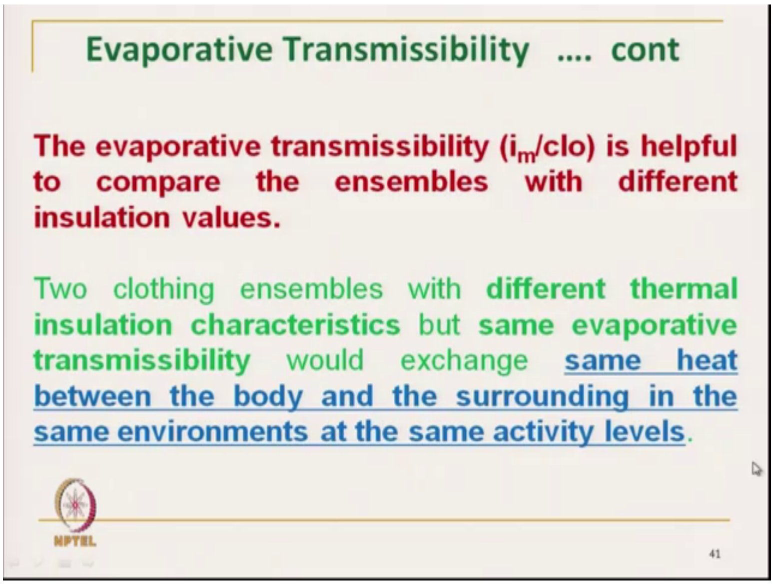

The evaporative transmissibility thus is helpful to compare the ensembles with different insulation value. As we have discussed two clothing and symbol with different thermal insulation characteristics, but same evaporative transmissibility would exchange same heat between the body and the surrounding in the same environment at the same activity level. That is important.

So, in here the thermal is dry. Thermal insulation clo value will give us misleading result. So, a person in activity and when he is generating sweat, in that case you should measure that ratio.

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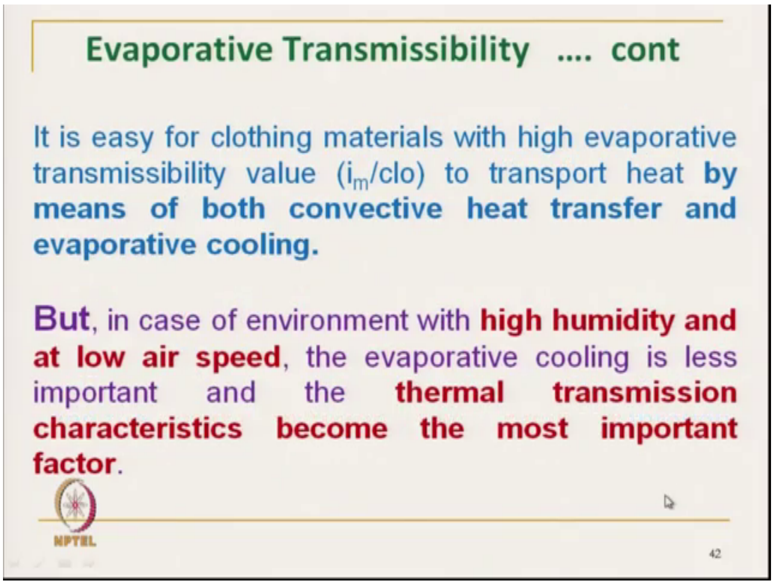

And it is easy for clothing material with high evaporative transmissibility to transport heat by means of both convective heat transmission and evaporative cooling. So, this is the best indicator in high activity condition, but in case of environment with high humidity and at low here as I have mentioned the evaporative cooling is less important and the thermal transmission characteristics, it is more important in that case. So, in case of that is high humidity condition, we can go for only thermal transmission condition.

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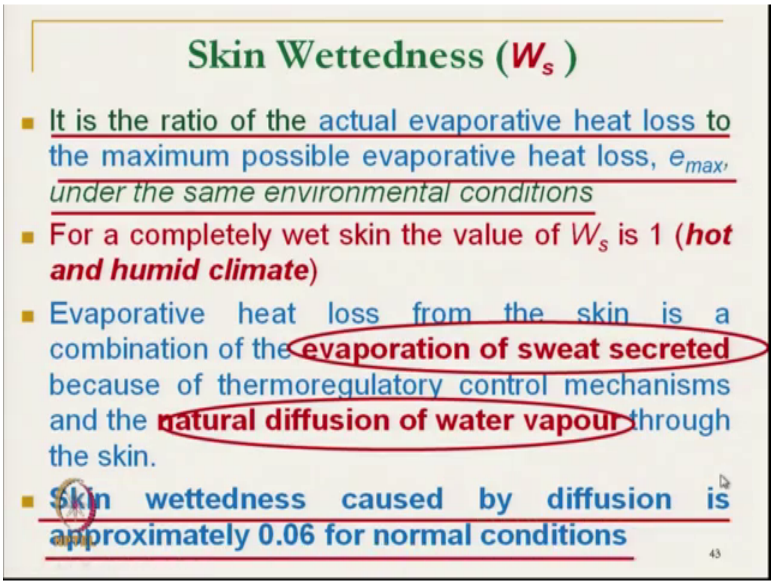

Next parameter is the skin wettedness the skin wettedness is a parameter which is the actually is the its a ratio of actual evaporative heat loss to the maximum possible heat loss that is the person is not wearing cloth.

So, that ratio is there and for completely wet skin its a maximum value is one hot and humid climate its the wetness of the cloth in skin is one its a which is the maximum value the evaporative heat loss from the skin from the skin is a combination of evaporation of sweat secreted because the thermoregulatory control mechanism and the natural diffusion of water so; that means, the one is evaporation of sweat another is natural diffusion of water vapour.

So, both the vapour form and liquid its coming in the vapour form. So, one is evaporation another is water in vapour form its getting transmission. So, transmitted that is gives the total evaporative heat loss at skin wettedness caused by diffusion is approximately 0.06. So, its a very low. So, only if is considered the diffusion its 0.06 ok. So, evaporative sweat secretion that is heat lose is of to with a two nature, one is the and another is the natural diffusion of water vapour its approximately 0.6.

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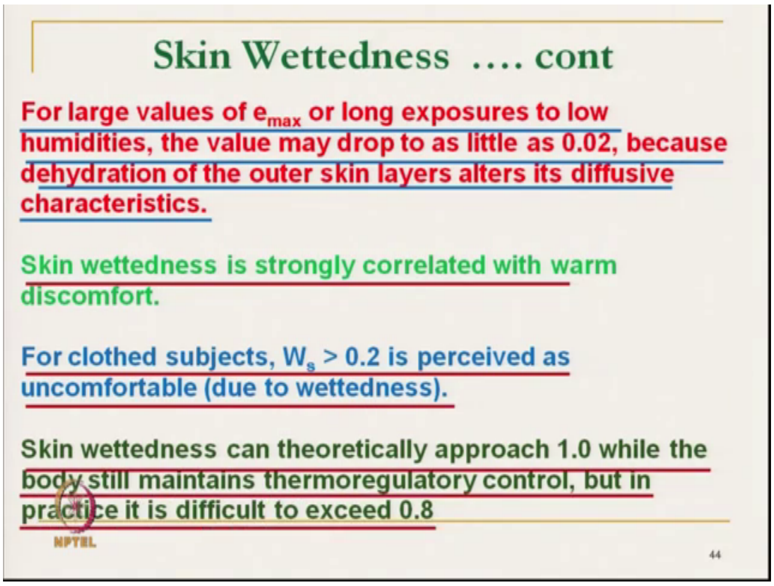

Now, for larger value of e max that the maximum evaporation and longer exposure to the humidity, the value may drop to 0.02. That is due to the diffusion. It may drop to 0.02. That means, a person when is actually secreting in the moisture in the liquid form, that means diffusion will reduce to 0.02. Out of one value, it gives only 0.02 because the dehydration of the outer skin layer alter its diffusive characteristics, ok. Skin wettedness is strongly correlated with the warm discomfort.

So, that means if a skin is wet, the person will normally feel discomfort. For clothed subject, the W value is actually typically it is more than 0.2 more than 0.2 it is and perceived as uncomfortable. It must be below 0.2, otherwise the person will feel wetness, ok. The skin will get wet and if it is only diffusion that means this is not wet. In that case, it will be say 0.02 or 0.06 that is totally comfortable. That means, a person will feel comfortable when his skin is dry. Skin is dry means is also releasing the moisture, but moisture transmission takes place only through diffusion.

So, 0.02 or 0.06 or 0.07 below 0.02, it gives comfortable. If it is above 0.02, that means the skin from dry to it is becoming wet, and theoretically it become, it should be, it is one means if it is totally wet, but it cannot happen maximum, it is 0.08. For all practical purpose, the skin wetness is 0.08. So, if it crosses 0.02, that means you will feel uncomfortable.

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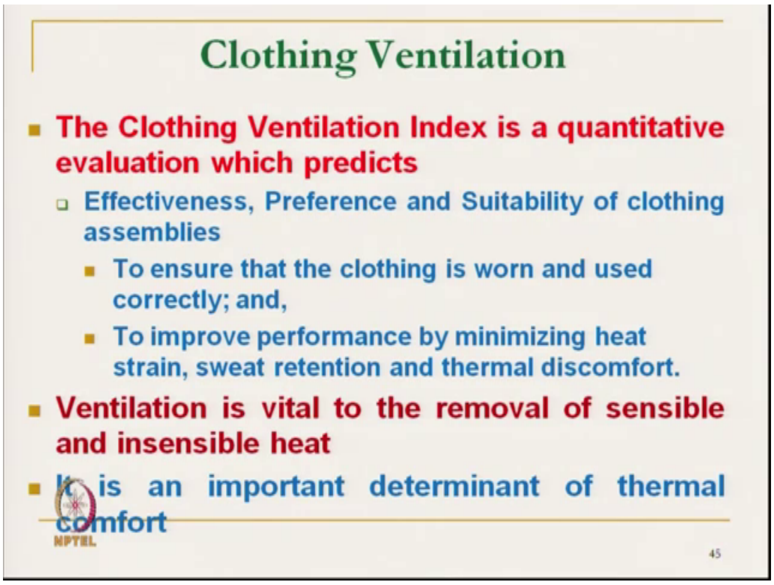

Now, coming to Clothing Ventilation What is ventilation? That means, it allows the outer atmospheric air, atmospheric air to penetrate inside and takes away the moist air from the microclimate. The Clothing Ventilation Index is a quantitative evaluation which predicts the effectiveness, preference and suitability of clothing assemblies to ensure that the clothing is worn and used correctly. So, if it is correctly if it is used correctly, that means ventilation will be perfect ventilator index to improve the performance by minimizing the heat strain, sweat retention and thermal discomfort. The ventilation is vital to the removal of sensible and insensible heat. So, that will try to heat hot air.

Hot humid air will get removed from the microclimate. It is an important determinant of thermal comfort. So, better humid ventilation will give us comfortable, but it is for particular humid particular condition. If it is extremely cold climate, then ventilation will give us discomfort. If it is hot and humid climate, then ventilation is required. So, we have to control the ventilation.

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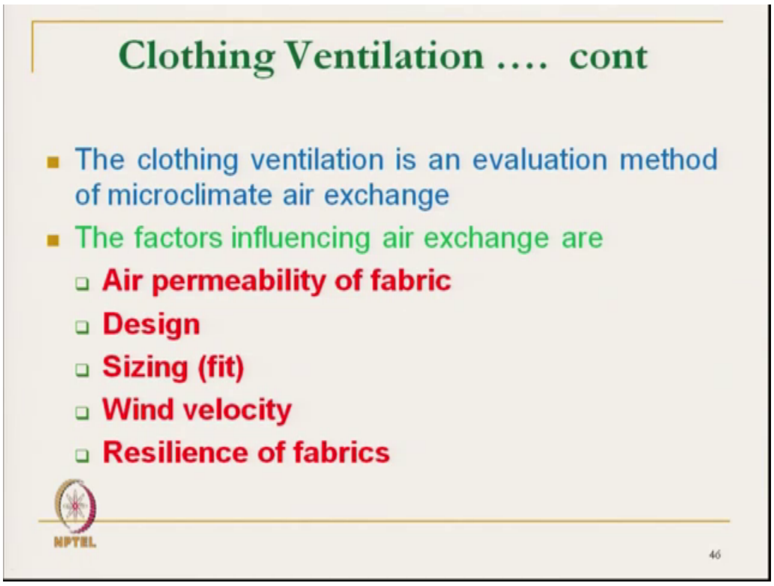

So, the clothing ventilation is an evaluation method of microclimate at air exchange, ok. So, microclimate air exchange, so depending on the ventilation, it will actually determine how much microclimate air will get exchanged, ok. The factors influencing the air exchange are because these other factors which influence the air exchange or air permeability of fabric, the more permeability, higher permeability means higher air exchange will be there.

Design of clothing, we can design the clothing, so that it gets better ventilation. Size of clothing, it is fit; it is loose or tight fit wind velocity. So, higher wind velocity will be having higher ventilation and resilience of fabric ok, how the fabric gets actually come back from its deformed condition.

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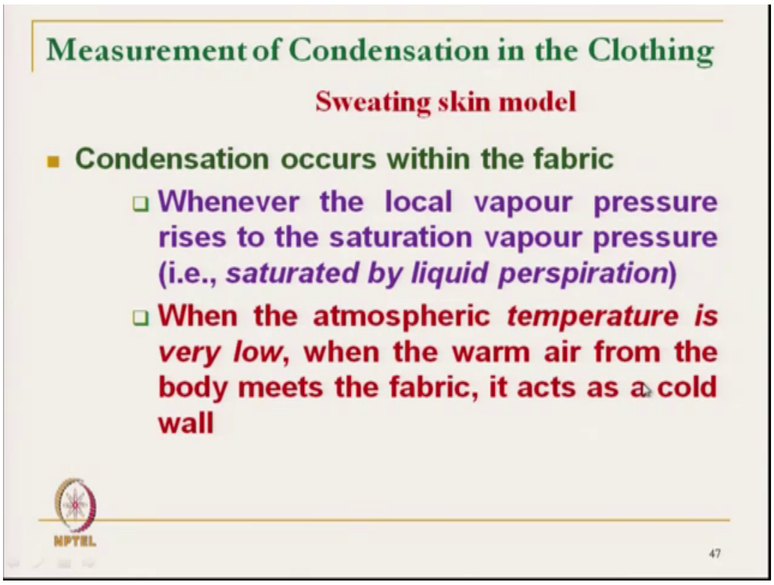

Condensation occurs within the clothing whenever the local vapour pressure rises to the saturation vapour pressure, ok. So, saturated heat transmission will be the saturated liquid perspiration will be there. In that case, the condensation will take place. Another case is that when the atmospheric temperature is low. So, in these two conditions basically the condensation takes place.

So, it is up with the Sweating skin model, this is called Sweating skin model which actually helps us in predicting whether the moisture which we are releasing, we will get condensed within the fabric or not and that depends on the vapour pressure and the temperature.

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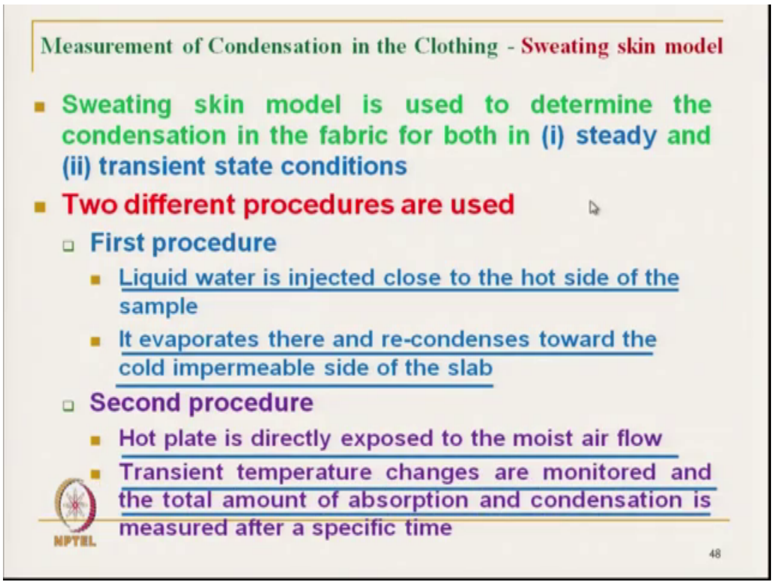

The sweating skin model is used to determine the condensation in the fabric for both steady state and transient state. So, two different processes are there. One first process is the liquid water is injected close to the hot side of the sample and it evaporates there and recondensates in the cold side. So, that is one procedure. Another procedure is that the hot plate is directly exposed to the moist air flow and transient temperature changes are monitored and the total amount of sorption and condensation is measured at specific time.

So, from there when the hot, at the hot plate, the moisture is directly exposed from there, it gets evaporated and takes the latent heat and it also result the condenses. So, that is the principle of measuring Sweating Skin Model, the Condensation Measurement.

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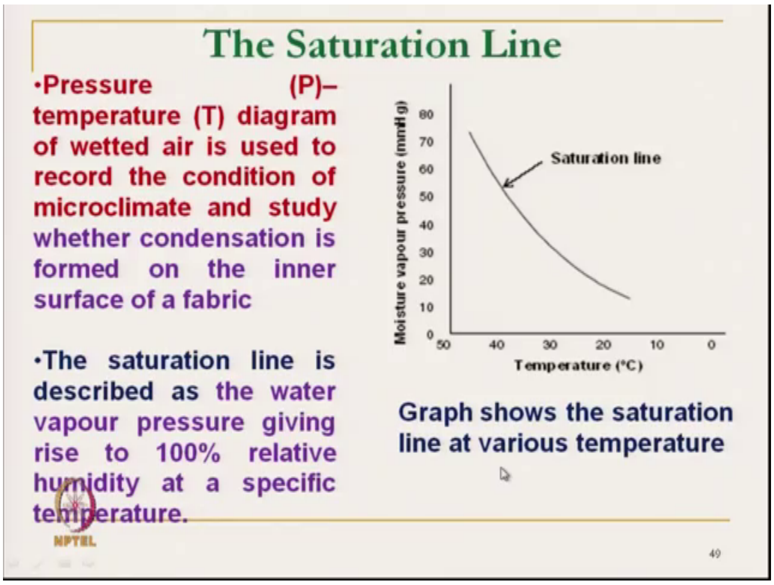

Next is its saturation line. So, this is, this will give us the idea of the microclimate condition where we will start feeling wet. Skin wetness, this is the saturation line where in x axis, the temperature and y axis is the moisture vapour pressure which means the pressure and temperature diagram of wetted air. That means, wetted air means the microclimate is used to record the condition of microclimate and study whether the condensation is formed on the inner surface of the fabric.

So, the pressure P and temperature T diagram of wetted air is used to record the condition of the microclimate and study whether the condensation is formed on the inner surface of the fabric that means at certain temperature given the vapour pressure. So, at the temperature is 30, 30 degree celsius, if the vapour pressure is at the as per the saturation line it is 40, 40 millimeter Hg.

So if the saturation line at this saturation line if it is beyond 40 millimeter Hg that means saturation will take place. The water content in the micro climate will increase and on the other hand at say 40 microclimate 40 pressure level, if the temperature is more in that also will give us the that wetted wetness degree of wetness in the microclimate.

The saturation line is described as the water vapour pressure giving rise to the 100 percent relative humidity at the specific temperature, so that if we have this idea about the saturation line in and if we considered in our microclimate, we can predict whether there will be wetness clamminess feeling on that.

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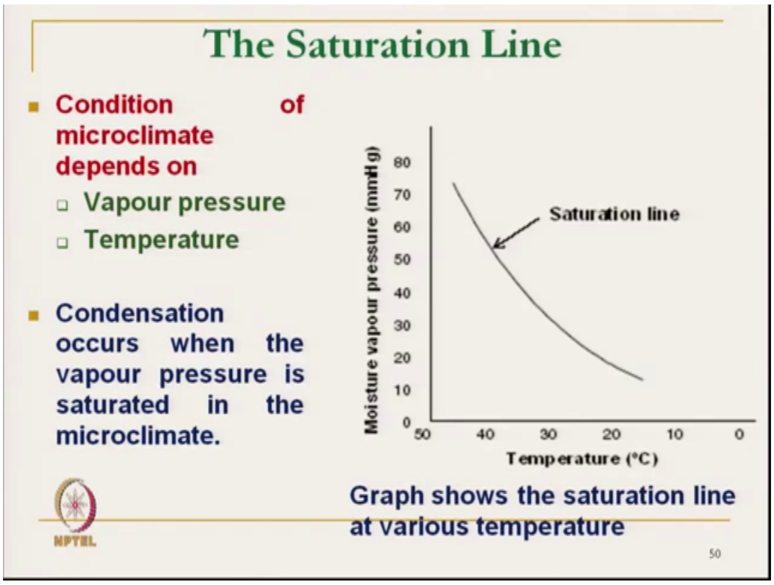

And condition of a microclimate depends on the vapour pressure and the temperature. So, that is an important vapour pressure means say relative humidity and temperature and from there if we know that saturation line, we can predict the actual discomfort feeling of our clothing and condensation occurs when the vapour pressure is saturated in microclimate, ok. We will stop here with this and next we will start the comfort related with the Garment Fit, ok till then.

Thank you.