Science of Clothing Comfort
Prof. Apurba Das
Department of Textile Technology
Indian Institute of Technology, Delhi

Lecture – 36
Combined Heat and Mass Transmission & Clothing Comfort

Hello everyone; so today we will start the Combined Heat and Mass Transmission and its relation with Clothing comfort.

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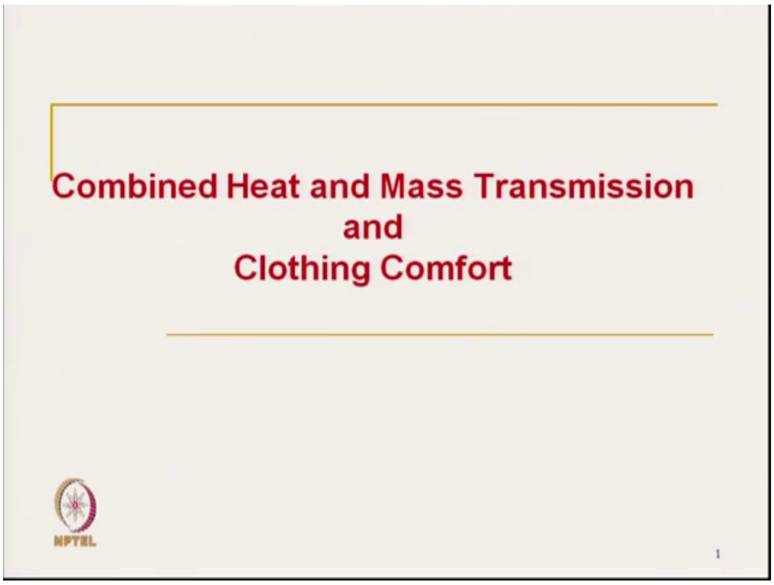

Till now what we have discussed the heat transmission, and a moisture vapour, and liquid transmission separately. And it is very important to know their transmission characteristics through clothing, to understand the comfort ok. But today we will discuss few phenomena; those who are interlinked. Actually heat and mass transmissions are interlinked phenomena so these are the dynamic state condition.

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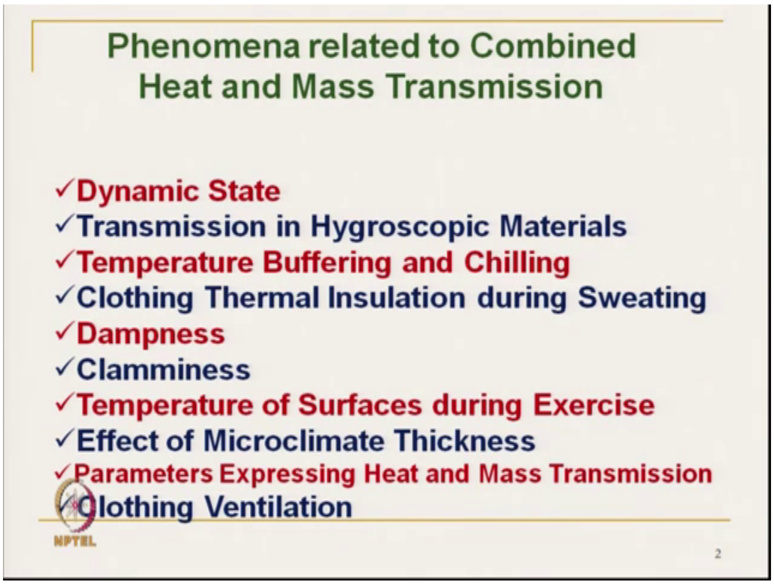

In dynamic state what we will see that the heat and moisture transmission takes place together we cannot separate them. And the clothing comfort like heat transmission warm feeling and cool feeling, those are actually related to the dynamic state. Because our most of the cases when we move when our body posture changes though the heat and mass transmission cannot take place in static condition, steady state condition those are in dynamic condition. We will discuss the issues related to dynamic transmission, then the transmission in hygroscopic material.

Basically hygroscopic material most of the hygroscopic material, after absorption of moisture they release, actually they release heat. So, the moisture transmission or absorption and heat are interlinked. So, this phenomena we will discuss; how hygroscopic materials are interacting with a moisture and to release the heat, this segment we will discuss. And then the buffering temperature buffering and chilling aspects they are related with the heat and mass transmission. The moisture absorption that is and then it sometime it causes a chilling that discomfort related to chilling, this we will discuss.

Clothing thermal insulation during sweating so during sweating the clothing normally actually if the release heat very quickly so this part we will discuss. Then the discomfort will take to dampness. Dampness related discomfort irrespective of the temperature it is it creates our severe discomfort if the microclimate is damp. So, this are actually the dampness related again with the heat and mass transmission.

The clamminess, so again clamminess; it is a high humidity condition this in the microclimate that we will discuss. Even in the atmosphere if there is a high humidity we sometime feel clamminess and in that state how the temperature or heat transmission take place and temperature rise takes place that we will discuss. And surface temperature of clothing during high activity this we will discuss. And this is related with the again with the moisture absorption because most of the hygroscopic fibre are actually the after absorption of heat they release heat.

So, if it again microclimate thickness if it changes the heat and mass transmission also changes, this aspect also we will discuss here. And parameters what there are various parameters which actually are used to express heat and mass transmission together. So, till now what we have discussed the parameters are separately which are used to express the heat transmission or mass transmission. So, here we will discuss the combined parameters. And then clothing ventilation, how the clothing ventilation affect the heat and mass transmission this aspects we will discuss here.

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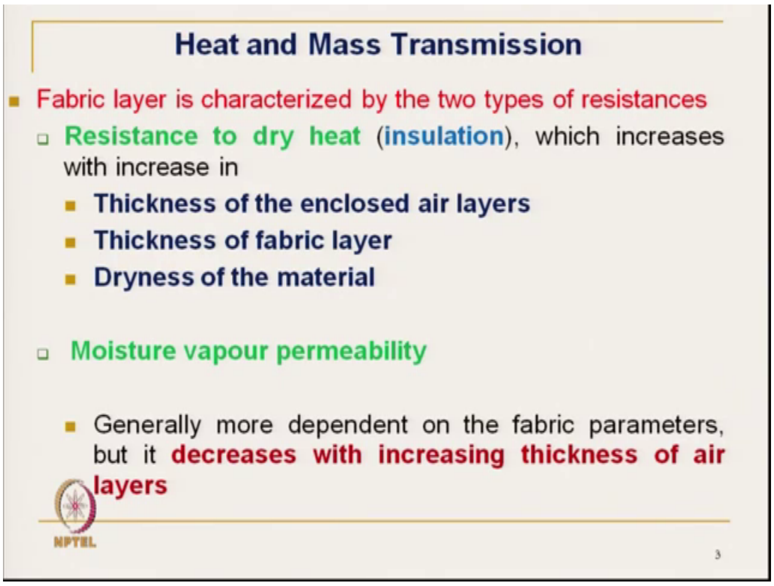

So, we will first start with the heat and mass transmission the phenomena. The fabric layers layer is a characterized by two types of resistance. One is heat resistance another is the moisture vapour resistance that is moisture vapour permeability ok. So resistance to dry heat that is insulation which is actual dependent on, it increases with the increase in thickness of the enclosed air layer. This thickness of enclosed air layer it may be within the structure or maybe outside the structure.

Outside the structure means it is a microclimate and within the structure means it is a within the pores of the yarns or fabrics. Thickness of the fabric layer so higher thickness means higher entrapment or higher more materials are there. So, that will also affect in the dry heat transmission. Even higher more material, more number of fibres in the cross section or across the of plane. Which restrict the radiative heat loss, so that also it affects and dryness of the material the dry material wet material; that means, that it loses it is insulation.

So, it is conductivity is more; so dryness of material is also directly related to the dry heat insulation. Coming to the moisture vapour transmission, it generally more dependent on fabric parameter. But it decreases with increase in thickness of air layer; that means, the moisture vapour permeability for thicker fabric its moisture vapour permeability will be less. There are various factors that we have already discussed in the last segment. Basically, if the micro pores are a larger in size that diffusion may will be slower. So, this are it decreases with the increasing thickness of air layer.

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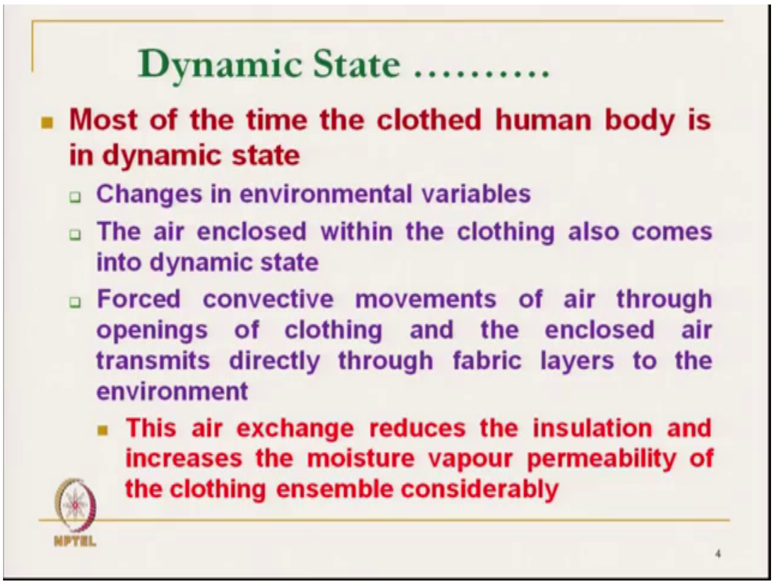

Now, coming to the dynamic state; in most of the conditions, most of the time the clothed human body is in dynamic state. While we are working, we are doing activities so changes in environmental variables. So, our atmosphere continuously changes its temperature, relative humidity, everything changes. Even wind, speed so that this changes in environmental condition always affect the heat and mass transmission.

So, this dynamic state it is apart from the standard atmosphere, a standard chamber, climatic chamber, or standard test chamber, normal environment is always changing. And that directly affect the heat and mass transmission we have to understand this one. Then air enclosed within the clothing that is in microclimate always in under dynamic condition. Even when we are sitting, even if we may we move little movement, that total air enclosed their volume will change.

Their total structure that is the microclimate total contour will change. So that will affect the heat and mass transmission and forced convection. So, when we move, when we are working while doing activity so, that fabric actually move around our body and that enclosed air actually it get pumped out and fresh air come. So, that is a forced convective movement of air takes place ok.

Through the opening of the clothing and the enclosed air transmit directly through the fabric layer to the environment. So, that also it is it take place it is a most of the cases. And this air exchange reduces the insulation so as air the still air moves away so, it takes moisture and that means, moisture vapour permeability is also increases due to the forced convection. So that total dynamics will change.

So, that means, in most of the cases our comfort feeling are totally different. Then what we try to get the data in still condition ok in standard atmospheric. So, this is due to the dynamic nature of this dynamic state of the of our clothing and our body.

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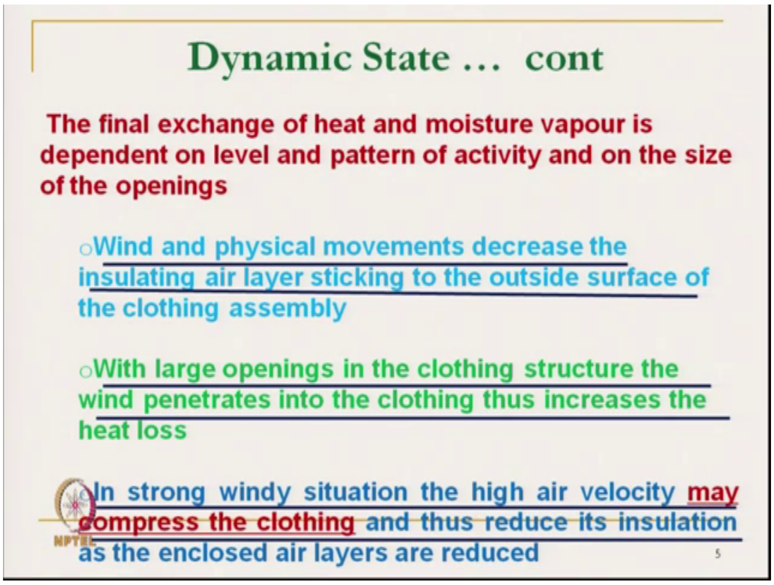

So, the final exchange of heat and moisture vapour is dependent on the level and pattern of activity and the size of the opening. So, if our activity is more or if it is a wind condition, the total dynamic with heat and mass change will be different. So, wind and physical movement decrease the insulation of air layer sticking to the outside of the surface. So, when our the wind is blowing so our still air which is just outside the clothing that will move out. So that will help in better forced convection.

So, with the large opening in the clothing structure the wind penetrates inside the clothing and changes the moisture, relative humidity and temperature. So, heat loss increases so if the opening size is more the forced air will enter due to the wind blowing and it will decrease the temperature; that means, heat loss will increase. So, in extreme conditions like in strong wind; some time what happened our clothing may get compressed; that means, it will take out the excess still air from inside.

And thus the in strong wind automatically the insulation reduces. So, for if you see so all these conditions they are totally related with the heat and mass transmission. So, if it is strong wind there will be a some effect, if it is light wind the effect will be basically from it will take away the still air from outside, so if it is strong wind it will compress as the fabric So these things are actually changing. And this is basically you have to understand, we cannot test, we cannot actually stimulate these things. But if you understand this phenomena then we can predict the comfort characteristics ok, this we have discussed.

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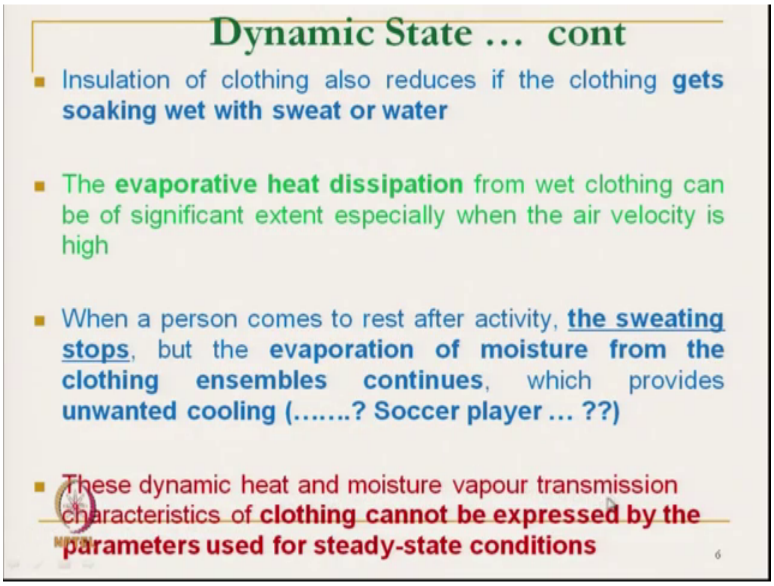

And next is that again if we continue the insulation of clothing also reduces, if the clothing gets soaked with the sweat and water. So that automatically it will reduce the thermal resistance if it is so. Because the water as we have discussed, the thermal transmission through water is very fast. It is the that is resistance of air is much higher than the water.

The evaporative heat dissipation from wet clothing can be significant actually significant extend. Especially when air velocity is high ok, this is due to forced convection when a person comes to rest so after heavy activity if the person comes to rest what will happen? He will actually stop sweating. And then the evaporative heat loss will take place. So, heat generation is less but heat loss will be very high so, that is why you will feel immediately cold. So, unwanted cooling will take place, so this we can typical example is a soccer player when is coming out from the field. So, there we will start feeling cold because of the less activity and the evaporative heat loss.

So, this dynamic heat and moisture vapour transmission characteristics of clothing cannot be expressed in a single term. So because we have to understand that the steady state condition of heat transmission separately, moisture transmission separately, this will not work actually. Those heat and moisture vapour transmission it is important just to understand the phenomena. But if we try to predict the clothing comfort, we have to actually think in different direction. So, and also we have to see that our body is in dynamic condition and activity level we have to understand. Then we can predict the comfort state.

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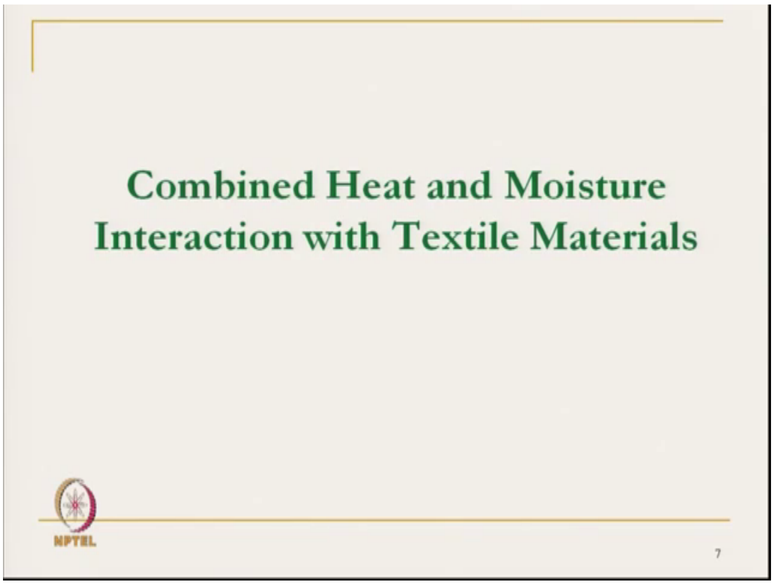

Now, so combined heat and moisture interaction.

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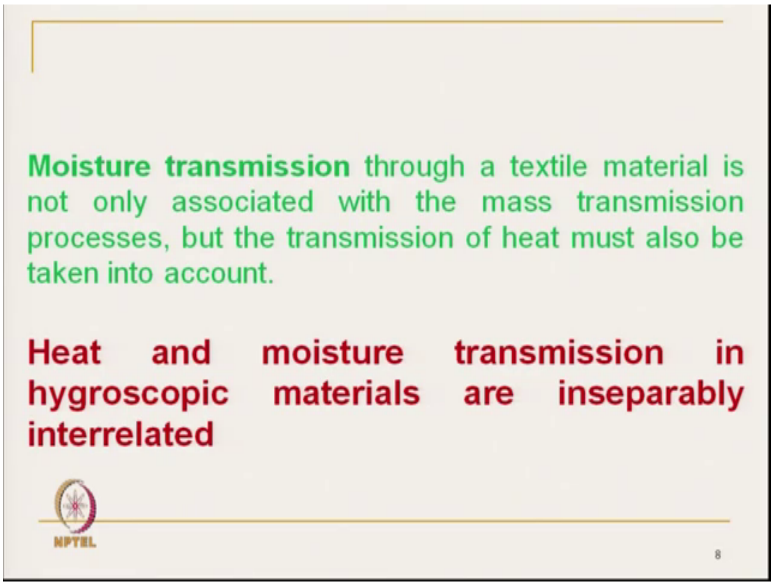

If we try to see here the moisture transmission through a textile material is not only associated with the mass transmission process, but the transmission of heat must also be taken into account. So, moisture transmission it is if we see it is a if in earlier segment we have seen the moisture transmission separately. It is not the only the moisture is getting transmitted it is not the sweat is getting transmitted, it is not the moisture vapour is getting transmitted. Along with the moisture heat is also transmitted that this phenomena we have to actually understand very clearly.

So; that means, heat and moisture transmission in hygroscopic material is inseparable ok. Actually they cannot be separated; if we particularly if we considered a hygroscopic material. When mass transmission takes place the heat transmission you have to also consider. Otherwise you will not be able to predict the comfort feeling. So, that is very important we cannot separate it.

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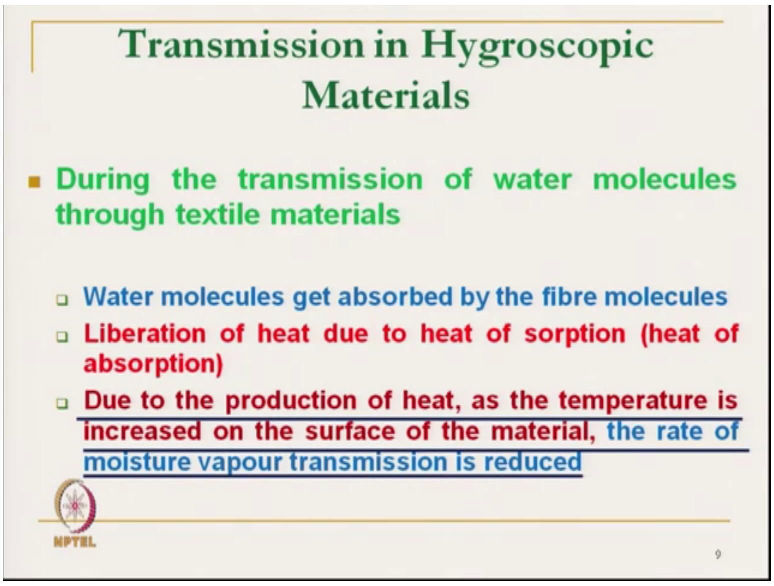

So now if we see the hygroscopic material let us see example is cotton so during the transmission of water molecule through the hygroscopic material the water molecule gets absorbed by the molecule. So, then as soon as it absorbs the moisture it will release the heat which is known as heat of absorptionor heat of sorption. So, this phenomena after absorption it releases heat; that means, automatically the moisture transmission and heat transmission comes into picture.

Understanding of heat transmission and moisture transmission we have to, it is actually it is necessary to understand this phenomena. So, due to the production of heat what happened the temperature of the cloth increases, surface temperature of the material increases and it affects the moisture vapour transmission also it reduces the moisture vapour transmission.

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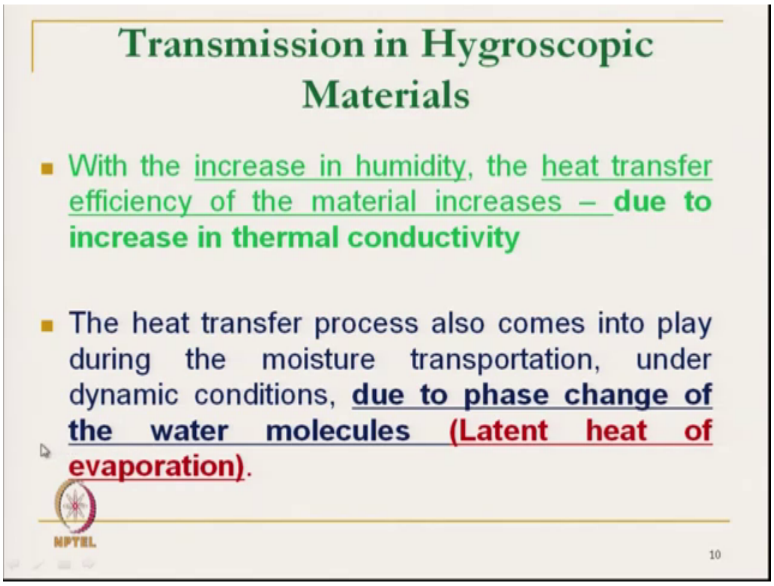

So, due to increase in the surface temperature with the increase in humidity; So what happened? The heat transmission efficiency of the material increases because the hygroscopic material absorb moisture become wet or moisture content increases. So, thermal conductivity automatically increases so, that is how it is interrelated the heat transmission process also comes into play during the moisture transmission; that is what we have discussed, under the dynamic conditions, due to phase change of water molecule. So one thing is that it is actually when hygroscopic material absorb moisture it releases the heat of sorption, that we have to understand.

When hygroscopic material absorb moisture, the thermal conductivity of the total fabric storage structure increases that we have to understand. And also another parameter is that when they actually changes it is phase that means from liquid phase to vapour phase ok. When it gets evaporated so that latent heat of evaporation it takes away from the body from the cloth so that we get cold. So, this all these interlinked phenomena ultimately affect the clothing sensation.

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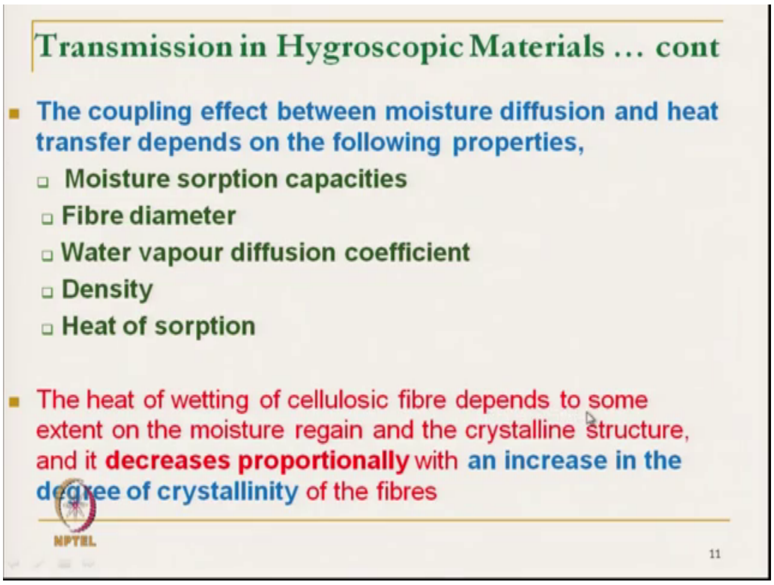

So, the coupling effect between moisture diffusion and heat transmission depends on the following properties when moisture actually diffuses through fabric. So, these are the factors what are the properties on which, this phenomena depends the moisture sorption capacity of the material. So, if the moisture get's absorbed through the, by the material so that will affect this heat and mass transmission characteristic. Let us see one polyester fabric another is cotton fabric.

In case of polyester fabric let us assume polyester is totally hydrophobic ok. So that hydrophobic fibre it is not absorbing the moisture, moisture is transmitting through the fabric structure by diffusion ok. So in that case in case of cotton on the other end when it absorbs moisture it releases the heat of sorption. The total phenomena of heat transmission will change and after absorption of moisture when it actually it is releases moisture it gets evaporated. It takes away the latent heat, in case of poly states it is not happening.

And fibre diameter also so higher fibre diameter means lower specific surface area and; that means, it is moisture vapour permeability will change. That will ultimately affect this heat and moisture sensation, water vapour diffusion coefficient. So, if the water vapour and diffusion coefficient is high; that means, the fibre will actually diffuse the moisture quickly ok.

Density it is depending on the density of the structure and also the fibre and heat of sorption so heat of higher heat of sorption of a fibre will give warm feeling when we and the heat absorbs moisture like wool. Wool fibre has got very high heat of sorption so at; that means, with the with the change in humidity level wool gives warmth. So, the heat of wetting of cellulose fibre depends on various factors, mainly it is a crystallinity. So, it decreases proportionally with the increasing degree of crystallinity so, that heat of sorption if the cellulose fibre has got higher crystallinity it is heat of sorption will reduces ok.

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Now, another phenomena which is temperature buffering and chilling. This phenomena is again linked with heat and moisture transmission of clothing. So what is the buffering?

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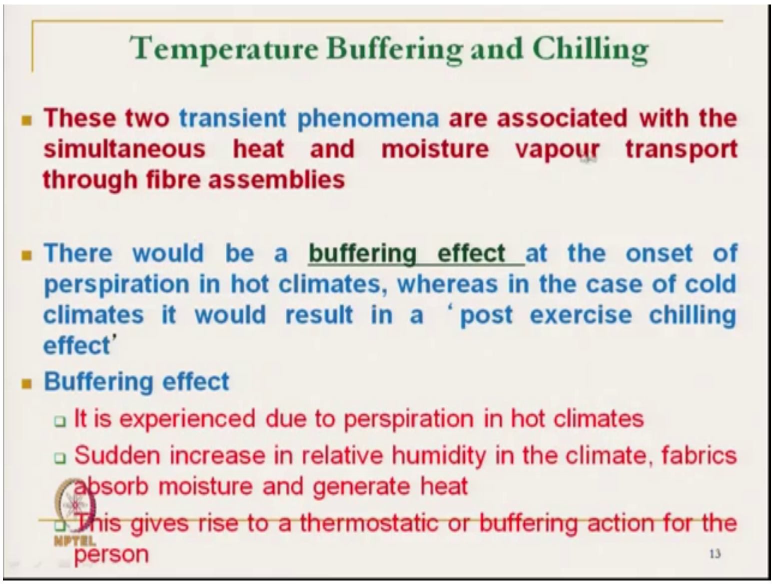

So, these two phenomena are associated with the simultaneous heat and moisture vapour transmission through fabric. There would be a buffering effect at the starting point, at the onset of the perspiration in hot climate. So, in hot climate and humid climate the perspiration will start and that will actually will give the buffering effect whereas, in case of cold climate it would result in post exercise chilling effect. So, in hot climate we will start sweating and that will give us warmth.

So, before we come out to the environment in a hot environment we will start getting hot feeling. So it is giving a buffering effect, so, buffering effect increases it is actually it is experienced due to the perspiration in hot climate as we have discussed. In hot climate we actually feel that it is warmth sudden increase in relativity in the climate fabric also absorbs moisture and generate heat. So, it releases heat this gives rise to the thermostatic or buffering action of the person.

So before he is going out to the hot climate the cloth also actually prepared him with the buffering effect. That that means it is a cloth has become warm ok. So, that heat he is not suddenly getting a shock. So, heat give some buffering effect. So, we will see in opposite case also it happens.

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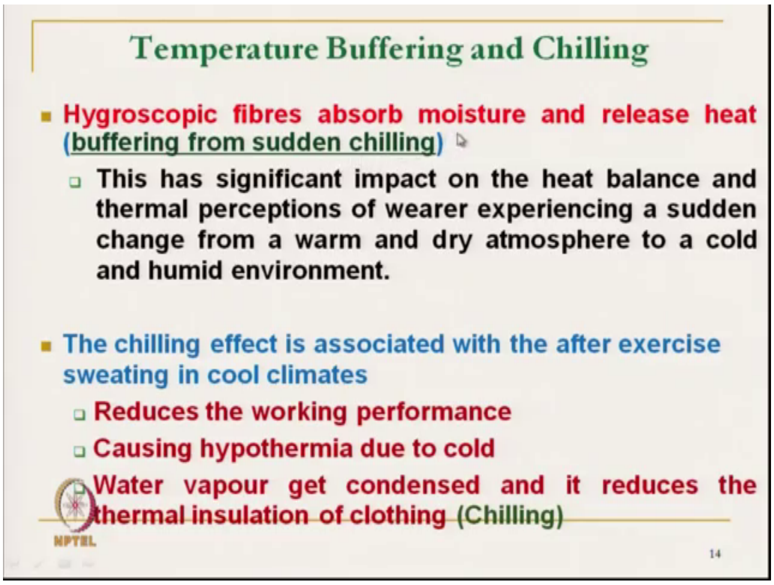

So, hygroscopic fibre absorb moisture and release heat. So, buffering from sudden chilling so this phenomena we can see in extreme cold climate zone. Where suppose it is a snowing, a person in a hot and dry climate at inside room when he is coming out what happens? This has significant impact on the heat balance and thermal properties of wearer experiencing a sudden change from warm and dry atmosphere to cold and humid atmosphere.

What happened; when as soon as he is going out the cloth suppose a woollen cloth he is wearing and as soon as he is going out in cold and humid environment, the fabric absorbs wool absorb moisture and releases sufficient quantity of the heat of sorption. That means, for some time he at least that cloth is protecting him. He is not getting sudden cold shock ok, reduces the working performance ok, the chilling effect is also associated with the exercise sweating in cold climate. So, in earlier case we have seen that when he is going out the heat is generated and even in the cold climate extreme cold when it is there and it is sweating high humidity he is feeling warm due to heat of sorption.

And the chilling effect is there; that means, chilling effect means when the cloth is wet he will actually the body will release the heat very fast, so it is just opposite. So, the chilling effect is associated with the after exercise sweating in cold climate. So, after suppose after working someone stops. So, this reduces the working performance because the he will start releasing heat at very high rate he will feel cold. So, it may cause hypothermia due to excessive cold.

So, water vapour may get condensed and it reduces the thermal insulation. So, all these phenomena may also take place if we actually the cloth is wet due to sweating. So, that; that means, here again we are saying that chilling effect is associated with the heat and mass transmission. In case of only if then if we see here the person is not sweating; that means, he will not feel the chilling effect, this chilling phenomena is associated with the heat and mass transmission.

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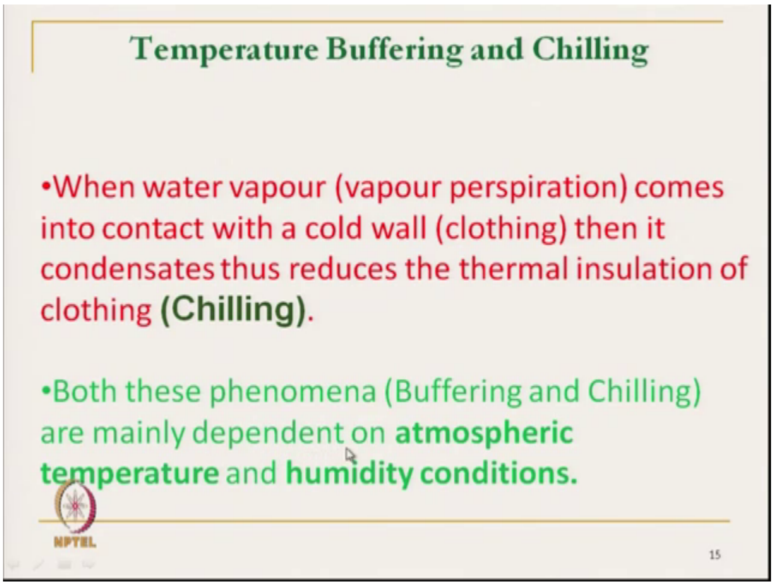

When the water vapour; that is perspiration, comes into contact with the cold wall; that is the cloth, then it gets condensed and reduces the thermal sensation that is that is chilling basically. So, it basically it is related with the again heat and mass transmission. So, both these buffering and chilling are mainly dependent on atmospheric temperature and humidity condition. So, if this changes like atmospheric temperature is if it is hot and if it is dry the buffering effect will be different.

If it is cold dry it will be different, if it is cold humid it will be different. So, this buffering and chilling it is mainly depending on the atmospheric condition, the activity of the person, the type of clothing, type of clothing material. So, these things are related, but effectively this buffering and chilling they are interrelated and they are related with the heat and mass transmission.

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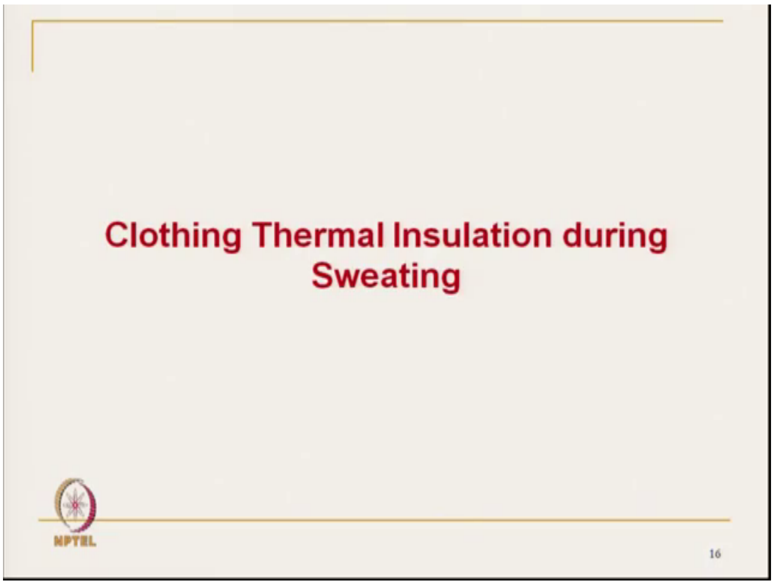

Now, next is the again another phenomena that is the thermal insulation during sweating.

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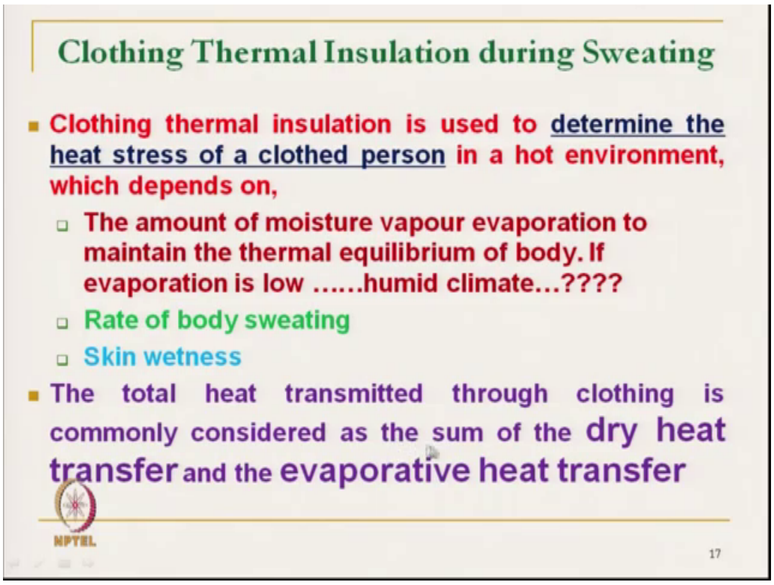

The clothing thermal insulation is used to determine the heat stress of the clothed person. So, if the insulation is high in hot environment; that means, he will have higher heat stress. So, in hot environment and in humid environment it is a very difficult, it will feel totally uncomfortable, the amount of moisture vapour evaporation mainly the just to maintain the thermal balance of the body ok.

So, that the thermal balance is actually maintained by the moisture evaporation. And if the evaporation is low; that means, in humid climate in hot and humid climate. If the evaporation is low then he will not be able to evaporate the moisture ok. And also it depends on the rate of sweating and skin wetness. So, this thermal clothing insulation it drops with the rate of sweating and if the skin is wet again thermal insulation will drop.

And then total heat transmitted through clothing is commonly considered as the sum of dry transmission and evaporative heat transmission,. So, this dry transmission means conduction convection, and radiation, plus evaporative heat transmission. At evaporative heat transmission is the phenomena, which is linked with the mass transmission ok.

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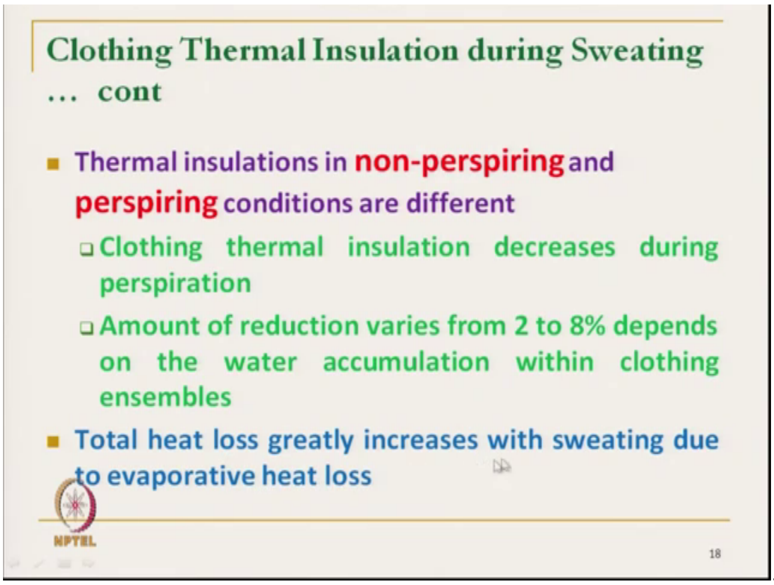

The thermal insulation of non perspiring and perspiring conditions are totally different So, the clothing thermal insulation decreases during perspiration that we have seen. And in the as compared to non perspiring condition the it reduces 2 to 8 percent and that reduction is mainly due to the conductive heat loss ok.

Thermal amount of deduction varies from 2 to 8 percent depending on the water accumulation. If the water accumulation is high, if a person is sweating profusely then it may go up to 8 to 10 percent reduction. And the heat loss greatly increase with the sweating due to evaporative heat loss also. So, it is basically the if the sweat gets evaporated then heat loss is also increasing.

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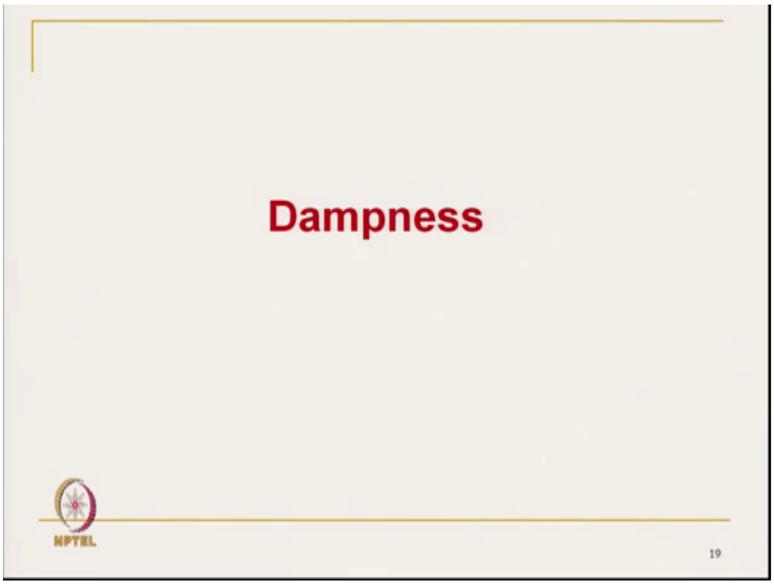

Now, coming to the phenomena of dampness, so most of the cases we feel that if it is a damp irrespective of the temperature of the environment; we feel discomfort it is a very common discomfort.

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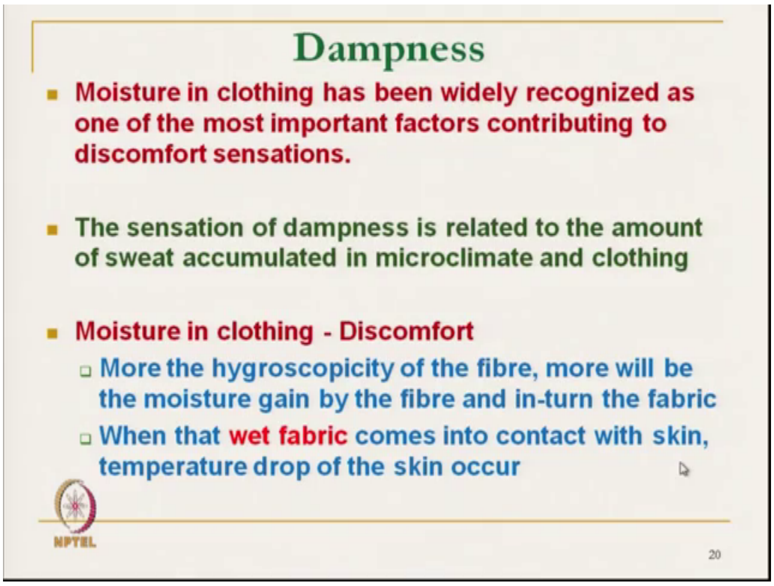

So, moisture in clothing has been widely recognized as one of the most important factor contributing to the discomfort sensation. So, it actually main factor which contribute the discomfort sensation. The sensation of dampness is related to the amount of sweat accumulation in the microclimate and the clothing. So, it may be in the liquid form or may be in the vapour form. So, higher humidity in the microclimate or higher moisture content in the clothing will give the dampness sensation which is very which creates a discomfort sensation.

So, moisture in clothing means discomfort. So, more the hygroscopicity of the fibre more will be the moisture gain by the fibre and in turn the fabric; that means, the fabric if it is if it absorbs the moisture the fibre that microclimate will be little bit dry and people will feel total comfort sensation. When the fabric is wet and it comes into contact with our skin, that it drops the temperature. So, one is the sensation, the dampness sensation another is the temperature drop due to the wet cloth. That is the chilling; chilling sensation is there and also in the dampness.

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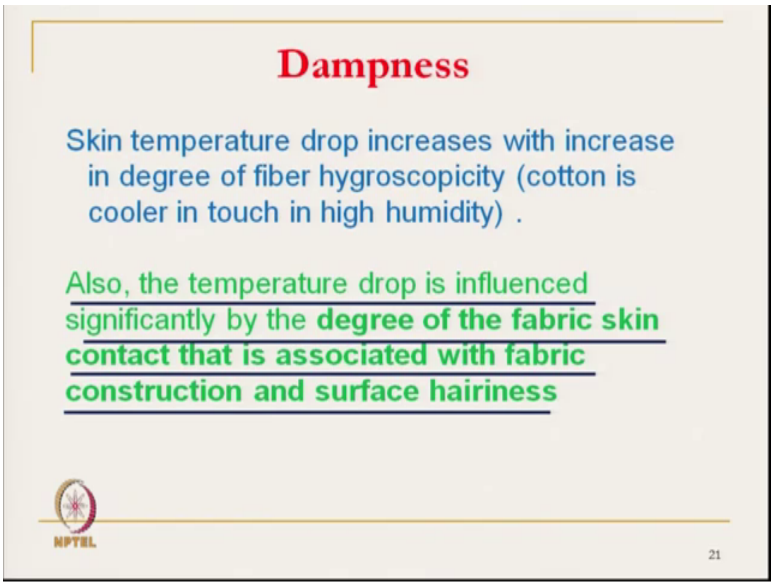

The skin temperature drops increases when it is coming into contact with the wet fabric. And the temperature drop increases with the increase in hygroscopicity of the fibre, the cotton is cooler in touch at high humidity. That is basically due to the hygroscopicity of the fibre. Also the temperature drop is influenced significantly by the degree of the fabric skin contact ok. So, that we have also seen in cold touch, warm touch. So, if the fabric structure is such that higher contact area, higher surface contact area is there with the skin that same fabric will that the fabric made of the same as of same fibre will give higher coolness ok.

Contact with the like fabric made of say wool fibre, wool fibre in high humidity some gives actually the warmth in nature. So, this warm nature with the wool fibre and cotton gives the cooler touch there are combined factors. One is that wool is actually heat of absorption is high in case of wool it gives automatic warmth. And also the wool fibre has got it is crimp natural crimp very high crimp. So that result less contact area so, that gives the wool fibre fabric made of wool is naturally it is warmth even if it is the high humidity condition.

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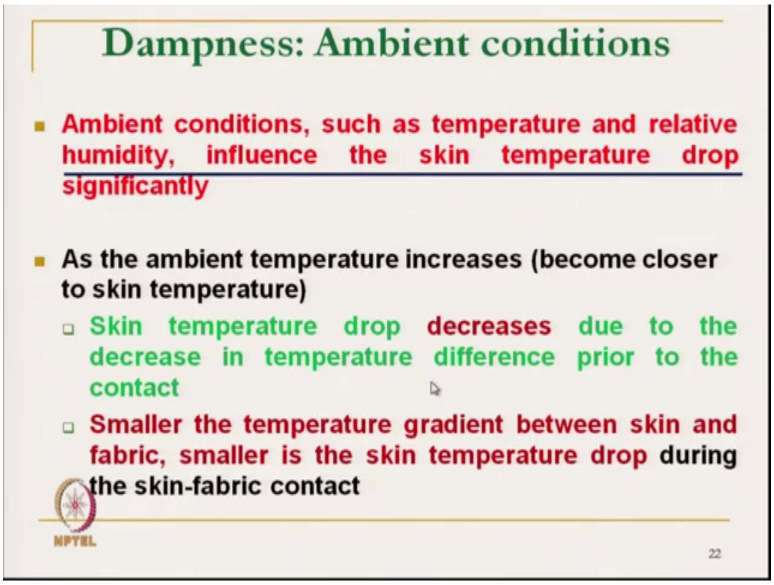

Now, dampness that in ambient condition such as temperature and relative humidity influence the skin temperature drop significantly. So, if the ambient temperature is high what will happen and that is close to the skin if it is high the skin temperature drop decreases. It is obvious, because of the lower difference in temperature. So, it decreases the temperature difference prior to the contact and similar that is the smaller the temperature gradient that means less will be heat transmission. So, that is why temperature drop it is not there.

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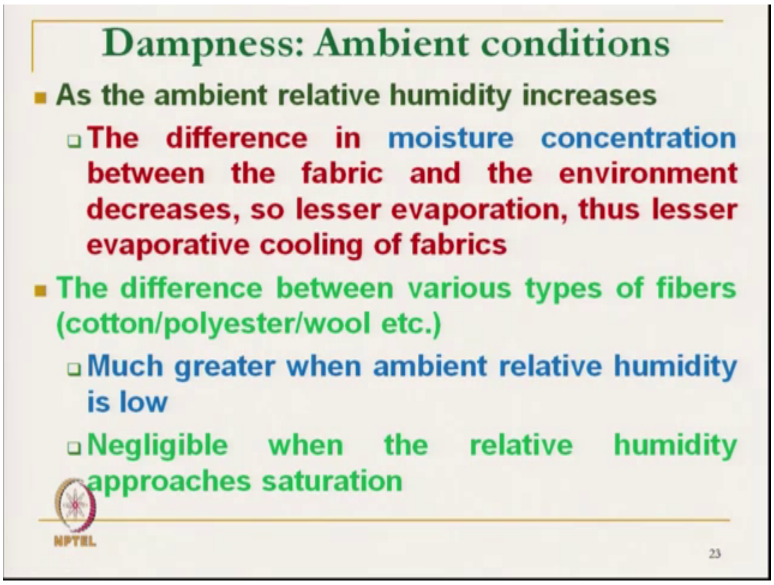

As the ambient temperature relative humidity increases so, what will happen the difference in moisture content between the fabric and the environment decreases. So, because initially the moisture content in the fabric was high that is why it gets evaporated. So, as the humidity in the environment increases so it will result less evaporation. So, less evaporative heat transmission will be there ok. So, the fabric will the less; that means, less evaporative cooling will be there will feel warm and humid ok and dampness sensation will be there.

So, with the increasing ambient humidity we will feel dampness because of less evaporative, less evaporation of the moisture entrapped in the microclimate. The difference between various type of fibre like cotton, polyester, and wool; if it is there it is at much higher when the ambient condition is, ambient humidity is less. So, at lower humidity so at 50-60 percent humidity the difference in sensation of dampness is high. In case of say polyester, cotton, or wool, but when the humidity is high say 100 percent relatable it is a saturating

So, that the difference in dampness sensation for cotton, polyester, and wool will be negligible because the phenomena of moisture transmission moisture evaporation is not there irrespective of the fibre whether it is absorbing more or it is not absorbing more. So, all the fibres a cotton will also give dampness at high humidity. But when we are talking about the normal humidity say 60 percent 50 percent humidity cotton will give better feeling because it absorbs and the it releases.

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Next is another phenomena which is clamminess. Clamminess is a feeling of discomfort.

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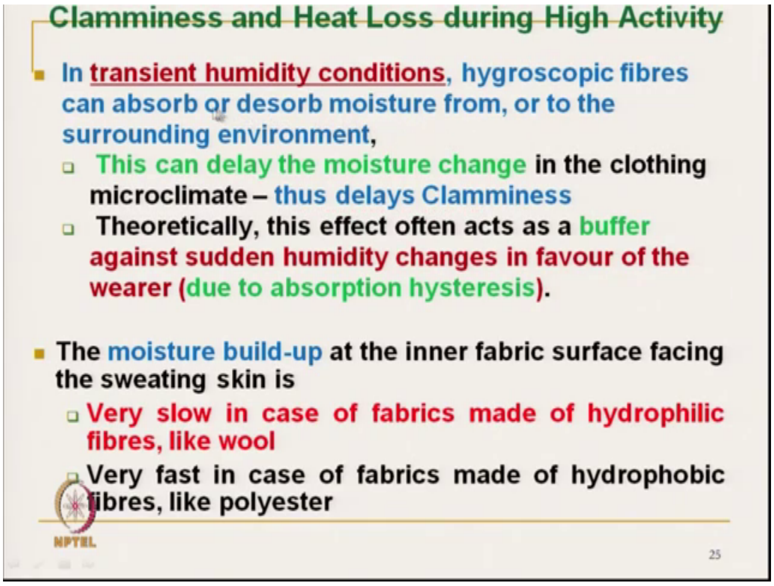

And it is related with the heat loss and clamminess and heat loss basically it is a linked with the high activity because we feel clamminess at the high activity level ok. In transient humidity condition the hygroscopic fibre can absorb or desorbs moisture from or to the surrounding environment ok. That is the transient condition the hygroscopic fibre can release the moisture to the environment depending on the humidity level or it can absorb ok. This can delay the moisture change in the clothing microclimate that we have discuss, it will absorb the moisture and it will delay the moisture change in the microclimate.

So thus delays the clamminess so, that means if we wear a fabric made of hygroscopic fibre like cotton and we are going to a an environment which is highly humid. So, two fabrics are there one is cotton another is say polyester. So, cotton fabric as it absorbs moisture, so it will absorb keep on absorbing moisture from the environment some from the microclimate. So, it absorbs the moisture micro from the microclimate at least for some time. It is trying to keep the microclimate dry irrespective of the fact that the outside humidity is high. That means a person when he is coming from a dry humidity to high humid area saturator humid area.

He will not immediately feel clamminess he will not immediately feel dampness; that means, it is basically delays the process but in case of polyester he will start immediately a start feeling the clamminess. That means, it delay it is it cannot delay ok. So, for hygroscopic fabric it actually delays the clamminess sensor. So, he will for sometime like wool fibre if he is wearing wool cloth made of wool; he will not immediately feel clamminess he will take time to feel ok. Theoretically this effect often acts as buffer against sudden humidity changes in favour of the wearer. So, if he is suddenly going out for some time in humid area; that means, it is suggested that he if he is going to a hot and humid climate he should wear a cloth made of the hygroscopic fibre.

So, that at least he will not feel uncomfortable for some time. The moisture built up at the inner fabric surface facing the sweating skin is very slow in case of fabric made of hydrophobic. So, that moisture build up; that means, he is it is that fabric is actually absorbing the moisture so moisture built up will be slow and in case of polyester the moisture built up at that high humidity condition will be high. So; that means, it will delay the moisture built up condition that it acts as buffering ok. A buffering from clamminess, clamminess means when the humidity is high at that time.

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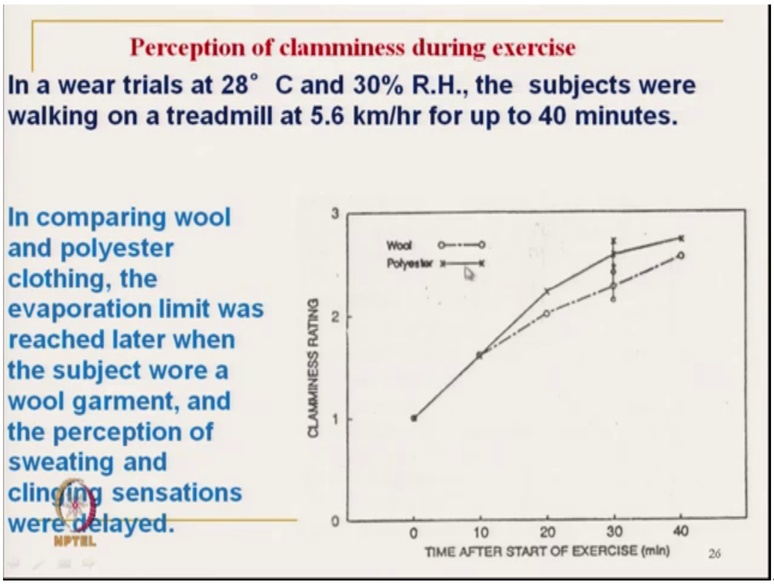

So, there is one study where wear trail study was conducted the temperature was kept at 28 degree Celsius, at 30 percent relative humidity. And the person was actually the volunteers were asked to walk on a treadmill at a certain speed ok. And the test was conducted up to 40 minute time. Now what we are observing the dotted line it is a wool ok. And this is a polyester, this solid line is this is polyester solid line which is up.

What does it does it show the clamminess sensation rating. Actually is a high in case of polyester, the reason we have which we have already discussed. In comparison to wool the polyester clothing actually that at the evaporation limit reaches faster, because polyester is not absorbing it has to actually immediately release the moisture. So, that is how it is not able to absorb really reduce the humidity in the microclimate. So microclimate is humidity is high and the clamminess sensation is high.

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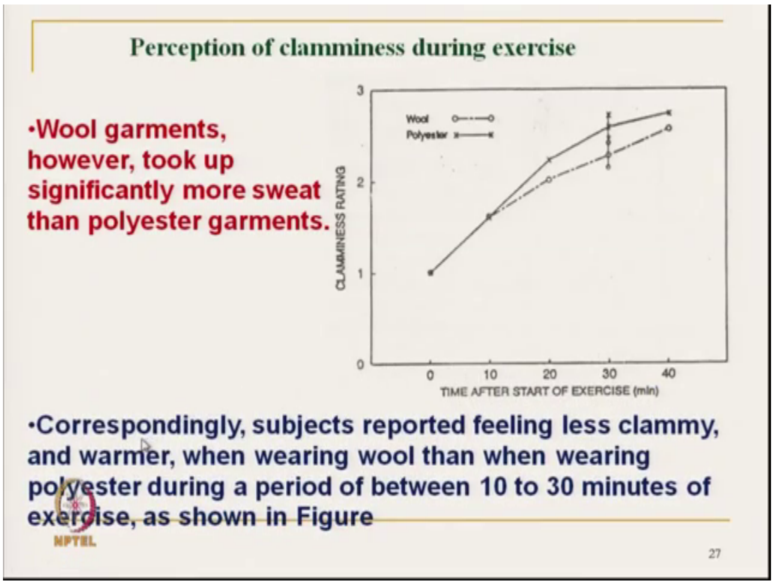

So, the wool garments; however, took up significantly more sweat than polyester garment. The correspondingly the subject reported feeling less clammy when he is wearing wool particularly in between 10 minute to 30 minute where the difference is high ok. So, we will stop here; we will continue this discussion in the next talk, till then.

Thank you.