Technical Textiles
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Lecture - 20
Extreme Cold Protective Clothing

Hello everyone, now, our new topic is that protective clothing. So, in protective clothing, we will discuss 2 aspects. One is extreme cold protective clothing and extreme heat protective clothing. So, today I will discuss extreme cold protective clothing.

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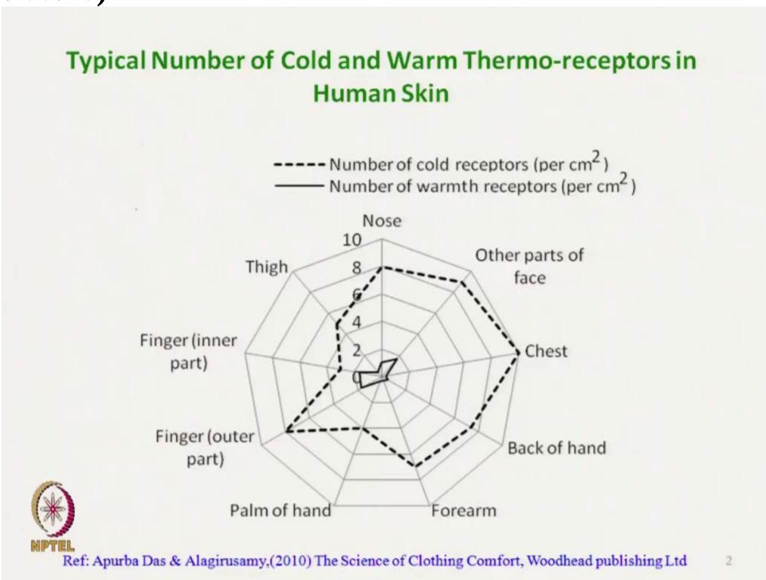

Here we will discuss different issues, what are the different layers in cold protective clothing, the material used their application their structures. So, all these aspects we will discuss here. If we see that the cold receptors in our body. So, these are the receptors, which receives the cold sensations there are 2 types of receptors, one is cold receptor and other is hot receptors. So, their distribution in our body at different parts are different.

So, their concentrations are different, at chest it is highest, it is expressed in terms of number per square centimeter and if we see, if we compare with the number of warmth receptors, the number of cold receptors are much higher than number of cold receptors.

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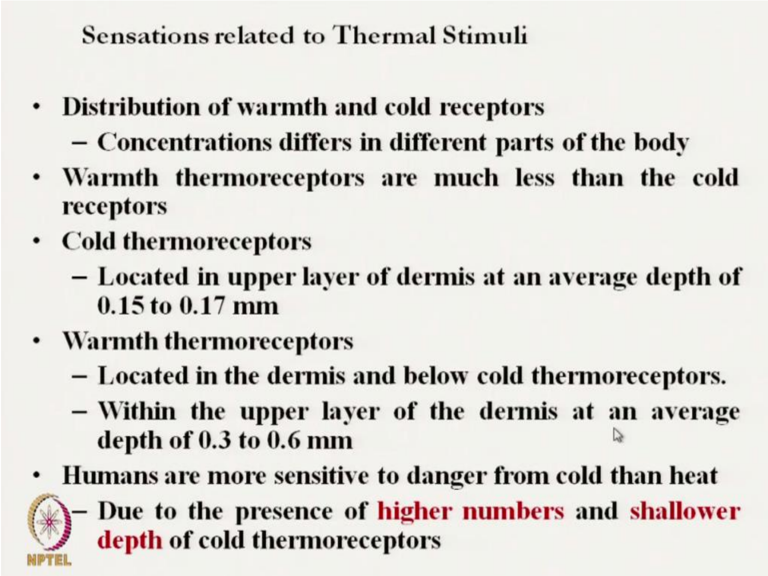

Also the depth of the cold receptors as compared to warmth receptor, they are present in much shallow depth. So, locations of the cold receptors are typically between 0.15 to 0.17 millimeter from the upper layer of our skin and average depth of warmth receptors are 0.3 to 0.6 millimeter. So, that is why we are more sensitive towards danger from cold receptors then heat receptors because of the higher number of receptors, higher concentration of receptors and shallower depth.

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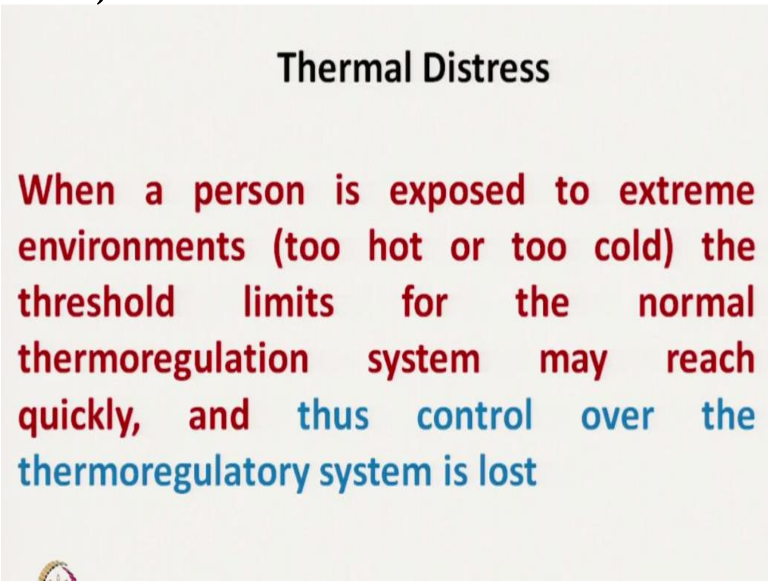

So, there are situations where we feel thermal stress, this thermal stress may be due to extreme heat or due to extreme cold. During this thermal stress, we need protective clothing. So, when a person is exposed to extreme environment that is too hot or too cold, the threshold limit of our normal thermoregulation in our body reach quickly, so that our normal thermoregulation system cannot perform due to this extreme condition, thus control over the thermoregulatory system in our body is lost.

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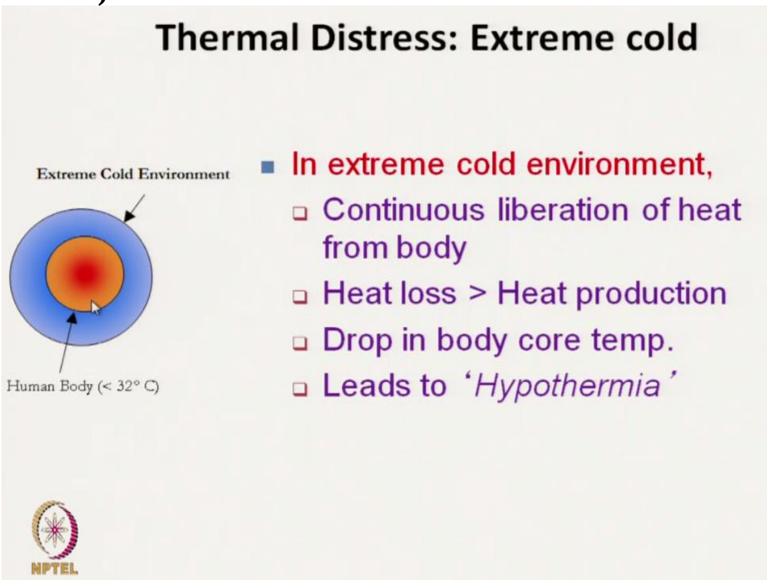

Which results thermal distress. So what happens during this thermal distress due to extreme cold is that in our environment, it is extreme cold shown by this blue zone and our body core temperature, it actually it falls rapidly. That situation is known as the thermal distress condition. And this condition, it is where we start liberating hate continuously from our body, where heat losses more than heat production and our body core temperature drops quickly and which may lead to a situation which is called hypothermia.

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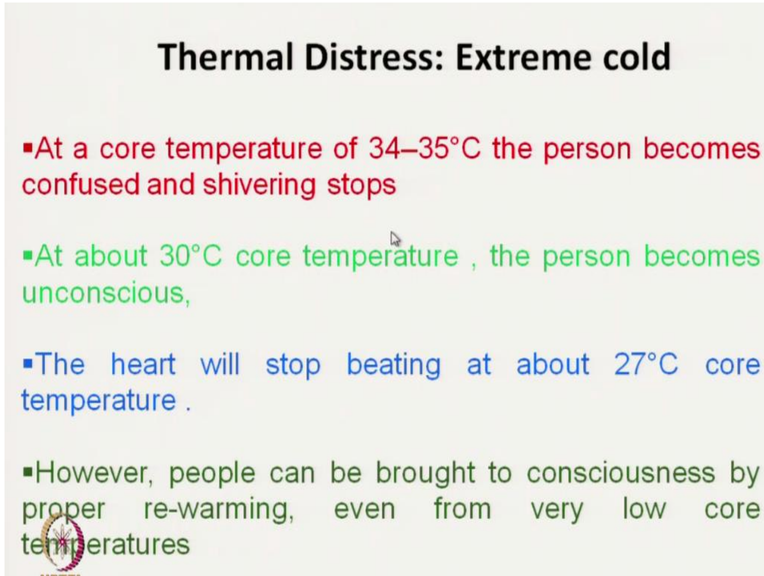

What happened during this at a core temperature, our body cold temperatures should be around 37 degrees Celsius, but it has been reported around 34 to 35 degrees Celsius body core temperature due to extreme cold the person becomes confused and shivering stops. So, just below 37 degrees Celsius around say 36 degree our body physiology due to that shivering starts which tries to generate extra heat but 34 to 35 degrees Celsius of body core temperature the shivering automatically stops, the extra heat generation mechanism is inactive.

If the body core temperature drops further, say at 30 degrees Celsius, so, a person becomes unconscious. So, heart stops beating at about 27 degree core temperature. So, if we want to get back from this unconsciousness or maybe confused or shivering stages, we may rewarm proper rewarming is needed. So, to prevent all this condition, we need clothing for protecting ourselves from extreme cold, because our internal physiological condition is not able to cope up all these situations.

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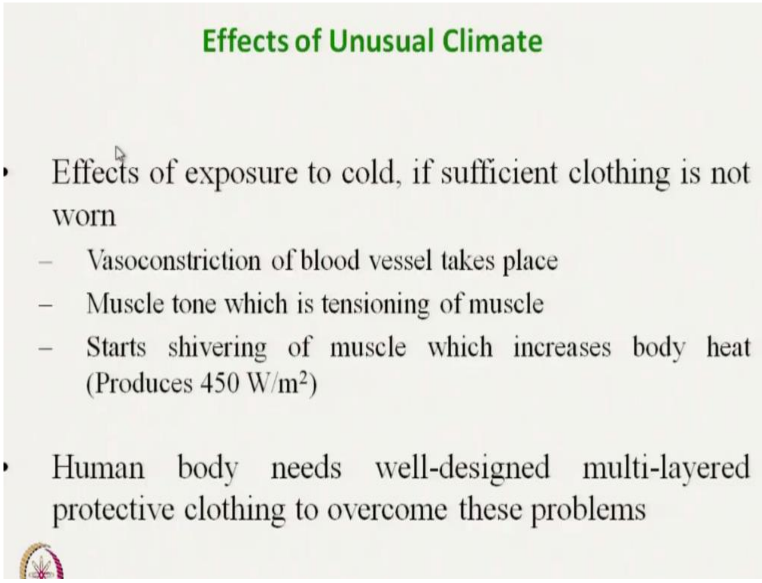

So, what are the effects of unusual climate, the effects of exposure to cold if we do not wear sufficient clothing initially due to body physiology, vasoconstriction takes place where it restricts blood flow to retain heat within our body, muscle tone which is tensioning the muscle and then shivering start. So, to avoid all this unusual climate and to protect us we need proper well-designed extreme cold climate clothing and most of the extreme cold climate clothing's are not single layer, they are multi layered clothing. So, if we use multi-layer clothing, so, we may overcome all these problems.

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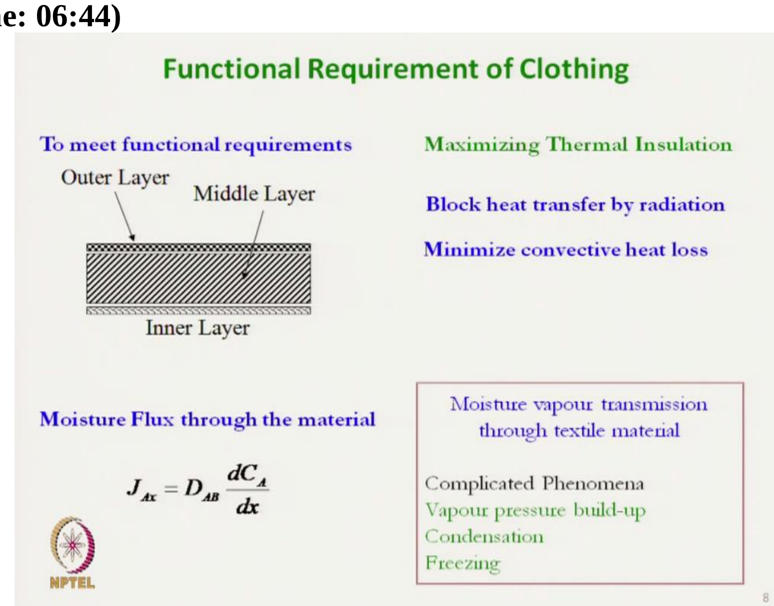

So, these are the functional requirement, there are typically 3 layers, outer layer, middle layer and inner layer. I will discuss in detailed, the functions of each and individual layer. So, this layers are required to minimize the thermal transmission that is maximize the insulation, we want to have higher insulation by blocking the heat transfer by radiation. So, we should prevent the heat to come out from our body by radiation and minimize the convective heat loss, along with this heat control of heat transmission.

So, during all this development, we must take into account that the moisture vapor transmission through this structure should be enough otherwise, there will be condensation problem and freezing problem will be there within the structure and all this may affect the thermal insulation characteristics of clothing and if we try to prevent the moisture vapor to pass through the clothing ensemble, so, basically the moisture it should allow the moisture vapor to flow freely through the body at the same time it should prevent the heat to come out. So that is why that the moisture vapor pressure buildup should not be there.

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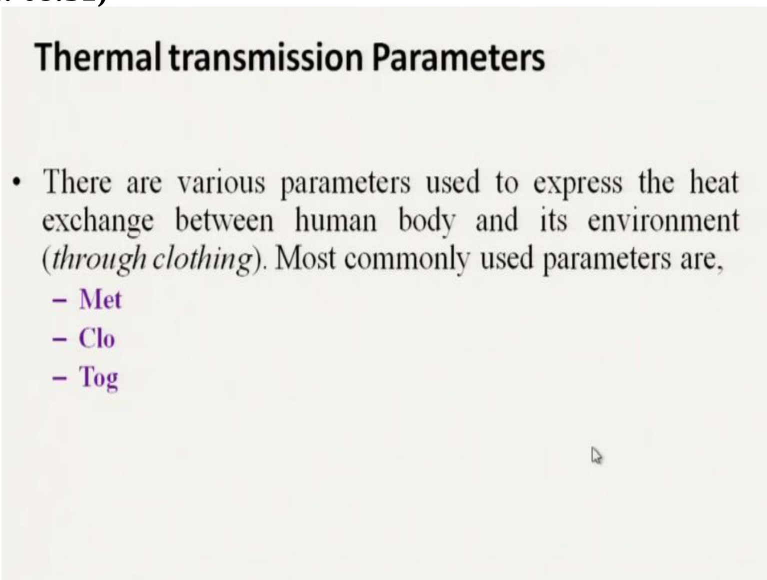

Before going into detail of different layers we must first understand the parameters thermal transmission parameters through which we will express the insulation characteristics. There are generally 3 parameters related to extreme cold protective clothing. These are met, clo, and tog. They are most commonly used parameters.

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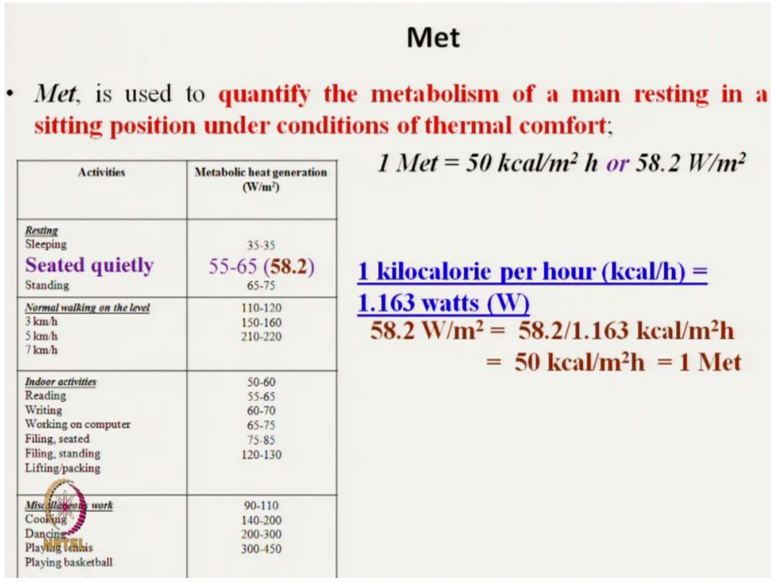

Met is the term which has nothing to do with the clothing, it is basically our metabolic heat we are developing we are generating this metabolic heat that met is the measure of our metabolic rate. It is used to quantify the metabolism of a man resting in a sitting position under the condition of thermal comfort. That is the definition of met. So, the table shows the different activities at different activity we generate different level of metabolic heat.

As we increase our activity our metabolic heat generation will be more and more and we may feel warm and at that time, we have to release the heat at a higher rate. So at steady state condition, from the table, we can see it is around 55 to 65 watt per square meter heat will generate, metabolic heat, but as per our definition of met, 1 met is 50 kilo calorie per square meter hour, which is equal to 58.2 watt per square meter approximately.

So, a seated quiet person will generate heat in this stage. So, that is why the met is defined as 50 kilo calorie per square meter. That is 1 met and which has nothing to do with the clothing. But this met value is used to develop other insulation characteristics, clothing insulation characteristics, other characteristics are clo and tog. This clo value is very widely used for clothing insulation measurement, particularly for extreme cold climate clothing.

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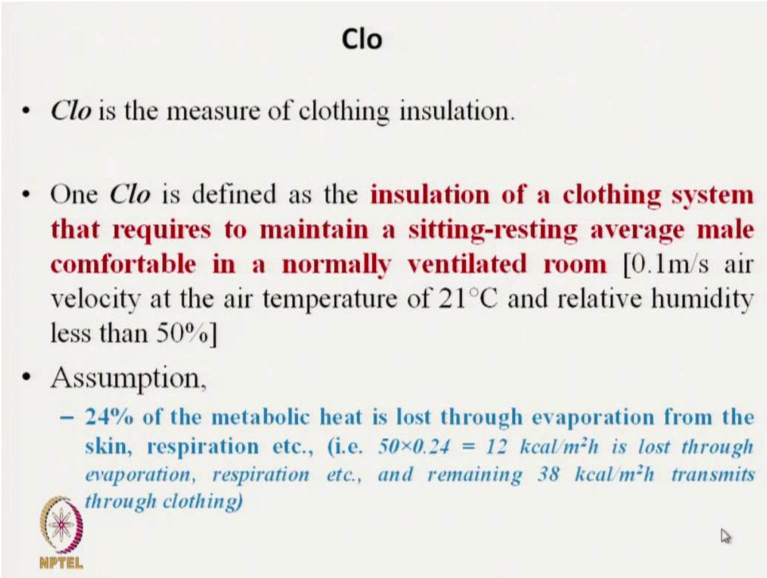

Clo is a measure of the clothing insulation, by clo we try to measure the insulation of total clothing, it is not the fabric in isolation. What is Clo? Clo is defined as the insulation of a clothing system. This clothing system includes total clothing, tops, bottoms, gloves, everything taken together that required to maintain a sitting resting average male, comfortable in a normally ventilated room. As I mentioned, that met means the metabolic heat which is generated by a person in normal sitting, resting position.

So, for that person, whatever heat he is generating, if the clothing is able to transfer that heat to the environment that clothing insulation is known as 1 clo and the definition of ventilated room is that where the speed is speed of air is 1 meter per second, the air temperature is 21 degrees Celsius and relative humidity is 50% or less. Now to derive Clo from basic definition, the assumptions are that 24% of metabolic heat is lost through evaporation from the skin and respiration.

So, through respiration and evaporation from the skin which is actually away from the clothed portion, so, where clothing is not coming into picture, so, that 24% and what we have seen 1 met is 50 kilo calorie per square meter hour so, it is 24% of 1 met value that is coming out to 12 kilo calorie per square meter hour is lost through evaporation and respiration and remaining 38 kilo calorie per square meter hour that is 50 - 12 is transmitted through clothing. So, that is the insulation of the clothing we require. So 38 should be transmitted.

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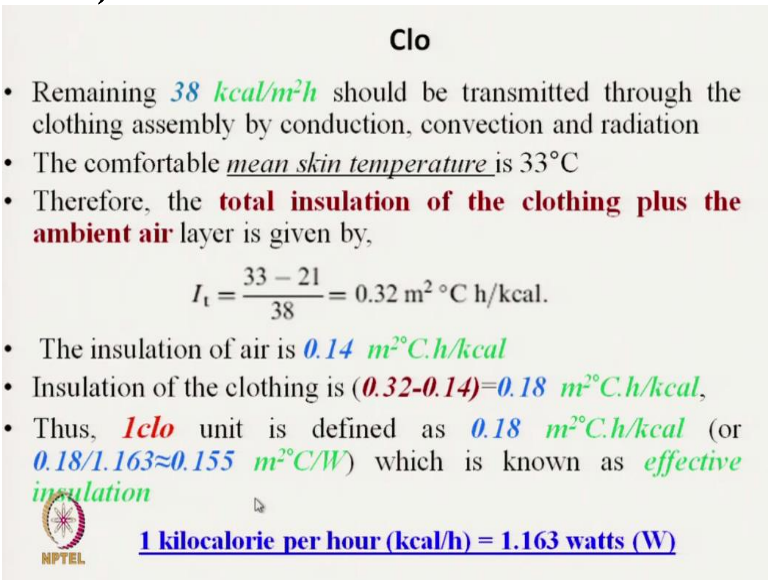

Now from the literature, we can get that mean skin temperature, that condition means at the ventilated room is 30 degrees Celsius 33 degrees Celsius. Therefore the total insulation of clothing plus air, the ambient air layer, it is given by 33 – 21 by 38. That means this is a temperature difference. And that is the insulation required. So that is the conductivity that was transmitted transmission is required 38 so, it is coming out to be 32 square meter degree Celsius, hour per kilocalorie.

So, 0.32 is the insulation, total insulation of clothing plus ambient air and air insulation is known to be 0.14 and if we consider the air and clothing they are in series that means they are in additive in nature. So, we can get insulation of clothing that is 0.32 – 0.14 = 0.18. So, that is the clothing insulation and that is equivalent to 1Clo. So, 1Clo is the unit is defined as 0.18 square meter degree Celsius hour per kilocalorie.

And if we convert into this wattage, so, that is 0.155 square meter degree Celsius per watts. So, that is the conversion here the relationship 1 kilo calorie per hour equal to 1.163 watts. So, from there, we get the relationship 1 clo = 0.155 square meter degree Celsius per watt.

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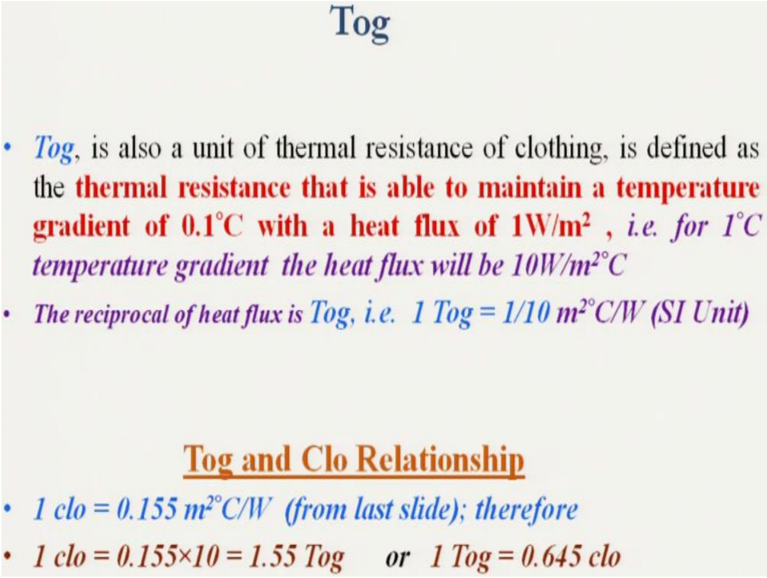

Another parameter for clothing insulation is that tog, tog is also a unit of thermal resistance of clothing. Here we use tog for clothing insulation, but tog we can also calculate from the instrument, which is defined as the thermal resistance that is able to maintain a temperature gradient of 0.1 degree Celsius with a heat flux of 1 watt per square meter that is for 1 degree temperature gradient.

The heat flux will be 10 watt per square centimeter the reciprocal of heat flux is tog. So, 1 tog will be 1 / 10 square meter degree Celsius per watt, which is in SI unit, from there we can get the relationship between clo and tog which is 1 clo = 1.55 tog. So, that is the relation we can convert, tog to clo, clo to tog by this relationship.

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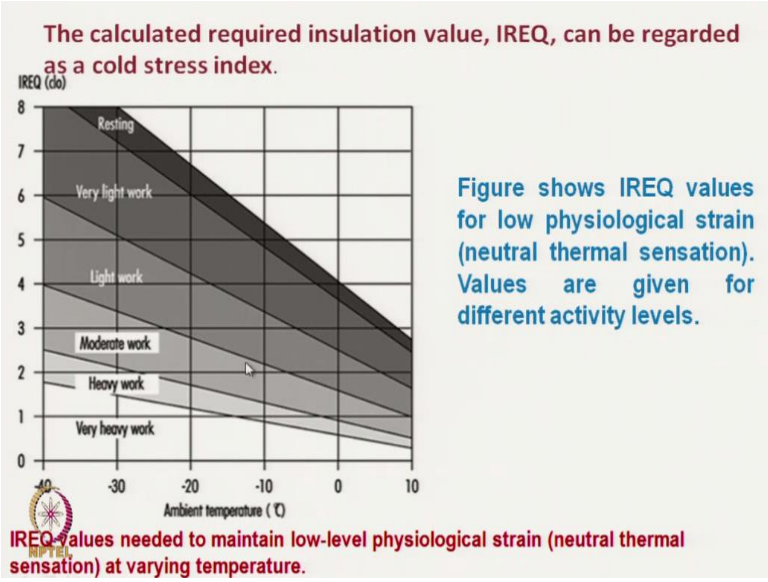

Now, this diagram shows required insulation and how to select clothing for a particular extreme cold condition. We must understand the cold stress index. So this IREQ, that is insulation required. It is a cold stress index, this figure shows the IREQ values for low physiological strain, that is neutral thermal sensation and at different activity level. Now, from this diagram, let us see a person at 0 degrees Celsius temperature environment, if he is sitting, idle, resting.

How much insulation of clothing, he requires, if it is he is sitting at 0 degrees Celsius, sitting idle, he would require a total clo value of clothing of around 4 clo. So he requires total clothing systems clo value of 4. Higher clo value means higher insulation required, thick clothing required, but at 0 degrees Celsius if he starts working so if he is say working very hard in that case he would require very light clothing, maybe 0.5 clo is required. On the other hand similarly if we keep on reducing the temperature, so at - 40 degrees Celsius.

If the person works hard, very hard work still he required clothing up 2 clo. So, at different temperature if we reduce the temperature then we require higher clo value in our clothing. So we need to have clothing of different clo, but for certain temperature say - 40 degrees Celsius if we increase our activity level, we may reduce we may need lower clo value. So, we may need lighter weight fabric with lower clo value. So, to decide the comfort sensation at different temperature, only the clothing selection is not enough, we must know the activity level average activity level.

Otherwise suppose for -20 degrees Celsius, we have designed clothing for resting person, say for that, if we use this diagram, we will select clothing of around 6.5 clo, but effectively if the person is not resting if he is working hard in that case, he actually requires a clothing of say 2 to 3 clo. But he has been provided clothing of say 6 to 7 clo, in that case he will feel warm. So, that will not serve his purpose he will be uncomfortable he is unnecessarily carrying higher load. So, that we have to take into consideration.

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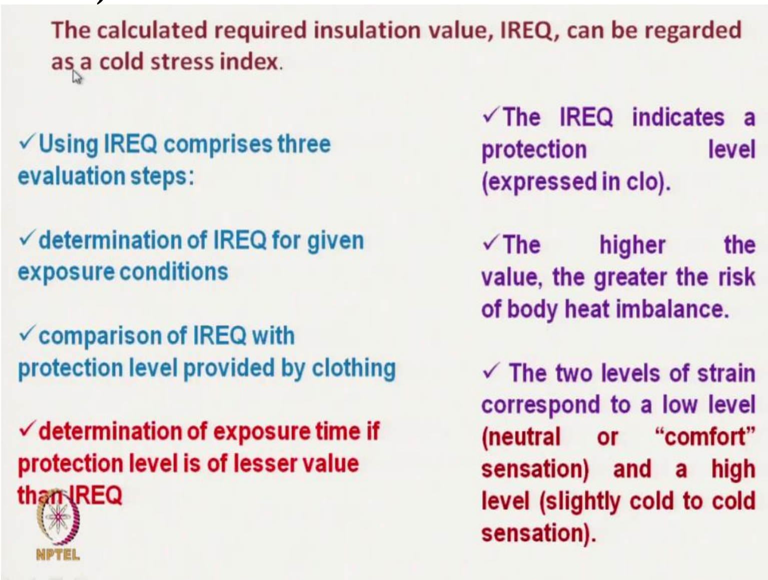

So, these are the steps here it is showing how to calculate the IREQ value how to select the IREQ value and which is known as cold stress index. So, how to use this IREQ value? First determination of IREQ for a given exposure condition. As I have mentioned, going back to earlier graph, suppose a person will be working under - 30 degrees Celsius condition, environmental condition and he is supposed to work to moderate work. So, from this diagram, we can decide what will be his insulation required.

So, here say he is doing moderate we can select. So, 3 as the insulation, requirement IREQ 3, we have determined comparison of IREQ with the protective label provided by the clothing. So, we will select the clothing protective value by in term of tog and accordingly, we can use. There are 2 levels of strain correspond to the low level or neutral or thermal neutral or comfort sensation. And another is a high level that is slightly cold or cold sensation. So, these are the 2 levels. Here, you can see in this diagram, the 2 levels are there here it is a normal it is a little bit cold sensation will be there.

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Clo Values

Clothing ensemble	I^{cl} (m^2 °C/W)	I^{cl} (clo)
Briefs, short-sleeve shirt, fitted trousers, calf-length socks, shoes	0.08	0.5
Underpants, shirt, fitted, trousers, socks, shoes	0.10	0.6
Underpants, coverall, socks, shoes	0.11	0.7
Underpants, shirt, coverall, socks, shoes	0.13	0.8
Underpants, shirt, trousers, smock, socks, shoes	0.14	0.9
Briefs, undershirt, underpants, shirt, overalls, calf-length socks, shoes	0.16	1.0
Underpants, undershirt, shirt, trousers, jacket, vest, socks, shoes	0.17	1.1
Underpants, shirt, trousers, jacket, coverall, socks, shoes	0.19	1.3
Undershirt, underpants, insulated trousers, insulated jacket, socks, shoes	0.22	1.4

This table shows basically rough idea about the clo value of the total clothing system. So, if a person wears briefs, short sleeve shirt, fitted trouser, socks, shoe, so his total in sample will have insulation of 0.5 clo. So accordingly if we keep on changing our clothing so we can control the clo value.

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Clo Values

Clothing ensemble	I^{cl} (m^2 °C/W)	I^{cl} (clo)
Briefs, T-shirt, shirt, fitted trousers, insulated coveralls, calf-length socks, shoes	0.23	1.5
Underpants, undershirt, shirt, trousers, jacket, overjacket, hat, gloves, socks, shoes	0.25	1.6
Underpants, undershirt, shirt, trousers, jacket, overjacket, overtrousers, socks, shoes	0.29	1.9
Underpants, undershirt, shirt, trousers, jacket, overjacket, overtrousers, socks, shoes, hat, gloves	0.31	2.0
Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, overjacket, socks, shoes	0.34	2.2

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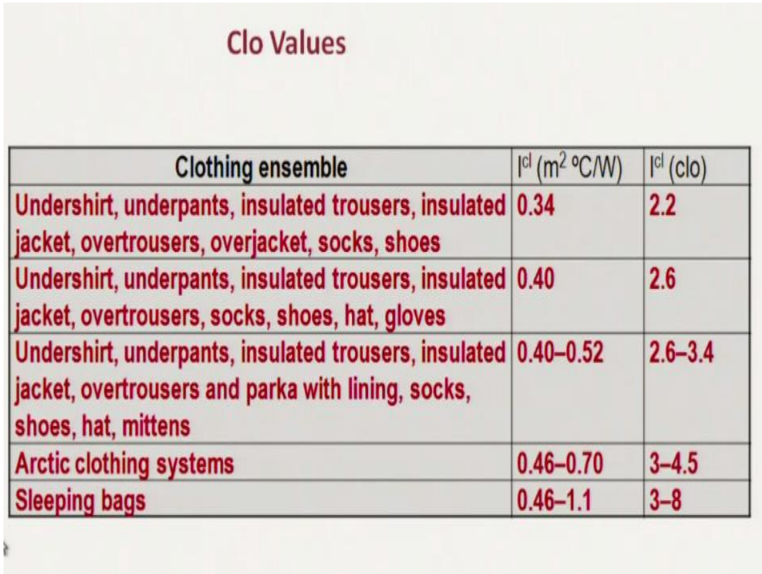
Clo Values

Clothing ensemble	I^{cl} (m^2 °C/W)	I^{cl} (clo)
Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, overjacket, socks, shoes	0.34	2.2
Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, socks, shoes, hat, gloves	0.40	2.6
Undershirt, underpants, insulated trousers, insulated jacket, overtrousers and parka with lining, socks, shoes, hat, mittens	0.40–0.52	2.6–3.4
Arctic clothing systems	0.46–0.70	3–4.5
Sleeping bags	0.46–1.1	3–8

So these are the different combinations we can use. A sleeping bag can have clo value between 3 to 8. So which is used for extreme cold climate clothing, these are the range.

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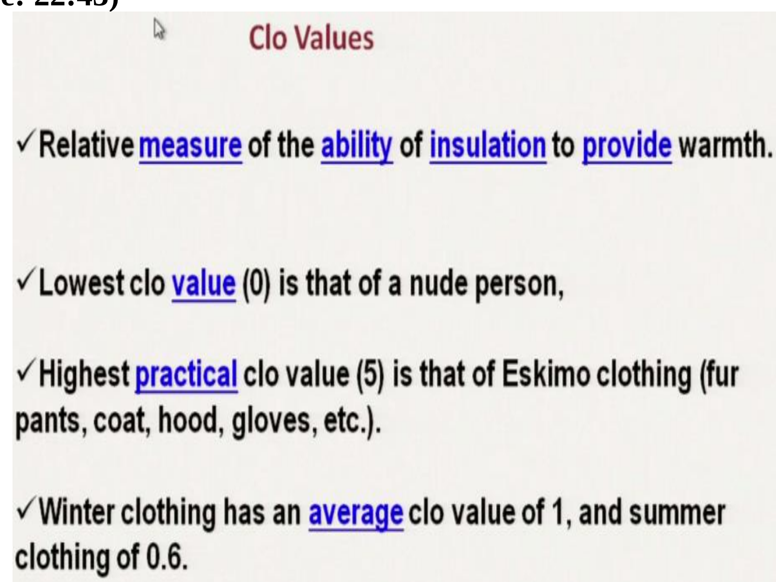

So the clo value is the relative measure of ability of insulation to provide warmth, so that is important. Lowest clo value of a nude person is which obviously 0 you know there is no clothing and highest clo value of say 5 is that Eskimo clothing which is comprises of fur pant, coat, hood, gloves, if we take together all these, so we may achieve 5 clo value. So average winter clothing is around 1 clo and summer clothing clo of 0.6. So afte understanding the parameters.

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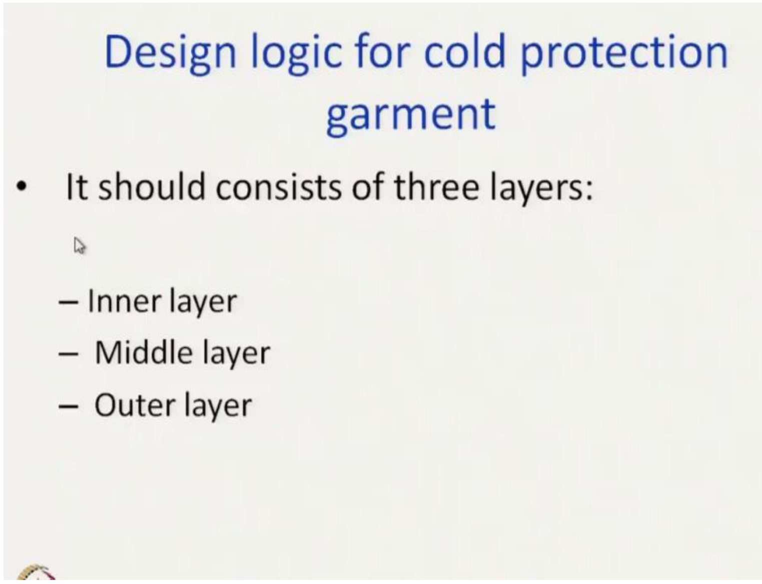

Now we will discuss the different layers used in extreme cold climate clothing. The layers as I have already mentioned the layers are 3 layers, inner layer, middle layer and outer layer.

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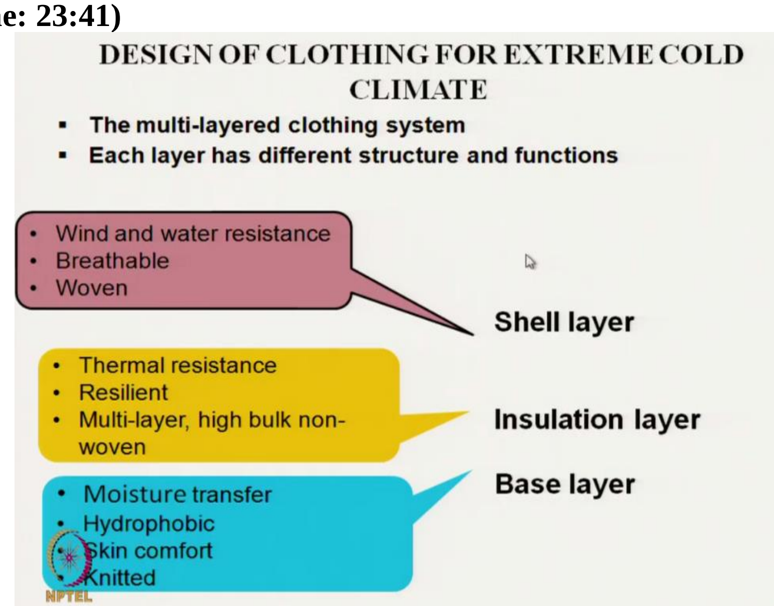

The outer layer which is also known as shell layer. The shell layer's main function is to protect the person from wind and water or snow. So it should be breathable water impermeable normally we use outer layer with a woven structure which is very thin woven structure is used because its main function is not insulation. So, here its function is basically wind and water blocking, but at the same time it should be breathable. The middle layer, which is also known as the insulation layer here main function is that it should be thermal resistant.

So, thermal resistance is the basic characteristics required in the insulation layer. And another important characteristics is that it should be resilient like after compression, it should retain its original position, otherwise what will happen, it whatever the air entrapment is there in the structure, this will be lost and this will lose its insulation and for that, here, we use high bulk nonwoven fabrics are used here and base layer the inner layer they have their function.

Basically, skin comfort, moisture vapor transmission, it should be typically hydrophobic in nature, because hydrophilic fibre like cotton, once absorb moisture or water; it tries to cling to our body. So, that becomes uncomfortable and we use knitted fabric for the reason the structure is not that smooth and it forms the comfort layer due to the loop structure.

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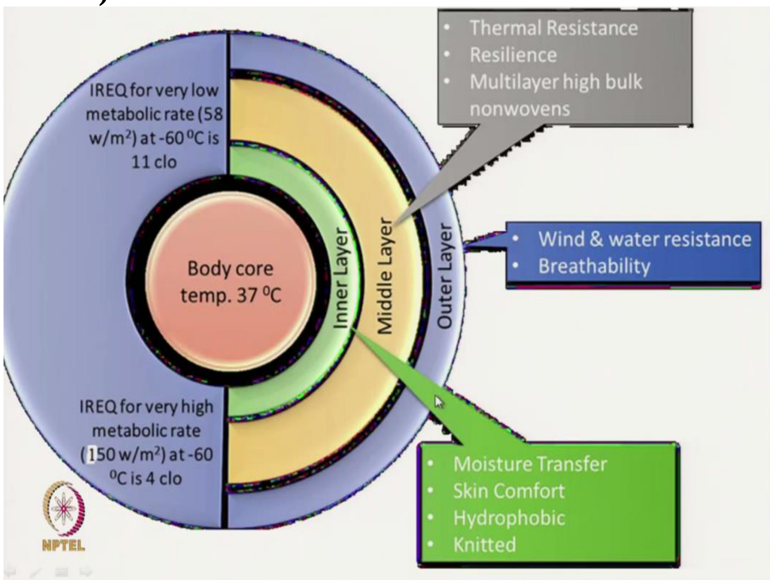

Now, this diagram shows this is the body core with a temperature 37 degrees Celsius is required. This is the inner layer, next is middle layer and third one is outer layer. So, as I have already mentioned, it is a moisture transfer, skin comfort, hydrophobic and knitted structure. This is the inner layer, middle layer, thermal resistance basically thermal resistance layer, it is there and here. It is wind and water is this it should be breathable. So, in doing the water proofing or water resistance, it should not the block all up pores. So, that type of coating should be there.

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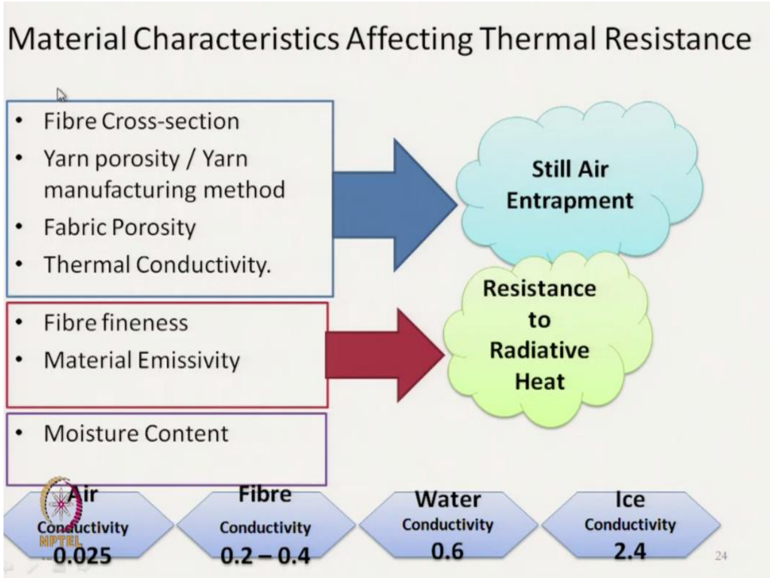

The material characteristics which affect the thermal resistance are fibre cross sectional shape. So, we may change the cross sectional shape or size like microfiber or coarse fibre that controls the air entrapment. If we use the hollow fibre or use the coarse fibre, then we can increase the air entrapment. Then, yarn porosity or yarn manufacturing method controls the air entrapment if we use a hollow yarn or use a textured yarn.

So, we can enhance the air entrapment, fabric porosity is also important. So, porous structure of nonwoven increases the still air entrapment and hence it has thermal resistance and we can select fibre with lower thermal conductivity. So, all these material characteristics are important for still air entrapment. Basically that for insulation, we require 2 aspects one is to control the conductive heat or convective heat and at the same time, we have to control the radiative heat.

So, radiative heat we can control by controlling the fibre diameter, fibre fineness and emissivity of the material used. Apart from this moisture content of material is also important for controlling the thermal resistance, higher moisture content means, higher thermal transmission. So, thermal resistance will reduce, so, we must use a fibre with lower moisture content or moisture regain to have better thermal resistance.

So, this is the comparison between the conductivity of different martials, air conductivity is 0.025 fibre general conductivity is 0.2 to 0.4, water conductivity 0.6 and ice the conductivity is

2.4. So, if we see within the fibrous structure, if the air is being replaced by water or moisture then we will lose our thermal resistance due to higher conductivity of water.

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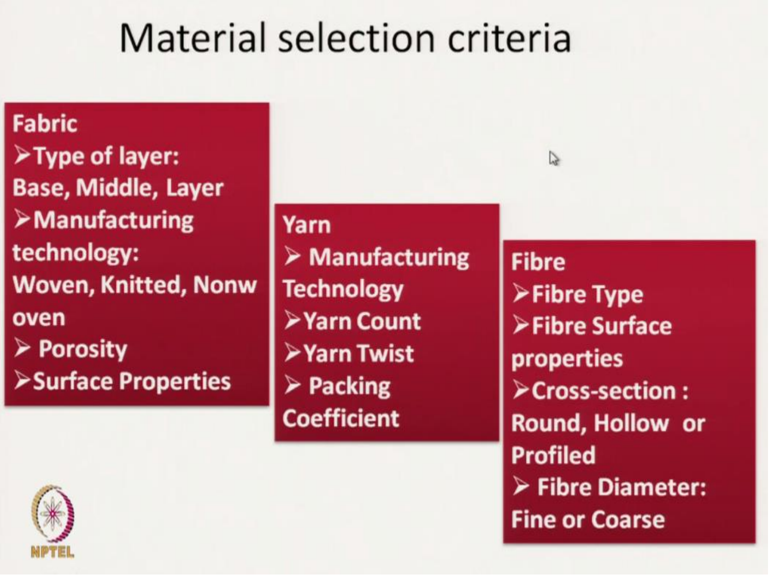

So, to select the material for extreme cold climate clothing, there are 3 different stages, the fibres what we can select the type of fibre, we should take into consideration, fibre surface properties, cross sectional shape whether it is a round hollow or profiled and diameter of fibre, so, we have to take all these things into account. So, fibre type is, whether we should go for natural fibre or synthetic fibre, if synthetic then what type of fibres we require those we have to take into consideration. After fibre then, if we use woven fabric or knitted fabric.

Then yarn selection is important, that whether we should go for the ring spun yarn or rotor spun yarn or DREF spun yarn, so, that we have to decide. What count of you and whether we should go for coarser yarn or finer yarn, type of twist we require or packing coefficient. So, depending on our application, we have to decide all these yarn related parameters and fabric related parameters are basically that a different layer, base layer, middle layer or outer layer.

We have to select which fabric we should use either woven, knitted, nonwoven what will be the porosity? What are the surface properties? So these are the different properties, what will be the thickness, what will be the mass per unit area of fabric, all these characteristics we have to take into consideration while selecting the fabric.

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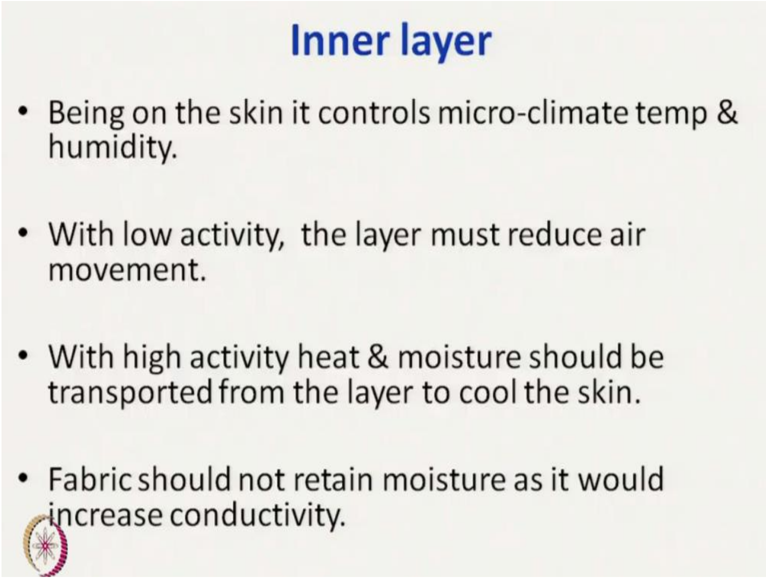

Now, we will discuss the construction and requirements of different layers. We will start with the inner layer. So, inner layer as we have seen, it is basically it is close to the skin always it is in contact with the skin. So being on the skin, it controls the microclimate, temperature and humidity. So microclimate means the climate, the environment between the clothing and our skin, so to control the microclimate, we must decide the inner layer properly, although its function, primary function is not insulation.

With low activity there, the layer must reduce air movement and with high activity heat and moisture should be transported from the layer to cool the skin that is at the high activity we generate moisture we generate sweat. So, this main function of the inner layer is that it should immediately transport the moisture and heat which has been generated in the body out from the skin. The fabric should not retain moisture as it would increase the conductivity. So the inner layers function is to transmit the moisture immediately from our skin.

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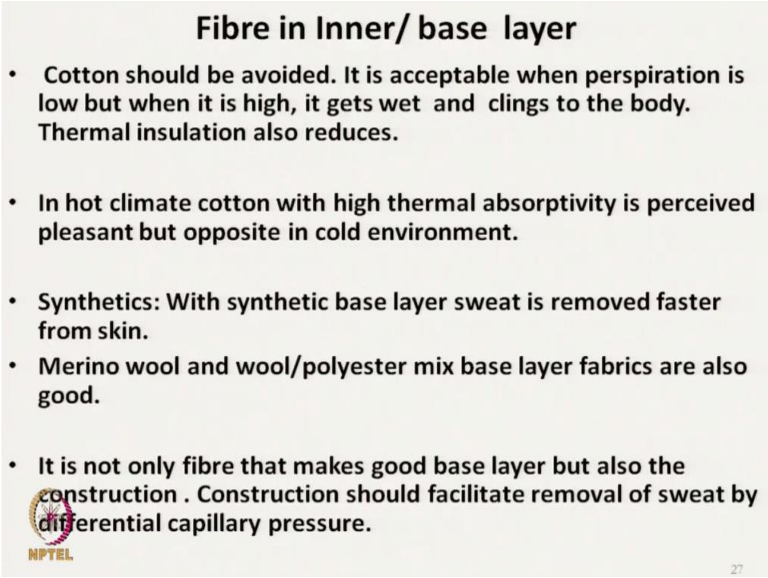

The fibres which are used, we will discuss now. Apparently it looks that cotton is very comfortable fibre but for extreme cold climate clothing, we should avoid cotton, it is only acceptable where the activity is low that means, perspiration level is low. But otherwise at a higher level of activity when it gets wet the cotton's characteristics is that it clings to the body as the cotton after absorbing moisture gets wet.

It reduces the thermal insulation of the structure. In hot climate cotton with high thermal absorptivity is perceived to be pleasant, but in cold it is opposite. So, in hot climate, we can use cotton because of the higher thermal absorptivity it absorbed heat, but as I already discussed that in cold we should not use cotton, because due to higher thermal absorptivity it will take unnecessary extra heat from the body that will make us uncomfortable cold.

The synthetic fibre we can use at the base layer because synthetic mainly the hydrophobic synthetic, they remove water that is removed sweat at faster rate, sometime wool, wool polyester blends are also used. It is not only the fibre selection in the base layer, but the construction of the fabric is important constructions should be such that it facilitate removal of sweat by differential capillary pressure. So, the sweat which has been generated it should not be only absorbed by the fibre, but through the capillary action, it should be removed from the skin.

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Wool & wool blends	Cotton	Synthetics
It posses high absorbing capacity and can handle small amount of moisture without loosing insulation properties. It can be used next to skin fabric and can keep skin dry. When the fabric gets saturated the moisture control is reduced.	Absorb moisture but clings to the skin when wet and therefore should not be too close to the skin in cold environment.	These are hydrophobic and moist air can move from skin through the fabric to the next layer. The skin microclimate quickly becomes humid during sweating. This humidity is uncomfortable.

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These are the comparison of different fibres in the base layer. If we use wool or wool blend, it is it poses high absorbing capacity and can handle small amount of moisture without losing the insulation properties. The wool’s main advantage that once it absorbs moisture, it releases heat. That is why it is insulation of the clothing is not compromised, it can be next to the skin fabric skin and can keep skin dry. But on the other hand, in case of cotton it absorb moisture, but clings to the skin when wet.

And therefore should not be too close to the skin in cold environment. So in cold environment, we must avoid cotton as inner layer. But synthetic fibres are hydrophobic in general, and moist air can move from skin through the fabric to the next layer. That is due to hydrophobic nature due to wicking action the moist air can move freely or quickly through this fabric layer. The skin microclimate quickly becomes humid during sweating. This humidity is uncomfortable.

So, if we cannot maintain the wicking property, then the problem would be that this synthetic fibres are hydrophobic in nature, they do not absorb. And at that same time, if they cannot wick then screen microclimate will be quickly humid and become uncomfortable. So, we have to decide the fibre as well as the structure of fabric for inner layer.

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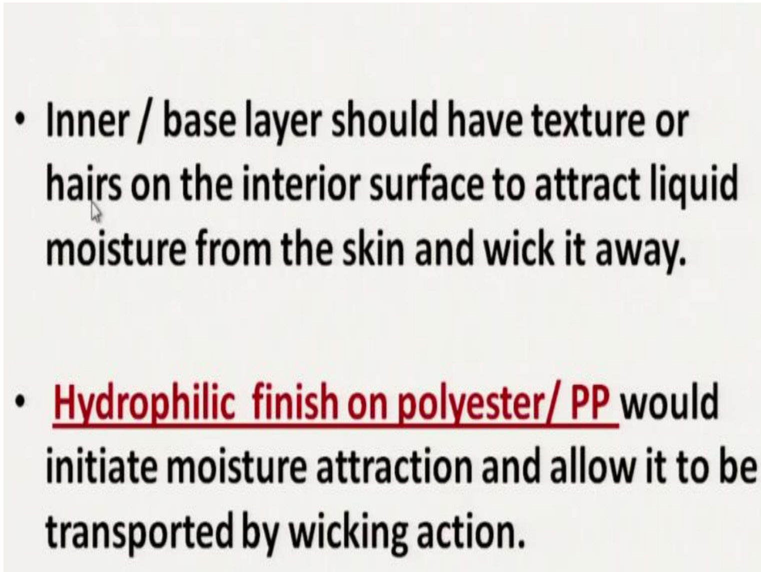

So inner or base layer should be textured basically, that layer should not be smooth, they should be textured, or we can have higher hairiness in that inner layer to attract liquid moisture from skin and wick it away with textured this surfaces is used. Hydrophilic finish on polyester or polypropylene sometime is recommended. And this would initiate moisture attraction due to hydrophilic finish and due to the hydrophobic nature of these fibres, they allow the moisture to be transported by wicking action. So, these are the different ways to improve the wicking characteristics of the inner layer.

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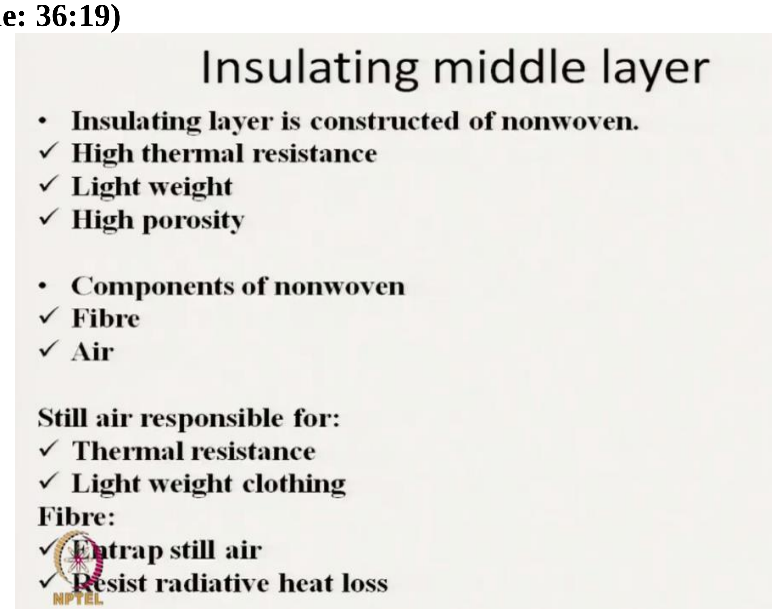

The next layer is that insulating middle layer. The function here is the basic function is the insulation, it to provide insulation of the clothing system. Mainly here the construction is nonwoven fabric with high thermal resistance it should be light enough because it is a thicker and porous layer. So, it should be lighter. Nonwoven can be used in nonwoven basically majority of the volume is occupied by air. So, that is why that still air provide thermal resistance and it provides lighter weight cloth.

So, due to the still air present fibres should be selected so that they can interact more air and resist radiative heat loss, which is very important, we should select fibre, which we reflect radiative heat to come back from our body to our body. So, it should not allow the radiative heat to come out from our body at higher rate. So, insulation in terms of conduction is important and also at extreme cold climate, we should prevent the radiative heat loss from our body as we know that majority of heat loss is through radiation.

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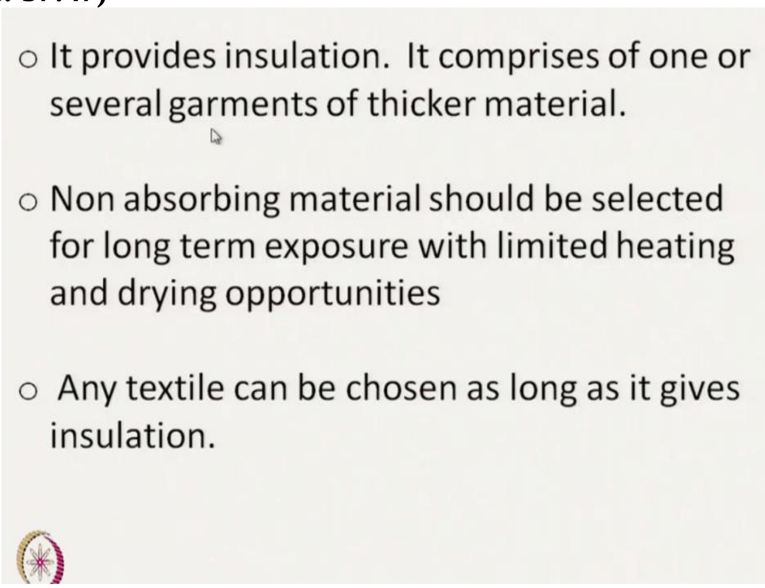

So, the middle layer provides insulation it comprises of one or several garments of thicker material. So, we can have different garments in the middle layer. It should be non absorbing material, because with the long exposure, it should not get wet and it should be dry, because the drying opportunity is less when we have to wear use this layer as it is inside. So, the drying opportunity will not be there. So, we should use non absorbing fibre. So, any textile can be chosen as long as it gives insulation. So, different textile structures can be chosen.

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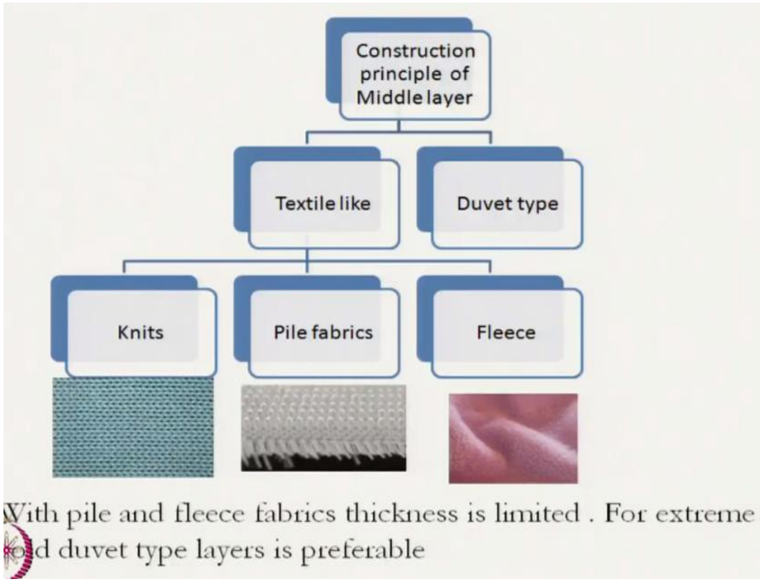

Here the construction of middle layer the construction principles are textile we can use in middle layer or duvet type we can use a textile knits, pile, fleece nonwoven, we can use and duvet type it is basically by filling we can use the down feather or different types of filling we can use in the middle layer basically to reduce the weight an increase the insulation. So, for extreme cold this duvet type layer is preferable. So, this will give us warmth.

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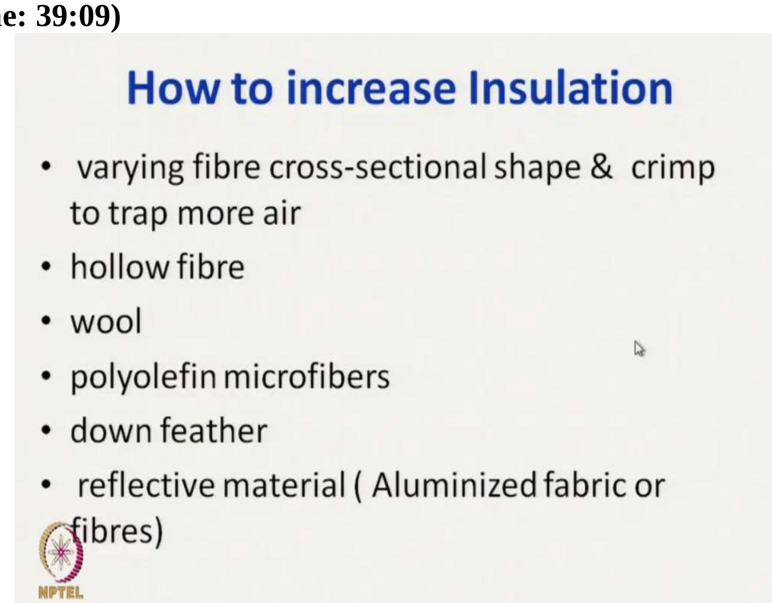

Now, to increase the insulation in the middle layer, different fibre cross sectional shapes and fibres with crimp can be used, because the crimp fibre entrap more air we can use hollow fibre, wool, natural fibre with natural crimp present can entrap more air, microfiber polyolefin microfibers are used for basically insulation it actually prevent the radiative heat to come out, down further in the as a filling material we can use, reflective martials are also used for extreme cold climate clothing, aluminized fabric or aluminized fibres are used, which actually reflect them radiative heat, it does not allow the radiative heat to come out from the body.

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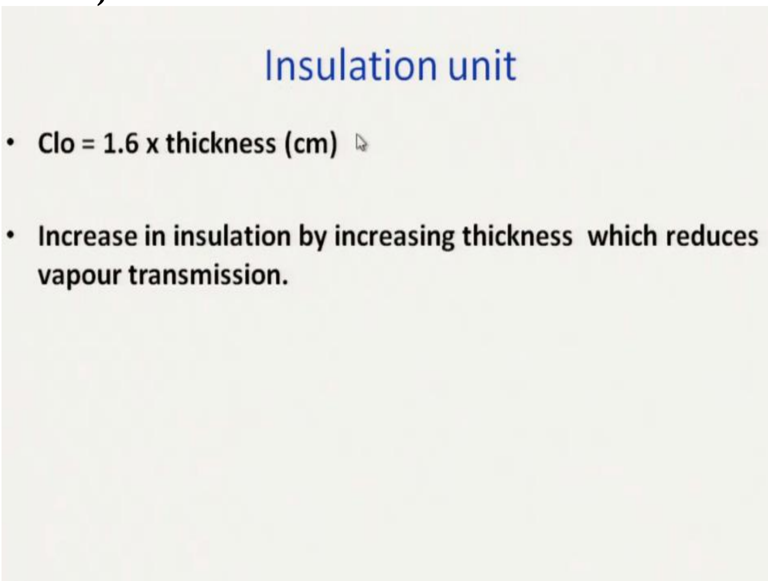

So, Clo we have discussed typically, Clo is can be related with the thickness of material, this is an empirical equation 1.6 multiplied by typical fabric thickness in centimeter that gives one the clo value. That means, if we can create a fabric of one centimeter thickness, we will get a clo of that system 1.6 Clo, so, we can increase the insulation by increasing the fabric thickness, but at the same time, if we only increase the thickness to increase the Clo at the same time. What will happen it will reduce the vapor pressure, it will reduce the vapor transmission that means it will increase the vapor pressure that will ultimately affect the clothing, comfort behavior.

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Typical thermal resistance valuesof clothing and bedding

Product	Tog value
Clothing	
Shirting	0.1
Underwear	0.2- 0.4
Thermal under wear	0.4-0.8
Suiting	1.0
Sweaters	1.0
Bedding	
Blankets	1-2
Continental quilts	7-14

So typical thermal insulation, its shirting 0.1 underwear 0.2 to 0.4 in this way, so blanket 1 to 2, these are the different continental quilts 7 to 14.

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Heat production rates and insulation for various activities(extreme cold climate)

	Required thermal neutrality		
	Heat production (W)	Required insulation (Km^2 / W)	Clothing thickness (cm)
Sleeping	80	2.0	8.0
Sitting	110	1.45	5.8
Standing	175	0.91	3.6
Walking with pack & snow shoes	250 - 450	0.64 - 0.36	2.6-1.4

Skin temperature: 33degree C, Air temperature: - 40 degree C

So, these are the different tog values, heat produced rate and insulation value for various activities. We have also seen earlier in sleeping, heat flow heat production is 80, required insulation is 2 and clothing thickness declared is 8. So, that way we can design our clothing. When a person standing, he needs a clothing of thickness 3.6 where his heat production is 175 a person one is walking is producing heat 250 to 450.

In that case, he may require clothing with a thickness of say, typically, 1 or 2 to 1 to 2 is 1.4 to 2.6 centimeter thickness here, these conditions are at a temperature of - 40 degree Celsius. So, at -40 degree Celsius if we want to design clothing that is an extreme cold climate. So, for different activity, we have to design clothing with these guidelines.

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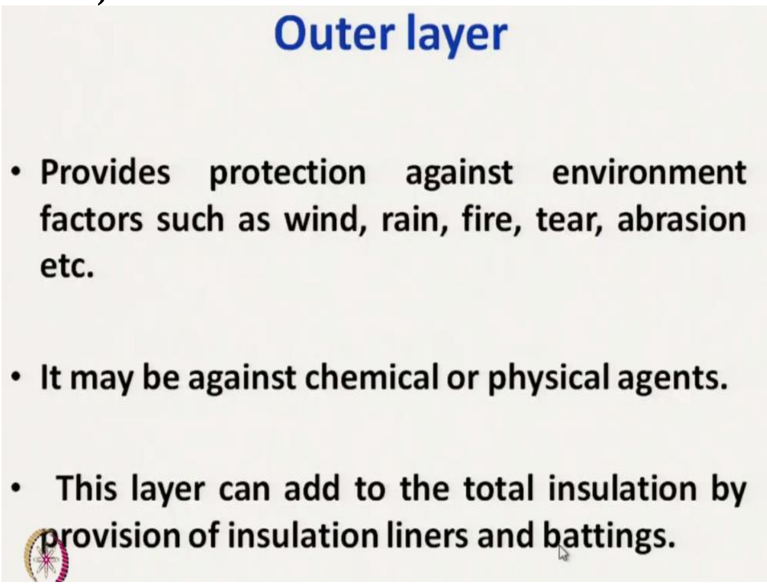

Coming to the outer layer, the outer layer as I have already mentioned, it provides protection against environment factors such as wind, rain, fire, tear, abrasion, these are the different conditions where this factors from which this outer layer protect us, it is sometimes it may be against chemical or physical agent like some puncher, some other things we should it should protect. This layer sometime can add to the total insulation of the clothing.

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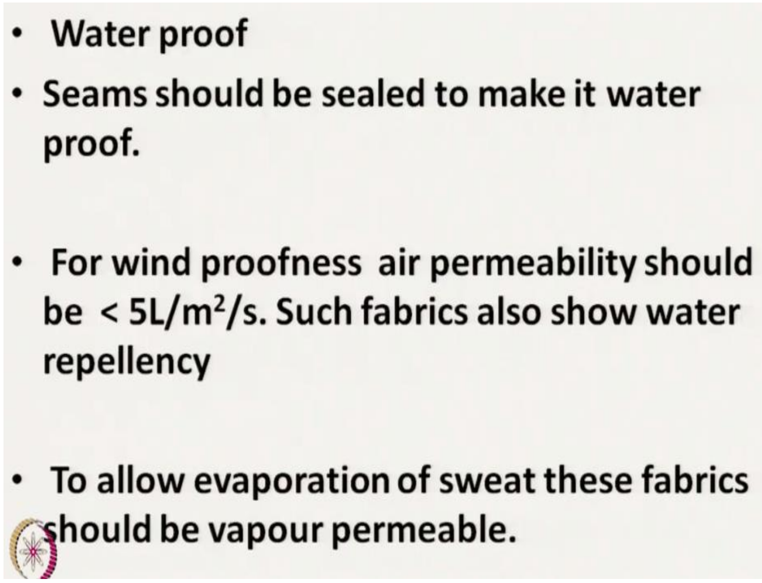

The outer layer should be waterproof. The stitches, the seams should be sealed properly. Because if the fabric is waterproof and the water penetrates through the seams, that will not work basically. So seams should be in outer layer seams should be sealed for wind proofing. Air permeability of the fabric for outer layer should be less than 5 liter per square meter per second. And if we can create fabric layer of that that will automatically be water repellent.

So, that this is the condition we need for the outer layer. And it is not that to reduce the wind flow that is to make the wind proof we should not seal all the pore it should be porous. So, it should allow the sweat in vapour form to come out from the body. So, it should be vapour permeable that is breathable.

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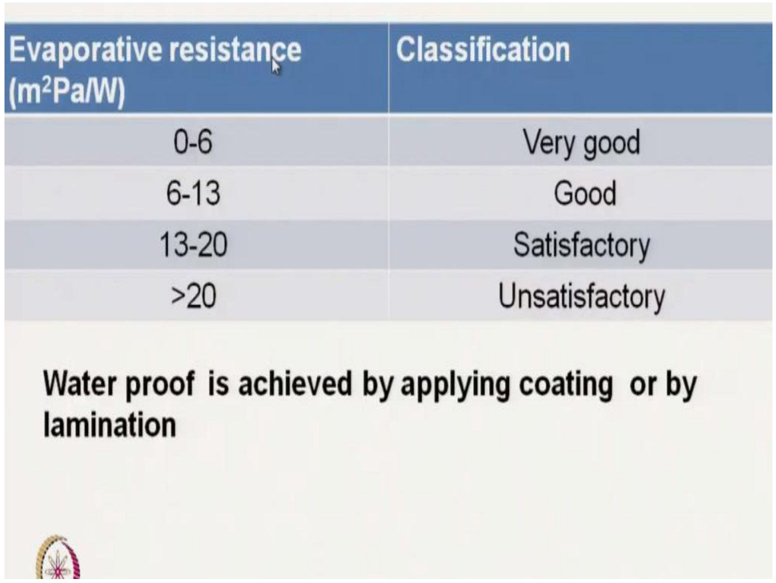

Evaporative resistance (m^2Pa/W)	Classification
0-6	Very good
6-13	Good
13-20	Satisfactory
>20	Unsatisfactory

So if the, evaporative resistance, so waterproof is achieved by applying coating or by laminating. So waterproof, breathable coating may be applied. So if the evaporative resistance is 0 to 6 then it is a very good and if it is resistance is more, then that total ensemble will be uncomfortable because the accumulation of moisture vapour will be there.

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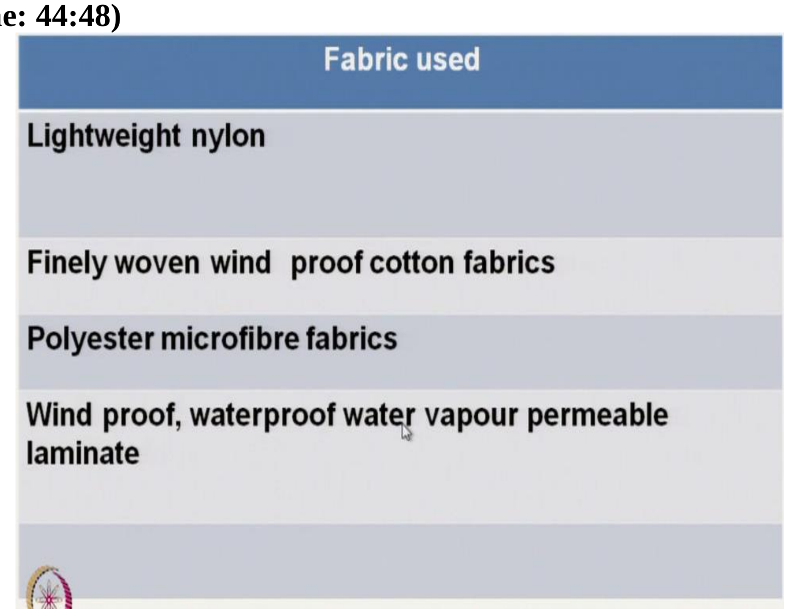

Fabric used
Lightweight nylon
Finely woven wind proof cotton fabrics
Polyester microfibre fabrics
Wind proof, waterproof water vapour permeable laminate

So, what are the fabrics used in outer layer? It should be light. So, typically nylon filament, lightweight filament woven fabrics are used, finely woven windproof cotton fabric sometime used, but they should be coated, polyester microfiber fabrics are used, windproof waterproof water vapor permeable laminates should be applied on these fabrics. Now, we will discuss one experimental condition where the thermal transmission was evaluated at different convective mode. So, this will discuss in the next class. So, till then thank you.