Technical Textiles
Prof. Apurba Das
Department of Textile and Fibre Engineering
Indian Institute of Technology, Delhi

Lecture - 21
Extreme Cold Protective Clothing (contd…)

Hello everyone. So, we will continue with the extreme cold protective clothing. So, while you use in extreme cold condition there are different situations, where we are actually come across.

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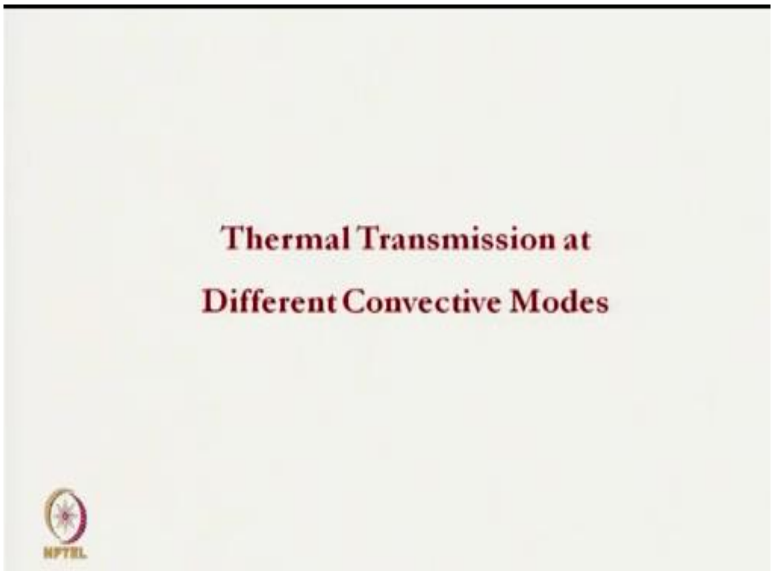

So, this situation one of them wind chilled effect where the wind at high velocity blows and that sometime takes away the heat in convective mode forced convective mode. So the experimental study which has been carried out here, it has been studied the impact of layer thickness and impact of different convective modes normal convective mode and forced convective mode and also non-convective mode. So, these modes of heat transmission we have studied.

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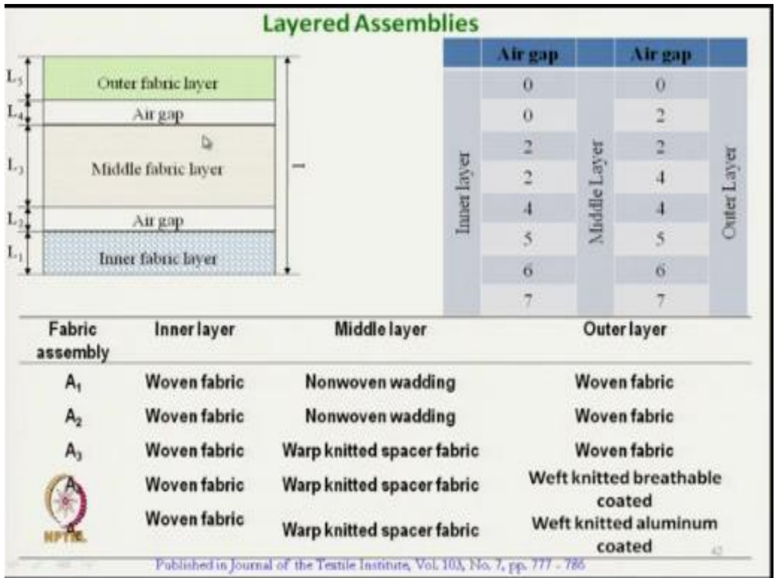

There are three layers as we have already discussed outer layer, middle layer and inner layer and between layers the air gaps where created, between middle layer and outer layer air gap was created and between inner and middle layer air gaps where created using the metallic frame where the air gap thickness between layers were this varied this air gap of thickness between outer and middle and middle and inner layers were varied, these are the different air gap combinations.

So, 0 thickness means there is no extra air gap. They are in contact; these two layers are in contact with each other. So, 00 air gap means the total thickness of ensemble will be the addition of this actual thickness of the fabrics. So, gradually the air gap thicknesses were changed and that means so, second combination if we see here additional air gap of 2 millimeter between middle and outer layer was created and where the 0 air gap between inner and middle layer.

So, total thickness would be thickness of 3 layers plus 2 millimeter of air gap. In this way, we have created large number of combinations here and the fabric variability are the inner layer we have taken woven fabric which is constant for all the layers and in middle layer what was created the fabrics with higher air pockets. These fabrics with higher air pockets were taken so, nonwoven waddings were used in sample A1 and A2 in middle layer.

In rest three samples A3, A4, A5 warp knitted fabrics were used, the spacer fabrics were used and the outer layers were mainly woven fabric for A1, A2, A3 and for A4 and A5 the knitted fabrics were used which were coated. So, for A4 it was breathable coated and A5 it was weft knitted aluminum coated. So, these five combinations were taken for different modes of convective heat transmission. The heat transmission was assessed using guarded hot plate.

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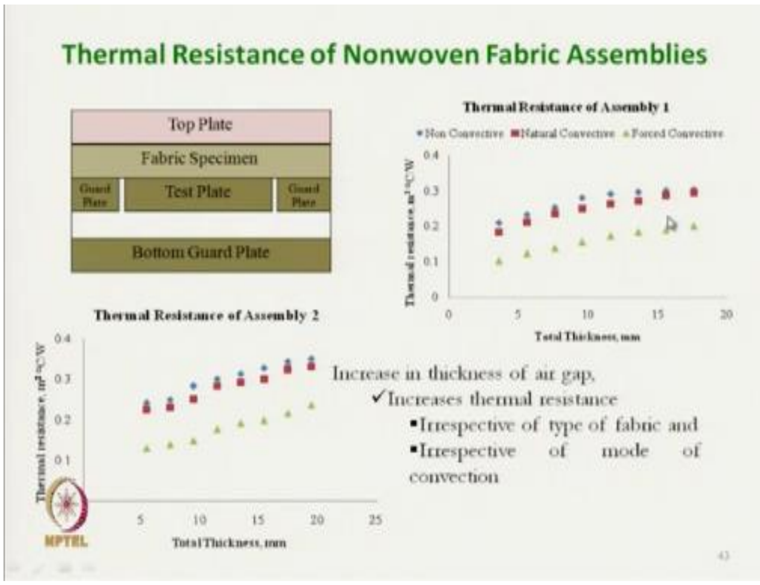

This is the guarded hot plate system where it is bottom plate, test plate, guard plate and fabric specimen and three modes of convective heat transmissions were created one is non-convective mode, natural convection and forced convection. If we do not want any heat to be transmitted through convection if we want to stop convection so, we can use a top plate here so there it will stop the heat transmission through transmission of medium, like air movement is being stopped here.

So, in this mode only heat will get transmitted through conduction and radiation, if we want natural convection, so we will remove the plate the heat will get transmitted through conduction, radiation as well as natural convection, due to the natural convection it was expected that the fabric will have higher thermal transmission. A third mode of convection was forced convection, where top plate was removed and extra air was blown along the plane.

So, that it takes away additional heat which normally encounter during application in windy condition. So, if we see here the fabric assembly, assembly 1 and assembly 2 where we have seen the outer layer was normal woven fabric with pores present. As we increase the total thickness, total thickness of fabric this assemble increase in thickness means the increase in only air gap because the convections are same for assembly 1.

Inner layer was woven fabric, middle layer nonwoven and outer layer again woven fabric, keeping the same combination of fabrics only we changed the air gap. So, the total thickness it is up to say 17 millimeter. So as we increase the thickness of ensemble total assembly 3 layer assembly along with the thickness. So as we increase the thickness means we are incorporating extra still air, so thermal resistance of the assemble increases.

When we compare the convective mode for a particular thickness, say at thickness 10, if we compare the thermal resistance for non-convective mode is highest, followed by natural convection. Between non-convection and natural convection, so only difference is that the transmission of heat in case of non-convection it took place due to radiation and conduction when we allow the natural convection additional heat was transmitted that is why resistance reduces.

But in case of forced convection, if you see the thermal resistance has dropped drastically, this is the thermal resistance. This is due to the fact that the pores present in the outer layer that is woven fabric which has helped extra heat transmission through force convection. So, that is why you can see the thermal resistance has dropped significantly, and the same phenomena was there for all other thicknesses, for all the air gaps the exactly same phenomenon was observed. The same trend was observed with the fabric assembly 2.

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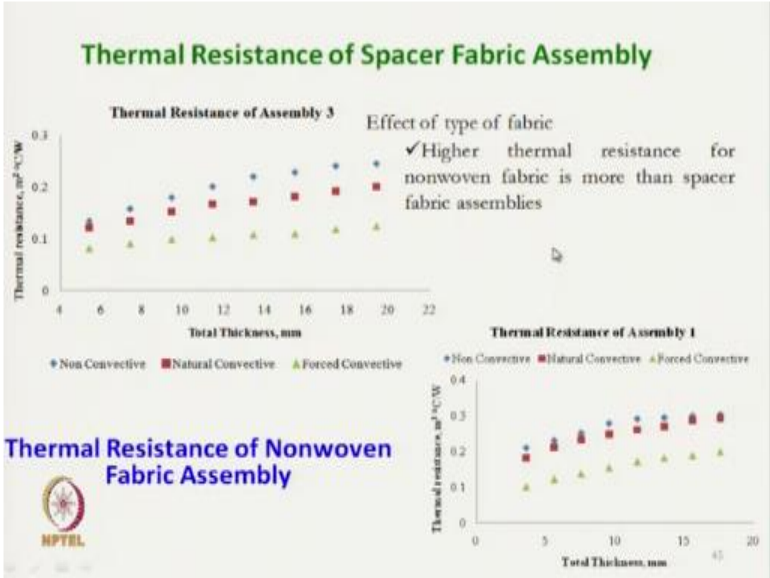

If we see the fabric assemblies 4 and 5 the trains are same with the increase in thickness the thermal resistance increases, but as far as convective modes are concerned the forced convection the heat loss due to forced convection has reduced to a great extent. So that means the resistance has increased that which shows for fabric assembly 4 and 5 there were least forced convection or forced convection was absent.

This is mainly due to the fact that breathable and metallic coated fabric improves the thermal insulation property at forced convective mode. Shows that in case of windy condition we must use coated or laminated outer layer fabric just to reduce the forced convection. Now, if we see go back to earlier, this is the fabric assembly 3 and fabric assembly 1 if we compare these two everything remain same only the middle layer was used warp knitted spacer fabric.

And fabric 1 it was nonwoven wadding, now fabric 3 and fabric 1, if we compare higher thermal resistance for nonwoven fabric which is more than spacer assembly. This is the thermal resistance of assembly 3 with the spacer fabric and overall thermal resistance of fabric assembly with nonwoven fabric. So nonwoven has got higher thermal resistance than spacer fabric that is mainly due to the alignment of fibers.

Although spacer fabrics were very high air entrapment but the space between two layers inner and outer layer, two layers, the air movement can take place so that helped in natural convection within that structure.

And also the radioactive heat transmission through air is higher than the through fiber. So nonwoven fabric it blocked the fibers blocked the radiative heat transmission, so overall thermal resistance in nonwoven is higher than the spacer fabrics. That means it is recommended to use nonwoven fabric instead of spacer fabric and also the outer layer needs to be coated, breathable coated, when we use for the high wind condition.

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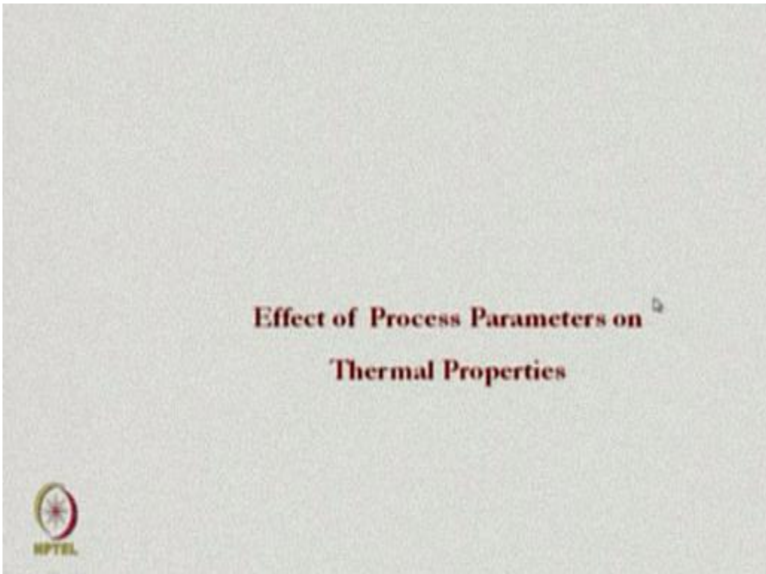

There are different parameters which control the thermal resistance or thermal transmission characteristics.

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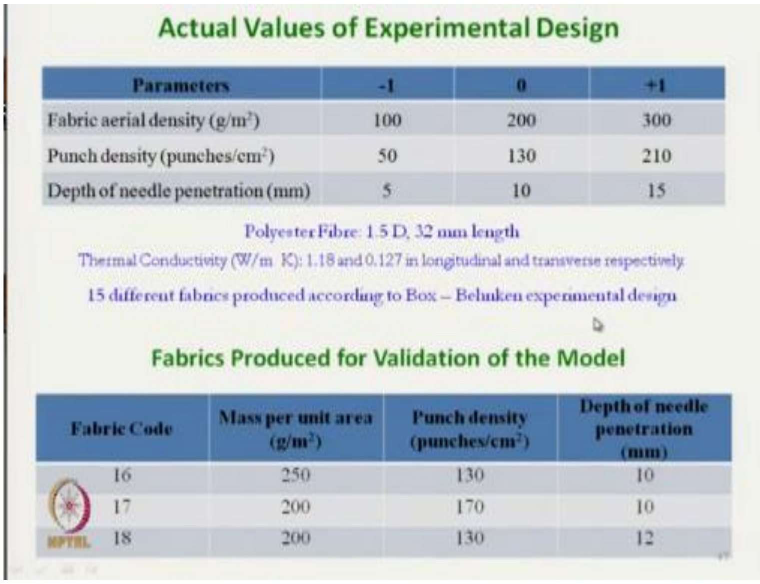

Actual Values of Experimental Design

Parameters	-1	0	+1
Fabric aerial density (g/m^2)	100	200	300
Punch density (punches/cm^2)	50	130	210
Depth of needle penetration (mm)	5	10	15

Polyester Fibre: 1.5 D, 32 mm length

Thermal Conductivity (W/m K): 1.18 and 0.127 in longitudinal and transverse respectively

15 different fabrics produced according to Box – Behnken experimental design

Fabrics Produced for Validation of the Model

Fabric Code	Mass per unit area (g/m^2)	Punch density (punches/cm^2)	Depth of needle penetration (mm)
16	250	130	10
17	200	170	10
18	200	130	12

So, next study is carried out on needle punch fabric, because needle punched nonwoven fabric is used in middle layer mainly for thermal insulation purpose. The aerial density was varied with 100, 200, 300 grams per square meter. Punch density, punches per square centimeter was varied 50, 130, 210 and depth of needle penetration 5, 10 and 15. So punch density and depth of penetration it is basically makes the fabric compact, keeping the mass per unit area constant, keeping the actually material constant.

It increases the compactness of nonwoven fabric. In this study, polyester fibre of 1.5 denier with 32 millimeter length was used. Box- Behnken experimental design was applied.

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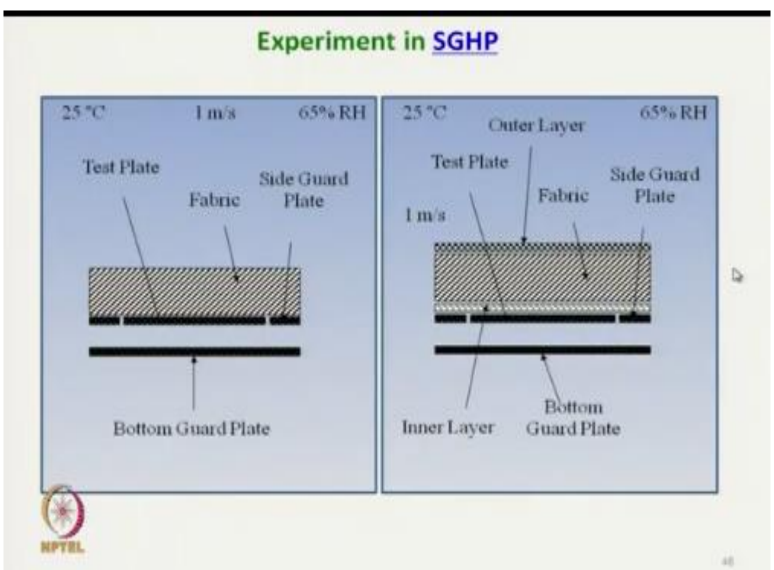

So, guarded hot plate was used for evaluating the thermal transmission characteristics. So this is the sweating guarded hot plate where we can measure the evaporative resistance also.

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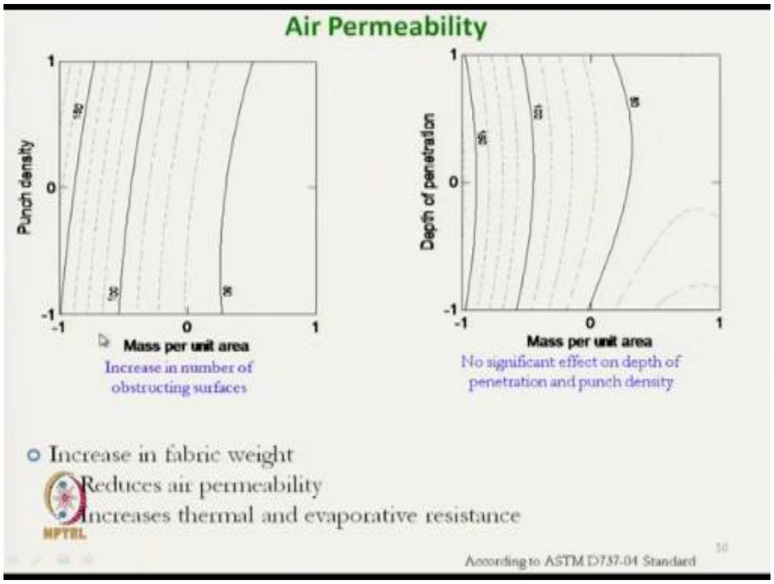

Now looking at this diagram, we can see as we increase the fabric mass per unit area, it reduces the air permeability, so it due to presence of more and more number of fibers it reduces the air permeability, but punch density and depth of needle penetration does not have significant effect on air permeability, increase in mass per unit area it increases thermal and evaporative resistance also.

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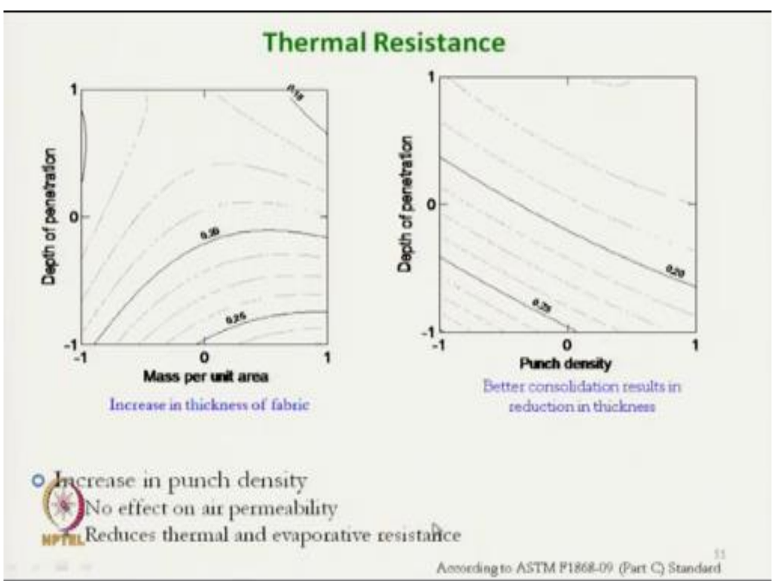

So thermal resistance so with increase mass per unit area thermal resistance increases, but with the increasing punch density, although there is no effect on air probability, it reduces thermal and evaporative resistance.

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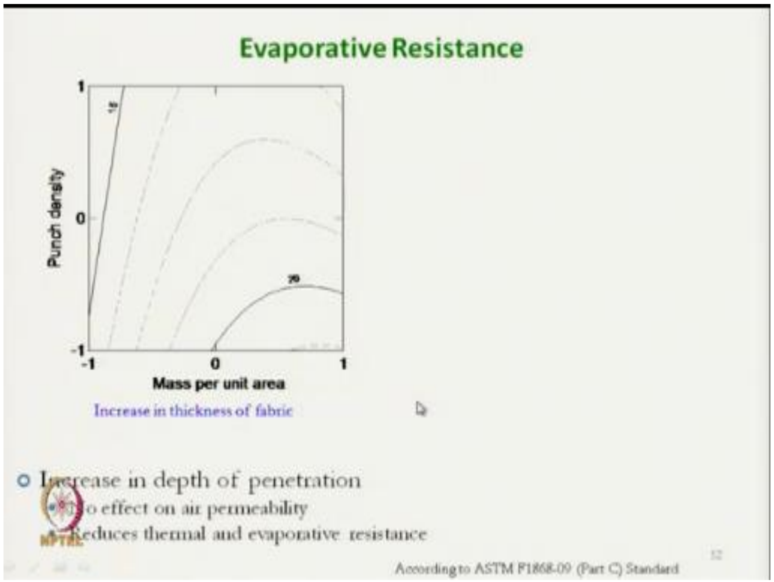

Similar effect was observed due to depth of penetration, it reduces thermal and evaporative resistance and as we see the increase in mass per unit area or increase in punch density, it reduces the thermal resistance, if we increase the punch density, this is due to the fact that as the punch density increases the fabric becomes more and more compact, the air pockets inside the structure reduces, so the thermal resistance also reduces.

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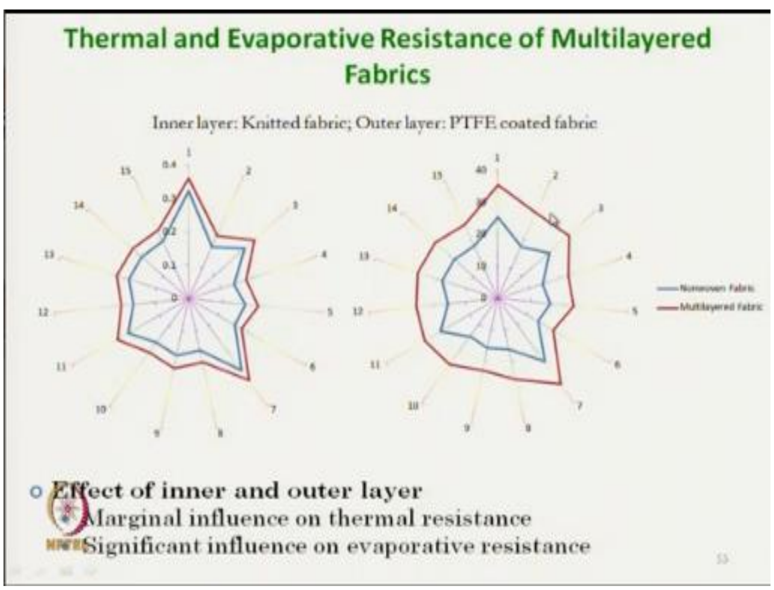

Now in the outer layer if we add inner layer and outer layer, so inner layer was used knitted fabric and outer layer PTFE coated fabric was used with the nonwoven fabric and this is showing the nonwoven fabric with the blue line and the red line showing the multilayer combination. So and this diagram is showing the thermal resistance and in right side it is showing the evaporative resistance.

If we see that introduction or addition of inner and outer layer with the nonwoven marginally influence the thermal resistance, marginally thermal resistance has increased, that means the nonwoven is performing mainly insulating function. The inner and outer layers are not adding the insulation too much, as far as evaporative resistance is concerned; addition of the outer layer which is coated fabric increases the evaporative resistance significantly. So this we should be very carefu,l the evaporative resistance should not increase too much.

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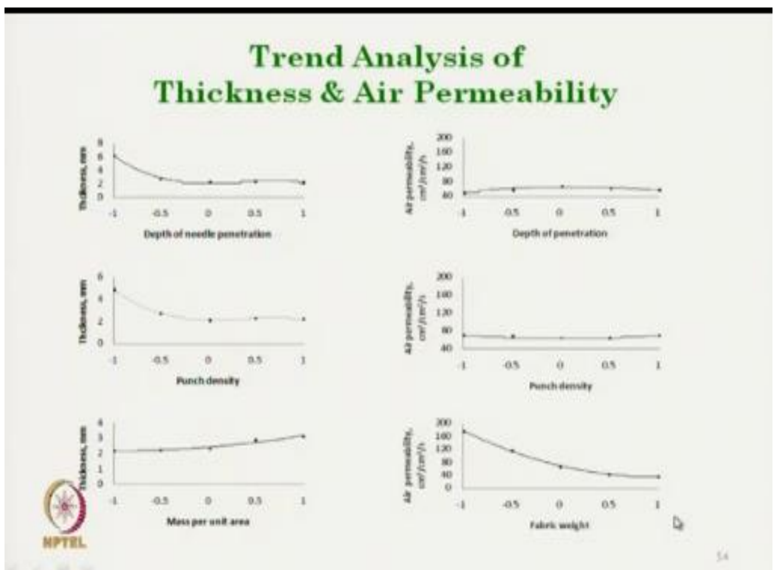

Now if we see the total overall trend as the depth of penetration increases the thickness of nonwoven fabric reduces. Similar trend is observed with the punch density and mass per unit area, as it is increasing the thickness also increases. But the increase in thickness is not that proportion because with the increase in mass per unit area, the fabric compactness overall density of fabric also increases due to more and more entanglement.

So that is why the thickness, although increasing but not with that proportion, as the depth of penetration increases, it has least effect on air permeability, but fabric mass per unit area has got great effect as the mass per unit area increases air permeability reduces.

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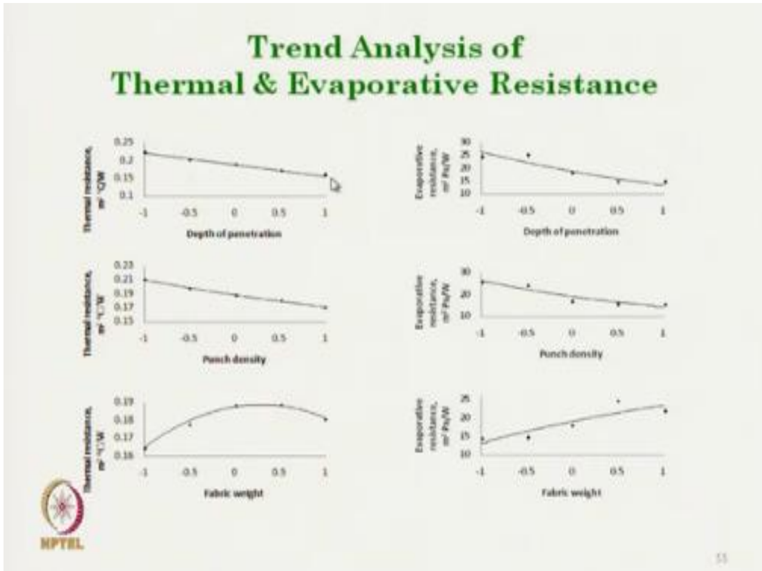

So with the increasing depth of penetration the thermal resistance reduces, as I have mentioned the fabric becomes compact. So this is true for punch density, needle punching density also but if you see the trend for fabric mass per unit area, initially with the increasing mass per unit area the thermal resistance increases, because with the increase in mass per unit area means more fibers are there for resistance but after reaching certain point the thermal resistance drops.

This is mainly due to the fact that at this point more fibers are there more entanglements will be there and fabric density, the air pockets within the fabric will be less. So that the air which actually is very highly insulating if less quantity of air is there that means overall thermal resistance of the fabric structure will drop. So with the increase in depth of penetration and needle punch density, evaporative resistance also reduces and with the increase in fabric mass the evaporative resistance increases.

So these are the overall trends, another problem while using the extreme cold protective clothing is that resilience property, during use the bulky meddle layer sometime gets compacted. So during compression the air, entrapped air comes out, so it is very interesting to understand the effect of compression on thermal resistance of fabric.

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So one instrument has been designed and developed where the thermal resistance can be measured under different compression level.

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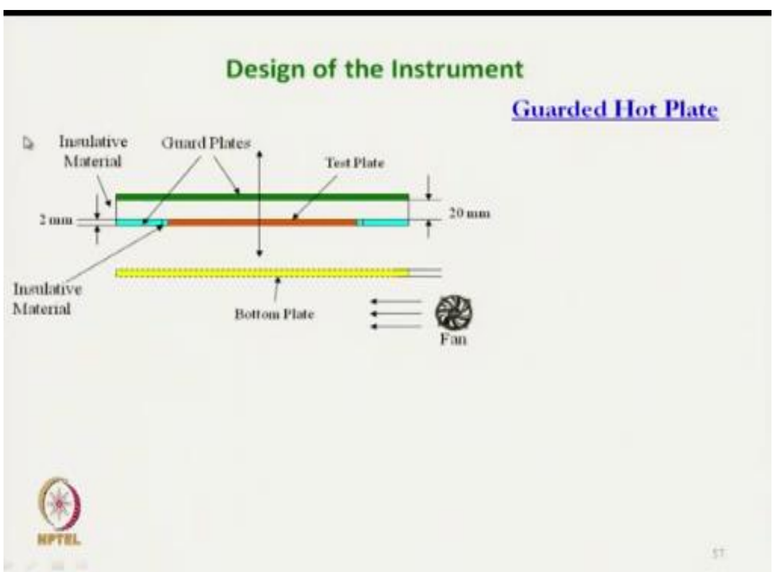

So this is the instrument where the guarded hot plate was used but it is in inverted manner. So the guarded hot plate, the principle is that let me explain.

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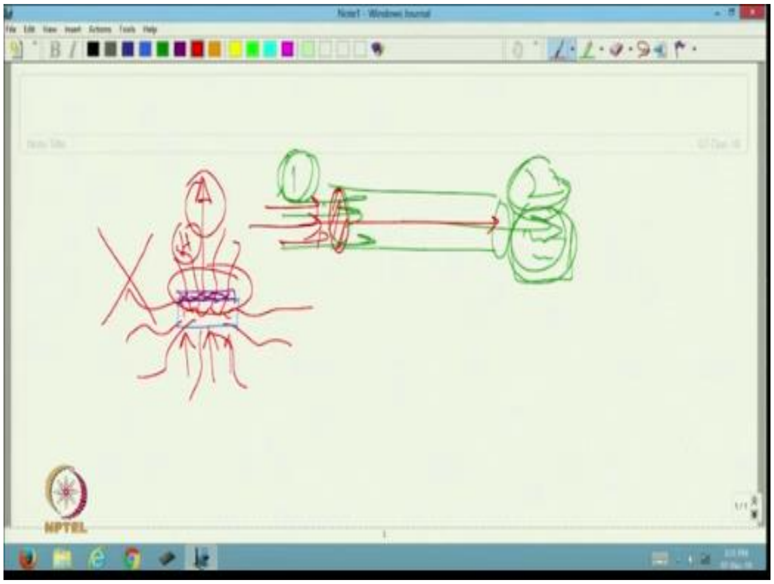

The main problem with control the heat flow direction, so we can control the air flow direction by channel, so by this channel we can flow we can control the air flow direction, we know the air is flowing from this portion to this portion. Even for liquid also that we can measure the air flow in any fluid liquid or air flow we can measure the quantity of fluid flowing through this pipe at certain time, so in that case we can calculate the flow rate.

But the main problem with heat is that, suppose this is heater and if we heat we cannot control the heat in one direction here, it can be controlled so that we can if we want to measure the flow rate through the fabric. So air flow rate, the air permeability measure like this, we will put the fabric sample here and we will measure the air flow rate air quantity of air flowing through the fabric very easily under certain pressure.

But as far as heat transmission is concerned, this is heater, if we place fabric on it and the heater is on, it is actually generating heat, it is very difficult to measure that how much quantity of heat is passing through the fabric, because the heater will try to dissipate heat in different directions. So quantification of proportion of heat through the fabric is very difficult, it is not known, that is why by this process it is not possible to measure the thermal transmission. So we have to devise the technique, so that is why guarded hot plate system was developed.

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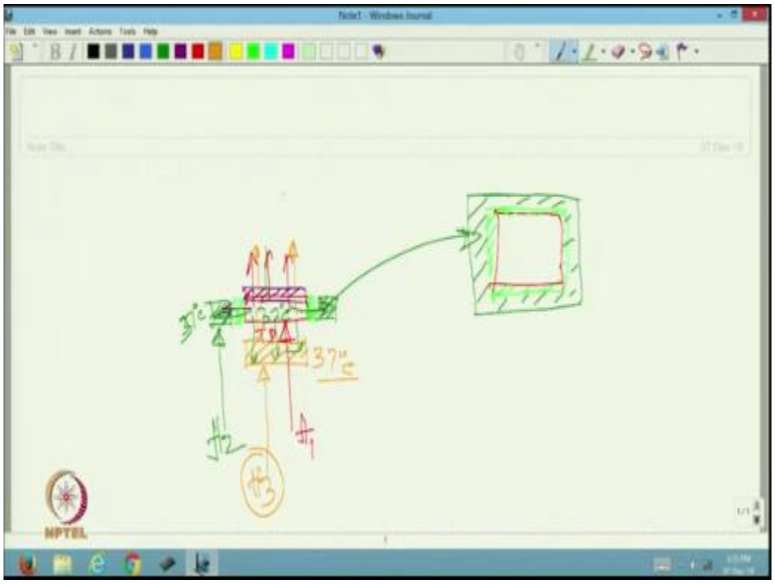

Here this is the heater ok, this is called test plate, and it is connected with the heater, heater 1. Now to prevent the heat flowing in other direction sideway, we want the heat to be flown only in this direction and we want to measure this heat. This is the fabric sample through the fabric specimen, this is what we want, now to prevent the heat to flow sideway direction one insulating material is placed here.

This is the insulator, so cork is a very good insulator is placed and also another ring was used, so this is the guard ring of metal, so if I draw the top view, this is the top plate, these are the insulating cork insulating material to prevent the heat flow and another ring this is a guard ring metallic guard ring. So this guard ring is again heated with H2, heater 2 to keep the temperature same as of test plate.

So typically the 37 degrees Celsius temperature is kept, here also 37 degree Celsius is kept, the reason is that to maintain the same temperature. So that there is no temperature gradient, the heat will not flow sideway to stop the heat flow from the sideway we add one guard ring, so heat can flow only in this direction, but it can also flow in the bottom direction. So to prevent the heat flow again in the bottom direction through the bottom so here another plate was used this is actually H3 that is bottom plate.

Bottom plate is used and here again temperature is kept say 37 degrees Celsius, so there is no temperature gradient, heat will not flow in this direction, so heat will only flow through the fabric specimen, so in this way we can guard the heat to flow from other directions and the actual data of the power required by test plate that is H1 heater is used to calculate the heat flow rate through fabrics. So whatever I explained let us see through animation here;

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In the case of test plate, only test plate this is top view, this is side view. Now we are putting fabric on that, on test plate and test plate is connected with the heater, that is a heater and a power supply, basically it is a power supply, now heat is flowing in all the directions. So we do not have any control. Now in guarded hot plate method, the test plate, this is the insulating material, guard plate.

This guard plate and bottom plate red one and fabric is placed on that and this all 3 plates are connected with the power supply and here heat it is only flowing through the fabric that heat from the test plate so we can measure, so by knowing the power requirement, and area, and temperature difference. So this is the way we can measure the thermal conductivity.

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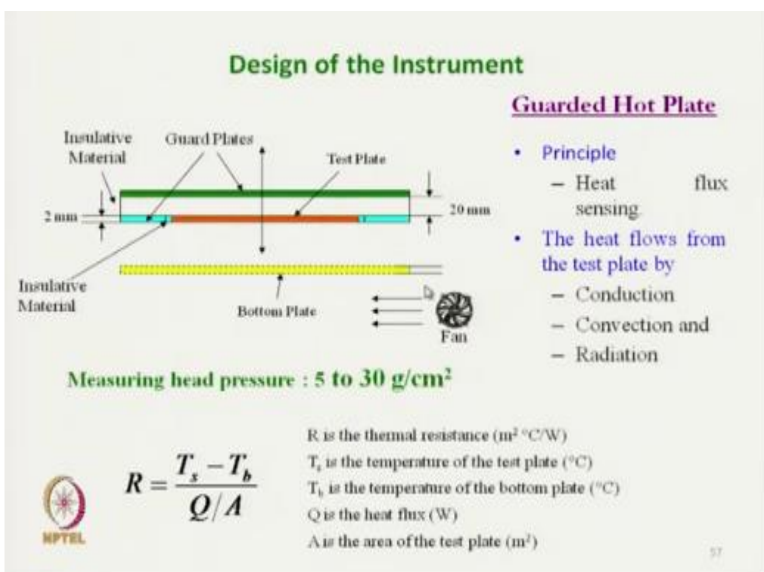

The similar technique was adapted here, but the bottom plate earlier it was it is placed at the top, this is the actual test plate and these are the guard rings, guard plate and the support plate here, which is perforated one and over this bottom plate here the fabric is placed and total this guard ring assembly is connected with the traverse element, where the pressure is applied on the fabric.

And this when it is moving down the fabric gets compressed and we can measure the compression as well as thermal transmission, the heat flows from the test plate by conduction, convection, radiation, the measuring head pressure 5 to 30 gram per square meter, square centimeter. So resistance can be measured here and also we can get the forced convection here by glowing fan and this bottom plate is perforated that will help in the convective, forced convection.

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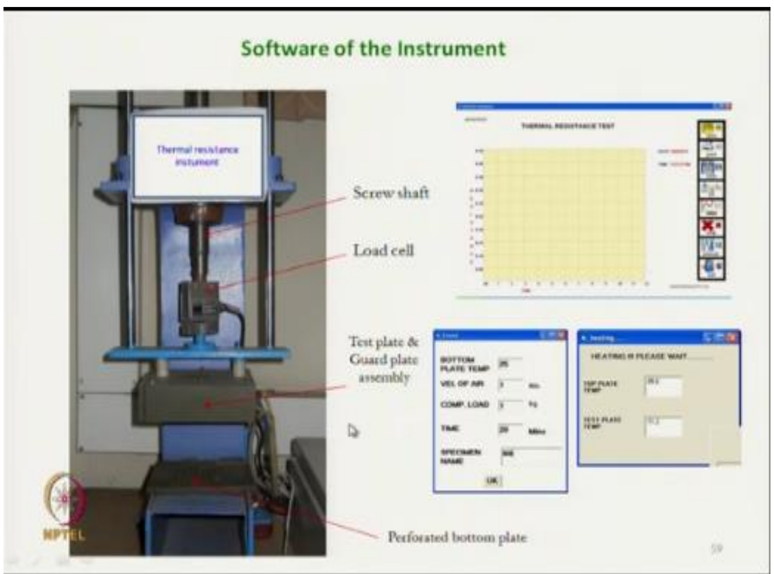

This is the system and this is the photograph of the system the total guard plate system is this is a load cell this is the total guard plate system and perforated bottom plate here and fabric sample is placed here. So we can get load versus thickness curve, as well as a different compression level we can calculate the thermal transmission.

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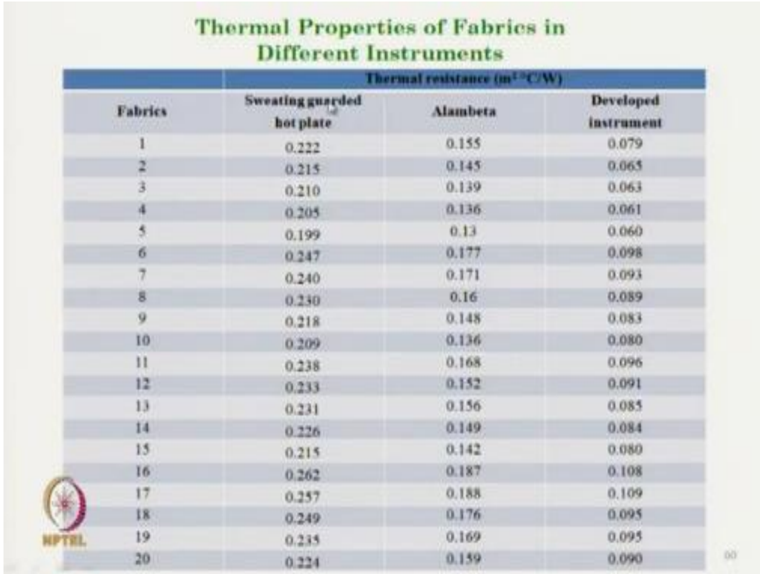

Thermal Properties of Fabrics in Different Instruments

	Thermal resistance (m^2°C/W)		
Fabrics	Sweating guarded hot plate	Alambeta	Developed instrument
1	0.222	0.155	0.079
2	0.215	0.145	0.065
3	0.210	0.139	0.063
4	0.205	0.136	0.061
5	0.199	0.13	0.060
6	0.247	0.177	0.098
7	0.240	0.171	0.093
8	0.230	0.16	0.089
9	0.218	0.148	0.083
10	0.209	0.136	0.080
11	0.238	0.168	0.096
12	0.233	0.152	0.091
13	0.231	0.156	0.085
14	0.226	0.149	0.084
15	0.215	0.142	0.080
16	0.262	0.187	0.108
17	0.257	0.188	0.109
18	0.249	0.176	0.095
19	0.235	0.169	0.095
20	0.224	0.159	0.090

This is the data we get from the instrument.

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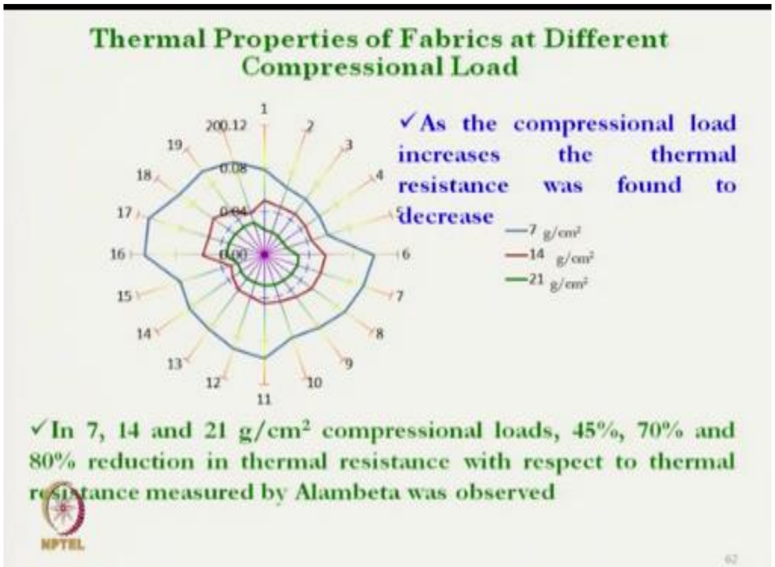

Now the data from this instrument was compared with other standard instruments like sweating guarded hot plate, Alambeta is another instrument for measuring the thermal transmission and this developed instrument and this instrument the minimum pressure available is the 700 Pascal. The thermal resistance of the fabrics, there are different, 20 different fabrics were tested just to understand whether the instrument is giving consistent result.

The looking at the trends it is clear that the developed system, developed instrument is giving similar trend as per as thermal properties are concerned but the thermal resistance value it is lower than the sweating guard hot plate as well as the Alambeta. The main difference between this 3 instruments are sweating guarded hot plate the pressure applied almost there is no pressure applied on the fabric.

In Alambeta, we need minimum pressure and pressure medium pressure is highest here in the developed system, so highest pressure that is 700 Pascal pressure is required and this trend it shows that as the compressional load increases the thermal resistance decrease sorry, so for any fabric. So this is the curve for 7 gram per square centimeter pressure this is for 14, 21 as we keep on increasing the pressure.

So fabric gets compressed, the reduction in thermal resistance is 45%, 70% and 80%. So in 7, 14 and 21 gram per centimeter square compressional loads, 45%, 70% and 80% reduction in thermal resistance with respect to thermal resistance measured by Alambeta. So that has been observed here next experiment was the wear trial technique.

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So actually the fabrics were, the outer wear jackets were prepared and the experiment was carried out in cold chamber.

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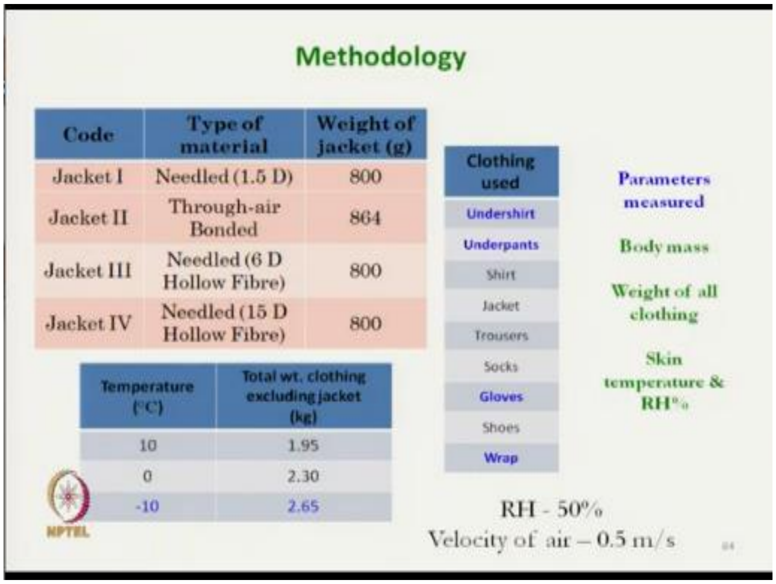

So 4 Jackets were developed, so Jacket 1 the meddler was needled punched fabric, typical mass of jacket was around 800 to 864 within that range. Here inner and outer layers were kept constant for all the 4 Jackets. So Jacket 2 through-air bonded fabric where thickness was very high and this through-air bonded fabric once it was measured in isolation this through-air bonded fabric was having highest thermal insulation.

And Jacket 3 was needled punched hollow fibre with 6 denier hollow fiber and Jacket 4 was needled punched 15 denier hollow fibre, so this four fabrics were used for nonwoven fabrics are used and the experiment was carried out at 3 different temperatures, 10 degrees Celsius, 0 degrees Celsius and -10 degree Celsius, along with the jacket there were other components were used and this components were used to constant for all other all the jackets.

So relative humidity at the skin and temperature at the skin at different body parts were measured.

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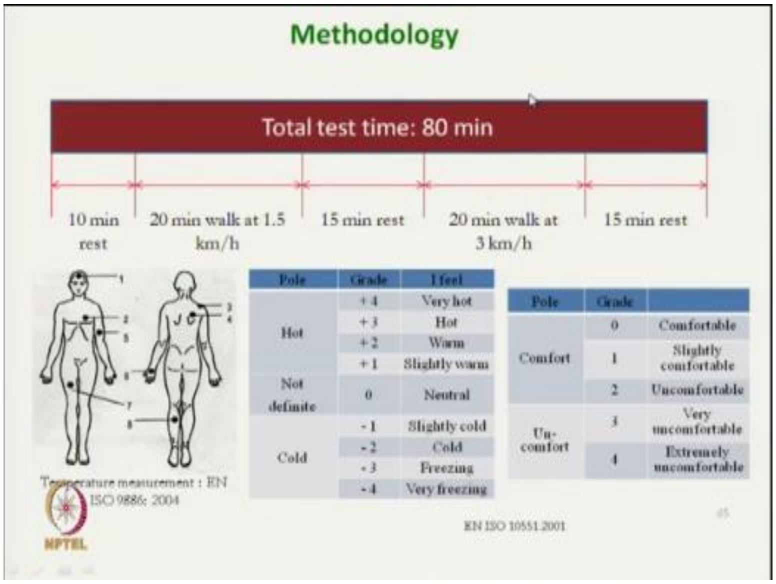

This is the test condition, total test time was 80 minutes, the test protocol here and the subjective assessment was carried out.

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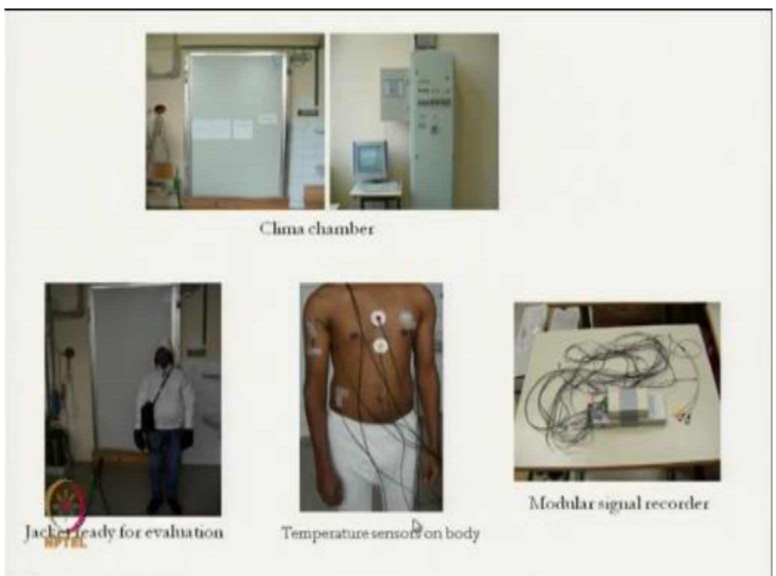

These are the test setup and climatic chamber was there so after wearing this jacket the person entered into the climate chamber.

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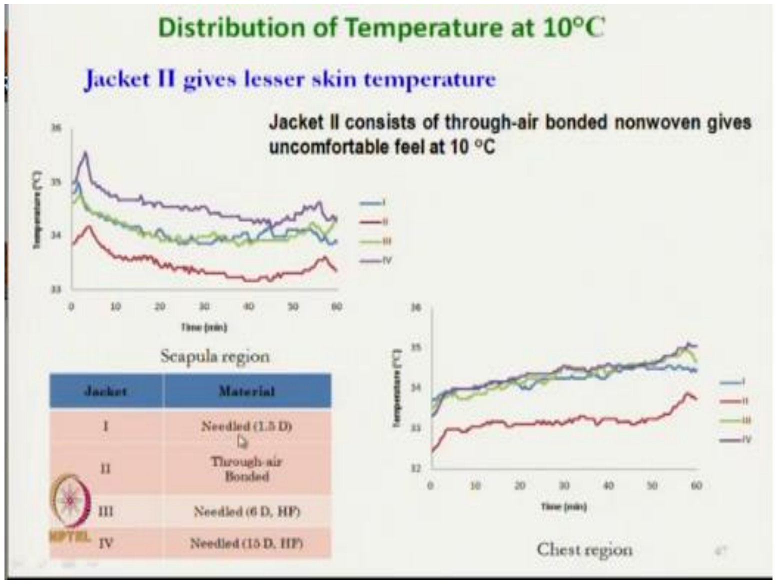

Now if we see the temperature at the skin for jacket 2, the temperature at the skin was lowest.

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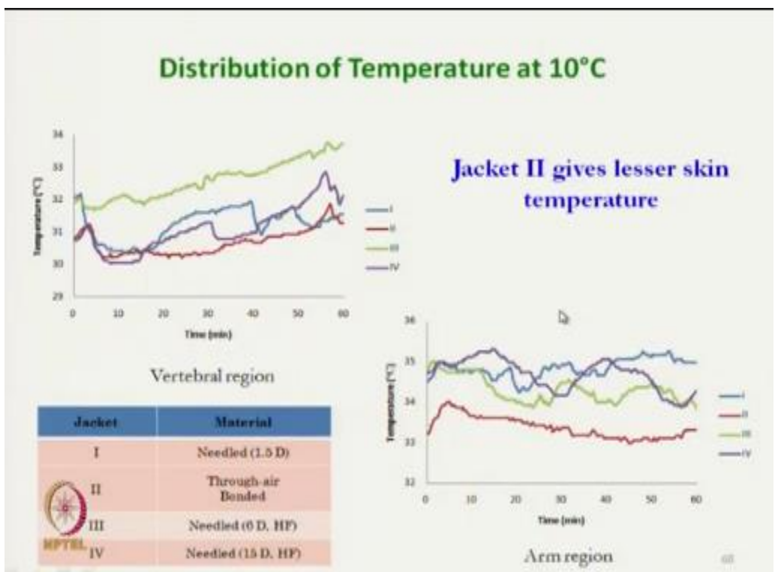

This is temperature is lowest temperature, for other this is much high, so jacket 2 was actually produced through, through-air bonded fabric.

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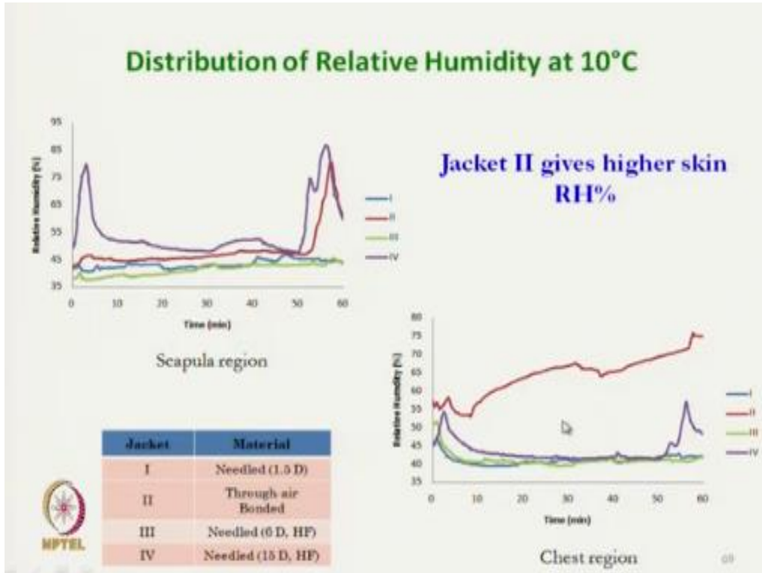

On the other hand if you see the humidity is maximum. So the and the person was feeling cooler due to higher humidity and temperature was low, although this jacket 2 which is made from through-air bonded, it was having very high insulation but once it is coming to the jacket due to higher heat the sweating was there, this is due to sweating, high humidity and that resulted the cooling of the at the skin.

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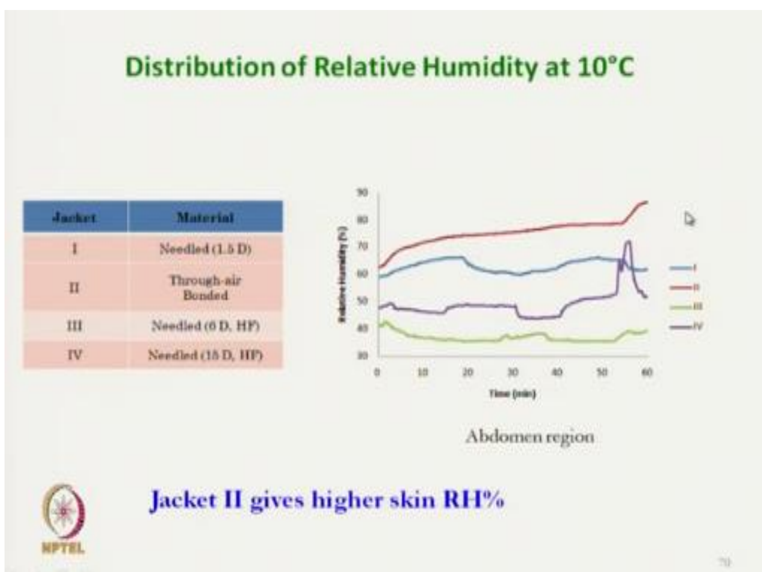

So high humidity is generated and this high humidity is also due to the fact that due to high thickness, very high thickness of through-air bonded. The moisture transmission was not proper.

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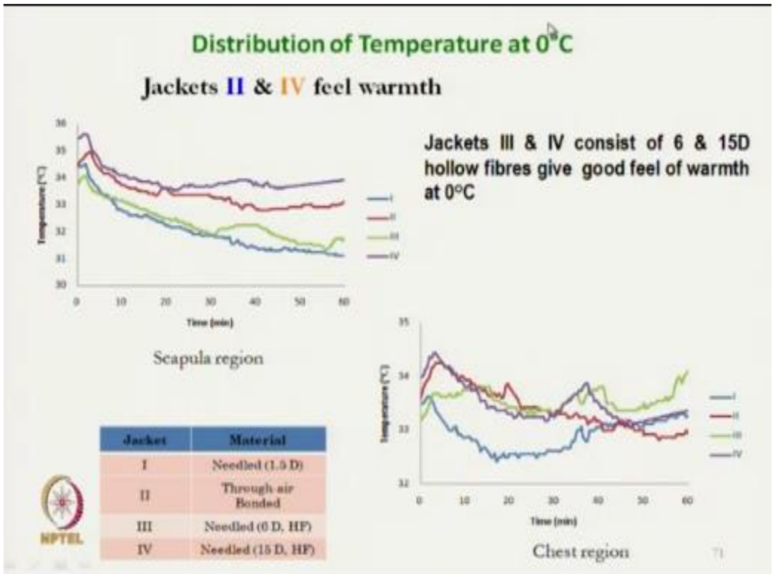

At 0 degree Celsius, these are the trends but if we see -10 degrees Celsius again the temperature at the skin was lowest for through-air bonded fabric at different region of the body.

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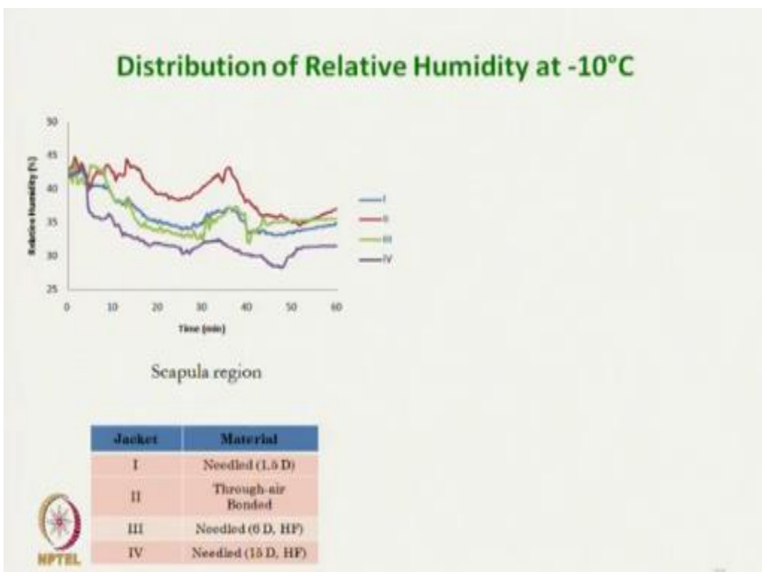

But once we see the humidity again at -10 degree Celsius the layer with very high thermal insulation, it is giving highest humidity at the skin, because the through-air bonded fabric again, its thickness is very high, so the moisture needle transmission does not take place at that rate.

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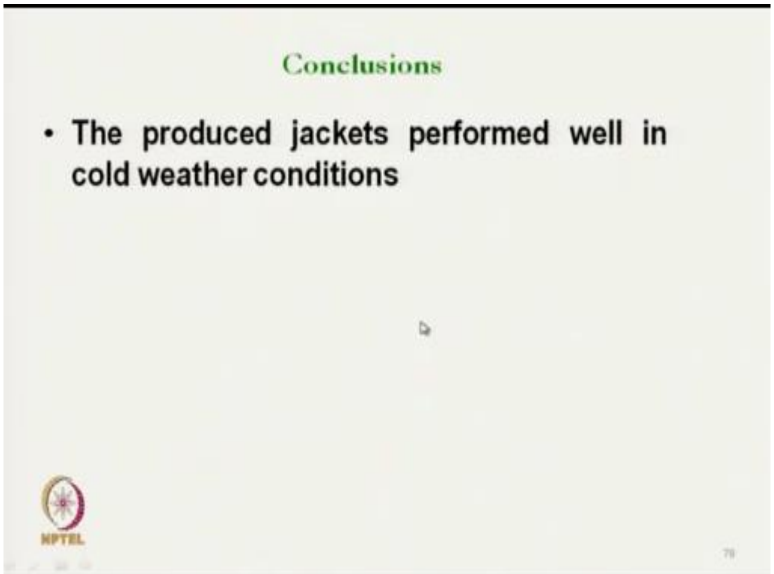

So the conclusion here is that the produced jacket although worked well at cold condition.

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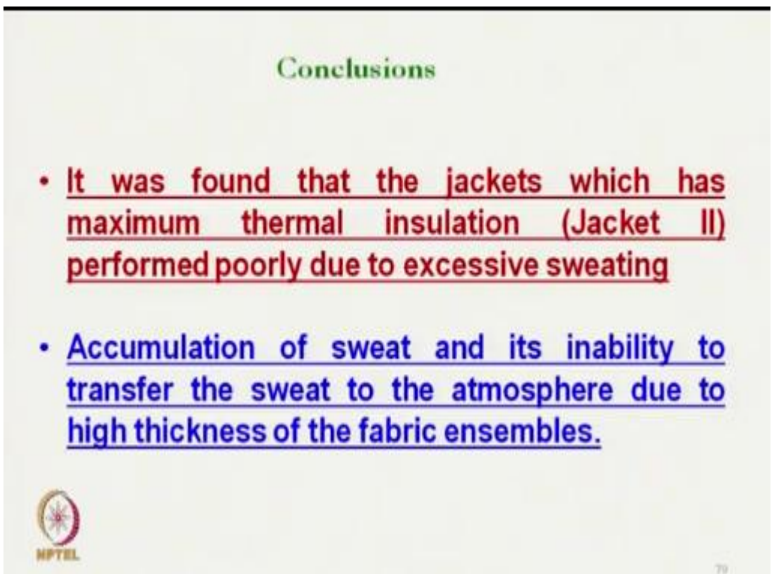

It was found that the jacket which has maximum thermal insulation that Jacket 2 for example performed poorly due to excessive sweating. The accumulation of sweat and its inability to transfer the sweat to the atmosphere due to high thickness of the fabric ensembles. So once we try to develop the fabric ensemble for the extreme cool climate clothing we must take into consideration the total thickness of insulating layer.

The thickness should not be too high which will prevent easy flow of the humidity, so we will end here, the extreme cold protective clothing. In next class as we will start with a new topic. Till then Thank You.