Testing of Functional & Technical Textiles
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Lecture - 07
Testing of Transmission Characteristics of Textile Fabrics (contd.)

Hello everyone. So, we will continue with the topic testing of functional textiles. So, the course is Testing of Functional and Technical Textiles. In first part we are discussing the different aspects of testing of functional textiles. In this segment first we have discussed low stress mechanical characteristics. After that we have started the transmission characteristics.

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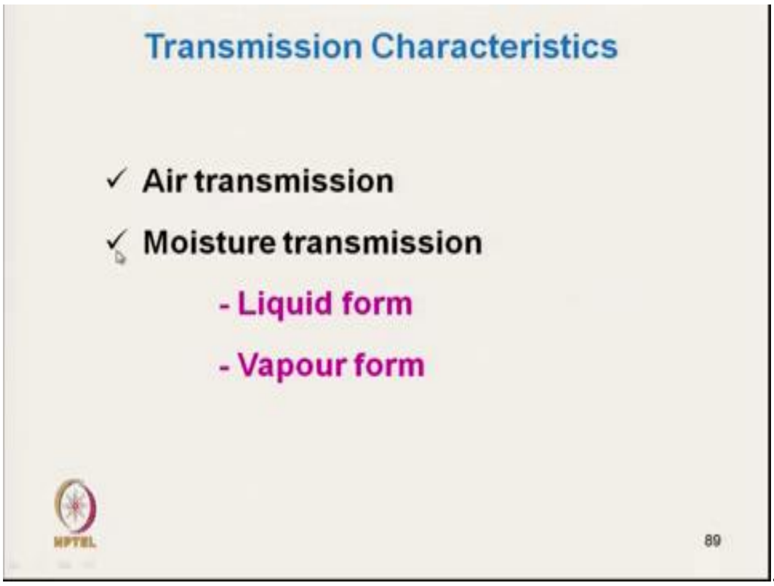

In transmission characteristics, we have already discussed the transmission of air transmission of moisture in the form of liquid and in the form of vapour. We have discussed various test methods to evaluate all these characteristics. So, after air transmission and moisture transmission, now we will discuss the method of measurement of thermal transmission.

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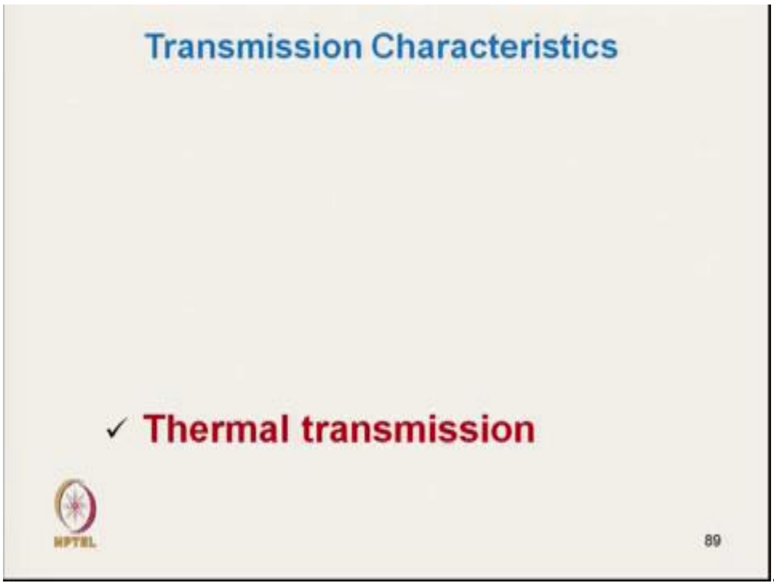

So, there are different methods available. So, before going to the measurement techniques, we will discuss basic aspects of measurement.

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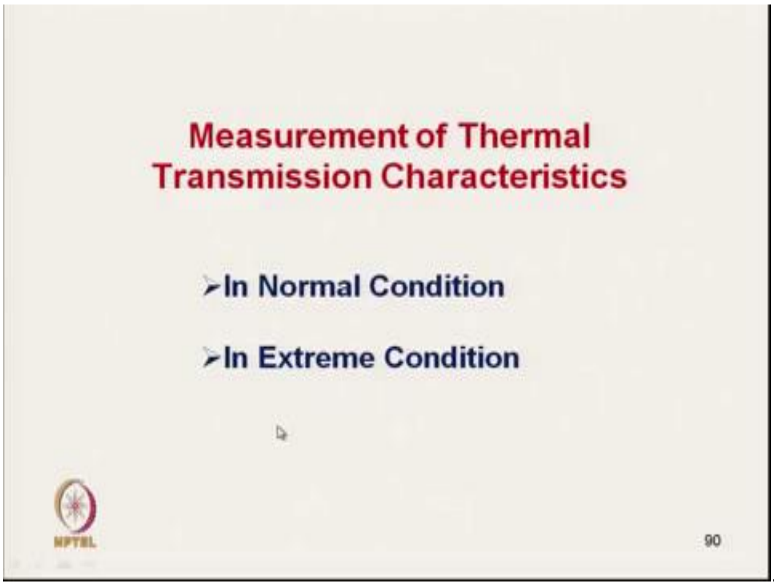

So, measurement of thermal characteristics, we will discuss in two conditions. One is in normal condition where we will discuss the thermal transmission measurement for normal clothing, considering the temperature is in normal condition and skin temperature is around 35 degree Celsius. In addition to the normal condition, we have another condition which is extreme condition like extreme cold condition and extreme heat condition may be in flame or radiant heat. So, the measurement techniques for extreme condition are entirely different from that of normal condition. We have different measurement techniques. So, we will discuss all these one by one.

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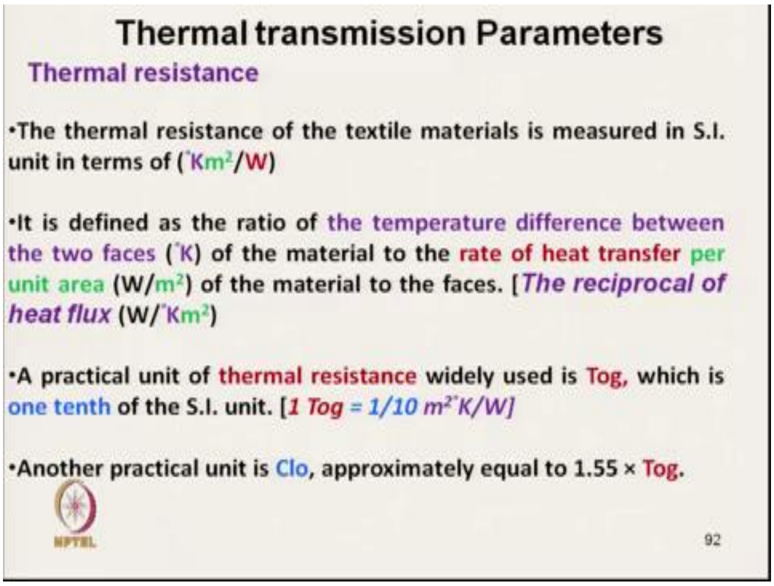

So, before going to the measurement techniques, first let us discuss the thermal transmission parameters. There are various thermal transmission parameters. Before we understand the testing methods, we must understand all this parameters clearly, then we can interpret the data. So, the thermal resistance is the basic parameter which we must understand ok. The thermal resistance of textile material is measured in SI unit in terms of **$^{\circ}Km^2/W$**.

So, what is this? So, it is a basically it is defined as the ratio of the temperature difference between two faces of fabric in **$^{\circ}K$** to the rate of heat transmission in **W/m^2**, that means, **$^{\circ}K/Wm^2$**, it is coming as **$^{\circ}Km^2/W$**. So, the reciprocal of heat flux is the thermal resistance. And heat flux is measured with the unit of watt per square meter per degree Kelvin. So, the ratio of the temperature difference between two faces and the rate of heat transfer per unit area is basically it is the thermal resistance.

Now, a practical unit is also there. So, practical unit of thermal resistance which is widely used it is a Tog, which is one-tenth of the SI unit. So, ***$1\ Tog = 1/10\ m^{2\circ}K/W$*** Another practical unit which is very widely used specifically for cold climate clothing, which is known as Clo. So, this is **1.55 × Tog**. So, we will see how we can reach to this conclusion, this relationship with some basic assumption.

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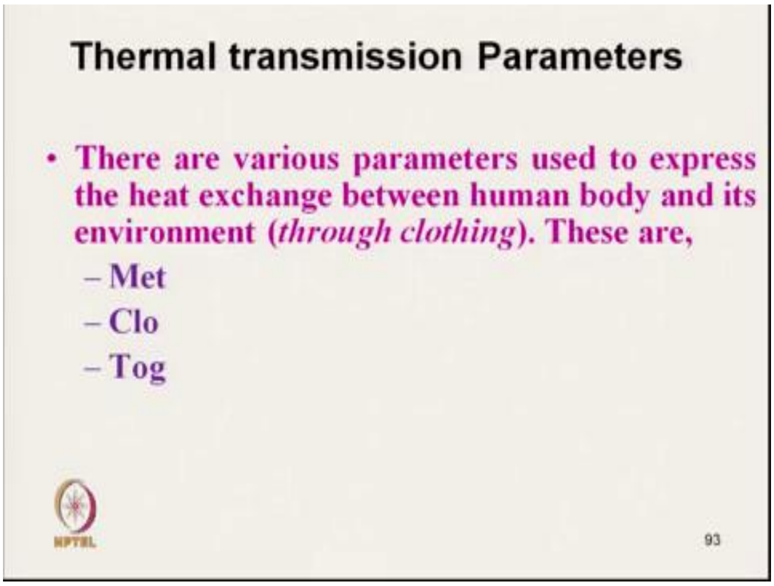

So, there are various parameters used to express the heat exchange between human body and its environment through clothing. So, these parameters are Met, Clo, Tog. So, we must understand all this parameter very clearly, then we can use this parameter these units for different application. First we will discuss the Met. Basically Met is nothing to do with the clothing insulation, Met is actually it is a metabolic heat, it is derived from metabolism.

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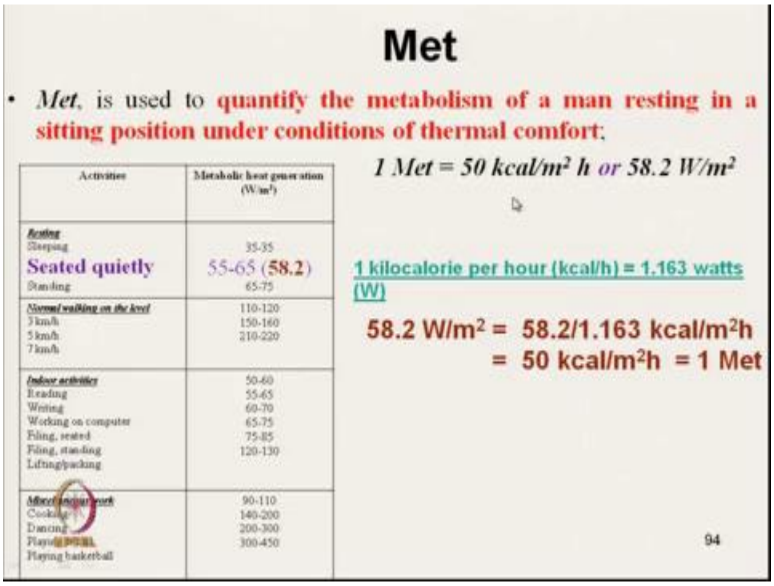

So, Met is used to quantify the metabolism of a man resting in a sitting position under condition of thermal comfort ok. Now, if we see this table, here in the first column, it is showing different activity level; and in the second column it is a metabolic heat generation, it is giving in ***W/m²***. As per the definition of Met where it is mentioned that the man is resting in a sitting position, so we can use the value of seated quietly which is around 55 to 65 ***W/m²***, and you can take the value 58.2 that means, ***1 Met = 50 kcal/m² h or 58.2 W/m²*** So, when it is a 55 to 65, so we can take 58.2, that means, ***1 Met = 50 kcal/m² h***. So, that is 1 Met that means, a person when he is sitting quietly, so he is generating a heat which is ***50 kcal/m² h*** and that is he is generating 1 Met.

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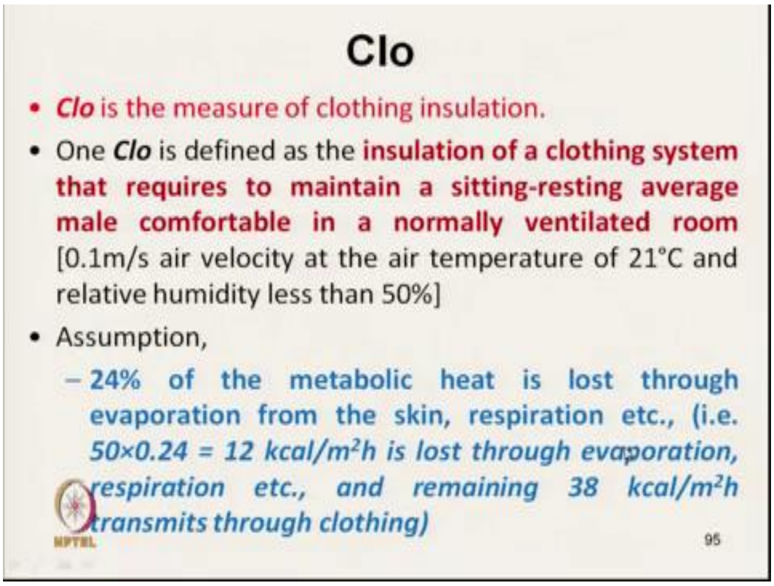

Now, next parameter which is Clo. Now, Clo is directly related with the Met. So, Clo is the measurement of clothing insulation. So, clothing insulation is expressed in terms of Clo. So, how is it related with the Met, let us see. One Clo is defined as the insulation of a clothing system that requires to maintain a sitting-resting average male comfortable in a normally ventilated room, that means, in sitting resting condition, a male is actually generating 1 Met. Once he is generating 1 Met to keep him comfortable, the level of insulation which a clothing should actually have that is called 1 Clo. And the room condition the ventilated room condition is expressed in terms of 0.1 m/s air velocity and air temperature is 21°C and the relative humidity should be less than 50 % that is the condition of room.

Now, using few assumption, we can derive the relationship. And the assumption is that twenty four percent of the metabolic heat is lost through the evaporation process from the skin and respiration that means this 24 % of the metabolic heat is lost where the fabric is not coming into picture. So, 24 % of 50 ***kcal/m²h*** is coming out to 12. 12 is the heat which is lost through evaporation and respiration, and remaining 38 ***kcal/m²h*** transmitted through the clothing. So, 38 that that much heat is required to be transmitted. The clothing insulation should take care of that much heat 38 ***kcal/m²h***.

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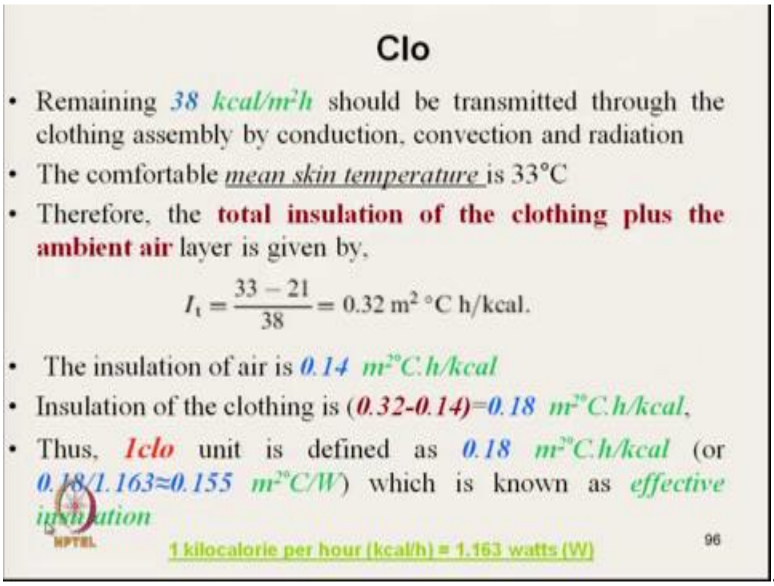

Now going further so remaining ***38 kcal/m²h*** should be transmitted through the clothing assembly by conduction, convection and radiation, these are all dry heat. We are not talking about the moisture vapour. The comfortable mean skin temperature is 33°C that is the actual taken from literature. Therefore, the total of insulation of clothing that is clothing insulation plus the ambient air layer insulation which is given by

$$I_t = \frac{33 - 21}{38} = 0.32 \text{ m}^2\ {}^\circ\text{C h/kcal}.$$

So, which is coming out to be 0.32 square meter per degree Celsius hour per kilo calorie. So, that is the amount of heat which is to be transmitted.

And this heat is includes the air insulation. This much insulation is actually including the air insulation. Now, let us consider the insulation of air is ***0.14 m²°C.h/kcal*** that is the insulation of air. So, insulation of at insulation of fabric they are in series. So, you can simply subtract from the total insulation. So, you will get the fabric insulation. So, insulation of clothing is 0.32 - 0.14, it is coming out to be 0.18, which is the insulation of clothing and that is actually the by definition it should be 1 Clo.

So, 1 Clo unit is defined as ***0.18 m²°C.h/kcal*** or if we want to convert into watt, so we must divide by 1.163,

$0.18/1.163 \approx 0.155\ m^{2}{}^{\circ}C/W$

it is coming out to be a 0.155 square meter degree Celsius per watt ok, which is known as effective insulation. So, effective insulation of clothing is 0.155, and this is the unit of SI unit. Now, we can get the value.

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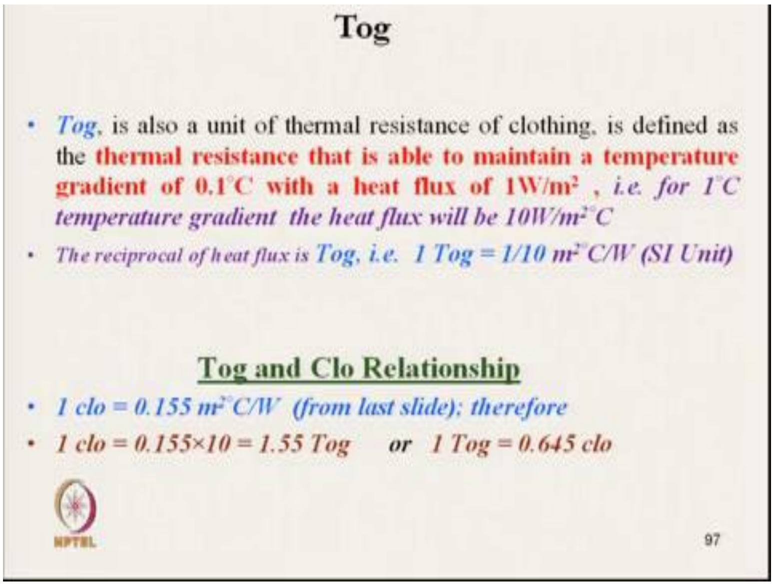

- The Tog is also unit of thermal resistance of clothing and is defined as the thermal resistance that is able to maintain a temperature gradient of **$0.1^{\circ}C$** with the heat flux of **$1 W/m^2$** that is ***$1^{\circ}C$*** temperature gradient; the heat flux will be ***$10 W/m^{2}{}^{\circ}C$***. So, for 0.1, it is 1 W/m^2. So, for 1 degree Celsius, it will be 10, so that means the reciprocal of the heat flux is Tog. So, ***$1\ Tog = 1/10\ m^{2}{}^{\circ}C/W$ (SI Unit)***

<u>Tog and Clo Relationship</u>

- ***$1\ clo = 0.155\ m^{2}{}^{\circ}C/W$ (from last slide); therefore***
- ***$1\ clo = 0.155 \times 10 = 1.55\ Tog$ or $1\ Tog = 0.645\ clo$***

So, here we can derive the relationship between Met, Clo, and Tog. So, we have understood this relationship. Now, we will discuss different measurement technique where we will use all these units for better understanding.

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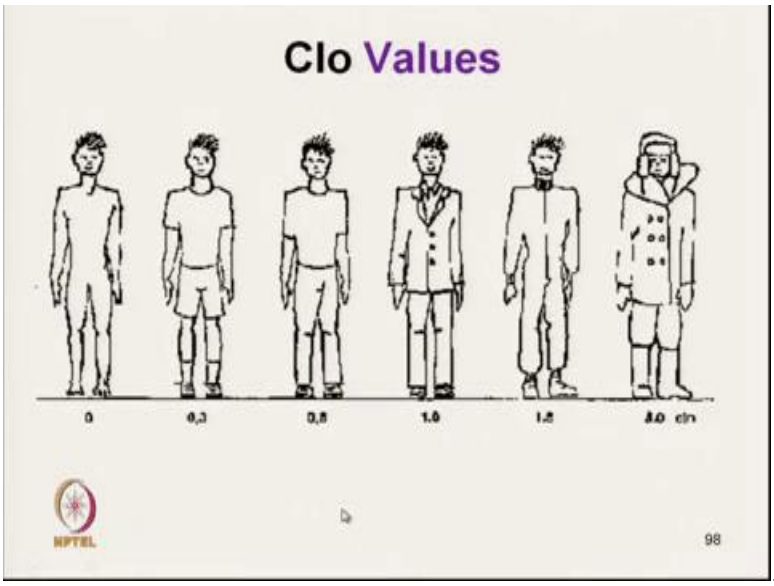

So, let us first understand the application of Clo value. So, as I have mentioned the Clo unit is the clothing insulation which is extensively used for the practical as a practical unit for extreme cold climate clothing or any cold climate clothing even we can use this for heat extreme heat clothing also. Now, the picture shows that this person without any clothing, that means, he has the Clo value 0. So, as the person is actually putting on the more and more clothing, the Clo value is increasing, that means, the Clo value is simply addition. So, he is actually wearing a t-shirt and say half pant. So, here if we know the Clo value of t-shirt and his half pant, so it can simply be added.

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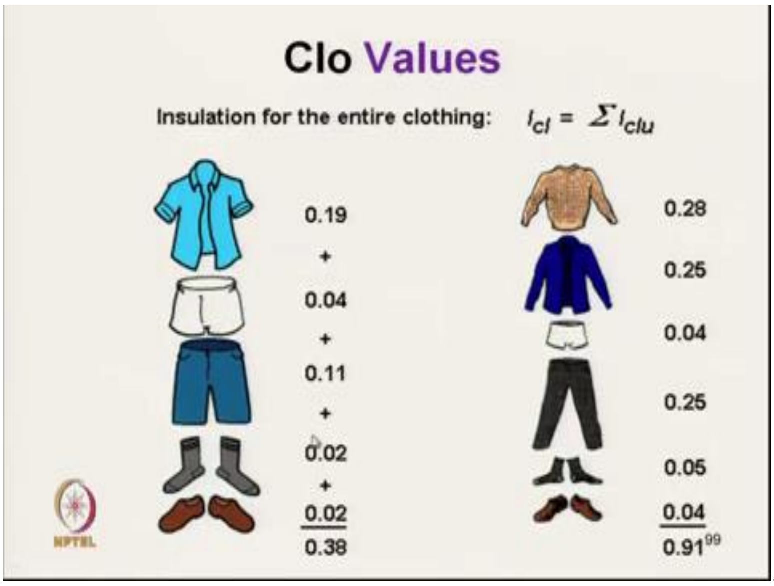

So, the example here it is given. So, insulation for entire clothing system is the summation of individual component. So, a person who is wearing a half shirt and all these components, if we simply add, it will be the total Clo. Here the all this things five components are added and we are getting total Clo value of this entire system as 0.38. Now, if you talk about this here Clo value with the system it is 0.91, it is approximately close to 1. That means, a person who is generating 1 Met, he will have to wear, this type of clothing to keep him comfortable that means the heat generation and heat release will be balanced.

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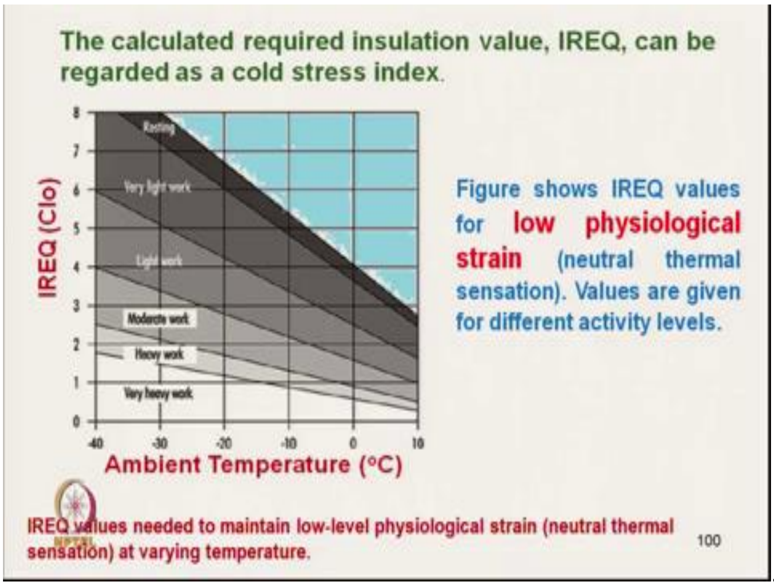

Now, this is the curve which is known as IREQ that is required insulation. So, the calculated required insulation value can be regarded as a cold stress index. So, this cold stress index is basically it is nothing but it is give us direct indication of the level of cold stress. Now, this let us see this diagram, where x-axis shows the ambient temperature, in this picture it starts from – 40 ^{0}C, -30, -20, -10, 0, +10. So, these are the temperature. And IREQ value that means required Clo value of the clothing to maintain, to keep the person comfortable. Here, it is given in y-axis.

What does it show, suppose a person who is actually at the temperature of -20 ^{0}C, and he will require different level of Clo value depending on his activity. Suppose at -20^{0}C he is resting. He is resting; that means, if it is around this zone, he needs a clothing with Clo value of 6.5, around 6.5 Clo value, he will required. But the same person, if he is working very hard at that temperature -20^{0}C, he will require a Clo a clothing with Clo value less than 1, that means, at -20^{0}C he if he is sitting idle, he is resting he needs of large quantity of clothing many layers of clothing, different types of clothing. But the same person will require relatively lesser number of clothing layer if he is working very hard. So, depending on the activity level, so if he is gradually becoming active, he will require less insulation in clothing.

So, figure shows IREQ value for low physiological strain. Low physiological strain means he is relatively in comfortable position. So, IREQ, IREQ value needed to maintain low level of physiological strain neutral thermal sensation at varying temperature. So, at different temperature, he needs different level of clothing insulation. Suppose, the same person working same level of activity. So, suppose he is working very hard, if he is been shifted to another location where temperature is -30^{0}C, so to keep him comfortable, he will require little bit higher Clo. So, accordingly the Clo can be adjusted, and we can select the clothing accordingly.

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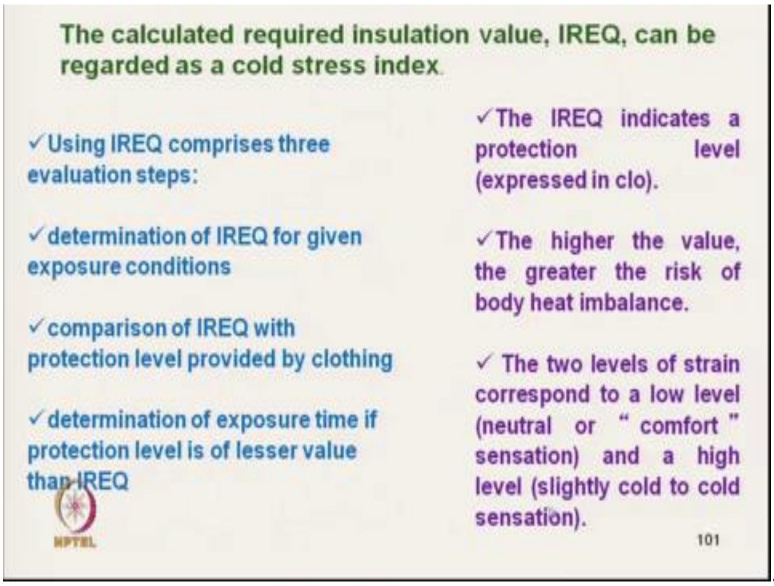

Now, the calculated required insulation value can be regarded as the cold stress of a person. Using IREQ comprises of three evaluation steps. First we have to determine the IREQ for given exposure condition; so from using this at this graph, we can select the IREQ value. Then comparison of IREQ with protection level provided by clothing; so we know the level of IREQ required then we have to compare this IREQ with the clothing IREQ value clothing Clo value. Determination of exposure time if protection level of is of lesser value than IREQ value, so that means if our clothing protection level is less, that means, suppose we meet the Clo value IREQ value 4, but we have a clothing say with the 3.5 Clo value. In that case, we have to know the exposure time. So, if the exposure time is less, then we can little bit safely use that, but if the exposure time is very high very long exposure time, then we should not take any risk.

The IREQ indicates a protection level. The higher the value the greater the risk of body heat imbalance; that means, a person who is at say IREQ value 2, you will have lesser threat from cold injury than a person who is at say 6 IREQ value. The two levels of strain corresponding to a lower level that is, neutral condition and higher level slightly cold condition.

Here, if you see for each and every condition, we have two-level, one is high level and another is lower level. Suppose, some person at -30^{0}C doing light work, his IREQ is say 3.5 to 5. 3.5 to 5 means if we have a fabric or clothing system with 3.5 Clo, you will be actually with 5 Clo, you will be basically comfortable, but if he has 3.5, he will feel little bit cold stress.

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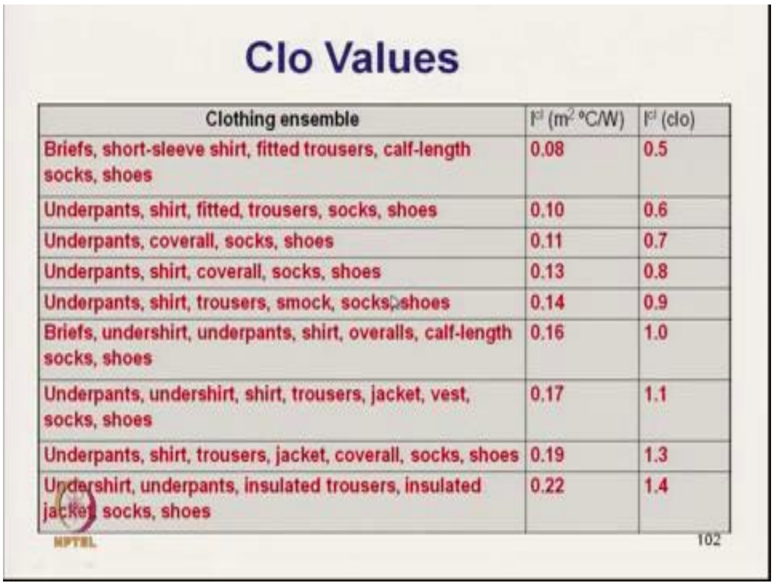

Clo Values

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

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Now, these are simple guidelines. These are available in published literature. So, we can have different combination. So, we have to simply select the combination, and we know the total Clo value of all these combinations. So, we know like for example, briefs, short-sleeve shirt, fitted trousers, calf-length socks and shoes. A person if he is wearing that, then his IREQ value will be the Clo value will be 0.5. So, accordingly we can select the combination, we can have different combination.

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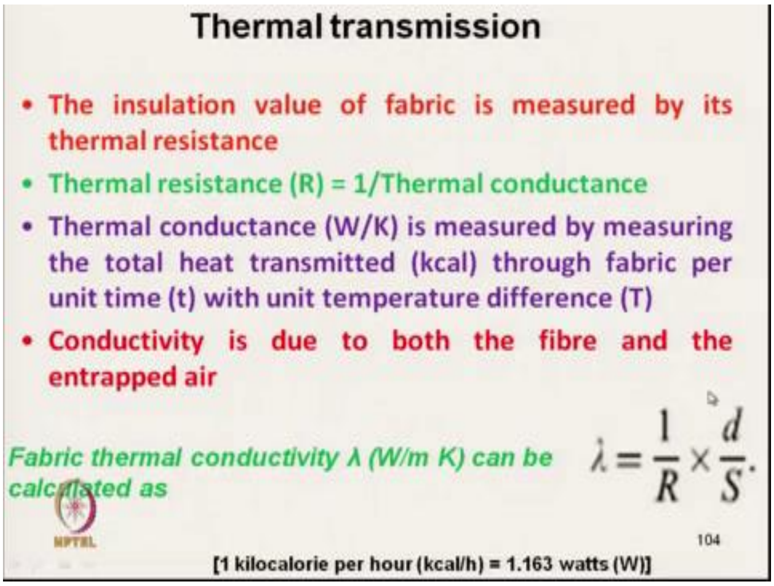

So, few combinations are given here. Now, few other parameters, the insulation value of fabric is measured by its thermal resistance, and thermal resistance is reciprocal of thermal conductance. What is thermal conductance? Thermal conductance is expressed in terms of **W/K**. It is measured by measuring the total heat transmitted in kcal through fabric per unit time with unit temperature difference, so that is a thermal conductance.

And conductivity is due to both the fiber and entrapped air. So, thermal conductivity is mainly through the fiber material and through the air. And it is expressed as a thermal conductivity, it is ***λ (W/m K)***,

$$\lambda = \frac{1}{R} \times \frac{d}{S}.$$

- ❑ **R is the thermal resistance of the fabric layer (K/W)**
- ❑ **[1 kilocalorie per hour (kcal/h) = 1.163 watts (W)]**

❑ d is the basically thickness, and S is the unit area.

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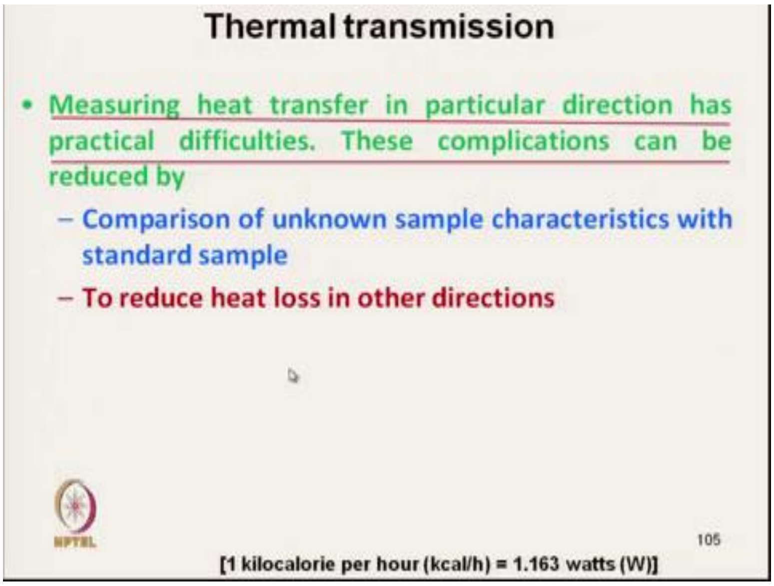

So, the measurement of heat transmission in a particular direction has practical difficulties. It is not like a fluid like air or water. Now, let us first see as we have seen earlier that if you want to measure the airflow air flow in a particular direction, so in this direction, we want to measure air flow. What we have to do we have to flow the air through a pipe, and this air will flow out, and we can measure the air flow rate in terms of say liter per hour. And here we can guide the air through this pipe or through any channel. So, in any form we can guide the air or any fluid.

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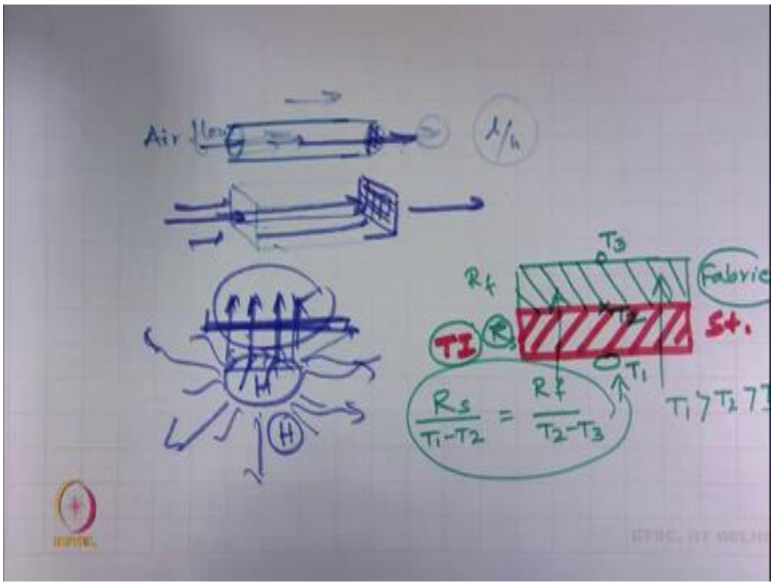

In case of say liquid also we know this channel and we can measure the flow rate ok. But if any heat we have to transfer say through a fabric, you have to measure the heat flow rate through fabric; if you want to measure the air flow rate through fabric so we can cover this side other side of the pipe for the tube with the fabric, and we can measure the flow rate. Similarly for liquid also, we can measure the liquid flow and can just cover this, the other sides of fabric and we can measure the flow rate through the fabric.

But the heat the problem of heat transmission is that heat we cannot have the flow in the one direction. It cannot flow in unidirectionally. If a heater, if it is a source, it is a heater; the heat will always try to flow in all the directions. So, if you want to measure the heat transmission only through the fabric, it is very difficult, because the whatever heat it is actually generating it is a portion of the heat is transmitting through the fabric, but rest heat are in other direction. So, it is very difficult to quantify this amount of heat which is through fabric. So, we have to use some alternate arrangement, some indirect arrangement to measure the heat transmission through fabric.

So, typically two approaches are being used. The approach one is that comparison of unknown sample characteristics with standard sample. So, if we can compare the thermal resistance of unknown sample that is our fabric with standard sample, in that case we can measure the thermal resistance of a particular fabric. Now here, suppose here we want to compare the unknown sample with the known sample. So, this is one known sample say plate standard plate with known thermal insulation value. Thermal resistance value is known. Another unknown sample which is placed in parallel, it is in series we are placing just above the known plate. This is fabric which is unknown sample.

And here, if you want to measure the thermal insulation of this fabric, in that case, you have to measure the temperature here, temperature at junction point T1 and T2 and T3. So, the temperature difference between the surface and the ratio of thermal insulation, thermal resistance, this ratio is constant when the materials are in series, that means,

$$\mathbf{R_{fabric} = R_{stand} \times (T_2 - T_3) / (T_1 - T_2), \text{ here } T1 > T2 > T3}$$

So, using this Rstandard, so using this simple basic equation we can calculate indirectly the thermal resistance of a fabric. So, this technique is used in Togmeter. This principle is used in Togmeter.

Another way of measurement is that to reduce the heat loss in other direction. So, if we can somehow direct the heat towards one direction and blocking the heat in all other direction. So, that we can channelize the heat only through the specimen, and we can measure the thermal transmission directly. So, fabric thermal conductivity as we have already discussed is expressed by this formula.

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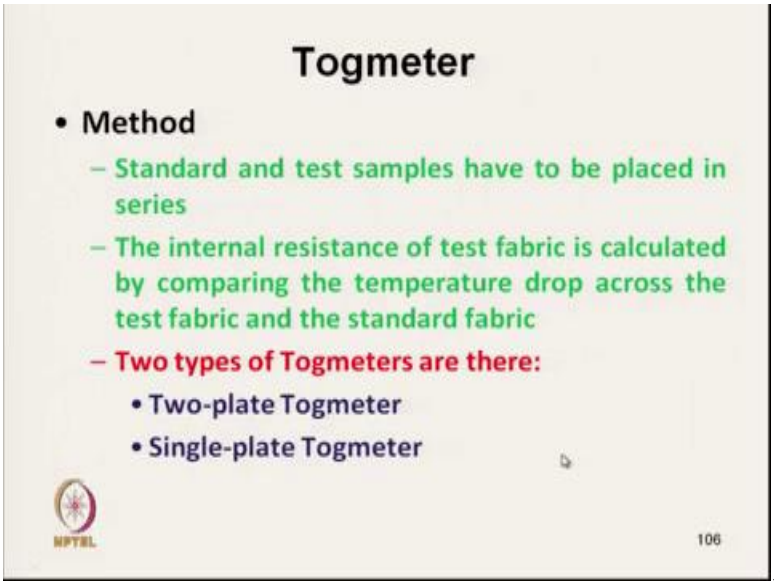

Now, first we will discuss the principle of Togmeter. So, togmeter we have two types of togmeter, one is the double plate togmeter - two plate togmeter, another is single plate togmeter. So, standard and test samples have to be placed in series. As I have mentioned the internal resistance of test fabric is calculated by comparing the temperature drop across the test fabric and the standard fabric that is standard maybe fabric or in this case we can use the standard plate. So, two types of togmeters are there; two plate togmeter and single plate togmeter.

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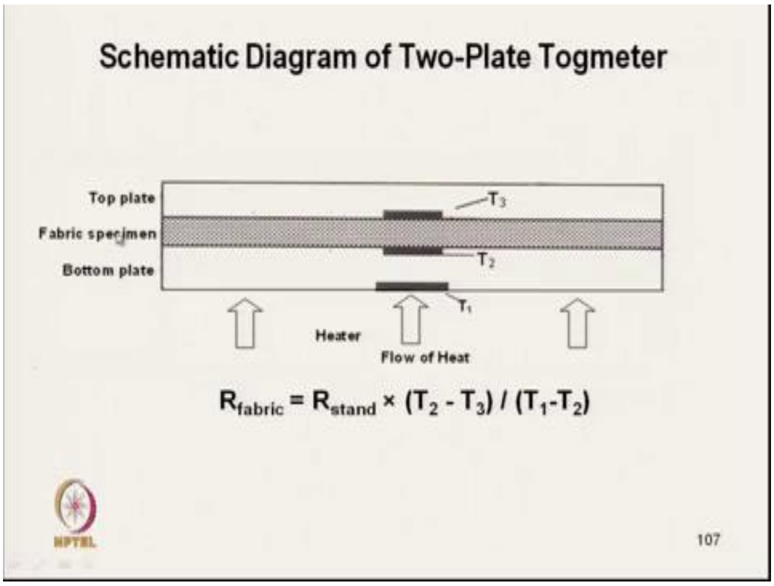

Now, this is the schematic diagram of two plate togmeter. There is a bottom plate which is heated by the heat flow. Just above the bottom plate, we can place the fabric specimen. And another plate that is top plate is used which is lower mass, lighter in mass, which is used in just above the fabric. The mass should be lower or otherwise it will compress the fabric specific and the insulation characteristics of the fabric will change.

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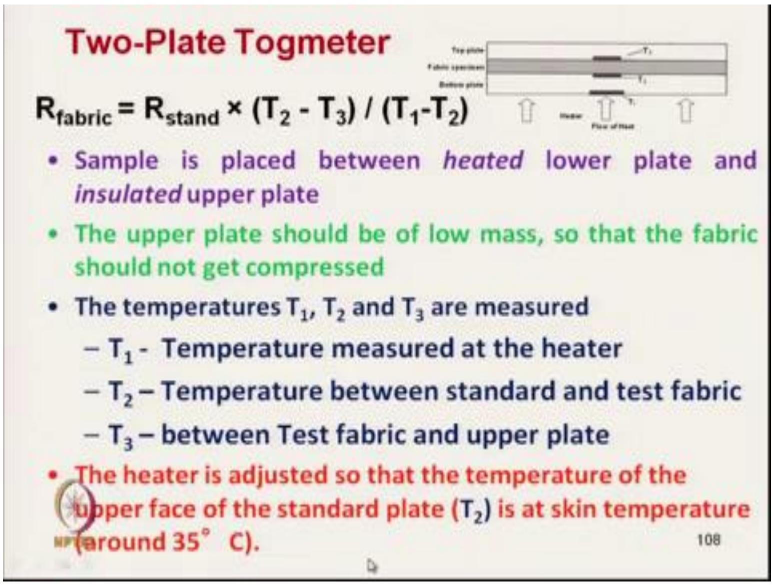

So, as I have mentioned the ratio of the insulation and temperature difference they remain same and that is the ratio

$R_{fabric}/(T_2 - T_3) = R_{stand} / (T_1 - T_2)$

Where ,T1 is the bottom side temperature, and T2 is the top side temperature of the standard plate.

The sample is placed between heated lower plate and insulated upper plate. The upper plate should be of low mass, so that fabrics should not get compressed. The temperatures T1, T2 and T3 are measured. So, T1 is the temperature measured at the heater; T2 is a temperature between standard plate and fabric; and T3 - between test plate test fabric and upper plate. The heater is adjusted so that the temperature of the upper face of the standard place T2 is exactly same as the skin temperature which is around 35 degree Celsius.

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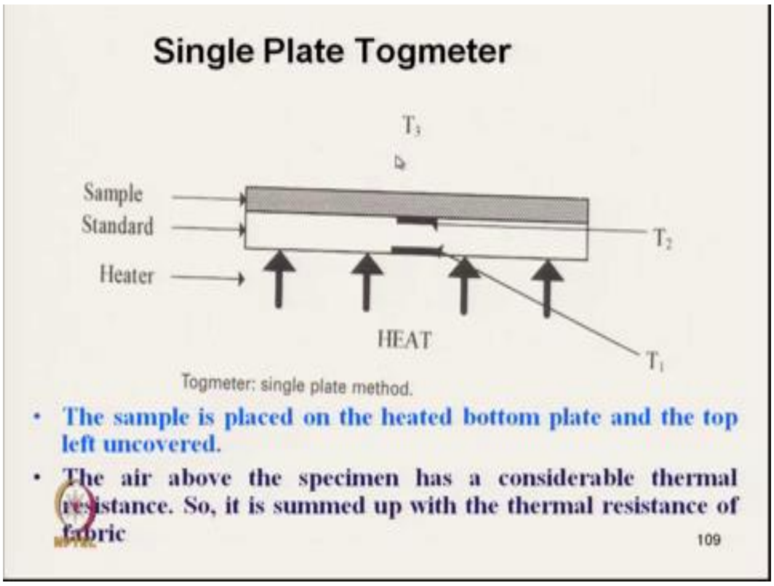

So, after the two plates, now we will discuss the single plate togmeter principle. In single plate we simply use one standard plate. Here top plate is not used. So, the temperature at the heater that is in at the bottom of the standard plate T1 and the temperature between the standard plate and fabric T2, and the temperature T3 which is the temperature of the air, ambient air which is typically above 1m of the fabric specimen where the temperature is actually standard. The sample is placed on the heated bottom plate, and the top is left uncovered, the air above the specimen has a considerable thermal resistance. So, it is the summation of the insulation of fabric and air ok, so that actually we have to measure here.

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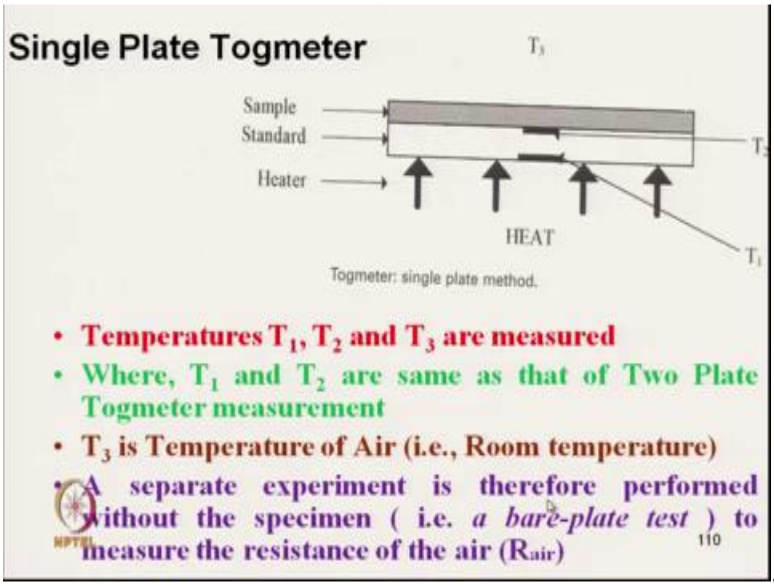

The temperature T1, T2, T3 as I have already mentioned, where T1, T2 are same as that of two plate togmeter measurement, and T3 is the temperature of air that is room temperature. A separate experiment is therefore, performed, because the insulation which we are getting here. It is the insulation of air and the specimen that is why we need to conduct a separate experiment without the specimen that is called bare-plate test to measure the resistance of air which is expressed as Rair that means, whatever value you will get with the sample if we actually subtract the Rair value. We will get the exact value of the fabric insulation.

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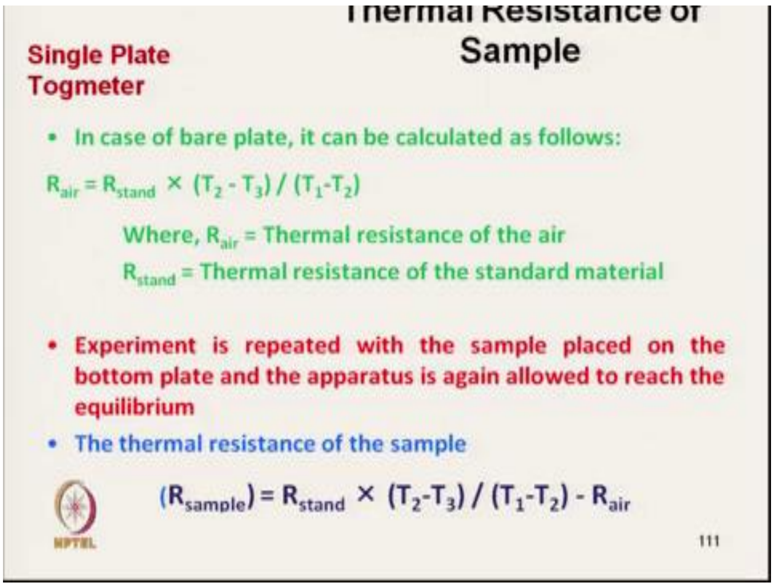

In case of bare plate, it can be calculated as follows:

$$R_{air} = R_{stand} \times (T_2 - T_3) / (T_1 - T_2)$$

Where, R_{air} = Thermal resistance of the air

R_{stand} = Thermal resistance of the standard material

So, as we have seen earlier also. Rair is the thermal resistance of air and Rstandard is the thermal resistance of standard material. So, the experiment is repeated with the sample placed on the bottom plate and the apparatus is again allowed to reach its equilibrium.

The thermal resistance of the sample is actually calculated by subtracting R air value.

- **The thermal resistance of the sample**

$$(R_{sample}) = R_{stand} \times (T_2 - T_3) / (T_1 - T_2) - R_{air}$$

So, these are the two methods which are actually used for measuring the insulation of fabric in actually comparing by knowing the standard plates resistance.

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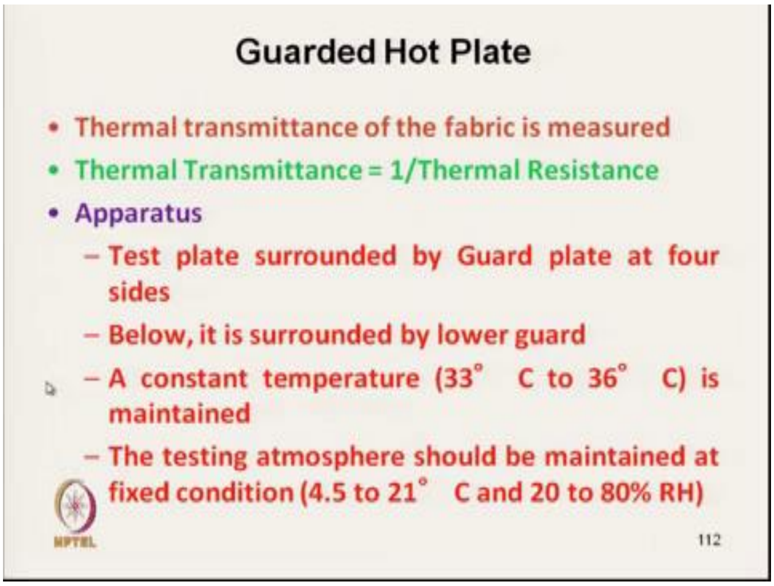

Next is the guarded hot plate. The guarded hot plate principle it works with the principle where we try to control the direction of heat flow in a particular direction where it only goes through the fabric specimen. The thermal transmission is measured here, the parameter which is called thermal transmittance of fabric. Thermal transmittance is reciprocal of thermal resistance. In this apparatus, a test plate which is surrounded by guard plate at four sides ok.

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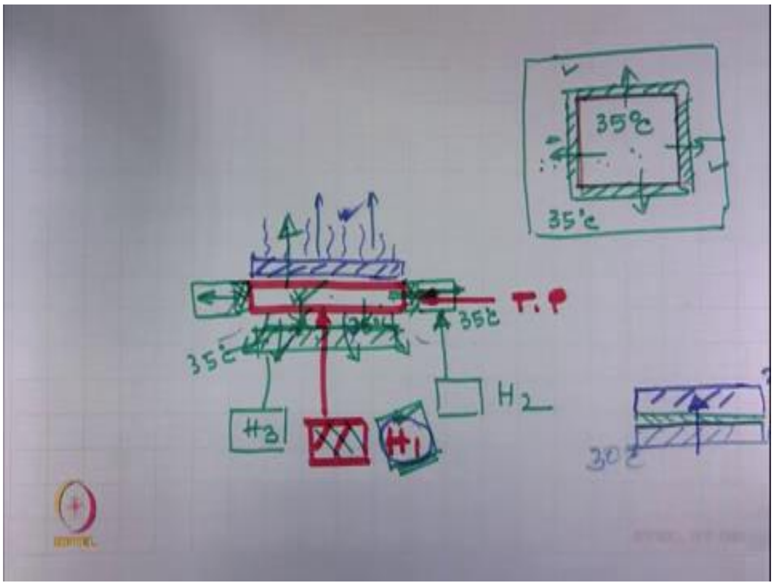

Now, let us see suppose this is test plate ok, test plate. Now, we have to heat, this is a heater, heater 1. So, the heater 1 is heating the test plate. And suppose we are placing the fabric specimen on this. This is a fabric specimen. And what we want we want to measure the heat which is flowing through the fabric, and the heater 1 is heating the test plate, but this heat is transmitting through other direction also. It is very difficult to know how much heat is getting transmitted through the fabric.

So, the guard plate guarded hot plate principle where you would like to direct the heat in to pass through a particular direction. Here, the heat which is flowing in other direction, so in side way direction, we can block the heat by providing some insulation some cork insulation we can provide. And this plate if we see from the top side, this is the plate, test plate ok, test plate. And the insulation is provided at four sides. These are the insulation, so which actually prevent the heat flow in sideways, but this insulation may not be sufficient the heat will still try to flow in sideway direction. For that we will provide another square guard ring.

So, we can provide, this is a guard ring is provided. So, guard ring is heated with another heater which is H2. And this heater is providing the heat to the guard ring to maintain the same temperature. Suppose, this is the temperature 35^0C, here also exactly 35^0C temperature we are maintaining. So, this heater temperature plate temperature 35^0C, guard ring temperature is 35^0C, that means there is no temperature gradient heat will not try to flow from the test plate to the guard ring. So, this side, the side way flow of heat is being blocked using two technique, one is the cork insulating cork, another is maintaining the same temperature of guard ring.

So, we have blocked the side way transmission then another side which is creating problem here heat can flow in bottom sides also. So, here what we do, we provide another plate which is called bottom plate. And it is again heated with another heater is H3 to maintain the temperature again 35^0C same temperature, that means, if we have no temperature gradient, so that heat will not flow in this direction also bottom direction.

So, we have blocked heat flow side way as well as the bottom way only one direction the heat can flow that is the top direction. And in the top direction, we have placed the fabric on the test plate and that is how we can measure directly the heat which is flowing through the fabric. And this heat is provided by heater H 1, that means, in guarded hot plate we measure the heat which is provided by H 1 that is which is heating the only the test plate. And bottom plate and guard ring the heat which we normally do not take into account, this heat are required to maintain the same temperature ok.

So, the test apparatus here the test plate surrounded by guard plate at 4 sides below it. It is surrounded by lower guard plate that is bottom plate a constant temperature around 33 to 36 degree Celsius, so same temperature is maintained. The testing atmosphere should be maintained at fixed condition 4.5 to 21 degree Celsius that is recommended we can use other temperatures also for different experimentation, and the relative humidity at different range.

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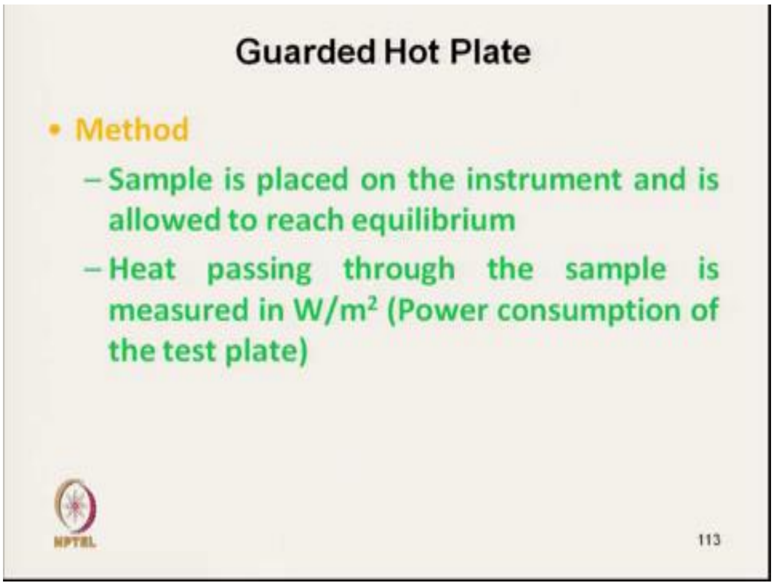

So, the method is that the specimen is placed on the instrument, and it is allowed to reach the equilibrium condition. Heat passing through the sample is measured in watt per square meter that is power consumed by the test plate per unit area.

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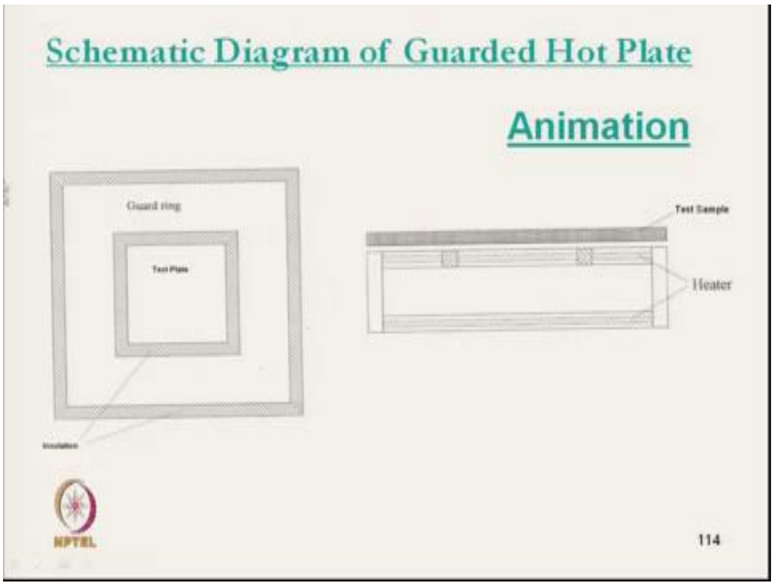

So, if you see this picture, this is the top view as I have already shown centre one is a test plate. Here, these are the insulation, and then it is a guard ring. And after that, another insulation, and above that we place the test specimen, and below there is another plate which is the bottom plate. And three different heaters are used for heating and to maintain the same temperature.

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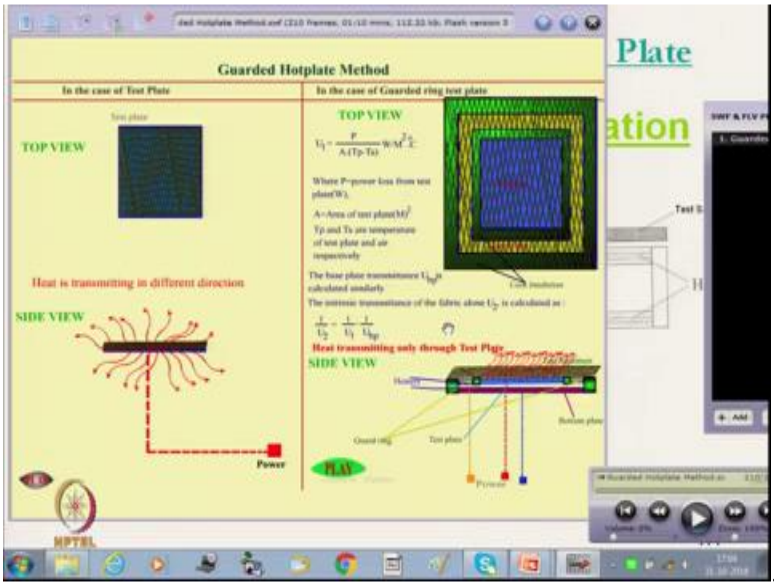

Let us see the animation here. In first, we will see the only the test plate without any guard plate and bottom plate. This is showing top view and it is side view. The plate is there above that we are placing the fabric specimen, and then the test plate is connected with heater and once it is heating, the heat will flow at different direction.

But in other animation, if we see this is the test plate, and this is a guard plate and insulation, and then it is a red one is bottom plate we are placing the fabric specimen, then this plates are connected with heater. And once to the temperatures are maintained same, the heat is only flowing through the fabric specimen that is recorded and which is the thermal transmittance is expressed in terms of U value which is the P is the power consumed by the test plate. A is the area of test plate and also the area of fabric and Tp - Ta these are the temperature difference ok. And we can use the bare plate test to know the constant for the instrument, and if we subtract we will get the thermal transmittance of fabric itself ok.

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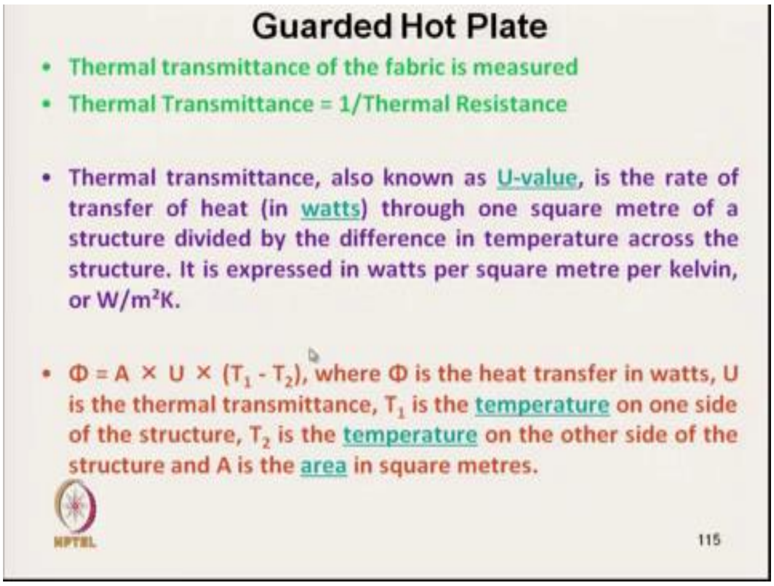

So, as already explained, the thermal transmittance also known as U value is the rate of transfer of heat in watt through one square meter of a structure, in this case, in our case it is a fabric divided by the difference in temperature across the fabric structure ok. It is a expressed in **W/m^2K**. And **Φ** is the heat transfer in watt is equal to

$\Phi = A \times U \times (T_1 - T_2)$, where Φ is the heat transfer in watts, U is the thermal transmittance, T_1 is the temperature on one side of the structure, T_2 is the temperature on the other side of the structure and A is the area in square metres.

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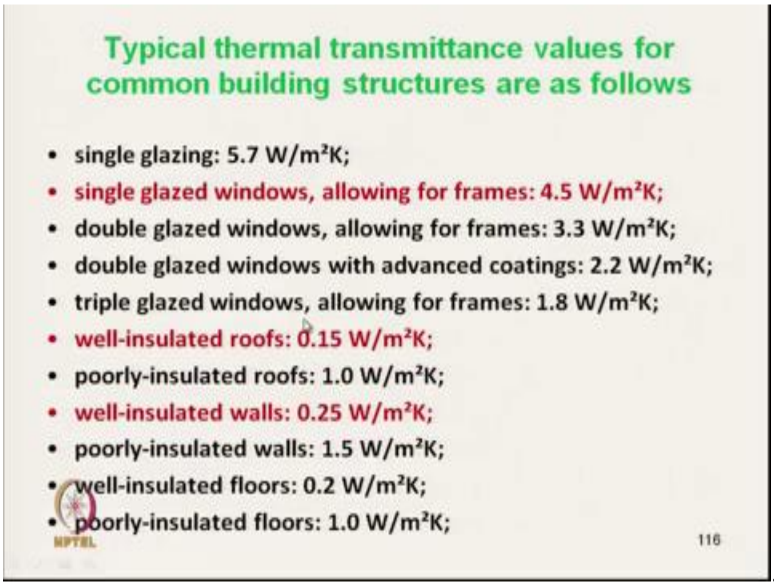

.

So, if we try to see the actual fabric thermal transmittance, we can compare with the standard metal standard material single glazing like window it is having 5.7 **W/m²K** ok. Now, likewise we can see the well insulated roof, because it has got value of transmittance value 0.15. Well-insulated wall, it has got value 0.25 ok, so well-insulated floor 0.2. So, in this way we can get the insulation value. So, 0.15 is the well-insulated roof.

Now, if we want to compare the insulation value, the insulated roof insulation value with our fabric we will get this value. Thick woven fabrics has thermal transmittance value 20 to 80 that is the woven value. Thin woven value 50 to 200 that is the range we can get and knitted medium weight cotton fabric is having 30 to 100 W/m^2. This is the range we will through when we test with the guarded hot plate.

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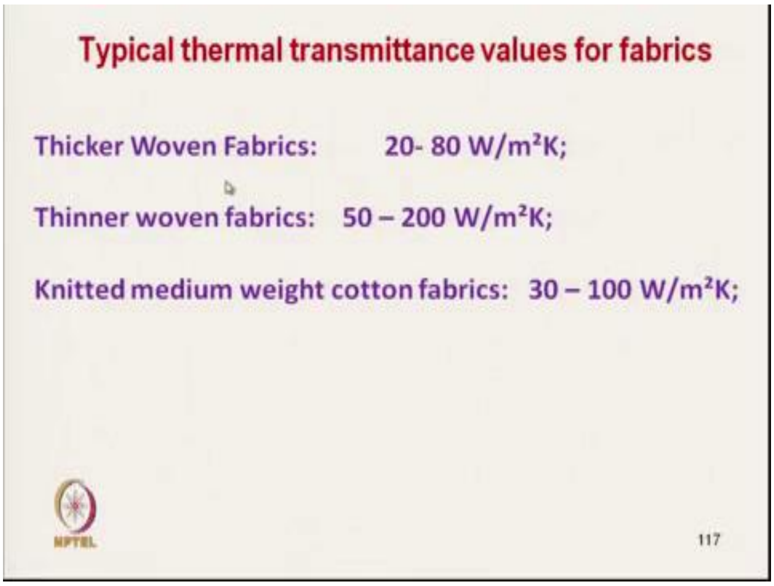

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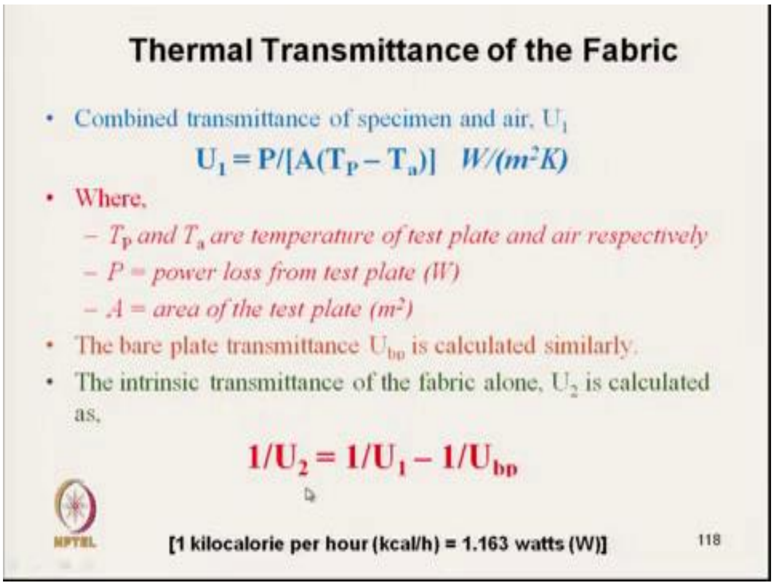

- So, thermal transmittance is the combined thermal transmittance of specimen and air which is calculated as Combined transmittance of specimen and air, U_1

$$\mathbf{U_1 = P/[A(T_P - T_a)]} \quad \mathit{W/(m^2K)}$$

- Where,
  - T_P *and* T_a *are temperature of test plate and air respectively*
  - *P = power loss from test plate (W)*
  - *A = area of the test plate* (m^2)
- The bare plate transmittance U_{bp} is calculated similarly.
- The intrinsic transmittance of the fabric alone, U_2 is calculated as,

$$\mathbf{1/U_2 = 1/U_1 - 1/U_{bp}}$$

So, we have discussed the togmeter principle, we have discussed the guarded hot plate principle, and another principle we will just discuss which is KESF thermo lab ok.

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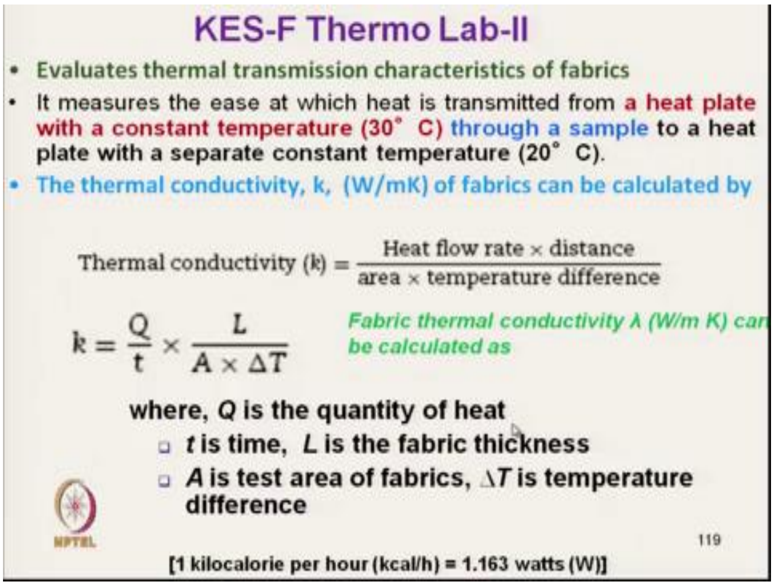

In this system, it is basically here it evaluates the thermal transmission characteristics of fabric. This is simple technique, it measures the; is at least the heat is transmitted from a heated plate with a constant temperature of 30^0C. So, there are two plates one plate is having 30^0C, and another plate it is 20^0C in between that these two plates there is a fabric specimen this is actually that technique is like that. Here is a plate, plate 1 which is kept at 30^0C and then we keep fabric specimen here this is a fabric specimen, and another plate which is kept say 20^0C. So, heat will flow from hot plate to relatively cooler plate, and it will flow through fabric.

The thermal conductivity k that is W watt per meter Kelvin of fabric can be calculated using simple formula thermal conductivity k is

$$\text{Thermal conductivity } (k) = \frac{\text{Heat flow rate} \times \text{distance}}{\text{area} \times \text{temperature difference}}$$

$$k = \frac{Q}{t} \times \frac{L}{A \times \Delta T}$$

where, *Q* is the quantity of heat

- ***t* is time, *L* is the fabric thickness**
- ***A* is test area of fabrics, ΔT is temperature difference**

So, using this simple technique the KESF, Kawabata evaluation system in thermo lab II, we can measure the thermal conductivity. So, we will stop here. So, we will continue with this discussion in next class.

Till then thank you.