Science of Clothing Comfort
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Lecture – 03
Understanding Clothing & Clothing Comfort (contd)

Hello everyone. Now today's lecture is on human clothing interaction.

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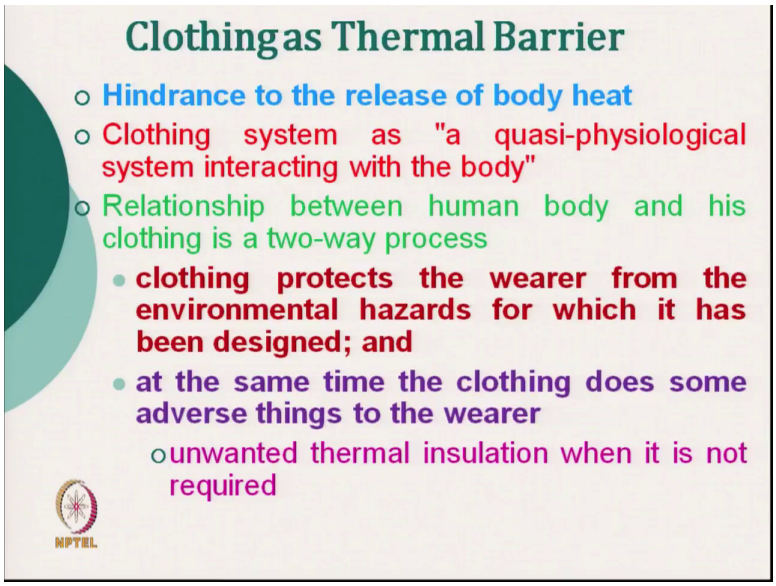

Now this human clothing interaction, we will try to discuss here, how the clothing our clothing interact physiology; thermal physiologically with the body. So, clothing if we can see as compared to our bare body if I am not wearing a clothing and when we actually wear clothing the difference is that clothing, you can see as a thermal barrier it may or may not be comfortable, but first thing is that clothing hinders the free flow of heat from our body or from environment to our body.

So, if we consider most of the environmental temperature are less than our body temperature which is 37 degree Celsius. So, what clothing does, it does not allow the free flow of heat. So, it hinders the free release of heat from the body, which sometimes it is may not be required like at high temperature, like it is close to our body say 35- 36 degree Celsius. We sometime feel comfortable when we remove our clothing.

So, it unnecessary heat hinders the free flow of heat from the body. So, clothing system; human clothing interaction human clothing system is actually is apparent physiological quasi physiological system, interacting with the body; it is a physiological system which interacts with the body. So, we need clothing it is a basic requirement, but at the same time it actually has got some interaction close interaction with the body. And that we have to understand. And in this course we will try to understand this clothing human interaction in various ways here. We will discuss basically the heat transmission heat and mass transmission, but we will discuss other gradually.

So, relationship with the body, the clothing has got it is a 2-way process. Sometime clothing helps us from protecting from the extreme environment and it has got it is negative impact also. Like clothing protects the wearer from the environmental hazard for which it is been designed. We will discuss in detail like in this time room say room temperature is at 21, 22 degree Celsius.

So, clothing is protecting us from the heat release. **So, un** due heat release it is protecting clothing. Otherwise we will feel uncomfortable or even extreme cold temperature it is protecting us or extreme heat. So, it protects us we need clothing beside our basic need. So, we need clothing to protect us, but at the same time, what it does, it has got some adverse effect by unwanted thermal insulation. Sometime we do not need thermal insulation and clothing provides that.

So, that is unwanted. So, it is a 2-way process one way it helps us a protecting and all this thing, but some time it provides unwanted thermal insulation. And it hinders the free evaporation of sweat from the skin which is very important. In extreme heat condition if our sweat evaporates quickly we will feel comfortable or we will feel cooler, because sweat during evaporation it will take the latent heat from our body and our body cools down. But the clothing layer which thus it is doing some adverse effect. Adverse effect in the sense it does not allow the free flow of the sweat.

So, we have design of clothing which actually this is the actually fire moisture absorption or moisture transmission is to get. So, the metabolic heat production.

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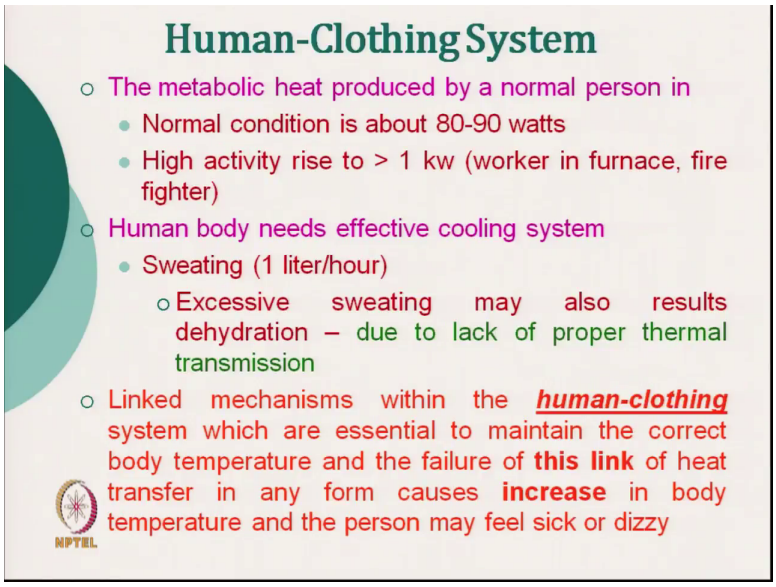

So, when we are sitting quietly and at normal it is 80 to 90 watts of heat we produce. So, that which means that particular heat has to be transmitted, and if you wear clothing and clothing hinders, that flow and at high activity level. So, when a worker works in front of furnace the level of heat generation may be more than 1 kilowatt.

So, at that level if clothing prevents the heat to flow out freely, then the body temperature will increase internal body temperature will. So, people may feel uncomfortable. So, that is the interaction we must first understand. Then we can design clothing for comfort. And the cooling activity is by sweating; so when if our body gets heated up.

So, our, another activity another physiological process starts the sweating. Through the sweating; so body tries to cool down, but if our clothing is such that it does not allow the free flow of free evaporation of sweat then we will feel uncomfortable. Just one simple example in normal temperature if we are wearing a clothing made of polythene sheet impermeable sheet what will happen? We will feel uncomfortably, warm because the moisture the sweat does not get evaporated freely. So, we have to design clothing which transmits moisture or sweat very quickly.

Excessive sweating may also result dehydration, due to lack of proper thermal transmission. So, the clothing and human it is a linked mechanism. So, that link has to be proper. So, we do not have any control over our human body, but we have proper control of our clothing.

So, depending on our human body requirement we have to select clothing. So, that proper linkage between human body and clothing is there. And if this linkage is not proper, what will happen? Either we will feel we will have body heat increase or excessive sweating and which actually result person feel sick or dizzy.

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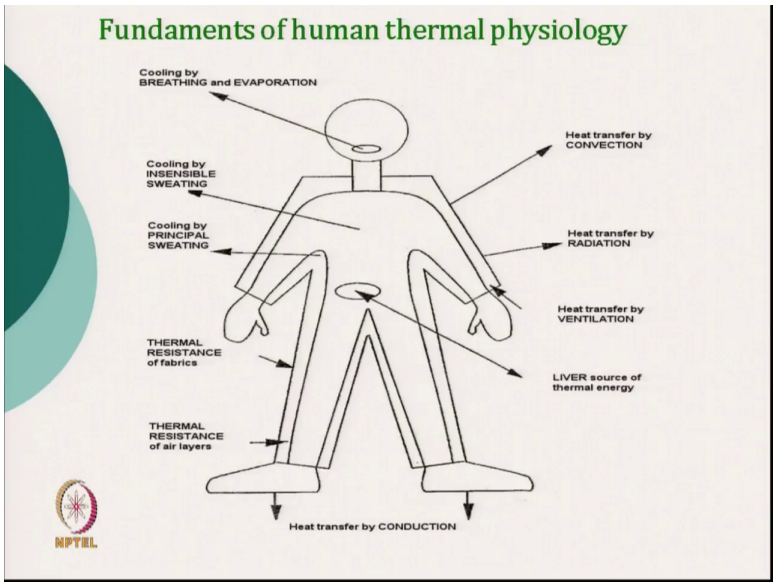

So, this type of proper linking we have to establish. So, this is the picture which is vey commonly available. And this diagram shows what are the activities going on what are the physiological or thermal physiological activities going on in this clothing human interaction. If we see the main the food the main metabolic heat source is our the liver, the main energy sources which generates heat, and that heat you have to actually get transmitted from our body and not only this heat, but other metabolic heat it generates.

So, this heat has to be transmitted ok. Otherwise our body will get heated up. So, this thermal transmission: if you see this picture the thermal resistance of fabric which is very important. So, we have to control the thermal resistance thermal transmission characteristics of fabric so that we can control the heat if we need the heat to be transmitted at high rate. So, accordingly we have to select the clothing.

Next is that thermal resistance of air layer. One is the clothing layer next is the air layer. So, we can control the thickness of air still air by selecting the tightness of the clothing. As I have mentioned that if we wear loose fit clothing. So, this air layer will be thicker;

that means, the fabric will give the clothing will give higher insulation. Next is the sweating. The sweating is the most important mechanism for cooling down.

Now, sweat has to be evaporated then only we will feel cooling, otherwise if sweat does not get evaporated suppose we are wearing a clothing as I have mentioned made of impermeable fabric, what will happen? Sweat is not coming out and it is not getting evaporated our body is not getting cold what to make our body cold, or physiologically that it will start body will start generating more and more sweat and we will at start losing sweat. And it will sweat will simply drip inside the body in the microclimate, but if our clothing is selected in such a fashion that it transmits moisture and evaporates. Then we will not have too much sweat our body gets cool down.

So, sweating is most important cooling mechanism of human body, and cooling by insensible sweating. So, what is insensible sweating? We are sitting idle we are not sweating we are not it is not visible it does not mean that we are not releasing the sweat. It is called it is in the vapor form directly in the vapor form it gets released from our body.

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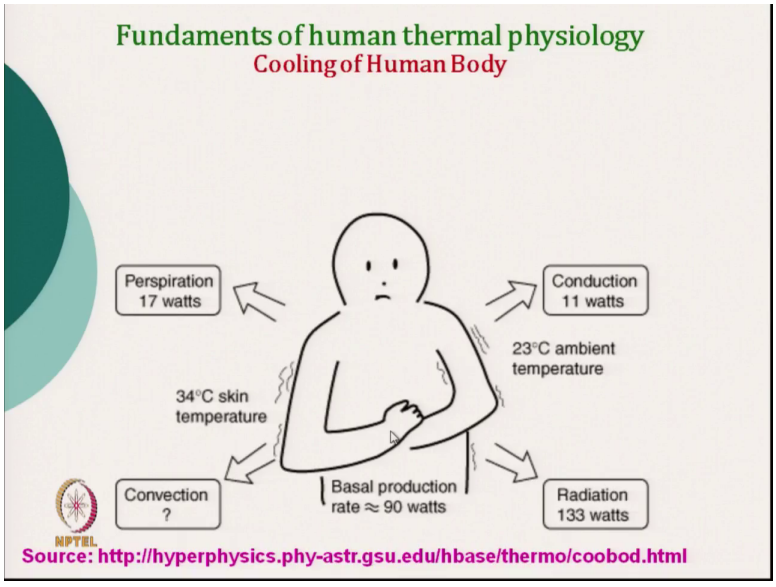

So, we are feeling comfortable and also cooling by breathing and evaporation that is also, but it is nothing to do with the clothing and heat transmission by convection.

So, convective heat transmission is a one of a parameter, but where it transmits through the movement of the medium. So, that is the convective heat transmission convective heat transmission is predominant, when in blowing air it is when air is blowing us; that means, it is a forced convection is taking place or else suppose I am wearing a loose fit shirt or loose fit dress.

So, during my movement there is a bellow effect, which actually pumps the air from the body. And it is a proper air circulation is taking place through that mechanism it is a convective mechanism we can release heat. And heat by radiation heat transmission by radiation this is the mechanism which is in clothing which is actually most important.

Radiative heat transmission is a major component in heat. If we can control the radiative heat transmission either from going out from our body or from receiving from our body if we can control, then we can be comfortable. Heat transmission by radiation then as I have mentioned heat transmission by ventilation. So, it flows an as. So, these are the mechanism of heat and conduction is also one of the major characteristic a parameters. So, this mechanism conduction mechanism and also from unclothed portion also we conduct.

Now, human body we can consider as a thermal engine with very low efficiency 5 to 25 percent of the efficiency.

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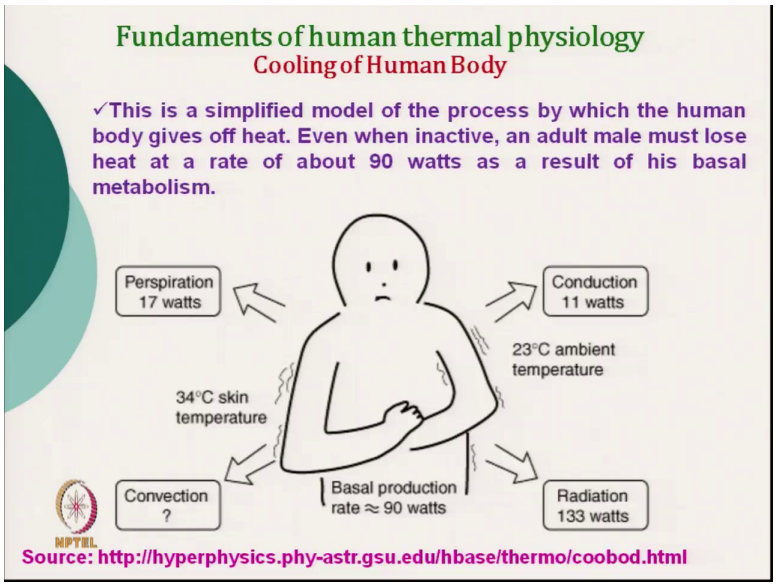

Now we will discuss the fundamental of human thermal physiology. So, if we understand this human thermal physiology without clothing will; now will first try to understand the human thermal physiology without clothing then we can incorporate clothing.

So, first we have to understand this is taken from a open source the source is given here. So, first we will discuss in 2 distinct situations. One is the cold situation, cold suppose a person without any cloth he is sitting in a room of say 23 degree Celsius it is ambient room ambient temperature is 23 degree Celsius. So, we will try to understand; what are the different mechanisms of heat transmission.

And quantify try to quantify then we will understand the importance of different mechanism.

This is the simple model which shows a person with at the room of 23 at the environment of 23 degree Celsius, and as is not doing any activity. So, the metabolic heat basal production of heat which is generating it is a 90-watt heat generally. So, 90-watt heat yes he is generating that much heat he has to transmit out, he has to transmit to the environment then he will feel comfortable. If this balancing is not there, then he will feel uncomfortable.

Now, try to see. So, if we understand these basic phenomena then we can incorporate clothing on it.

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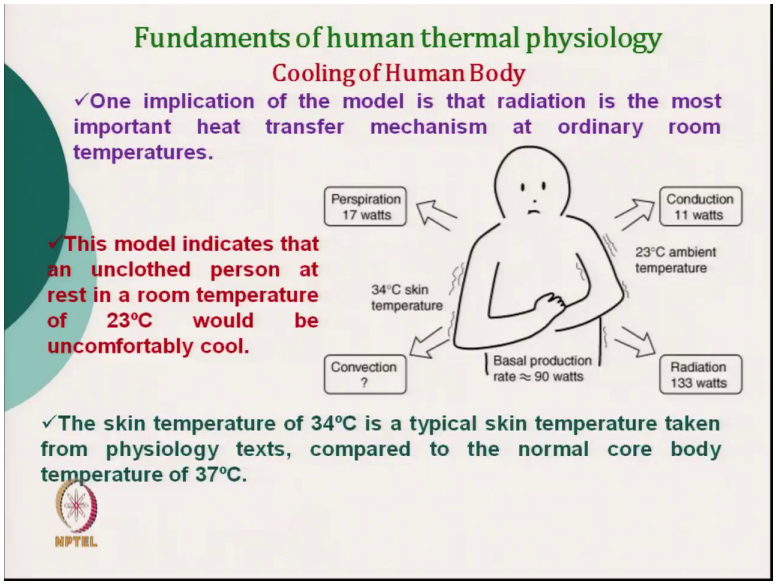

Now try to see one just implication you can see in this model the radiation radiative heat transmission is 133 watt. So, this is the most important phenomena or principle of heat transmission.

So, this person at this temperature of 23 degree Celsius he is a releasing heat through perspiration at the rate of 17 watt through conduction it is a 11 watt. And through radiation 133 watt; That means, whatever what is the amount of heat he is producing is 90 watt, but what is the amount of heat he is releasing it is much more than the heat production; that means, it is heat balancing is not there.

So, he is actually he will feel uncomfortably cold. So, if you know the difference of this. So, to make him comfortable what we have to do we have to use a cloth to balance these things. This heat flow it is very simple. So, if we know the basic calculation. So, then we can select our clothing. So, these things we will do gradually. So, this model indicates that an unclothed person at rest in a room temperature of 23 degree Celsius would feel uncomfortably cold, but normally in AC room at 23 degree Celsius we do not feel uncomfortably cold because we control our heat flow ok.

Now, let us see how we achieve all this parameter value. So, first is that the assumption is that the at this 23 Celsius temperature, our average mean skin temperature is 34 degree Celsius. So, there is there are techniques to measure the temperature skin temperature, because it is a weighted.

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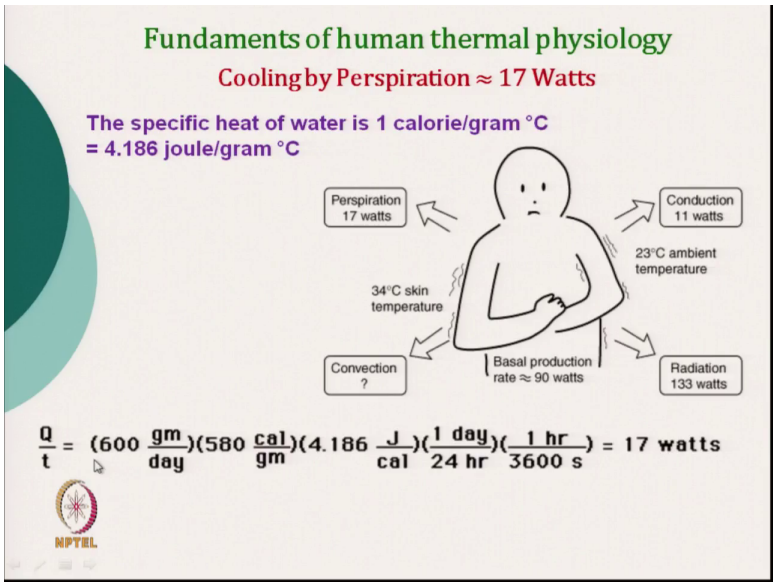

So, at different body different places our temperature body temperature skin temperature although body temperature is 37 degree Celsius it, it does not change, but skin temperature is it changes it may be say some in at some places you may it may be say 20 degree Celsius or 25 degree Celsius or different. So, mean temperature we assume we will assume here at 34 degree Celsius, that is our assumption.

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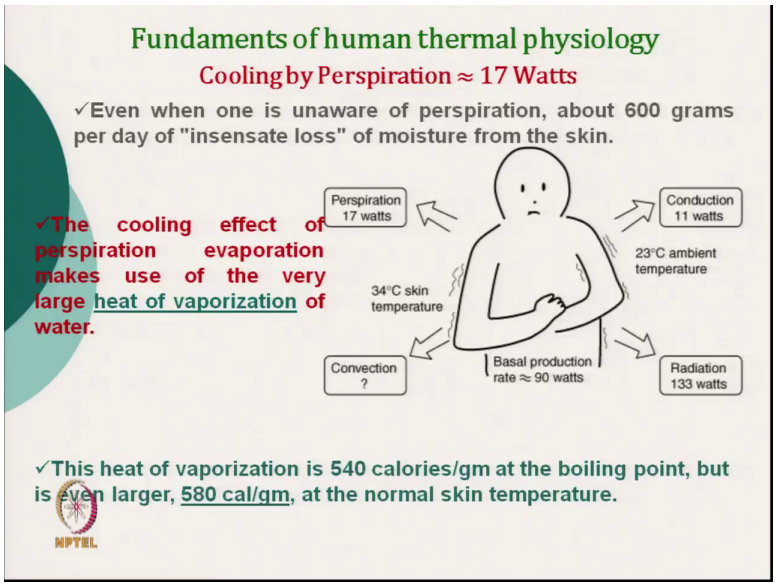

Now, first we have to see that we will try to calculate the perspiration. Through perspiration we have mentioned that he is going to release the heat of 17 watt. Now let us see how to achieve this 17 watt ok. There are various assumptions not only we cannot say assumptions these are the standard values are available in the literature.

So, first assumption is that, even when one is unaware that is insensible perspiration we release around say about 600 gram of moisture in one day, at that temperature say 23 degree Celsius that this is an assumption. But we normal release in that if you increase the temperature this value may be little bit high.

So, at that temperature it is assumed that it is a 600 gram he is releasing the heat in one day. The cooling effect of perspiration is due to evaporative cooling, that is heat of vaporization it is a latent heat of vaporization. So, what is the latent heat of vaporization normally we think 540 calories per gram, but this latent heat of vaporization it is a boiling at the boiling point of 100 degree Celsius of water, but if we talk about the skin temperature, at the skin temperature if the moisture has to get evaporated.

It needs little bit higher latent heat. So, you can refer the literature at skin temperature it is around 580 calorie per gram. So, we will not use 540, we will use 580 because we are using the room our body temperature.

Now, the calculation is very simple.

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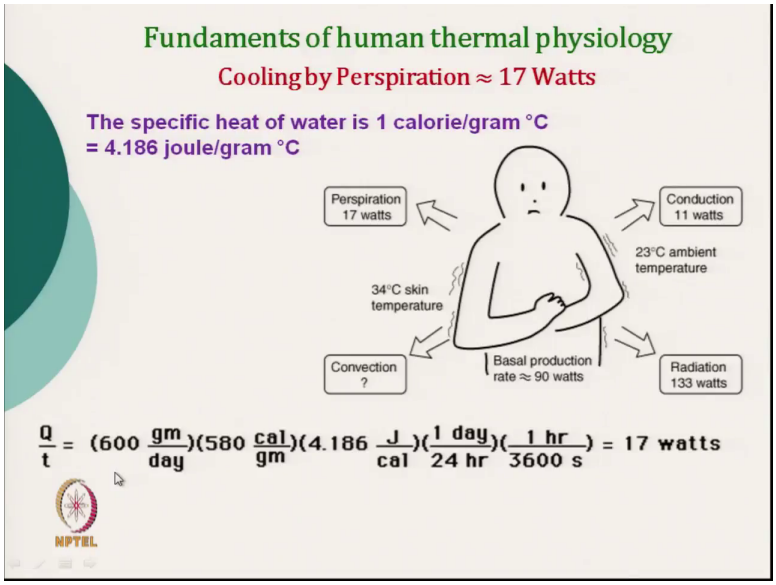

So, we are we are concentrating only on this, only on the perspiration. What is another thing the specific heat of water is one calorie per gram per degree Celsius. That is the specific heat and if we convert it the calorie to in joule it will be 4.186 this much joule per gram per degree Celsius. That is specific heat of water.

Now there is a simple calculation you just try to see, what is this 600 gram per day is releasing the moisture. It is not sweating he cannot sweat because at we have our assumption is that it is a 23 degree Celsius.

$$\frac{Q}{t} = \left(600\frac{gm}{day}\right)\left(580\frac{cal}{gm}\right)\left(4.186\frac{J}{cal}\right)\left(\frac{1}{24}\frac{day}{hr}\right)\left(\frac{1hr}{3600\,s}\right) = 17\ watts$$

So, around 17 to 20 watt, we release the heat when we are not sweating. And our temperature difference is that 23 degree Celsius ok.

Now, this is all about the only evaporation. And we can that that 600 gram as we have mentioned it changes with the temperature. So, if we increase the temperature our rate of moisture release will be more. And if we reduce the temperature it will be little bit low, but there will it will be there, but you can see that this is not that significant it is a 17 watt we are generating the heat at 90 watt right. Next is that by conduction.

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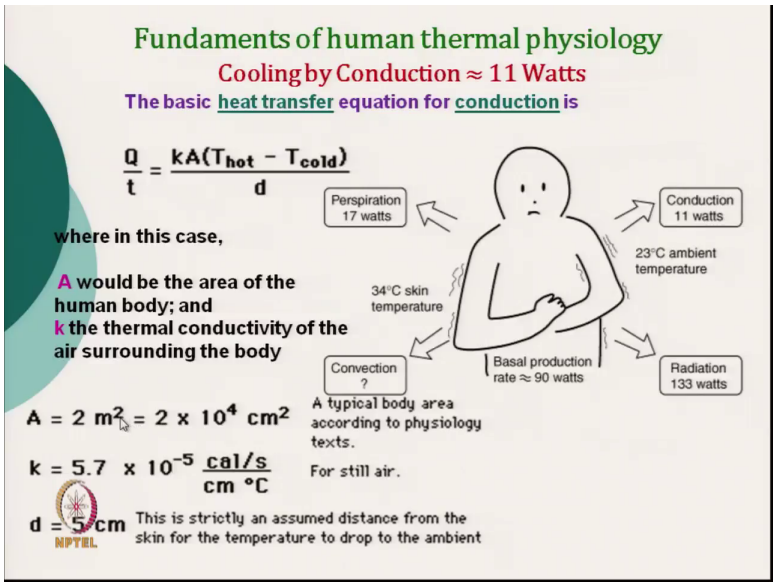

Now, assumption is that we are not considering any clothing it is an unclothed person. So, only conduction is by the air layer heat conduction by the only by air layer, still air layer. The basic heat transmission equation is this one. So, you can see it is the thermal conductivity of the medium. Here nothing is there it is air, but if we consider some clothing the clothing's thermal conductivity we have to use.

$Q/t = k A (T_{hot} - T_{cold}) / d$

$A = 2\ m^2 = 2*10^4\ cm^2$ $k = 5.7*10^{-5}$ cal/sec/cm°C d= 5 cm

k thermal conductivity of still air this is the standard value and d is the thickness in our in this; in the present case the thickness is the thickness of the air layer [FL].

Here the assumption is that from the basic study research study the assumption is that the (Refer Time: 27:41) it is a these 5 centimeter. What does it mean? This is strongly as an assumption; that means, which is a distance from this is the distance from the skin,

after that point after 5 centimeter the temperature will be 20 degree Celsius, because skin temperature is 34 degree Celsius.

Gradually, the temperature will drop and after 5 centimeter it is assumed that temperature will be as per the room temperature. So, if we use all this parameters and apply on this equation we will get the value around 11 watt. You can test. So, these are the basic a value. So, we know that by conduction cooling by conduction is it is also insignificant it is 11 watt only.

Now, what is the next is the cooling by a radiation which is major chunk.

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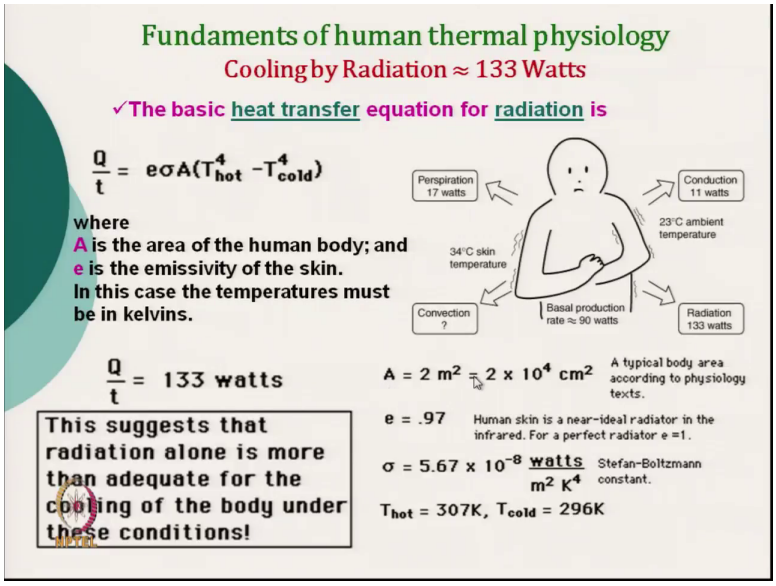

So, radiations is actually takes place and see it takes place using the Stefan Boltzmann law this is the heat due to radiation.

$Q/t = e\ \sigma\ A\ (T_{hot}^4 - T_{cold}^4)$ $Q/t = 133$ watts

$A = 2m^2 = 2*10^4\ cm^2$ $e = 0.97$ $\sigma = 5.67*10^{-8}$ watts/m^2K^4 $T_{hot} = 307$ K, $T_{cold} = 296$ K

And here that this is the temperature of the skin and t cold is the again temperature of air and it is a fourth order, in conduction it is an order is one, single order, it is a radiation, it flows in the fourth order. What does it mean; which means a temperature smallest temperature change in which will affect the radiative heat very high radiative heat. So, this is these are the answers again.

So, area of the human body is that it is a 2 square meter. And this e is the emissivity of the skin it is 0.97 it is a basically for near ideal radiator. It is close to ideal. So, for perfect radiator it is e is 1, it is a 0.97 for e this is the standard value which is available in the literature. And this sigma is the it is a Stefan Boltzmann constant which is known and t hot here actually it is a you have to use you must use the in Kelvin scale ok. It is not the difference it is a difference in the fourth order difference; so Kelvin scale. So, our body temperature what we assumed it was 34 degree Celsius.

So, in Kelvin it will become 307 degree Kelvin. And cold it was 23 degree Celsius. So, it will become 296. So, degree and if you apply if you use all this parameters we will get the value of 133 watt. So, what does it show? It shows that the major heat transmission from our body it is by the radiation.

So, and also we have mentioned that the person is in when he is unclothed he is actually uncomfortably cool feeling, he is having feeling of uncomfortably cool. So, if we want to make him comfortable. So, what we have to which parameter which mechanism we have to target by in a clothing. If we try to target say conduction it will not work. It will not be or perspiration all though this you have to also take care because perspiration and all this what we are taking it is a heat we are talking, but there are other impacts also.

But if we normally we try forget the radiative heat control, but this model shows in our clothing if we control the radiative heat moving out from our body, by whatever means we can control the we can impart comfort on it. Radiative heat you can control by in ends per inch, picks per inch or fabric structure or different layers you can control that, we will discuss, but radiative heat which shows it is an extremely important.

Now, another implication you can see; we can just do little bit calculation. If you calculate suppose in place of 23 degree Celsius you will simply change 1 degree. So, it is become 22 degree Celsius; so it if it is 22 degree Celsius. So, it will be 295-degree Kelvin. So, you will see there will be a significant impact on the radiative heat transmission, but the impact on this will not be that much independent.

So, huge change in radiative heat transmission; so radiative heat is extremely important in and we have to control this we have to block this radiative heat and cooling by convection.

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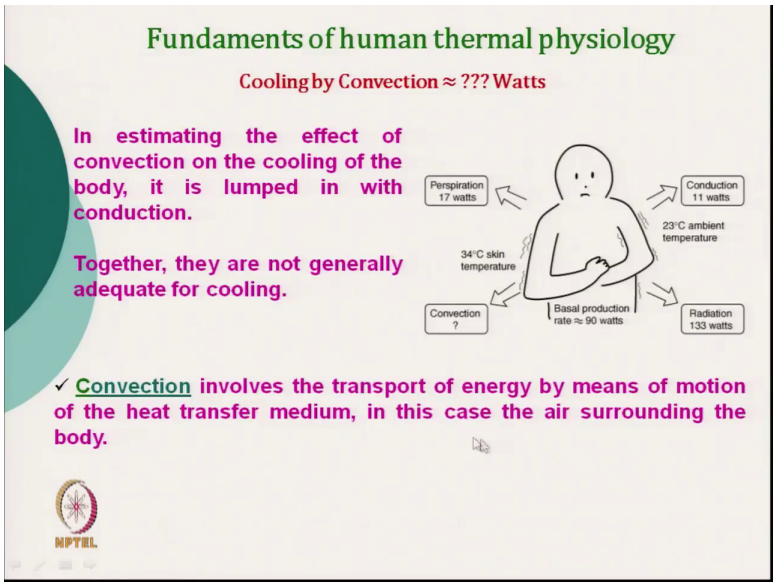

So, it is a basically convection, we cannot quantify. Now it is linked with the air flow linked with the ventilation linked with the bellow effect, what is bellow effect loose clothing when it moves it tries to keep a bellow effect it pumps air from inside to outside and it takes air from outside to inside. So, these are linked. So, ultimately it gives cooling effect.

So, convection involves the transport of energy by means of motion of the heat transfer medium. So, it has to move heat transfer medium has to move. And in this case the surrounding air when it is unclothed person it is a surrounding air, when it is a clothed person it is a heat in micro climate.

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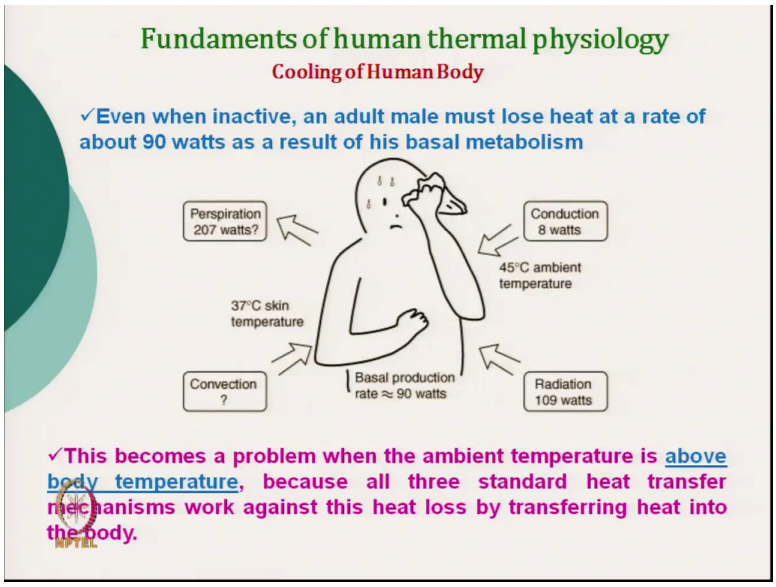

Now, next parameter is that next situation is a person who is in the warm condition. Earlier we have discussed a condition which is cooler condition. And suppose the condition is which is the environmental temperature is above the body temperature like in summer, or a person in front of any furnace or fire fighter. So, in this type of situation what is happening; so here simple model. Here it is assumed that say environmental temperature is the say 45 degree Celsius.

So, 45-degree Celsius temperature what is going to happen what is happening here just a; so all the mechanism works in against that it is opposite direction, like radiative heat outside temperature is more than our body temperature; that means, radiative heat in earlier case what we have observed the radiative heat is going out from our body, but here we will start receiving also convection.

So, and at the same time our body is generating a metabolic heat. Suppose in this room the temperature is suddenly increased to 45 degree Celsius. And unclothed person will feel like that he started receiving the heat from all the sources. So, now how will you balance the heat how the body will be balanced?

So, even when he is inactive. So, he will generate at 90-watt heat. So, here this model says he is generating 90-watt heat. That is basal heat through radiation he is receiving heat of 109 watt. Earlier case he was releasing heat here he is release receiving heat through conduction he is receiving 8 watt. So, this calculation we will do again; that

means, his total heat in the body is it is 90 plus 109 plus 8 is a total amount of heat is added.

Now, his body will start getting warm up. And as you keep on receiving heat the body temperature will keep on increasing. And then it will become fatal sometime. So, our body can we can survive 37 degree plus minus maximum 3 to 4 degree Celsius.

So, if we keep on receiving heat what will happen our body temperature will increase. So, there is the physiological parameters happen; that means, the due to body physiology our sweating will start. So, at that temperature at 45 degree Celsius temperature when we start receiving the heat from different sources our body will actually temperature will increase to keep our body cool, our body another physiology activity will start body will start sweating. And sweat will come out from the body and this sweat if it is simply drips out then we will not get cold. We will not actually our body will not cool down this sweat has to get evaporated from the body.

So, for unclothed person it is, if the sweat evaporates then it will be then you will actually maintain the body heat. Suppose at 45-degree Celsius temperature very high temperature or 50-degree Celsius temperature, it is highly humid since it is a very humid 100 percent humidity relativity, what will happen? The sweat will not get evaporated. It will simply drip then it is a danger it is basically it is a dangerous condition.

So, sweat has to be evaporated then what we have to have some other you have to you can actually switch on the fan. So, that body air movement is there. So, somehow that sweat has to get evaporated if sweat start dripping then you will keep on losing the water and at the same time temperature will not be reduced will not be under control.

So, to have things; so proper perspiration and evaporation of perspiration should be there. And here we can see the evaporative perspiration is actually is losing 207 watt; that means, almost it is balanced. So, we can imagine for a clothed person how to control all this things.

So, first we will discuss. So, first thing by clothing what we will have to do? We will have to actually block the radiative heat. If we can block the radiative heat and it because you will actually we can reduce the intake of heat from the body. So, we will do this

things. So, at present we are discussing a person unclothed person. So, he is receiving the heat from the body.

So, this becomes a problem, when the ambient temperature is above the body temperature. So, ambient temperature when it is a lower than the body temperature he is uncomfortably cool, but we can simply wear a clothing simple layer of clothing. You use single layer you use double layer you keep on increasing the thickness. And you can control the body heat to be released from the body to the environment, but it is not that simple to block the heat from coming out.

So, it is above. So, this is become a problem; when the environmental temperature is above the body temperature, because all this standard heat transmission mechanism work against the loss of heat. So, we have to finally, release the heat. So, all these standard means conduction convection and radiation these are actually working against the normal body heat. So, the parameter which is the evaporating cooling is at this point it is a significant one. So, evaporative cooling as we have seen it is a 207 watts.

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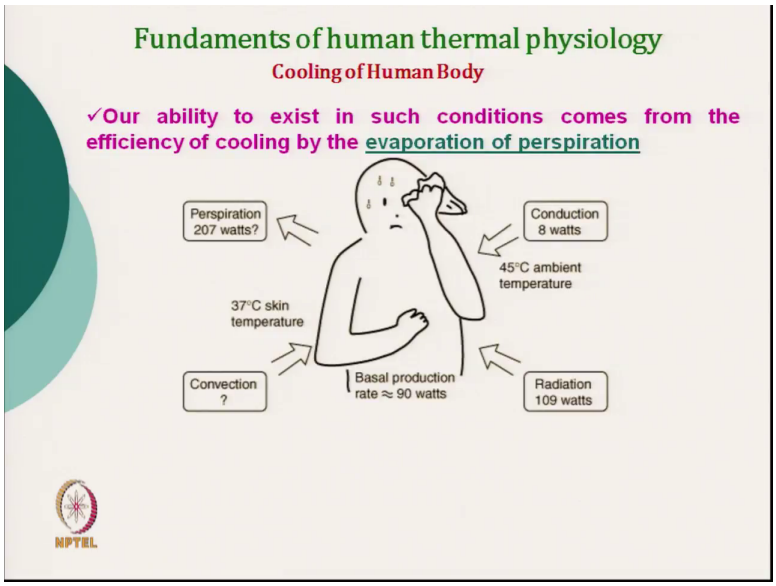

So, first we will discuss that the different types of phenomena different types of mechanism. Here we will discuss our ability to exist in such condition comes from the efficiency of cooling by the evaporative cooling of person. So, we can actually survive in that condition if evaporative cooling is so. And, in our next lecture we will discuss these phenomena in detail, ok.

Thank you.