Science of Clothing Comfort
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Lecture – 23
Clothing Comfort Related to Thermal Transmission (contd..)

So hello everyone, we will continue with the thermal comfort, this in this segment we are now discussing the basic factors which controls the thermal comfort sensation.

(Refer Slide Time: 00:33)

And the basic and there are a 6 factors we have mentioned and we have discussed the air temperature, radiant temperature, air velocity. And, now we are discussing the environmental one of the environmental related factors which is humidity related factors. So, which is extremely important the factor that typically and this humidity related factor we cannot consider in isolation. It has to be in combination with other factors like air temperature or radiant temperature.

So, typically humidity between 40 to 70 percent relative humidity does not have much impact on thermal comfort. And if it is more than that it is in a and 70 percent and a particularly in warm condition. So, a hot and humid condition then main problem would be that our body will not be able to evaporate the or so, then whatever sweat it generates. So, it will not be able to evaporate.

So, then the evaporative cooling will not be there. So, high humidity environment have a lot of vapor in the air, which prevents the evaporation of sweat from the skin. So, at a high and a hot humidity; so, it is extremely uncomfortable.

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But if there is a airflow at that humility. So, we may feel comfortable. So, it is related to the air flow also. The evaporation of sweat is the main method of heat loss of a human in a hot environment as we have seen. So, that is that evaporation is actually assisted by the airflow. And in a any personal protective clothing like firefighter clothing, if the wearer is not able to the release of that evaporation of the sweat if it is there it is of vapor permeability is poor. So, in that case she will not be able to be comfortable ok.

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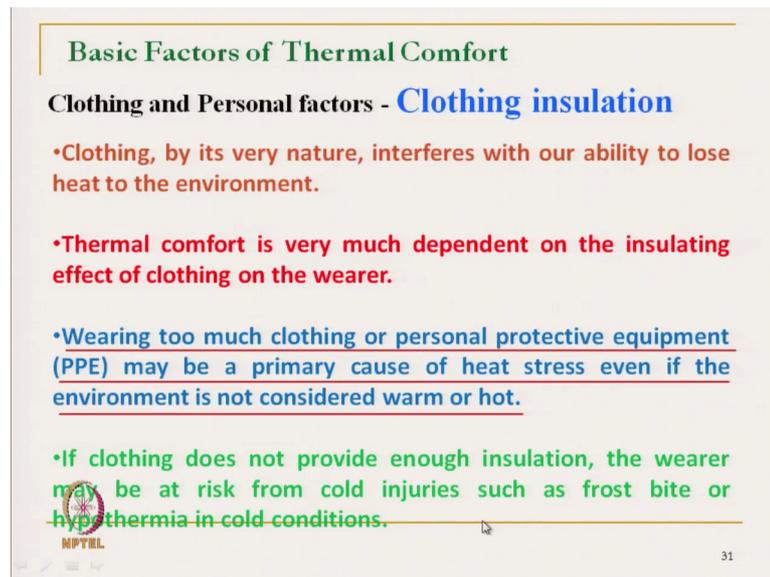
Now the next factor is the clothing related factor, the clothing insulation which is a very important for to keep body thermally comfort. So, by clothing by it is very nature interferes with our ability to lose the heat to the environment. So, if we want to restrict the heat loss or we can increase the insulation of the clothing. So, thermal comfort is very much dependent on the insulation characteristics of clothing. Wearing too much clothing is sometime creates problem because, it will give unnecessary the insulation which may cause the heat stress.

So, it is a primary cause of heat stress in that personal protective equipment. So, if the clothing does not provide enough insulation. So, on the other hand if we does not provide enough insulation so; that means, it our we our body will lose the heat unnecessary at a higher rate. So, we may land up with either a first bite or hypothermia ok, in extreme cold condition. So, clothing insulation and control of this clothing insulation is a very important; so, that we will discuss with a different studies how to control this clothing insulation.

(Refer Slide Time: 04:29)

So, clothing is both potential cause of the thermal discomfort as well as it controls the it actually a it enhance the comfort, as it adapt to the climate in which we live in or it is we play. So, we may add layers of clothing. So, depending on the type of environment so, we can adapt gradually. If we need the to restrict our body heat to go out at a higher rate, we may a keep on adding the layer. And if we feel it is a it the it is be giving a higher insulation we may remove. So, that way by changing the type of clothing we can control the our heat balance.

So, it is important to identify how the clothing may contribute to thermal comfort or discomfort. So, for a particular condition so, for a particular air temperature in front of a radiant heat temperature or in a particular air humidity or air velocity. So, we have to select or depending on our physiological condition, we have to select the particular clothing to keep our self comfortable. It may be insulating or higher insulating, higher insulation or lower insulation.

So, accordingly we have to select our clothing. So, it is very important and last one is that metabolic heat. So, different it depends on the it is a varies from person to person. So, depending and different level of activities so, at different level of activities and at for different person. So, if we know the level of metabolic heat then we can select our clothing.

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So, the more physical work we do so, higher will be the metallic heat will produce. And more heat we produce higher rate of heat loss we should actually we have to have otherwise our body will get over heated.

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So, and the impact of metabolic rate on thermal comfort it is very critical. Person's physical characteristic should always be kept into mind. So, depending it there are various factors like his weight age, fitness, height. So, the all these things actually related with the it is controls the type of metabolic heat.

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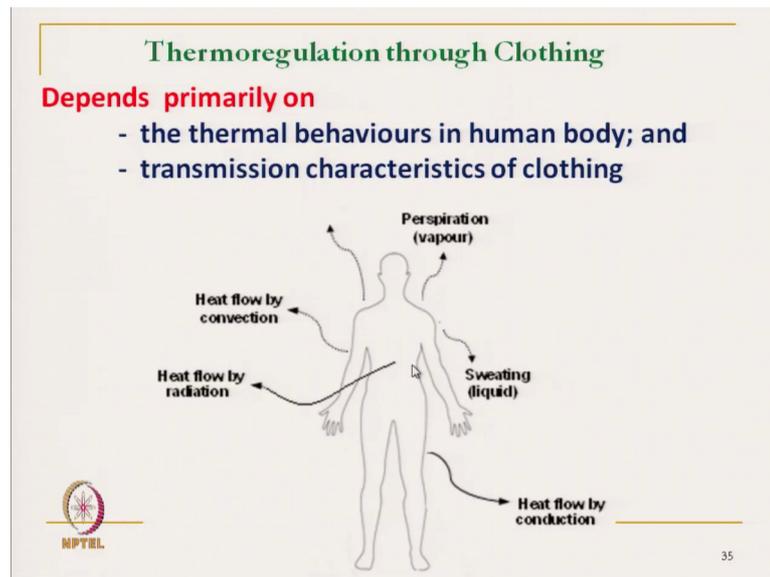
So, and the thermal behavior of human body and transmission characteristics of the, it is shown by this diagram. So, heat actually heat flows in and out by conduction, convection and radiation or by sweat evaporation.

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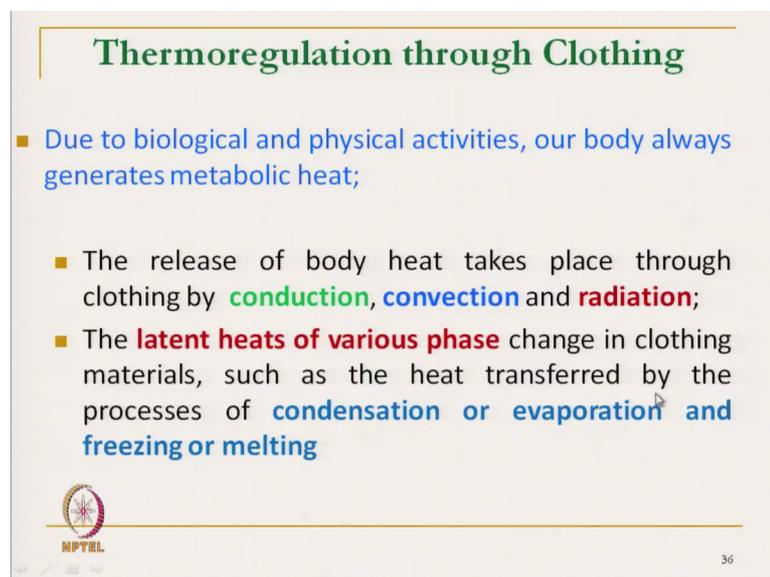
So, basically it is a mainly the heat is in a dry heat, it is released through clothing by conduction, convection or radiation. This is that dry heat and in case of say heat also we release in terms of the moisture in a liquid or in vapor form. So, in the form of a latent heat at a various phase it actually we release heat transferred by this process of

condensation or evaporation or by freezing or melting. So, the latent heat at different form it gets transferred.
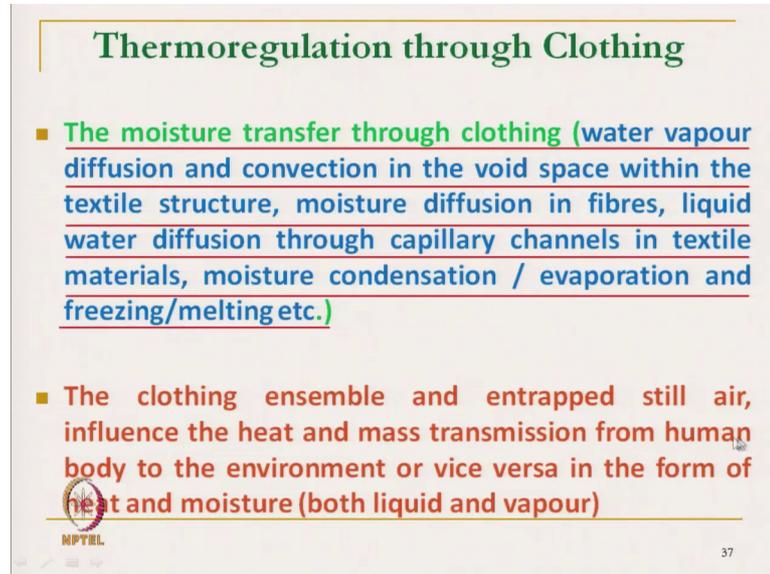
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So, moisture transmission through clothing we will discuss in the next segment in detail by water vapor diffusion convection in void space within the textile structure, moisture diffusion in fiber surface, liquid water diffusion through capillary which we normally known, it is known as the weaking characteristics capillary channel, moisture condensation. Some time moisture gets condensed, if the bath is longer and it is an extreme cold condition it gets condensed, or evaporates and freezing or melting may takes place.

So, these are the moisture related phenomena and clothing assembly and this entrapped still air influence the heat and mass transmission of the human. So, and it heat transmission actually majorly depend on the how the clothing entrap the still air. So, that we will see that by controlling the amount of entrapped heat we may control the heat and mass transmission.

So, if we can entrap a more and more air inside the clothing ensemble. So, we can increase the insulation, without increasing the mass, without increasing the amount of quantity of a material. Also we can control the moisture transmission.

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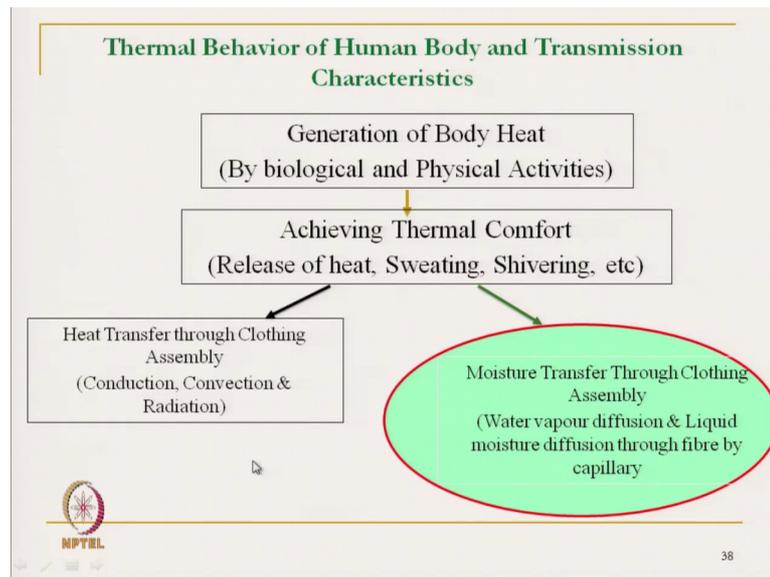
So, if you see the generation of body heat that is biological and physical activities in terms of metabolic heat. So, it is a thermal comfort is achieved by release of heat, by sweating, by various other physiological activities. We can achieve the thermal comfort and it is by it is basically through we have to do all these things through clothing. And by the means of the heat transmission through clothing, one is the dry heat transmission through the clothing by conduction, convection and radiation.

Another way is that through moisture transmission that is a water vapor diffusion, liquid moisture diffusion through fiber or various through various mechanisms. This part we will discuss when we will discuss the moisture related comfort aspects. Now, we are going to discuss in detail the try heat transmission.

(Refer Slide Time: 11:17)

Typical Range of rate of Metabolic Heat Generation for Various Activities

Activities	Metabolic heat generation (W/m²)
Indoor activities	
Reading	50-60
Writing	55-65
Working on computer	60-70
Filing, seated	65-75
Filing, standing	75-85
Lifting/packing	120-130
Miscellaneous work	
Cooking	90-110
Dancing	140-200
Playing tennis	200-300
Playing basketball	300-450

[1 kilocalorie per hour (kcal/h) = 1.163 watts (W)]

So, as we have mentioned that with the increasing activity human activity or the metabolic heat generation increases. So, as we increase the activity. So, it generates more and more heat.

(Refer Slide Time: 11:38)

Typical Range of rate of Metabolic Heat Generation for Various Activities

Activities	Metabolic heat generation (W/m²)
Resting	
Sleeping	35-45
Seated quietly	**55-65**
Standing	65-75
Normal walking on the level	
3 km/h	110-120
5 km/h	150-160
7 km/h	210-220

[1 kilocalorie per hour (kcal/h) = 1.163 watts (W)]

So, you can see that at when we sit as we sleep it generates around 35 to 45 watt per square meter. That is the type of heat we generate, but when we some play an high active game. So, we may generate a approximately 10 times of that heat we generate.

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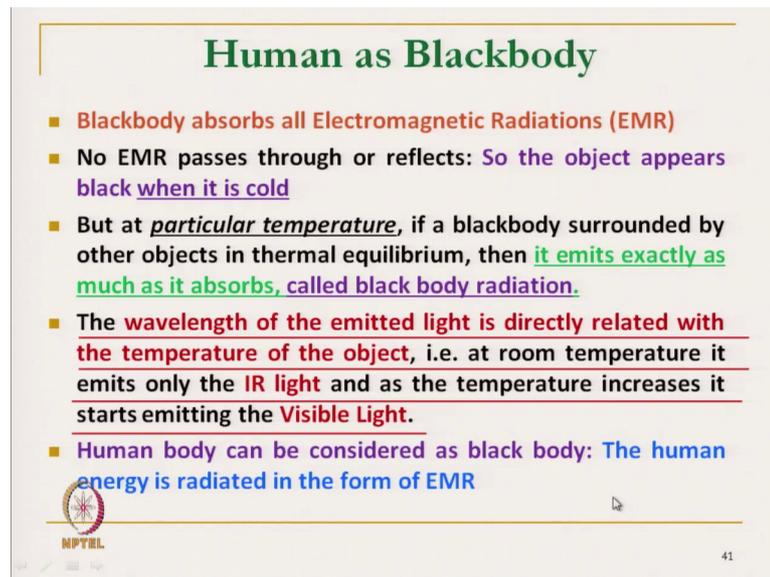
Now, let us try to see our human body how. So, if we see our human body it as we have discussed that it is it receives a heat. It does not reflect back. So, human body absorbs all the electromagnetic radiation. So, that is which is the it is the nature of the blackbody.

So, human body we can consider as equivalent to black body. So, no EMR electromagnetic radiation pass through or reflect ok. So, the object appears black when it is cold. That is why it is called black body, but in as the temperature increases. So, the, but at particular temperature, if the black body surrounded by other objects in thermal equilibrium condition, then it emits exactly as much as it absorbs called it is called blackbody radiation.

So, it will start radiating the heat ok, if it is surrounded by the different objects. The wavelength of the emitted light is directly proportional to the temperature of the object. So, that is at room temperature it emits only the infrared light ok, which is not visible, but as the temperature increases it starts emitting the visible light. So, for any if we increase the temperature. So, it will start emitting the visible light so, that the human body can be considered at as a black body.

The human energy is radiated in the form of electromagnetic radiation. So, we whatever heat we generate we actually release the heat in the form of electromagnetic radiation.

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Human as Blackbody .... cont

- The net power radiated is the **difference between the power emitted and power absorbed**

$$P_{net\text{-}rad} = P_{emit} - P_{abs}$$

- The total energy radiated by an adult male in one day is about 2000 kcal (food calories) [1 kilocalorie per hour (kcal/h) = 1.163 watts (W)]

[J/s = W and 1 Kcal = 4184 J]

- Primary metabolic rate (sleeping) for a 40-year-old male is about 35 kcal/(m².h), which is equivalent to 1700 kcal per day assuming the 2 m² area. [35 × 24 × 2 ≈ 1700]

- However, the mean metabolic rate of an adult without any activity is about 50–70% greater than their basal rate

42

So, the net power radiation is it is a whatever the power we radiate whatever heat we radiate it is basically it is a difference between the power emitted and power absorbed. So, we keep on absorbing the heat and we also release the heat.

So, net emission is net emitted heat is that is a difference between that and the total heat, now try to see the simple calculation. The total heat energy radiated by an adult male in one day is about 200 kilo calorie ok. So, that the whatever a food calorie we told the total throughout the day we emit 2000 calorie 2 kilo 2000 kilo calorie heat we emit. So, that much heat we emit.

Now, let us see the calculation. As we have seen that primary metabolic rate say when we sleep, typical value is at 40-year-old male healthy male is about 35 kilo calorie per square meter per hour. That is the rate which we produce which is equivalent to 1700 kilo calorie per day. So, if we is how do we get this 1700? Because, 35 kilo calorie per square meter per hour or if we assumed our body surface area 2 square meter.

So, 35 multiplied by 24 hour in a day multiplied by 2. So, we get a around 1700 kilo calorie per day. So, a person actually releases that heat 1700 kilo calorie it is that it is a heat generates that much heat ok. So, this is the heat he generates when he is sleeping 1700 kilo calorie heat. Now, if we see when is little bit active we are we normally do not sleep 24 hours we if we active. So, average activity if we see it is typically a 1 point it is a 70 percent more than this, this 35.

So, its average activity it is 50 to 70 percent more than that the when he is sleeping so; that means, it is a more 50 to 70 percent greater than the basal rate. So, ultimately what are we getting? So, it is still if we see 70 percent. So, 1700 he is generating for 24 hours multiplied by 1.7 so, multiplied by 1.7 ok.

(Refer Slide Time: 17:37)

So, the thermal loss this mechanism of the body it is a conduction which is very low we have already seen earlier, through conduction it is a low because most of the textile materials are insulating in nature. Even a air is insulating, convection is very high when it is a very significant when it is a air is blowing it is a forced convection radiation is very high.

Sometime if in case of forced convection when air velocity is very high; so, it may actually suppress the radiation also otherwise, radiation is a generally very high and then evaporation. So, in case of if the dry condition, dry air condition. So, humility is low. So, evaporation will be high. So, we are discussing the radiative heat. So, radiative heat loss the heat lost by radiation is a approximately two third of the total heat loss by other total method total mechanism.

So, conduction, convection, radiation and evaporation among all these the, if we take all this together two third of this is by the radiation as radiation is normally high. So; that means, if we see 1700 is the heat he is radiating throughout the day when he is sleeping

multiplied by 1.7 because he is not sleepy he is active; so, 70 percent higher than that 1.7 and multiplied by two third.

So, it is coming out to be 2000. So, 2000 that this value we have discussed earlier. So, 2000 kilo calorie he is generating heat person is actually it is radiating, if the radiative heat is typically 2000 ok. So, ambient air motion causing forced convection as we have discussed sometimes actually reduces the relative importance of the radiative heat loss.

So, in that case if it is air is moving then this factor 1.7 will not be there, it may be 1.5 or may be 1.4. So, in that way; so, the radiative heat loss will be will lower than the other heat loss. So, in that total heat loss will remains same, but this factor two third and 1.7 may get changed, but in normal condition so, it is typically 2000 kilo calorie.

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So, another thing is that our as we have discuss it is not a steady state. Our body cannot be it is normally it is not in steady state condition and heat flow condition is always in dynamic. So, basically a throughout the year season changes; so, a temperature gets changed, in summer winter even it is a humidity condition changes. And, in addition to this the atmospheric condition like temperature, vapor pressure, air velocities always changes.

So, it is, but if we feel that a particular cloth will keep our self comfortable throughout the day throughout the year it is not possible. So, due to all these variables so, internal

body condition also changes. So, our metabolic rate or activity level also changes. So, accordingly or if you want to keep our self comfortable thermally comfortable we have to actually use different types of clothing. So, our total thermal behavior always changes depending on the quantity of food consumption also nature of activities. So, these are the factors it is going to.
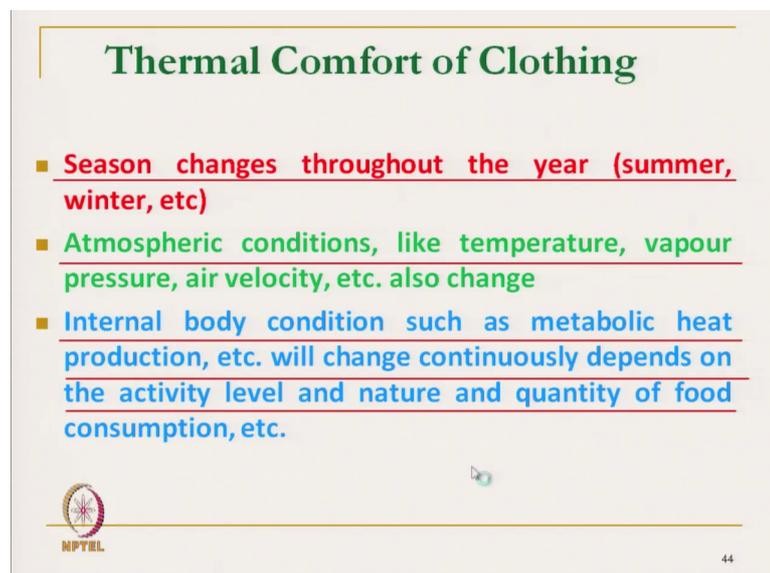
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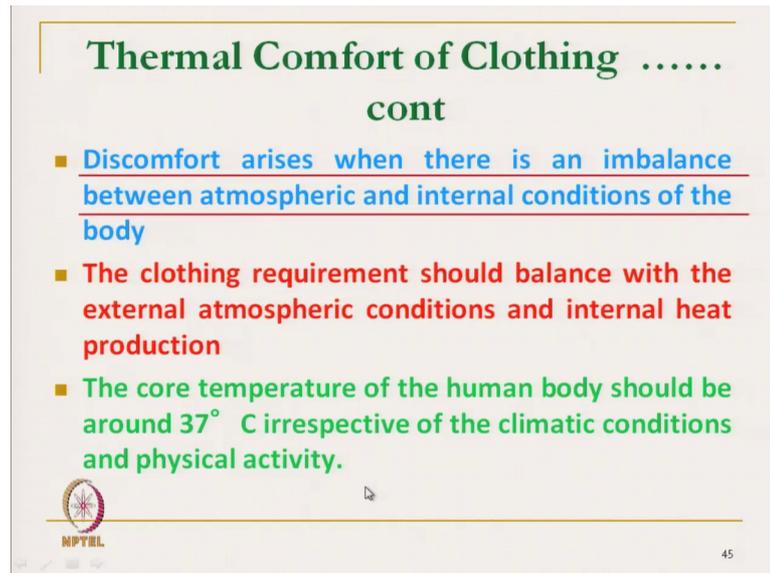
So, discomfort arises when there is an imbalance. So, this is the, these are the conditions in a summer winter or activity level or type of air velocity, type of vapor pressure.

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So, all this activity, all these factors actually controls the thermal comfort nature, but we feel discomfort when there is an imbalance between the atmosphere and internal condition. There has to be proper balancing of heat balancing otherwise we will feel uncomfortable. So, the clothing requirement should be balanced with the external atmospheric condition and internal heat production. So, that these things always changes. So, our external environmental condition always changes or body physiological condition, body heat production is called it always changes.

But our clothing has to be such that it make keeps the balance ok so, that we feel comfortable. So, that means, our body core temperature should be around 37 degree Celsius irrespective of anything, any climatic condition and any physical, physiological activities.

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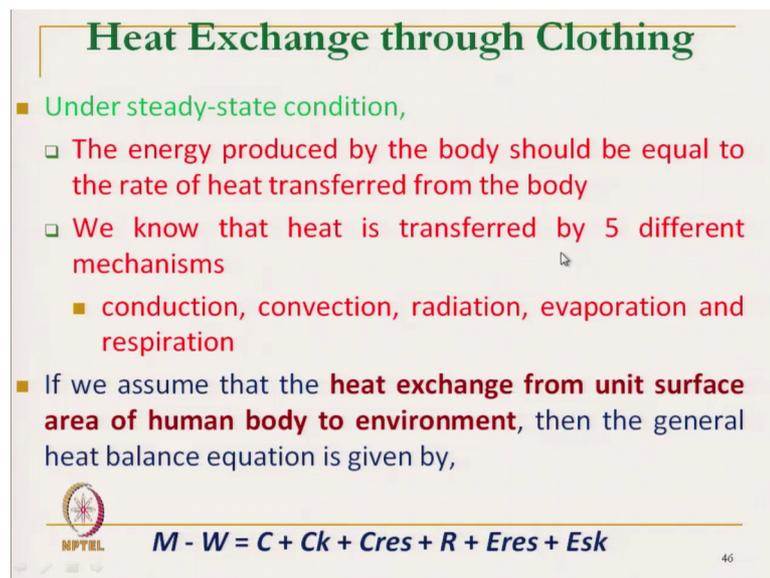
So, under a steady state condition although we hardly reach any steady state condition, the energy produced by the body should be equal to the rate of heat transferred from the body.

So, we know that it is a typically it is a 5 mechanisms conduction, convection, radiation, evaporation and respiration. So, if we assume that the heat exchange from the unit surface area of body to the environment then the general heat balance equation is this. This is the general heat balance equation per unit area of the body. So, this takes care of all these principles of all these mechanisms of heat transfer.

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So, what are this? So, M is the metabolic rate which actually our body produce and W is the external work which is lost, the metabolic heat is lost by some external physical work also. So, that M minus W which is the net heat inside our body which has to come out from the body by the heat lost, by convection, by a heat loss by conduction, which is normally it is a very low. Convection, convective heat loss is it depends on the air velocity. Heat loss due to respiration, sensible respiration it is a switch may not be directly related to the clothing. Heat loss by radiation maybe through clothing or maybe a open area, E res is the evaporative heat loss due to the respiration and heat loss by evaporation from the skin.

So, this is from the skin evaporative heat loss by respiration, these are not directly related to this clothing. And, the heat loss by conduction is that the rate of heat loss by conduction is influenced by the nature of clothing. So, this is the conduction which we can control by if we can control the clothing type of clothing.

(Refer Slide Time: 25:41)

So, the let us discuss one by one the this equation for heat loss due to convection is a C is the heat loss due to convection that we have seen earlier it is a convection, which is equal to, it is a watt per square meter the. In here all these are converted into watt per square meter which is it is a product of clothing factor area factor f cl is the clothing area factor coefficient of convective heat transfer h c and T cl clothing surface area temperature of clothing surface and T a is the ambient air temperature.

So, as from this equation we know that as if we increase the clothing area factor and if the convective heat transfer is high and if the temperature difference is high, then we will have higher convective heat transmission. So, what is clothing area factor? It is a basically it is a ratio, clothing area factor is the ratio the area which is actually covered by our cloth by the total area of a total area of the body. So, it is a Acl is the it is area by a cloth body and AD it is a total area of nude body total area. Similarly, for manikin also for manikin test it is a Acl by A, A is the total area of the manikin. So, that is so; that means, higher is the value this is fcl is that that air clothing area factor.

(Refer Slide Time: 27:35)

So, the convective heat transfer coefficient h it depends on the air velocity ok. So, it is basically directly related to the air velocity, if we increase the velocity of air. So, convective heat transfer coefficient will change. So, it is a basically it is a function of air velocity and also it depends upon the position of the person and orientation to the air.

So, if the if the orientation towards the towards air flow it changes, that h c value that is convective heat transfer coefficient value changes. So, if the air velocity is air flow is some in a particle direction ok. If the person position changes so, that h c value will get changed. So, h c is depending on the on the mainly on the air velocity and also to some extent on the position and relative position of the person.

So, there are studies cannot out. So, h c value has been plotted against the velocity of air. So, it is this is an empirical equation. So, which has been which is this is the 12.1 multiplied by velocity to the power 0.5. So, this is the empirical growth from where we can get some idea about the this the value of this h c this is the coefficient.

Convective Heat Transfer … cont

The Clothing Area Factor

- The clothing area factor (f_{cl}) can be evaluated by the following empirical equation is expressed as follows,

$$f_{cl} = 1.05 + 0.1\, l_{cl}$$

where l_{cl} is the thermal insulation of clothing (clo)

1clo **unit is defined as** *0.18 m²·°C.h/kcal* **(or** *0.18/1.163≈0.155 m²·°C/W***)**

[1 kilocalorie per hour (kcal/h) = 1.163 watts (W)]
50

And clothing area factor fcl that it is can be evaluated by following empirical equation. So, that we know the clothing area factor is the ratio, but there are there is a another empirical formula which is related with the clo of the that is insulation of the clothing.

So, this is the clothing area factor f cl it is you although it is a unit less, but it is actually empirically this is we can get this value ok. If we know the clo of the it is directly related with the clo of the clothing because, it is a higher area covered will means higher clothing area factor that will indirectly give the value of the clo ok.

Radiative Heat Transfer (R)

$$M - W = C + Ck + Cres + R + Eres + Esk$$

- Depends on the **mean temperature of surrounding environment**, temperature of clothing surface and **characteristics of clothing and environment**

- The equation for radiative heat transfer from human body to environment is given by,

$$R = \sigma\ \varepsilon_{cl}\, f_{cl} \cdot F_{vf}\,[(T_{cl} + 273.15)^4 - (T_r + 273.15)^4]$$

51

Now, radiative heat loss as we know that it is a it depends on the mean temperature of the surrounding environment and temperature of the clothing surface and characteristics of clothing and environment. So, this is the basically it is a basically the temperature difference. So, this radiative heat loss and the equation for radiative heat loss as we have also seen earlier; so, it is a basically this is the equation radiative heat loss R is actually a it is a function of the 4th order of the temperature.

(Refer Slide Time: 30:29)

So, if we see where this sigma is the Stefan Boltzmann's constant ok. And what is the Stefan Boltzmann law? It is a basically total energy that radiates per unit surface area of a black body in unit time. It is proportional to the 4th power of the thermodynamic temperature. This is the it is a actually it changes with the 4th power of the thermodynamic.

And epsilon cl is the emissivity of the clothing. So, if we can control the emissivity of the clothing, we can control the R value and T f is the so, T r is the radian temperature that is if that the radiant temperature here it is a less than it is that is the temperature of the surrounding environment, it is here. In this case if it is a less than the body the cooling surface temperature; that means, we will release the heat, and F vf means it is a view factor, view factor between body and the surrounding ok. It is about 75 percent it is a view factor that is a affective area of the body for radiation. So, that is a view factor.
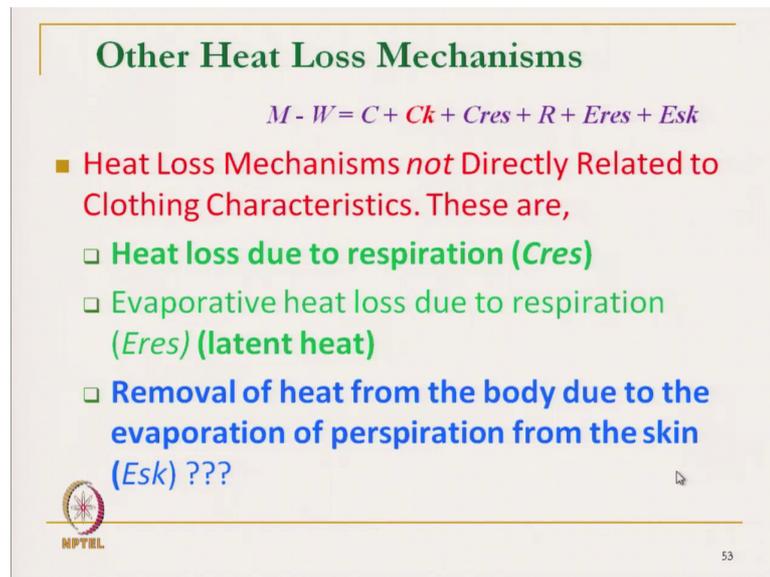
Other Heat Loss Mechanisms

$$M - W = C + Ck + Cres + R + Eres + Esk$$

- Heat Loss Mechanisms *not* Directly Related to Clothing Characteristics. These are,
  - Heat loss due to respiration (*Cres*)
  - Evaporative heat loss due to respiration (*Eres*) **(latent heat)**
  - Removal of heat from the body due to the evaporation of perspiration from the skin (*Esk*) ???

53

And heat loss mechanism which are not directly related with the clothing is that this is the rest other mechanism that is there is a heat lost due to respiration. We will not consider here, evaporative heat loss due to respiration latent heat and removal of heat from the body by a due to the evaporation of perspiration from the skin. That is the, that is a which is actually this skin means which is not covered by the clothing. If it is covered; that means, our clothing will come into picture.
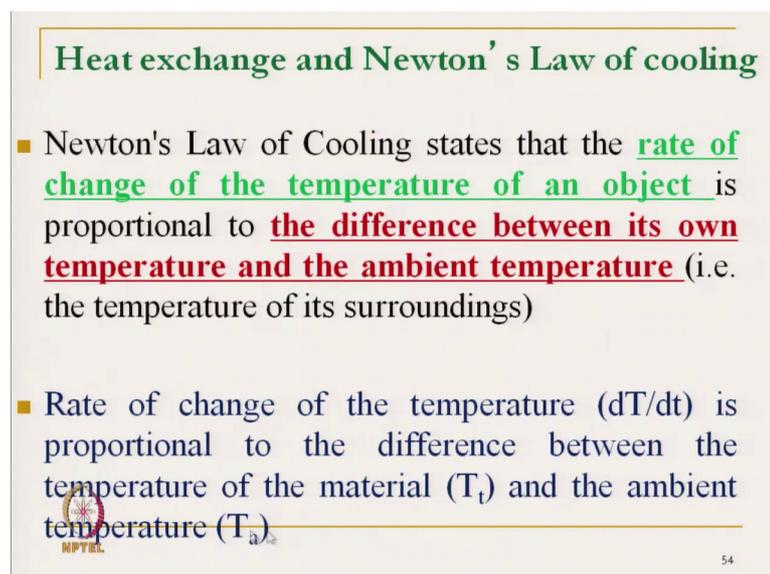
Heat exchange and Newton's Law of cooling

- Newton's Law of Cooling states that the <u>rate of change of the temperature of an object</u> is proportional to **the difference between its own temperature and the ambient temperature** (i.e. the temperature of its surroundings)

- Rate of change of the temperature (dT/dt) is proportional to the difference between the temperature of the material (T_t) and the ambient temperature (T_a)

54

Now, we will discuss the Newton's law of cooling and how this law helps us to derive the equation for thermal resistance or thermal transmittance. So, what is Newton law of a cooling? It states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and a main temperature. So, if the difference that that is high that is the heat flux heat the temperature difference is high; that means, the rate of change of temperature will be high.

So, it is a proportional. So, rate of change of temperature is a dt the d capital T the temperature by dt the time. So, is proportional to the difference between the temperature between the material and the ambient temperature t a ok.

(Refer Slide Time: 33:51)

So, dT by dt is proportional to the T of the material and T of the ambient temperature ok. And where T t is the temperature of any material at time t and T 0 we will see it is a initial temperature because, air temperature it is keeps on changing the temperature rate of change of temperature the T a is the ambient temperature ok.

So, at any time at initially it was T 0. So, at certain after certain time it is a rate of change of due to a temperature change it has become T t. So, this rate is proportional to the temperature difference. So, initially if we to say it is a say at a lower temperature. So, it is a so, that time the temperature difference was high.

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So, the rate of change of temperature was high. So, clearly if the material is warmer than the ambient temperature. So, T t minus T a is more than 0 then the material cools down.

So, it is a typically it is if it is a warmer, than environment material will cools down which means that the derivative dT dt should be negative so; that means, that is why this negative sign is given here ok. And k is the positive constant which is known as the cooling constant. So, this the proportionality and then it is a k is a constant. So, dT dt equal to minus k T t minus T a this is the general formula where, k is the cooling constant.

(Refer Slide Time: 35:47)

Heat exchange and Newton's Law of cooling

- $y(t) = T_t - T_a$ = Difference between material and ambient temperatures at time t
- $y_0 = T_0 - T_a$ = Initial temperature difference at time t=0
- Now, the derivative of y(t), and use the Newton's law of cooling, we arrive at

$$\frac{dy}{dt} = \frac{d}{dt}(T(t) - T_a) = \frac{dT}{dt} - \frac{dT_a}{dt} = \frac{dT}{dt} = -k(T - T_a) = -ky$$

Now the difference between material and ambient temperature at time t y t is a function of t is equal to T t minus T a and at initial stage y 0 T 0 minus T a while at the time t equal to 0. Now, the derivative of y t if we try to get the derivative using Newton's law of cooling; so, what are we getting, dy dt equal to d dt by T t minus T a. So, ultimately we get the dy dt equal to minus ky; so now, this actually solving this differential equation finally we get this is the value.

(Refer Slide Time: 36:37)

Heat exchange and Newton's Law of cooling

The solution of the differential equation is,

$$y(t) = y_0 e^{-kt}$$

Therefore,

$$T(t) - T_a = (T_o - T_a)e^{-kt}$$

Or,

$$T(t) = T_a + (T_o - T_a)e^{-kt}$$

So, if we solve this if differential equation yt equal to y e to the power minus kt. This is the solution of this a differential equation where and we if we replace yt by T t minus T a and y 0 by T 0 minus T a. So, we get this form and by rearranging this we will get T t equal to T a plus T 0 minus so, this is the generalized form of from the Newton's law of cooling.

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Heat exchange and Newton's Law of cooling

By rearranging the Newton's equation for clothing assembly it becomes,

$$(T - T_{\text{amb}}) = (T_0 - T_{\text{amb}}) e^{-(1/RC)t}$$

where

    T is the temperature of the body at a particular moment,

    T_0 the initial temperature of the body

    T_{amb} the ambient temperature,

    t is the cooling time (s)

So, by rearranging again we get this value. So, T 0 by T m ambient so, T a we have we have used on a. So, T 0 minus T ambient equal to e to the power 1 by RC multiply by t.

(Refer Slide Time: 37:35)

Heat exchange and Newton's Law of cooling

The solution of the differential equation is,

$$y(t) = y_o e^{-kt}$$

Therefore,

$$T(t) - T_a = (T_o - T_a) e^{-kt}$$

Or,

$$T(t) = T_a + (T_o - T_a) e^{-kt}$$

So, here if you see K, K is the cooling constant is has been replaced by 1 by RC where, T is the temperature of the body at a particular moment, T 0 is the initial temperature of the body T ambient temperature, t is the cooling time, this t is a cooling time and this R, R is a thermal resistance.

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Here this C is the thermal capacity of the system. So, K has been actually replaced by 1 by RC. So, where C is the thermal capacity of the system in joule per Kelvin R 1 is the thermal resistance of both the fabric medium and the air medium around that the this R is that both this medium. Now, if we try to segregate and that R becomes R 0 plus R where, R 0 is the thermal resistance of air and R is the thermal resistance of clothing layer. So, and again by rearranging this so, this is the if we know the cooling constant from Newton's law then we can calculate the resistance of the clothing.

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Heat exchange and Newton's Law of cooling

- The thermal resistance of fabric could be calculated by the relation

$$R = \frac{1}{C}\left(\frac{1}{K_1} - \frac{1}{K_0}\right)$$

- where
  - K_0 is the cooling constant of the system without fabric

So, resistance of the clothing we can by rearranging that equation we get in this form. So, where, K 0 is the cooling constant of the system without any fabric. K is the cooling constant with fabric and C is the thermal capacity.

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Heat exchange and Newton's Law of cooling

- Knowing the thermal resistance (R) as well as the fabric sample surface area S (m²) and fabric thickness d (m), the fabric thermal conductivity λ (W/m K) can be calculated as

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

From there now this is a one way of expressing the thermal resistance of the clothing. Now, if we see the if we know the thermal resistance then thermal resistance if we can calculate from there. So, as well as knowing the thermal resistance as well as the fabric sample surface area, if we know the surface area and the thickness d, surface area S then

we can calculate the thermal conductivity. So, thermal conductivity lambda is the unit will be watt per meter Kelvin, can be calculated by 1 by R multiplied by d by S.

(Refer Slide Time: 40:11)

Heat exchange and Newton's Law of cooling

- The thermal characteristics of fabrics are influenced by **ambient temperature**. The **heat transfer coefficient** h **(W/m² K)**, consisting of conduction, convection and radiation mechanisms, is calculated by the relation

$$h = \frac{1}{S\,\Delta T} \times \frac{dQ}{dt}$$

- where
  - dQ/dt (W) is the measure of heat transfer rate from the system through the fabric to the ambient surroundings,
  - S (m²) is the area of the fabric sample
  - ΔT (K) is the difference between the average temperature of the system and the ambient temperature

Therrmal conductivity $\lambda = \frac{1}{R} \times \frac{d}{S}$. (W/m K)

[1 kilocalorie per hour (kcal/h) = 1.163 watts (W)]

So, where R is the thermal resistance, another way of looking at that it is we can measure the heat transfer coefficient h. So, earlier we measure the thermal conductivity. So, this is the thermal conductivity lambda the unit is watt per meter Kelvin ok. And here the heat transfer coefficient is the unit is the h it is expressed in h, which unit is watt per square meter Kelvin.

So, that heat transfer coefficient is another way of expressing the thermal conductivity of the clothing, where dQ dt is the it is it is a measure of heat transfer rate; that means, it is a unit is in a watt, S is the area of the fabric; so, watt per square meter. And the temperature is a difference of temperature the average temperature of the system and the ambient temperature that is the end Kelvin. So, watt per square meter per Kelvin that is the unit of heat transfer coefficient whereas, thermal conductivity the unit is watt per meter per Kelvin. So, that is way two ways of expressing the thermal conductivity.

(Refer Slide Time: 41:39)

And this is that way of another way of expression the Newton's law of cooling is applied to evaluate the thermal properties of the textile material. So, this is the way we can express. Now after knowing all these things so, if we know that the amount of heat and a thermal capacity so, that we can calculate the temperature of the body ok. So, dQ dt into R is the thermal resistance of the body. So, this R we can calculate.

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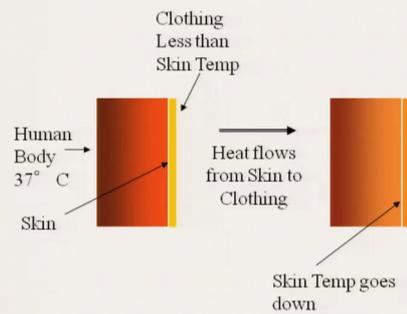
Now, after all these things are steady state heat transmission then next is the transient heat transmission of through clothing. So, what is transient heat transmission? The

human body it is normally it is in temperature of human body is it is 30 degree Celsius, 37 degrees Celsius sorry. And the skin temperature we know it is around say 34 degree mean skin temperature and clothing, if we see clothing temperature is normally it is less than the skin temperature if it is there. Then heat will flow from the skin to the clothing and we will feel coolness. So, this phenomena is called transient heat flow and the detail transient heat flow, behavior we will discuss in the next class.

Till then, thank you.