Refrigeration and Air Conditioning
Prof. M. Ramgopal
Indian Institute of Technology, Kharagpur
Department of Mechanical Engineering
Lecture No. # 36
Inside Design Conditions Thermal Comfort

Welcome back in this lecture I shall discuss selection of inside design conditions based on thermal comfort criteria.

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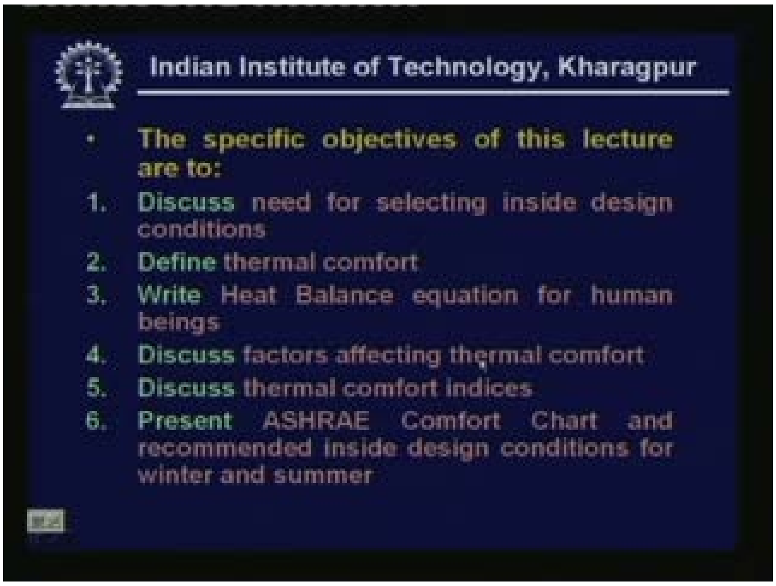

The specific objectives of this particular lecture are to discuss need for selecting inside design conditions, define thermal comfort write heat balance equation for human beings, discuss factors affecting thermal comfort, discuss thermal comfort indices and finally present ASHRAE comfort chart and recommended inside design conditions for winter and summer.

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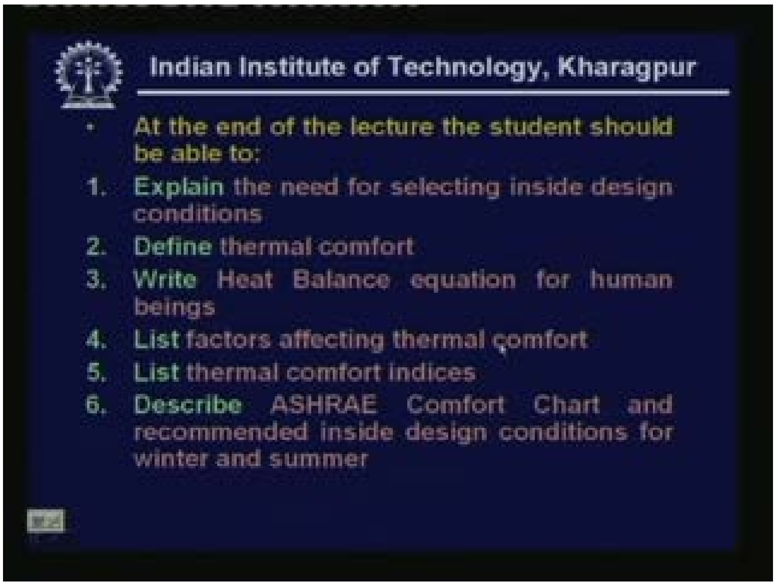

At the end of the lecture you should be able to explain the need for selecting inside design conditions, define thermal comfort write heat balance equation for human beings list factors affecting thermal comfort list thermal comfort indices and describe ASHRAE comfort chart and recommended the inside design conditions for winter and summer.

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Let me give a brief introduction design and analysis of air conditioning system involves a following steps selection of suitable inside outside design. And supply conditions estimation of required capacity of cooling or heating equipment selection of suitable cooling and heating equipment design of air transmission distribution system controls etcetera. And generally the inputs are the building specifications its usage pattern special requirements etcetera. So these are the various steps one has to go through while designing an air conditioning system okay.

So let us begin with a first step that is the selection of design inside and outside conditions. In this particular lecture I shall describe selection of inside design conditions.

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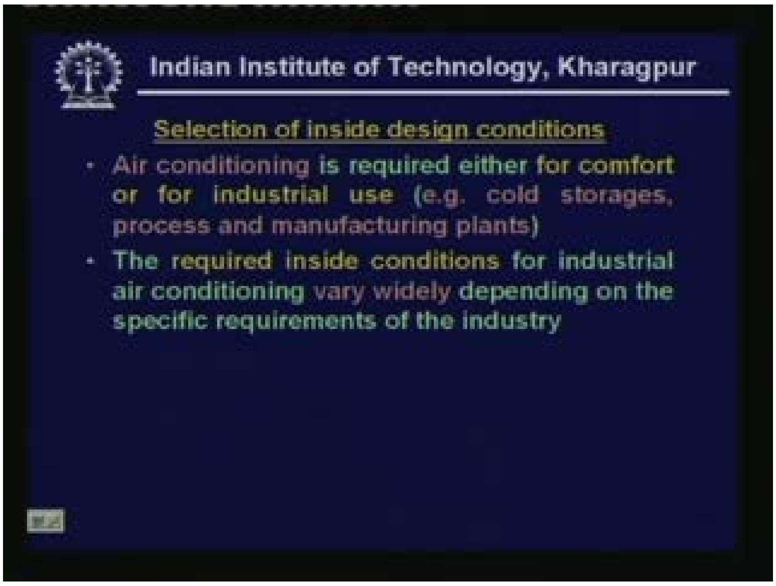

Air conditioning is required, as you know it is required either for comfort that means comfort air conditioning or for industrial use for example industrial use means it could be used in cold storages for preserving food products or it would be used in process and manufacturing plants to provide the right conditions for the processes or the products being manufactured. The required in inside conditions for industrial air conditioning vary widely depending on the specific requirement of the industry. So in fact there are many industries and many processes many products being performed and all. So each product each process requires different inside conditions. So you cannot have a universal criteria or universal value for inside conditions similarly for the cold storages the required conditions inside a cold storage depends upon the type of product being stored how look it is begin stored etcetera okay. So we cannot really generalize. So for these applications that means essentially for industrial air conditioning applications the inside conditions have to be chosen based on the specific require mental okay.

When I say i inside design conditions what do we mean, what I mean is what should be the inside dribble temperature what should be the inside moisture content inside means in the occupied space okay. So what is the dribble temperature in the occupied space what is the moisture content in the occupied space what should be the air velocity in the occupied space right what should be the level of purity required etcetera okay.

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Unlike industrial air conditioning system the required inside conditions for comfort air conditioning systems remain practically same as this is related to the thermal comfort of the human beings in fact the human body for very much alike. So the required conditions for providing thermal comfort to human beings remains same irrespective of the location or the type of the building or usage etcetera okay. So we can have or we can formulate the required inside design conditions for comfort air conditioning systems these are topic of this lecture.

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So first let us define thermal comfort what do we mean by thermal comfort? Thermal comfort is design defined as that condition of mind which expresses satisfaction with the thermal environment the definition is bit wag. Because it is really very difficult to put it in words okay. So basically what it means is it a state of mind when a user or when an occupier occupant if he feels satisfied with the thermal environment then the environment is comfort okay so it depends upon the response of the occupant. So there is lot of find to this okay. We will also see that the thermal comfort requirements vary from person to person okay. So it is not really possible to satisfy all the occupants okay. So this reason we, I will discuss a little later.

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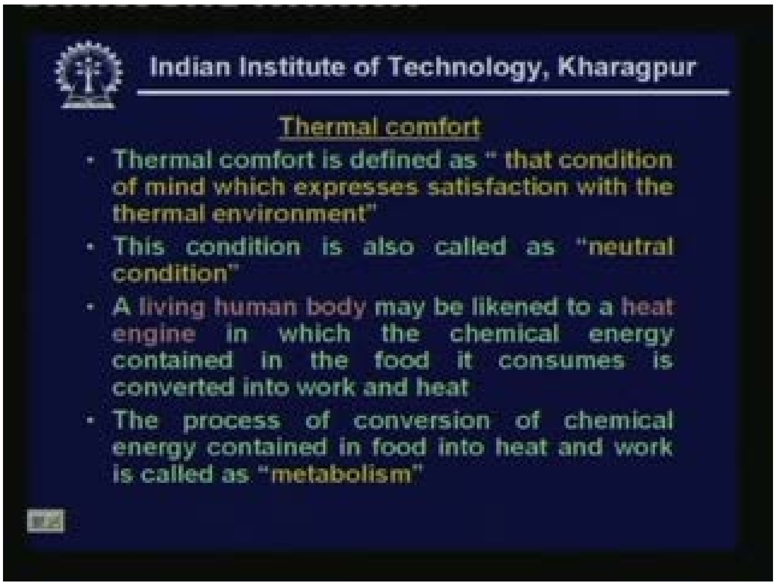

The condition of the thermal comfort is also sometimes called as neutral condition even though strictly speaking they are not exactly same. But as far as we are concerned the thermal comfort or neutral condition mean the same thing a living human body may be likened to a heat engine in which the chemical energy contain in the food it consumes is converted into work and heat okay. So now I will explain what is the basic bases for thermal comfort and all first let us look at the human body okay. The process of conversation of chemical energy contained in food into heat and work is called as metabolism okay. So we know that all living beings including the human beings consume food is required because this food is converted inside the body into heat and work okay.

The work is used for used for doing some useful task and the heat generation the heat is required. Because especially human beings we are warm blooded animals. So okay, our bodies have got to be maintained at some particular temperature okay, so the continues heat generation is required. So the food we consume is utilised for these two purposes so in this respect a human body is like any heat engine okay. If you remember we discussed heat engine. And I mentioned that heat engine is nothing but a device which takes in some chemical energy in the form of a fuel and converts a part of it into work and a part of into heat okay. So human body is also like that.

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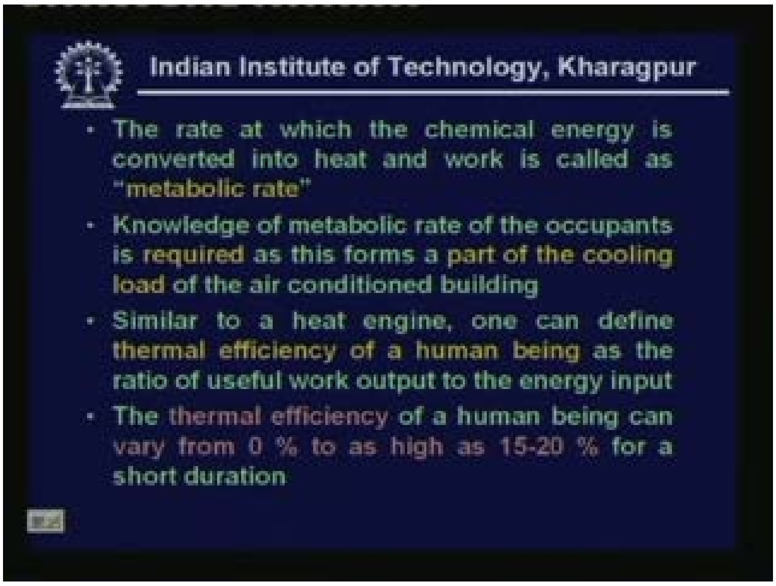

The rate at which the chemical energy is converted into heat and work is called as metabolic rate knowledge of metabolic rate of the occupants is required. As this forms the part of the cooling load of the air conditioning air conditioned building why do we need to know about the metabolic rate or why do we have to bother about the metabolic rate when we are discussing air conditioning systems. Because finally we shall see that what are energy human being is consuming in the form of food is ultimately rejected in the form of heat okay. So once it is rejected in the form of heat it becomes a load it becomes a cooling load on the air conditioned building okay. So we want to estimate what should be the capacity of the cooling system you must know what is the amount of heat rejected by human beings. That means what is the metabolic rate okay. That is the reason why we have to have information on metabolic rates okay.

Similar to a heat engine one can define thermal efficiency of a human being as a ratio of useful work output to the energy input. So we can also define a thermal efficiency and its absorbed that the thermal efficiency of a human being can be can vary from zero percent to as high as fifteen to twenty percent for a short duration. Most of the time for most of the activities common activities we find that the thermal efficiency of a human being is very low okay. It is almost close to zero percent but a human being can work within a efficiency as high as percent for very short duration okay. This is a under prolong prolonged manner you cannot work with that kind of efficiency right. For most of the air conditioning calculation we assume that the thermal efficiency is zero percent okay. That means whatever raise the metabolic rate is finally converted into heat.

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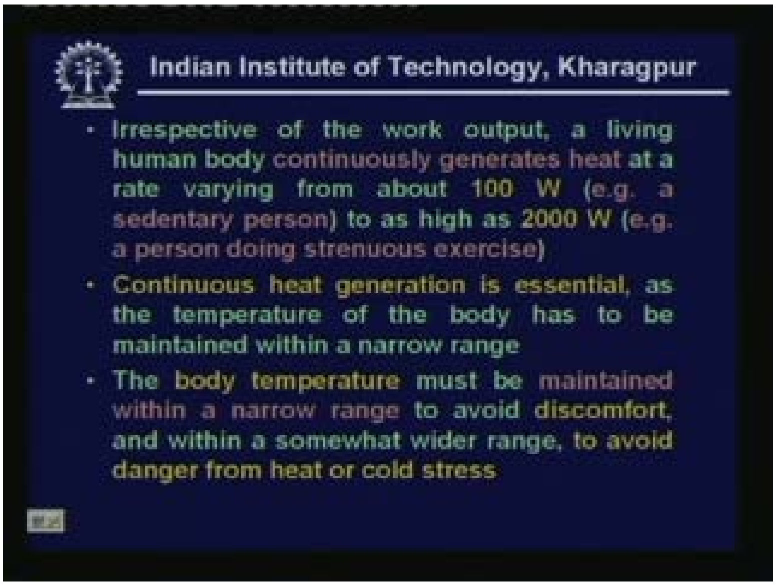

Irrespective of the work output a living human body continuously generates heat at a rate varying from about hundred watts to as high as two thousand watts. So for a sedentary person that means for a person who is sitting quietly the heat rejection rate is about hundred watts. However the heat rejection rate can be as high as two thousand watts when he is doing some strenuous exercises continuous heat generation is essential. As I have already explained since the temperature of the body as to be maintained within an narrow range. The body temperature must be maintained within a narrow range to avoid discomfort and within a somewhat wider range to avoid danger from heat or colder from heat or cold stress it's very important that the human body temperature should be maintained within a certain range okay. If it falls below the particular temperature or if it goes beyond a particular temperature it could be become very dangerous it could become even lethal okay.

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Now study show that at neutral condition the temperature should be the skin temperature should be about thirty-three point seven degree centigrade. And the core temperature should be about thirty-six point eight degree centigrade at other temperatures the body will feel discomfort or it may even become lethal. For example let me show this.

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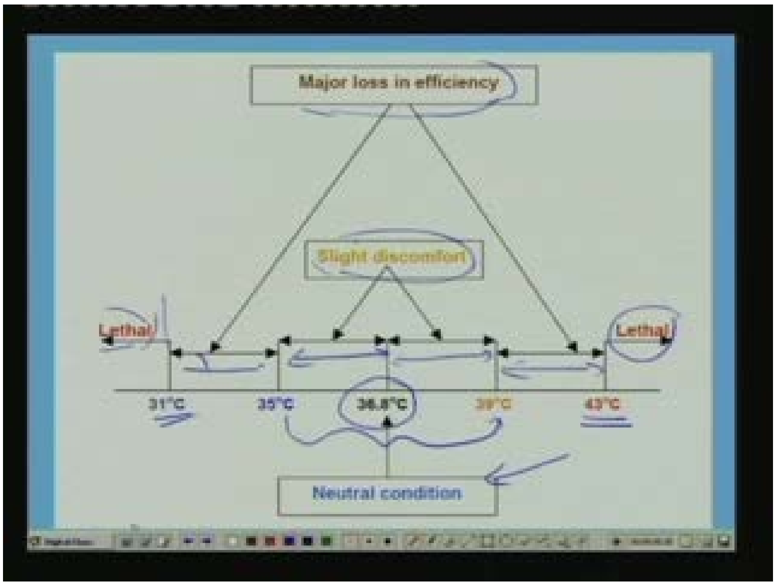

If symmetric you can see here the when the temperature is thirty-six point eight degree centigrade the human body is at a neutral condition okay. But when the temperature varies from thirty-five to thirty-six point eight or thirty-six point two eight to thirty-nine centigrade. That means in this range a human being feels slightly uncomfortable okay. That means it is a slight discomfort is cost to the human being but when the temperature falls below the thirty-five degrees or goes above thirty-nine degrees. That means in this reason it is observed that there is a major loss in efficiency of the human being okay. If he is performing any task that will he will be performing it with very low efficiency okay. So from thirty-one to thirty-five and thirty-nine to forty-three. But when the temperature falls below thirty-one degree centigrade or when it exceeds forty-three degree centigrade it can become lethal okay it may even lead to death. So you can see that affectively the temperature of the human body this is the core temperature should always maintained between above thirty-five to thirty-nine degree centigrade okay. Beyond that it is not recommended or it could become dangerous to the human being.

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As I have already explained when the temperature is lower than thirty degree centigrade or higher than thirty-nine degree centigrade then people suffer major loss in efficiency. It becomes lethal the temperature falls below thirty-one degree centigrade or raises above forty-three degree centigrade.

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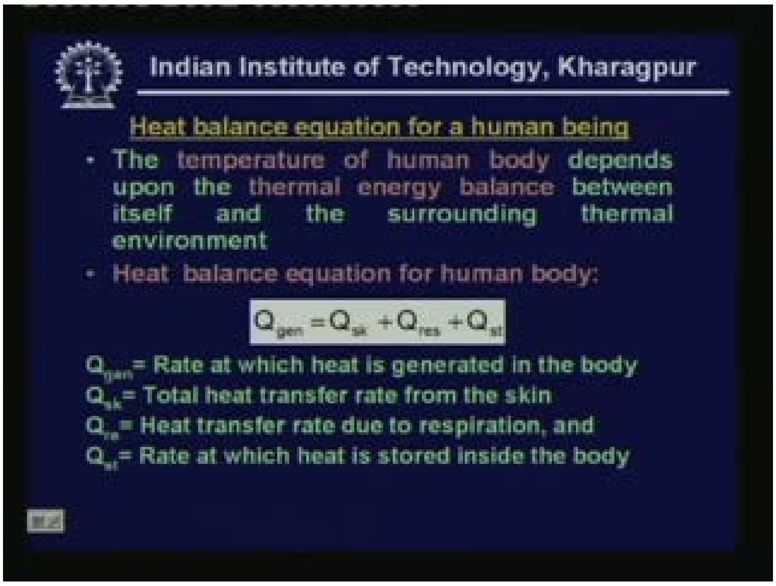

Now let us look at heat balance equation. Let us see what decides the temperature of a human body how the temperature of a human body varies okay for that we have to understand heat balance equation for a human being the temperature of a human body depends upon the thermal energy balance between itself and the surrounding thermal environment. As I said the human body can be considered to be a heat engine. So you can apply the conservation of energy to human body. You can take the human body as a control volume and you can apply energy balance if you apply thermal energy, this, what is known as heat balance okay. What do we get so when we apply this we get what is known as heat balance equation this heat balance for a human body is given like this Q generator Q gen is equal to Q subscript sk plus Q subscript res plus Q subscript st where Q gen is the rate at which heat is generated in the body that should be equal to Qsk. Qsk is nothing but total heat transfer rate from the skin plus Q subscript res which stand s for heat transfer rate due to respiration plus Q subscript st Q subscript st. As you can see stands for the rate at which heat is stored insides the body. That means this is very simple energy balance equation the rate at which heat is generated inside the human body should either be rejected or it is stored okay. Because it has to be conserved right now.

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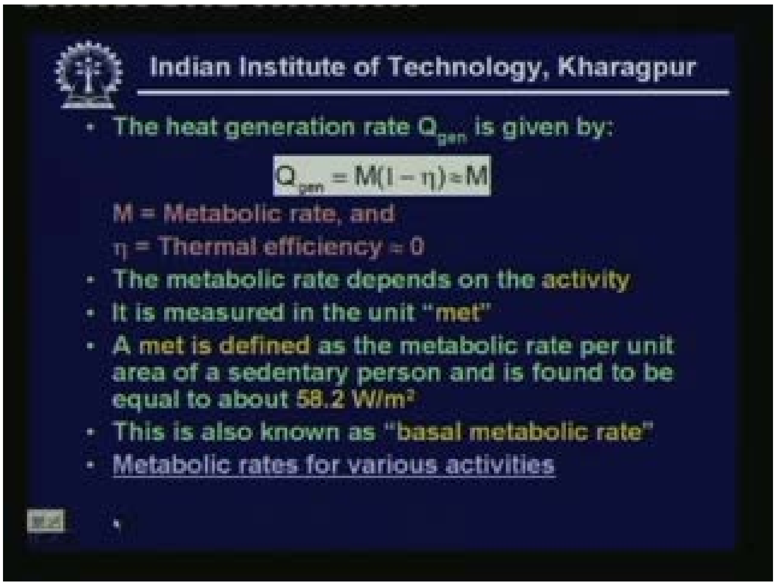

Let us look at each of these terms the first term is the heat generation rate the heat generation rate Q gen is given by Q gen is equal to M into one minus eta where M is the metabolic rate and eta is the thermal efficiency. As I said for most of the applications or for most of the common task this thermal efficiency term is almost close to zero. So you can neglect it if neglect it you find that the heat generation rate is equal to the metabolic rate M okay. And the metabolic rate on what does it depend the metabolic rate depends on the activity okay. The human activity and the it is measured in the unit met okay. This a new unit the metabolic rate of a human being is measured in a unit called met. And what is a met a met is defined as a metabolic rate per unit area of a sedentary person sedentary person means a person who is sitting quietly okay, with doing any activity. So a met is defined as a metabolic rate per unit area of a sedentary person and it is found to be equal to about fifty-eight point two watt per meter square okay.

This is also known as basal metabolic rate. Now let us the metabolic rates for as I said the metabolic rate depends very much on the human activity okay. So people have conducted several experiments and they have determined the metabolic rates for a wide variety of activities. As I said why do we need the metabolic rate because the metabolic rate finally becomes a load on the cooling system. So we have to have a knowledge of this that's the reason why people have determined the metabolic rates. This data is available for example in ASHRAE hand books. So I will let me show some typical metabolic rates.

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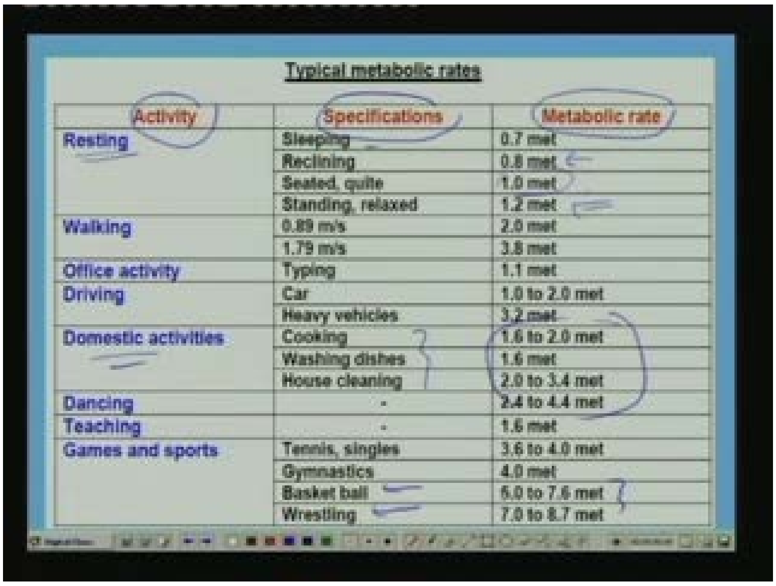

Typical metabolic rates

Activity	Specifications	Metabolic rate
Resting	Sleeping	0.7 met
	Reclining	0.8 met
	Seated, quite	1.0 met
	Standing, relaxed	1.2 met
Walking	0.89 m/s	2.0 met
	1.79 m/s	3.8 met
Office activity	Typing	1.1 met
Driving	Car	1.0 to 2.0 met
	Heavy vehicles	3.2 met
Domestic activities	Cooking	1.6 to 2.0 met
	Washing dishes	1.6 met
	House cleaning	2.0 to 3.4 met
Dancing	-	2.4 to 4.4 met
Teaching	-	1.6 met
Games and sports	Tennis, singles	3.6 to 4.0 met
	Gymnastics	4.0 met
	Basket ball	6.0 to 7.6 met
	Wrestling	7.0 to 8.7 met

This table shows typical metabolic rates here we have the activity. Then the specifications of the activity and the metabolic rate and as I said the metabolic rates are expressed in the units of met. For example if a person is resting, resting means let us say he is sleeping then the metabolic rate is about point seven met if he is reclining, reclining means he is okay. Then the metabolic rate is about point eight met and if he seated quite. As I said the metabolic rate is one met in fact these the definition of met and if he standing in a relaxed manner metabolic rate is one point two met like that you can see the metabolic rates for different activities. For example for walking for office activity for driving domestic activities dancing teaching games and sports extra okay.

You can see that for domestic activities the metabolic rate is quiet high. It is about one point it can vary from about one point six to three point four met depending upon the specific activity you can also see that for very strenuous activity such as wrestling or playing basket ball. And all the metabolic rates are very high okay. It is as high as about eight point seven met in case of wrestling this kind of data is available in a ASHRAE hand books for more number of activities okay. So one can use the hand books for getting these kind of a data okay.

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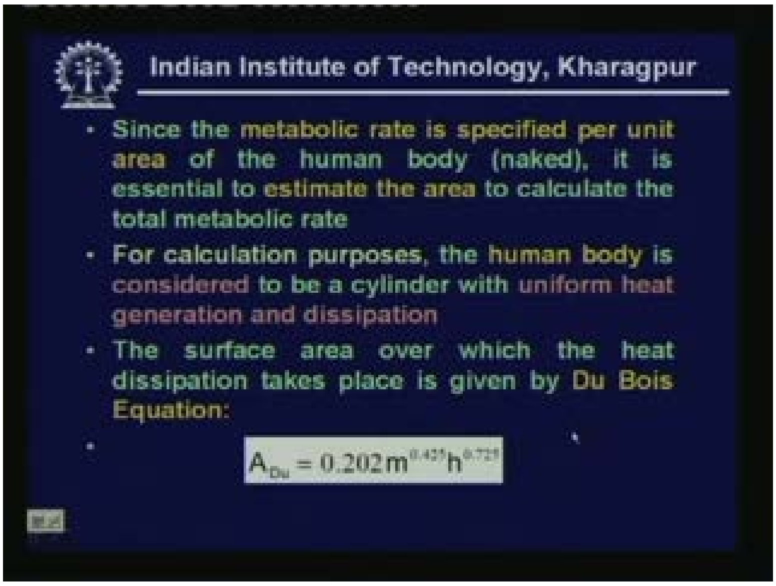

Since the metabolic rate is specified per unit area of the human body when we say unit area of the human body normally it is preferred to the unclothed or naked body. So it is essential to estimate the area to calculate the total metabolic rate you have seen that the metabolic rates are specified in terms of met and met itself is defined in terms of watts per meter square okay. The, that meter square the denominator refers to the surface area of the human body okay. We want to find out what is the total heat rejected form the human body then we have to know not only the metabolic rate. But we also have to know what is the surface area from which the heat dissipation is taking place okay. So we have to calculate the surface area of a human body how do we do that. So people have found empirical equations for the surface area of human body this a famous equation called as Du Bois equation this equation relates the surface area of a naked human body to its mass and height okay. If you know the mass and height of a human being you can calculate its surface area okay.

So for calculation purposes the human body is considered to be a cylinder with uniform heat generation and dissipation actually the human body is very complex okay. So it is very difficult, in fact it is almost impossible to model a human body perfectly okay. So for but for calculating purposes you have to make certain assumptions in an actual human being the heat generation takes place in a very non uniform manner okay. That means a heat generation throughout the body is not same right. Similarly the heat dissipation is also not same throughout the human body okay. But to take all these affects into account it is very difficult theoretically. So what is done in theory is we assume that a human being is like a uniform cylinder and the heat dissipation and heat generation of this human being is uniform okay. So under this assumption the surface area over which the heat dissipation takes place is given by as said this Du Bios equation the Du Bios equation gives the surface area A subscript Du. This is equal to point two zero two m to the power of point four two five multiplied by h to the power of point seven two five. Here the area if is in meter square okay, area is in meter square m as I said is the mass of the human being this in kg's and h is the height in meters okay. So that you can see an empirical equation.

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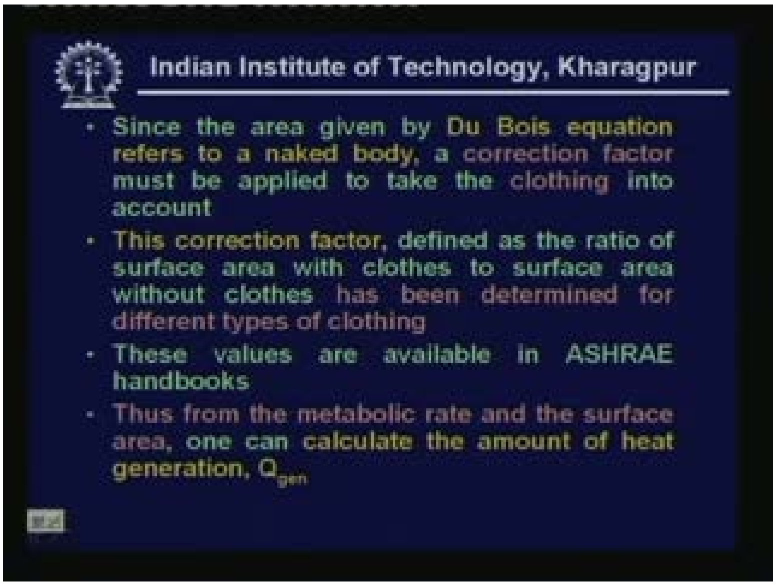

Since the area given by Du Bios equation refers to a naked body a correction factor must be applied to take the clothing into account. So this correction factor defined as ratio of surface area with clothes to surface area without clothes as been determined for different types of clothing and these values are available in ASHRAE hand books thus from the metabolic rate. And the surface area one can calculate the amount of heat generation Q gen okay. So the procedure for calculating what is the heat generation is that first of all depending upon the activity you have to find what is the metabolic rate in watt per meter square using the data books then depending upon the mass and height one can calculate. What is the area of the body okay, so if you multiplied multiply the metabolic rate into the area. That will give you the total amount of heat transferred but this area refers to the unclothed body. So we have to take the affect of clothes into account. So you have to multiply this heat transfer rate into a correction factor which considers the affect of clothing.

So for correction factor again one as to look at a data book such as ASHRAE data books where the correction factor for different types of clothing is given okay. So then you have to take the correction factor and multiply that correction factor by metabolic rate and the area which will finally give you the heat generation rate okay.

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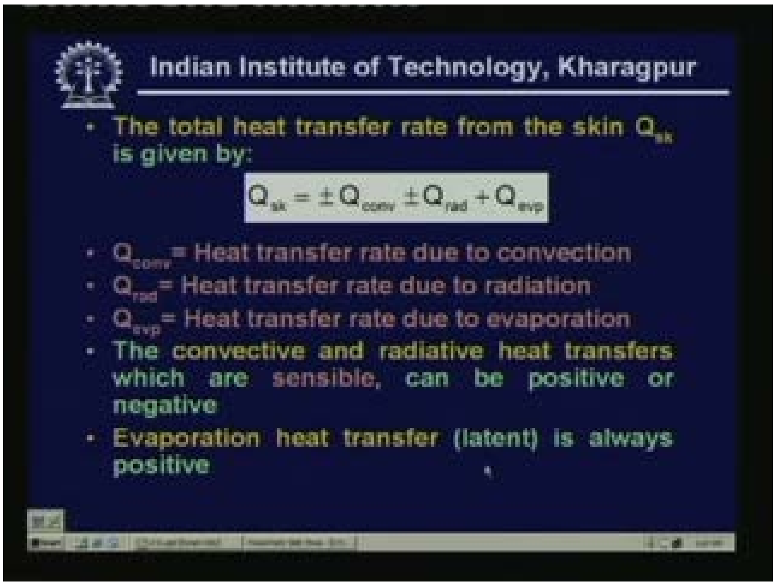

Now let us look at the second term that this the total heat transfer rate from the skin this is given by Q skin is equal to plus or minus Q convective plus or minus Q radiative plus Q evaporative. Here you can see that this Q convective is a heat transfer rate due to convection Q radiative is the heat transfer rate due to radiation Q evaporative is heat transfer rate due to evaporation. So the heat transfer rate from the skin of a human being takes place by these three modes that is first is by convection the other one is by radiation. And the third mode by evaporation in the equation it is shown that convective and radiative terms could be either plus or minus.

That means convective heat transfer from a human body can be either from the body to the surroundings or from the surrounding to the human body when it is from the human body to the surroundings we use the sign plus okay. That means it is positive when the human body is losing heat when he is gaining heat it becomes negative okay. So the convective and radiative heat transfers can be positive or negative. For example the convective heat transfer can be negative when the ambient temperature is higher than the human body temperature okay. Whereas the evaporative heat transfer that is Q evaporative is always positive that mean human being always losses heat by evaporation. And there is another differences between these two and the evaporative heat transfer the convective and the radiative heat transfer are sensible in nature whereas evaporation heat transfer is latent in nature okay.

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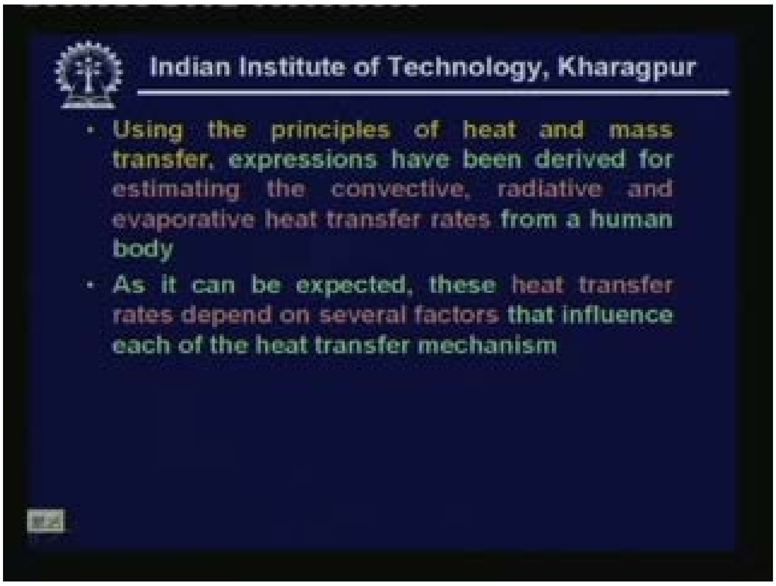

Using the principles of heat and mass transfer expressions have been derived for estimating the convective radiative and evaporative heat transfer rate from a human body as it can be expected these heat transfer rates depend on several factors that influence each of the heat transfer mechanism. So if you look at advanced books on air conditioning or on thermal comfort you will find that people have derived impherical equations fro estimating the convective heat transfer and radiative heat transfer and evaporative heat transfer from a human being okay. So using those equations one can calculate the heat transfer rates different heat transfer rates but since all these heat transfer modes depend upon several factors such as what is the air velocity what is the air drivel temperature what is the humidity of the air etcetera one as to take all these factors into account.

In fact the impherical equations do take these factors into account okay. So you must note the complexity in evaluating all these parameters okay. As I said that is the reason you really do not have a perfect analytical theory or a analytical model. So most of the time all these parameters are estimated based on experiments okay.

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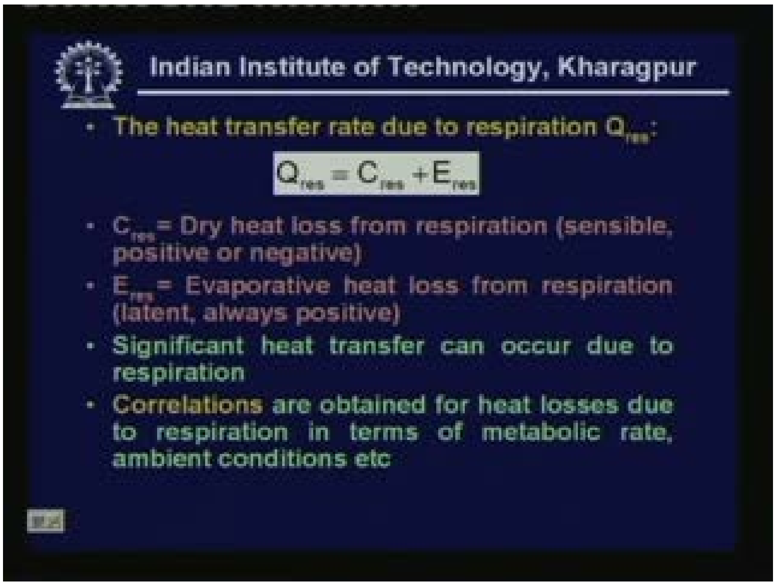

Now let us look at the heat transfer rate due to respiration the heat transfer rate due to respiration is given by Q res is equal to C respiration plus E respiration where C subscript res stands for dry heat loss from respiration and E sub script res stands for evaporative heat loss from respiration what is this heat transfer rate by respiration. So you know that all the human beings inhale air and exhale air. So the air that you breathe in is at a condition same as that of the surrounding air. That means when you breathe air inside the air enters into the body at a temperature equal to the surrounding ambient temperature. And the moisture content also will be same as the surroundings but the air that you breathe out. That means the air that you exhale that will be that is considered to be at the temperature equal to the core temperature of the human body okay.

Similarly that air that you exhale is treated as saturated okay. So you take in ambient air and you exhale air which is at core temperature and which is saturated. So in this process a human body can gain or loss heat for example outside air is cold let us say outside air is twenty degree centigrade. And it is very dry. So when we are inhaling that air. So we are inhaling cold and dry air and what we are exhaling is warm air and humid air. Because the core temperature is about thirty-seven degrees. So the air that is coming out of the body is thirty-seven it is at thirty-seven degree centigrade and it is also saturated. Okay, so in this process of inhaling cold and dry air and exhaling warm and humid air a body losses heat body losses both sensible heat and latent heat okay. This is and this is one example in another case for example outside air is very hot. So when you the air that you inhale will be hotter than the air that you exhale so in this process body gains heat okay.

So this sensible heat loss or sensible heat gain because of this respiration process is known as dry respiration heat transfer heat loss or gain okay. And the heat gain or loss because of the evaporation is known as evaporative loss. You will find that the dry as I said the dry loss is sensible whereas the evaporative loss is latent. And most of the cases the evaporative loss is always a loss. That means the body always losses heat by evaporation where as the body can gain or loss heat by sensible heating or cooling okay. Again correlations are obtained for heat losses due to respiration in terms of metabolic rate ambient condition etcetera. And the heat transfer rate due to respiration can be significant okay. And as you can guess this depends upon what is the respiration rate what is the rate at which you are taking in air and what is the rate at which you are which you are breathing out the air.

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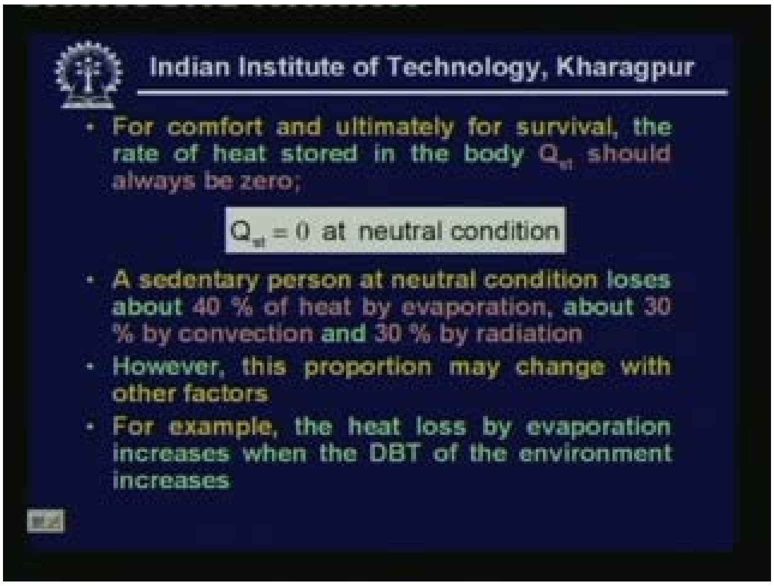

And the last term that is Q storage for comfort and ultimately for survival the rate of heat stored in the body Qst should always be zero. That means a body should neither store heat nor should loss heat. Because the body as I said its temperature should be maintained at a fixed tem, at a fixed point okay. There should not be either heat accumulation or continues heat loss. That means the Qst should be zero and this should be zero at neutral condition. And it is found that a sedentary person at neutral condition losses about forty percent of heat by evaporation about thirty percent by convection and about thirty percent by radiation. So you can see that the evaporation loss is quiet high however this proportion may change with other factors. For example the heat loss by evaporation increases when the dribble temperature of the environment increases okay.

So if you look at what is the mechanism by which a body losses heat when outside is very hot. Let us say in a typical summer outside temperature is forty-five degree centigrade okay. When outside temperature forty-five degree centigrade and a body has to got to be maintained at thirty-seven degree centigrade. So body cannot loss heat by convection or radiation in fact the body gains heat by convection or radiation. Because the temperature of the outside is grater then the temperature of the inside the human body okay. So body gains heat by convection and radiation.

So whatever heat is gaining it as to loss over and above the heat that is being generated in the human body. So how it can loss so the only way it can loss this heat is by evaporation okay. That is why we pursfier in fact I will explain this a little later okay. So the body as to uh loss heat by evaporation these sweat when the temperature is higher outside and due to the sweating they will be increased amount of evaporation as a result we loss more amount of heat okay. So what I am trying to say is the percent by which a human body losses heat does not remain fixed it varies from condition to condition okay.

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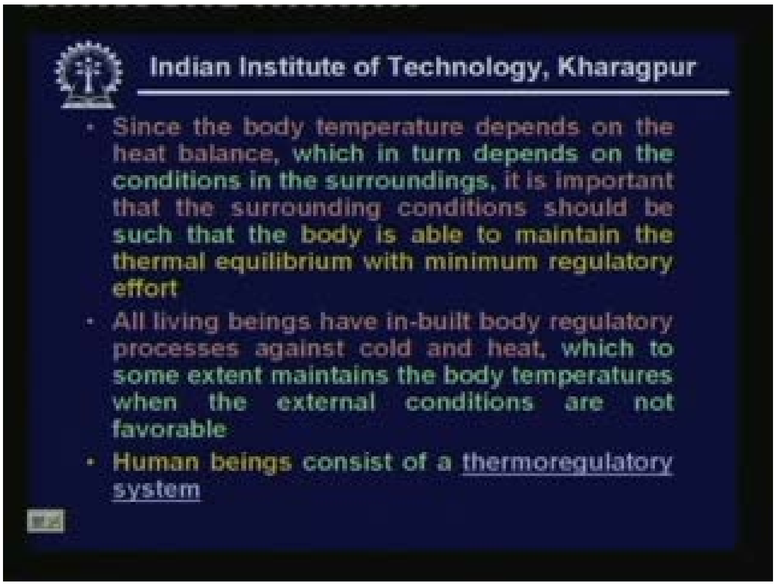

Since the body temperature depends on the heat balance which in turn depends on the conditions in the surroundings, it is important that the surroundings should be such that the body is able to maintain the thermal equilibrium with minimum regulatory effort okay. So in fact I was talking about the neutral condition and thermal equilibrium and all basically what it means is that without much effort or without any effort a body should be able to loss heat okay. You should not make any extra effort to loss the heat that is being generated inside the body. So the that is known as the neutral condition okay. But all living beings including human beings have some regulatory mechanisms inside the body okay. These are inbuilt regulatory mechanisms which will try to maintain the body temperature when the outside conditions are not favourable okay. That mean when the outside becomes colder or hotter than the neutral condition. Then this regulatory mechanism comes into the picture and it will try to maintain the body temperature by initiating certain processes okay. As I said all living beings have inbuilt regulatory processes against cold and heat which to some extend maintains a body temperatures when the external conditions or not favourable human beings consist of a thermo regulatory system. Now let me quickly explain what is this thermo regulatory system and how does it work.

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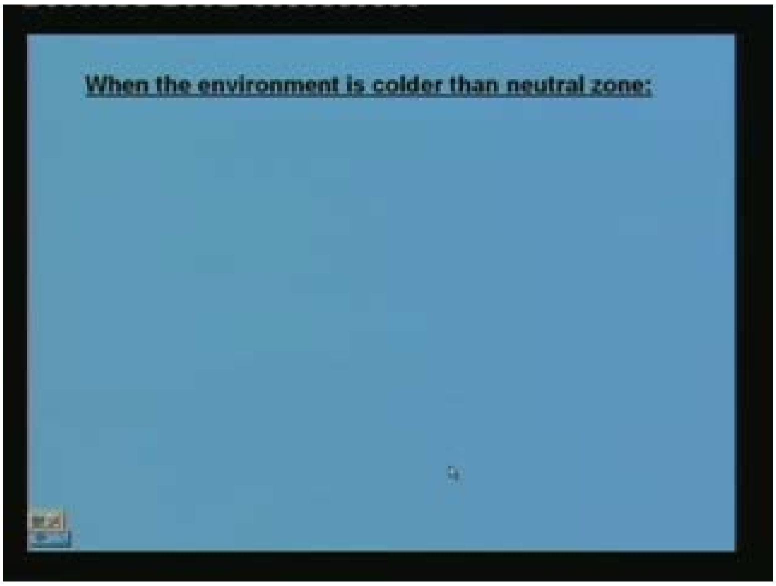

So what happens when the environment temperature is colder then neutral zone. So what happens when the outside temperature is cold? We know from experience that when the outside temperature is cold we loss more heat than is being generated okay. So that means the heat generation inside the body is less and heat loss is more okay. So momentarily you will find that body will turn to loss temperature okay. That means its temperature tries to go down but the thermo regulatory mechanism of the body will try to prevent this so it fights this affect in a different steps. Okay. The first step is like this when the outside temperature is cold the first action is what is known as zone of vaso motor regulation against cold. This also known as vaso constriction. So what happens during this process is that the blood vessels adjacent to the skin constrict. So what happens because of this because of this the flow of blood to the outer skin is reduced once the flow of the blood is reduced heat transfer to the immediate outer surface is reduced okay.

As a result outer skin tissues act as insulators okay. So basically how heat is last from the core of the body to the surroundings the blood acts as a carrying agent okay. As you know that blood continuously circulates through the human body. So the blood carries the heat from the inside of the core of the body and it brings the heat to the surface that means to the skin and from the skin heat is lost to the surroundings okay. So when the outside temperature is low body is losing more heat okay. That means this heat loss as to be reduced so what the regulatory mechanism does is it constraints the blood vessels okay. That means blood vessel become constricted or they become smaller or narrower. When they become narrower less blood flows to the outer skin of the body okay, when less blood flows to the skin less amount of heat is carried from the core of the body to the skin okay. Since less heat is carried less heat is lost okay.

So this is the first step against the cold so during this process the outer skin or the tissues of the outer skin act as insulators and they prevent the heat loss. But if the temperature drops further then vaso motor regulation does not provide enough protection okay. Then the body enters into what is known as zone of metabolic regulation. In this zone of metabolic regulation a spontaneous increase of activity is initiated. And this is nothing but the shivering okay so we start shivering when the temperature falls down. What happens due to shivering? Because of the shivering since the activity is increasing body heat generation is increased okay. That means temporarily we increase the generation of heat to take care of the increased heat losses okay. So when the losses are increasing the only way it can compact this losses is to increase the heat generation. That is the reason why we have to eat people say that you have to eat good food in winter. So that energy can be there is sufficient energy which will take care of the increased losses okay.

So if the temperature falls further if the environment temperature drops further then the body is not able to come back cooling of its tissues okay. As I said as to certain extend only the thermoregulatory mechanism can work beyond a certain point it cannot simply work okay. So its starts failing so what happen if the temperature drops further. So temperature drops further the body enters into what is known as the zone of inevitable body cooling. That means the regulatory mechanism cannot do anything okay. So there will be continuous loss of heat from the body as the heat is being lost your queue storage term in the heat balance equation becomes positive it becomes, sorry, negative. That means body temperature starts dropping okay so this is what is known as zone of inevitable body cooling okay. And as we have seen if the body temperature falls below say thirty-one degrees also it can become lethal okay. So this is got to be prevented.

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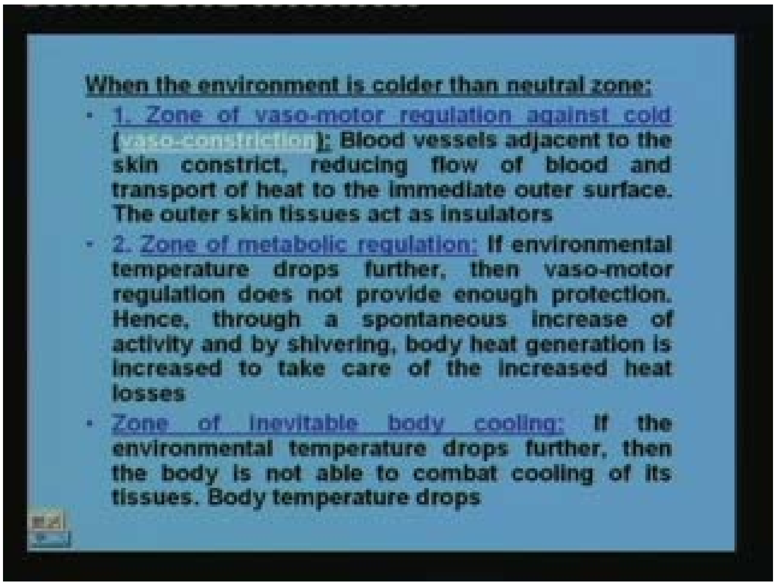

So this is the action of the regulatory mechanism against cold. Let us see how the body the fights the heat.

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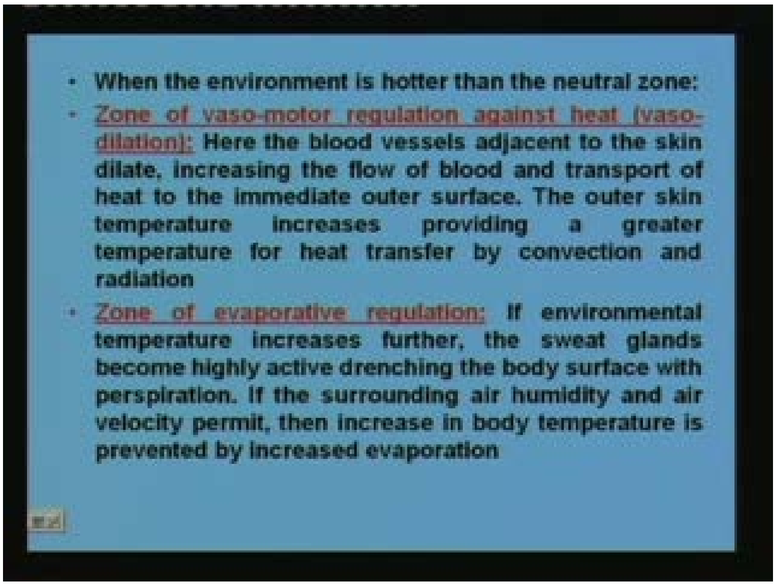

When the environment is hotter than the neutral zone, as you know when the environmental is hotter than the neutral zone less heat is lost and more heat is generated okay. That means generation is more compared to the loss once generation is more compared ot the loss the Q storage term becomes momentarily positive. That means body starts cumulating or storing heat once body starts storing heat its temperature again tries to increase, when the again temperature starts increasing the thermal thermo regulatory mechanism comes into picture. So what does it do? First thing it does is, it initiates an action and the body enters into what is known as the zone os vaso motor regulation against heat. This is exactly opposite to the zone of vaso motor regulation cold or vaso constriction. Unlike vaso constriction when the external temperature increase the blood vessels adjacent to the skin dilate. That means they become larger once they become larger. The flow of blood and transport of heat to the outer surface increases okay so the outer skin temperature increases because of this providing a greater temperature for heat transfer by convection and radiation okay. Since less heat is being lost because of the smaller temperature difference available for heat loss. What the body does is its pumps more blood to the outer skin okay. Once more blood is pumped to the outer skin outer skin temperature increases because more blood flow means more heat flow right. Then the outer skin temperature increases means larger delta t is available for heat loss from the outer skin okay, these the first step.

The second step is what is known as zone of evaporative regulation if environmental temperature increases further the sweat glands become highly active drenching the body surface with perspiration if the surrounding air humidity and air velocity permit then increase in body temperature is prevented by increased evaporation. These also we normally experience on a hot day when the outside becomes very high. Then the vaso dilation is not sufficient some other mechanism should come into picture. So that body can reject heat this mechanism is what is known as zone of evaporative regulation okay. That mean s the outer surface of the body that is the skin of the outer skin of the body is covered with perspiration okay. The, this is achieved by triggering the sweat glands okay. The regulatory mechanism triggers the sweat glands the sweat glands starts sweating more okay. So you have lot of water on the outer surface of your body.

If the outer surface humidity is low and if there is sufficient air velocity. Then the water that is accumulated on the outer surface of the human body can evaporate okay. Since evaporation is latent heat transfer process lot of heat can be transferred during this process the body. Temperature can be maintained within the required limits by the process of evaporation okay.

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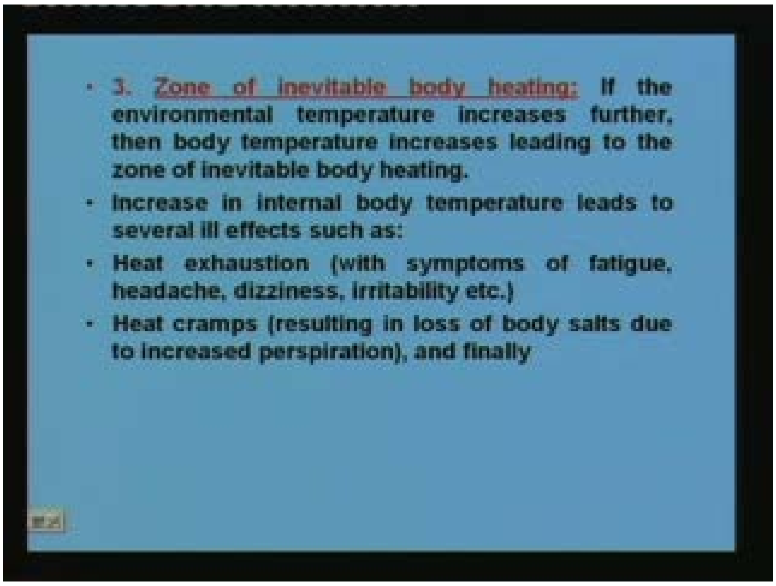

Now if the temperature increases further and outside conditions are not favourable then the body enters into what is known as zone of inevitable body heating and due just like zone of inevitable body cooling during this zone the tem body temperature increases leading to the zone of inevitable body heating okay. That means body temperature starts increasing in internal body temperature leads to several ill affects this could be very dangerous the first ill affect is what is known as heat exhaustion the symptoms of this heat exhaustion is fatigue headache dizziness irritability etcetera. Of course heat exhaustion is not dangerous or lethal because the person can recover from this okay. If he takes rest in a shadow or in a shade the second problem is heat cramps heat cramps is means by basically loss of body salts due to increased perspiration okay. Whenever the body is losing water by perspiration along with the water salt also lost okay.

Once the body losses too much of salt then it goes into what is known as the heat cramp okay heat it feels the heat cramps heat cramps. In fact you might have seen that typically cricket players or football players when the play cricket or so football under hot conditions they experience. This because when they are playing the games their activity level is quite high. So they have to loss lot of heat because lot of heat is generated inside the body. So all that heat generated as to be lost so they cannot lose all that heat just by convection or radiation okay. So they have to lose they will be losing most of the heat by evaporation okay. That means they will be losing lot of water. So along with this water they also loss salts body salts okay. If the body salt loss is very high then they experiences heat cramps okay. So the remedy for this heat cramp is they have to take some salt tablets or and take some rest okay. So that again the body gain the salt right.

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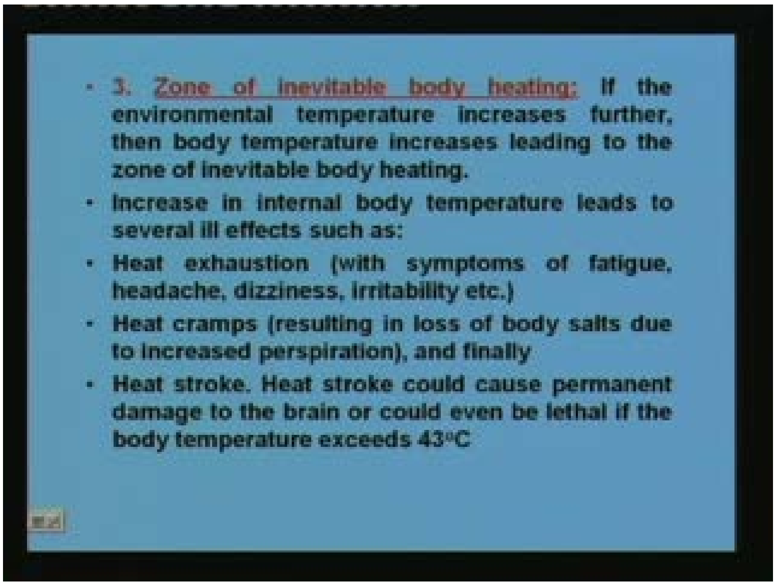

The third ill affect which is most dangerous is known as heat stroke. Heat stroke could cause permanent damage. It is very dangerous and it can lead to the damage of the brain or it could even be lethal. That means it could even cause death if the body temperature exceeds forty-three degree centigrade okay.

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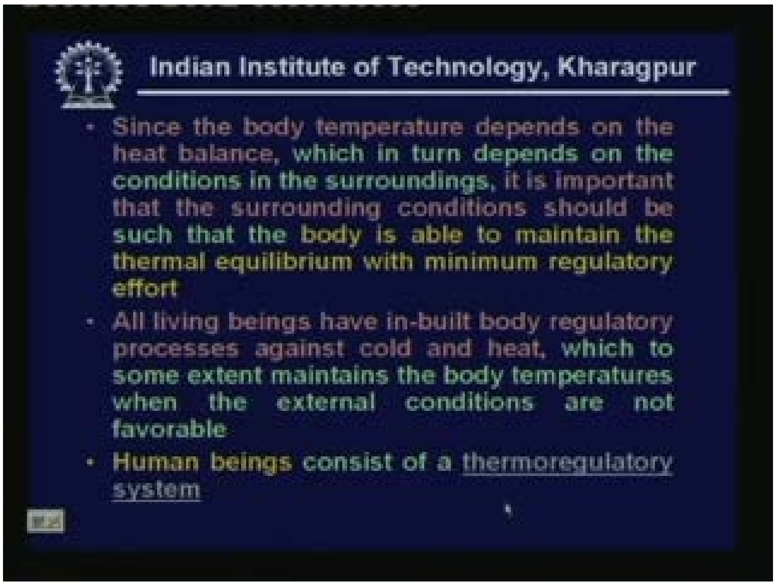

So this is the thermo regulatory system and how it works.

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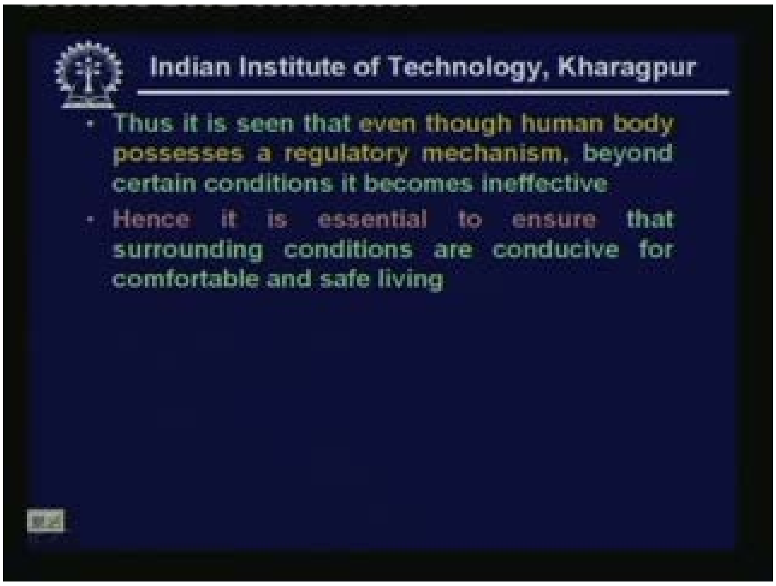

Thus it is seen that even though human body possesses a regulatory mechanism beyond sudden conditions it becomes ineffective. Hence it is essential to unsure that surrounding conditions are conducive for comfortable and safe living okay. So you cannot simply relay on the thermo regulatory mechanism okay. You, it cannot take care for ever. So outside conditions also must be conducive if the outside conditions are not conducive then an air conditioning system is will be required to provide the required conditions okay. These conditions are required first of all for comfort and second for survival also okay.

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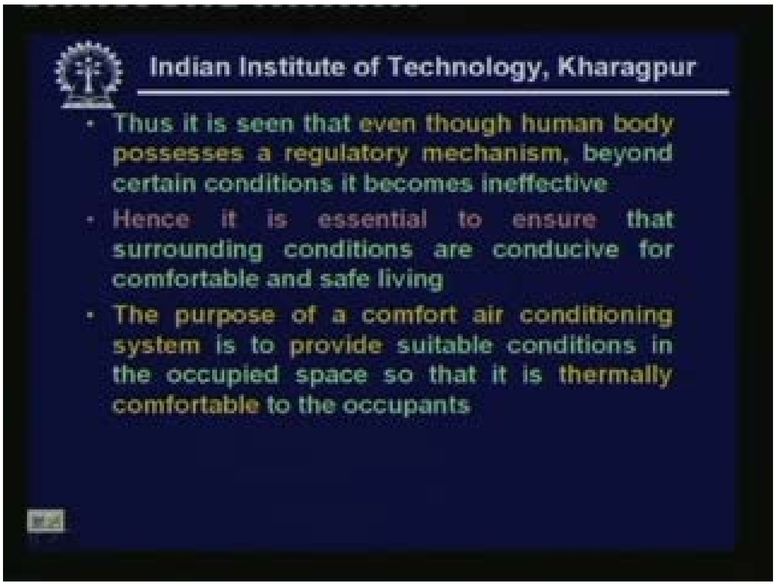

The purpose of comfort air conditioning systems to provide suitable conditions in the occupied space. So that it is thermally comfortable to the occupants.

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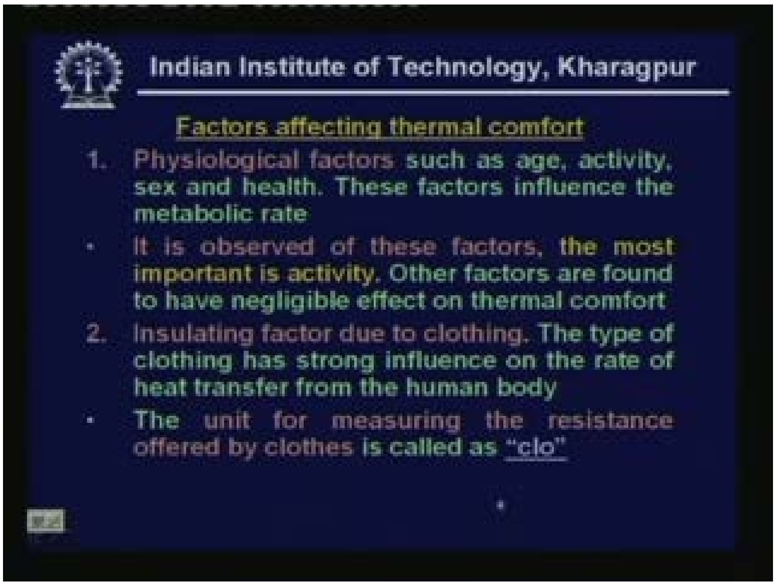

Now let us look at the factors affecting thermal comfort physiological. The first factor is what is known as physiological factors. The physiological factors are age activity sex and health these factors influence basically the metabolic rate. So it is observed that of all these factors, the most important is the activity other factors are found to have negligible effect on thermal comfort. That means factors like age and health do not have significant affect. The second factor affecting thermal comfort is what is known as insulating factor due to clothing. Because I have all the human beings wear clothes and clothes act as insulation okay. So this type of the type of clothing as strong influence in the rate of heat transfer from the human body okay. So this is the important the unit for measuring the resistance offered by clothes is called as clo. So just like met for metabolic rate people have defined a unit for measuring the resistance of the cloths and this unit is called as clo okay. So let me briefly explain what is this clo.

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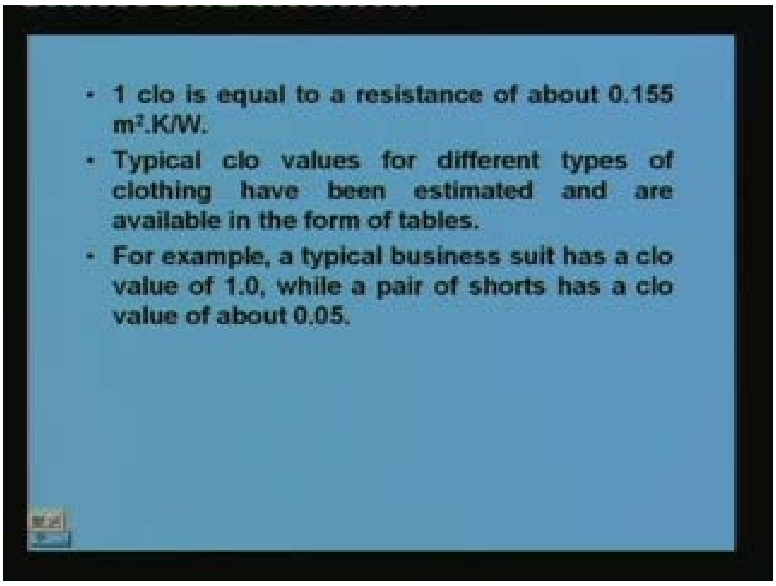

One clo is equal to a resistance of a heat transfer resistance of about point one five five meter square Kelvin per watt okay. Typical clo values for different types of clothing have been estimated and are available in the form of tables. For example if AHSRAE hand books for for example a typical business suit has a clo value of one okay, while a pair of shorts has a clo value of about point zero five. Obviously higher the amount of clothes you wear the resistance offered by the clothes also increase okay. When you wear minimum clothes then the resistance offered by the clothes will be less sometimes the unit tog is also used for measuring resistance of clothing. Of course clo is more common one tog is equal to about point six four five clo.

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Now let us look at the third and most important factor that is known as the environmental factor. The environmental factors are dry bulb temperature of air relative humidity or moisture content of air motion or air velocity and finally the surrounding surface temperature. So what is the affect of these factors the dry bulb temperature affects heat transfer by convection and evaporation relative humidity affects heat loss by evaporation air velocity influences both convective and evaporative heat transfer and the surrounding surface temperature affects the radiative heat transfer.

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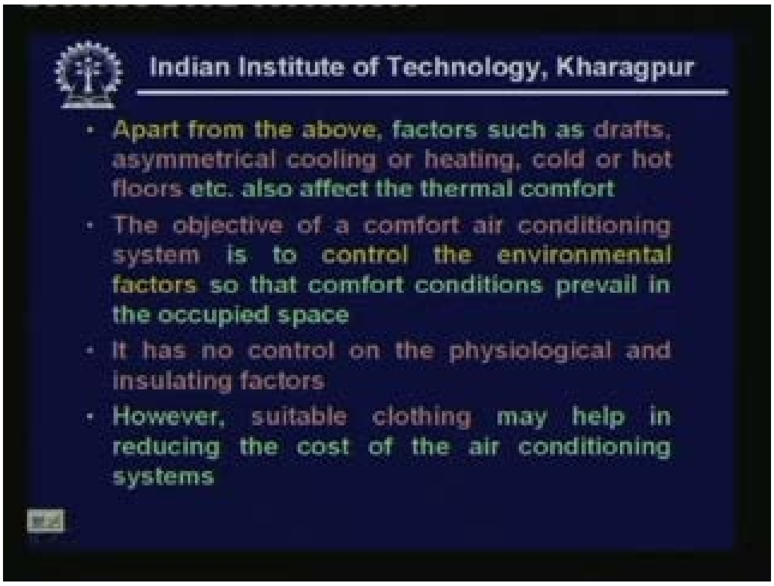

Apart from the above factors such as drafts asymmetrical cooling or heating cold or hot floors also have affect the thermal comfort the objective of a comfort air conditioning system is to control the environmental factors. So the comfort conditions prevail in the occupied space the typical air conditioning system has no control on the physiological and insulating factors. However suitable clothing's may help in reducing the cost of the air conditioning system okay. So by providing an air condition system what is that you can control? You can control only the environmental factor. That means you can control the dry bulb temperature moisture content air velocity inside the conditions space okay. You cannot control or you have no control on the physiological factors such as age. You cannot decide what should be the age of the occupant okay. Similarly you also do not have any control on the activity right. Of course air conditioning system or a air conditioning system designer as no control on the clothing. But it is seen that by varying or by suggesting suitable clothing one can reduce the cause of an air conditioning system.

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Now let us look at indices for thermal comfort important factor which affect thermal comfort. As we have seen are the human activity clothing air dry bulb temperature relative humidity air velocity and surrounding temperature. Since so many factors are involved many combinations of the above conditions provide comfort there is no unique combination. There are many combinations possible all of which will give equal amount of comfort. Hence to evaluate the effectiveness of condition space several comfort indices have been suggested. These indices can be divided into direct and derived indices. So how do you estimate, for example you have got an air conditioned building okay.

You have you wanted an air conditioned building and you have got an air conditioning building. How do you know that it is good or bad okay, how do you evaluated the affections of an air conditioned building? So the effectiveness of air condition building ultimately depends on the thermal comfort okay. Whether it is providing thermal comfort or not and as we have seen that the thermal comfort depends on several factors okay. So all these factors will affect the thermal comfort okay. So in order to judge the effectiveness of an air-condition building all these factors must be considered. Since so many factors are involved as I said a combination of a many combinations of these factors can give you comfort to measure, basically the effectiveness of conditions space people have devised the comfort indices okay. The direct indices are dry bulb.

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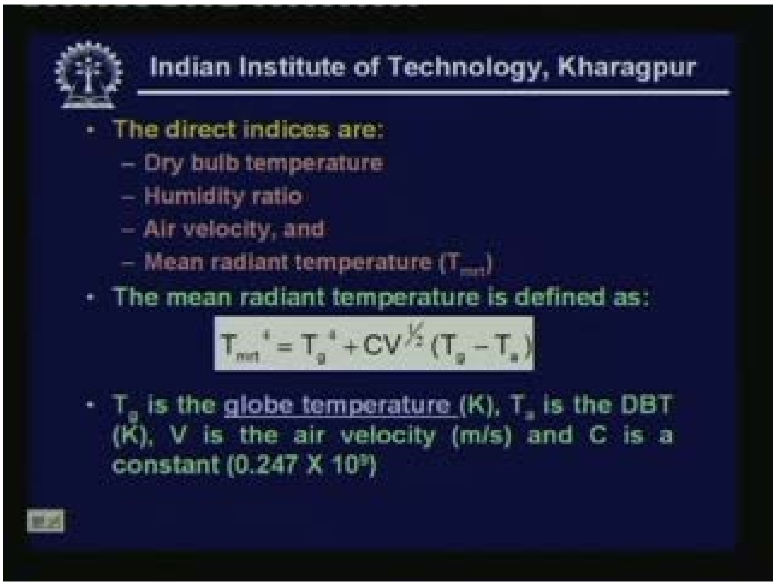

Temperature humidity ratio air velocity and mean radiant temperature. We know dry bulb temperature humidity ratio and air velocity mean radiant temperature is a new parameter. And this is defined as the mean radiant temperature T subscript mrt is defined by this equation Tmrt to the power of four is equal to Tg to the power of four plus CV to the power of half into Tg minus Ta where tg is called as the globe temperature Ta is a dry bulb temperature V is the air velocity and C is a constant whose value is equal to point two four seven into ten to the power of nine. Here all the temperatures are in absolute Kelvin scale velocity is in meter per second and dry bulb temperature is also in Kelvin okay. That I have already mentioned what is this globe temperature by the way.

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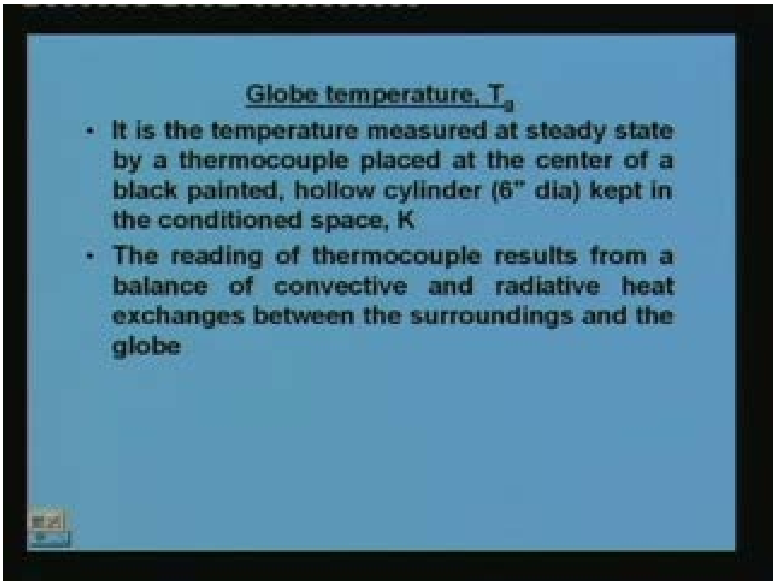

This globe temperature is the temperature measured at steady state by the thermo couple placed at the centre of black painted hollow cylinder of six inch diameter kept in the condition space. This is given in Kelvin the reading of thermocouple results from a balance of convective and radiative heat exchanges between the surroundings. And the globe that is how the globe temperature is measured which is related to the mean radiant temperature or the surrounding surface temperature.

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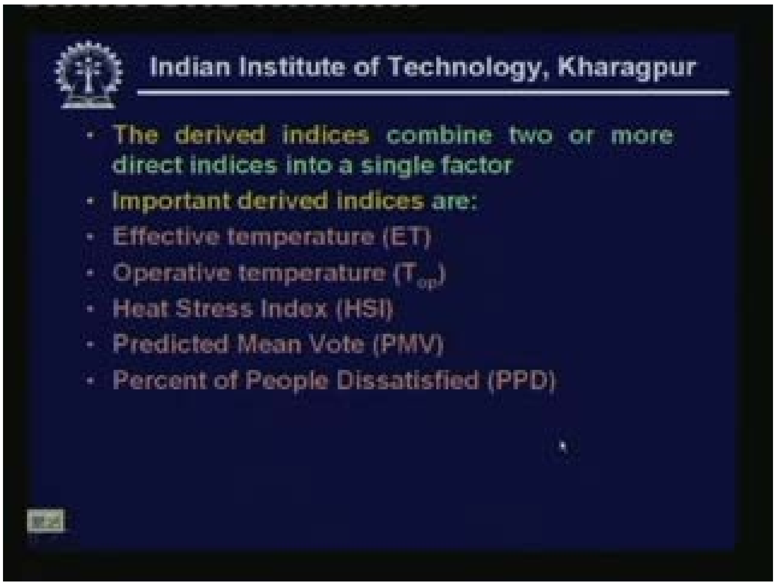

The derived indices is a combine through two or more direct indices into a single factor important derived indices are effective temperature ET operative temperature Top heat stress index HSI predicted mean vote PMV percent of people dissatisfied PPD etcetera.

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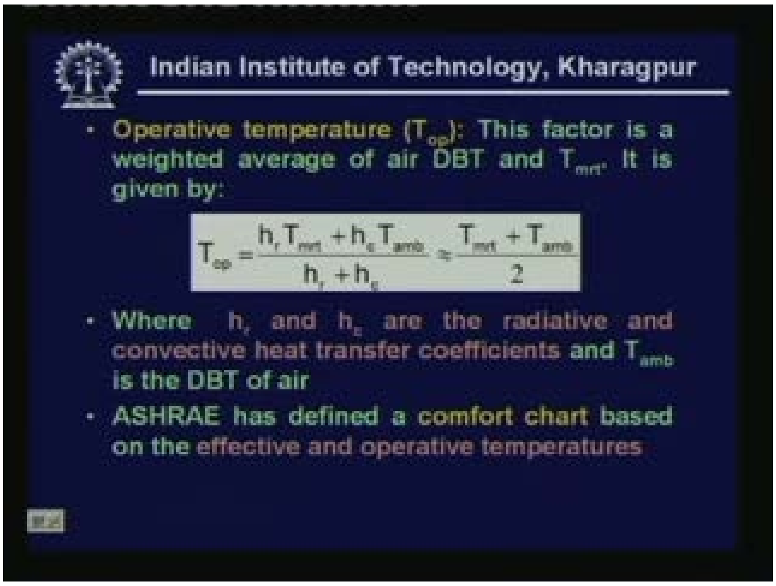

Now let us define effective temperature ET if effective temperature combines the affects of dry bulb temperature and relative humidity into a single factor. It is defined as the temperature of the environment at fifty percent RH which results in the same total heat loss from the skin as in the actual environment. So this is the definition of effective temperature since the value depends on so other factors such as activity clothing and air velocity and T mean radiant temperature. A standard effective temperature is defined for the following conditions. That means standard effective temperature is defined for a clothing value of point six clo activity of one met air velocity of point one meter per second and the mean radiant temperature is taken as same as the dry bulb temperature.

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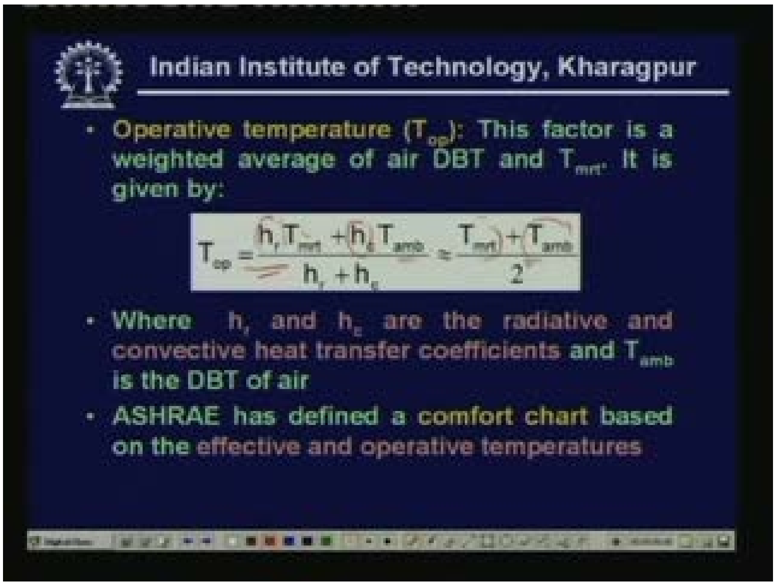

Now the operative temperature this factor is a weighted average of air dry bulb temperature and mean radiant temperature. That means basically it combine the dry bulb temperature and the surrounding surface temperature. This is given by Top is given by this equation okay, hr into Tmrt plus hc into T ambient divided by hr plus hc where hr is a radiative heat transfer coefficient which we have defined earlier and hc is the convective transfer coefficient Tmrt is the mean radiant temperature T ambient is the ambient dry bulb temperature and if hr and hc are almost same. Then the operative temperature is almost equal to the arithmetic average of mean radiant temperature and the ambient dry bulb temperature okay. ASHRAE has defined a comfort chart based on the affective and operative temperatures okay. Let us look at this.

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ASHRAE comfort chart the comfort chart shows the recommended inside conditions for summer and winter because this is a ultimate objective of this lecture okay to find the inside required inside conditions for summer and winter air conditioning systems okay the comforts chart is based on statistical sampling of a large number of occupants with activity levels less than one point two met okay this is valued for this kind of activities

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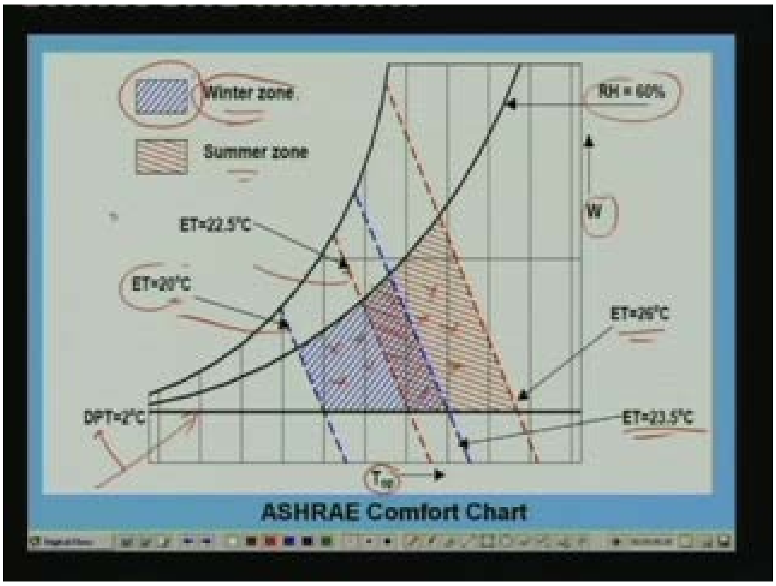

This picture shows the ASHRAE comfort chart this looks almost similar to a cyclomatic chart. But here what you have on the x axis is operative temperature not the dry bulb temperature. And the y axis you have the humidity ratio and the effective temperature lines are shown here this is a twenty degree centigrade of effective temperature line. This is a twenty-two point five degree centigrade line. This is twenty-three point five degree line and this, the twenty-six degree centigrade line. And you also see the sixty percent RH line and two degree due point temperature line this is the two degree due point temperature line okay. And here some areas are hashed areas are shown and this blue zone okay. All this blue zone is a recommended comfort condition for winter okay. That means if you are inside condition paces lies anywhere here during winter. Then the conditioned pace will be comfortable. Similarly for summer this red hashed area is the recommended zone for summer okay. That means if you are condition lie somewhere in the red zone then the condition pace will be comfort during the summer. And you can see that there is some area which is being over lapped there is an over lapping area for winter and summer zones okay. So if the conditions pace in this lies in this over lapping zone then a person wearing summer cloths will feel slightly cooler and a person wearing winter clothes will feel slightly warmer okay. So this is the comfort chart as I said.

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And you can say you might have noticed that the comfort zones are bonded by effective temperature lines a constant relative humidity line of sixty percent. And due point temperature of two degree centigrade the upper and lower limits of humidity. That is sixty percent relative humidity which is the upper limit and two degree centigrade due point temperature are based on the moisture content related considerations such as dry skin eye irritation respiratory health and microbial growth okay. All these problems are related to the moisture content okay. So these upper and lower limits for humidity are based on these considerations.

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Now based on the chart ASHRAE makes the following recommendations inside recommended inside design conditions for winter. The operative temperature between twenty to twenty-three point five degree centigrade at relative humidity of sixty percent T operative between twenty point five to twenty-four point five degree centigrade at a due point temperature of two degree centigrade. Inside design conditions for summer or like this T operating temperature between twenty-two point five to twenty-six degree centigrade at a relative humidity of sixty percent and T operative between a twenty-three point five to twenty-seven degree centigrade at a due point temperature of two degree centigrade. So you might have seen that when the air humidity is over then you can maintain the conditions pace at a slightly higher temperature okay, when the humidity is higher than the required temperature will be lower.

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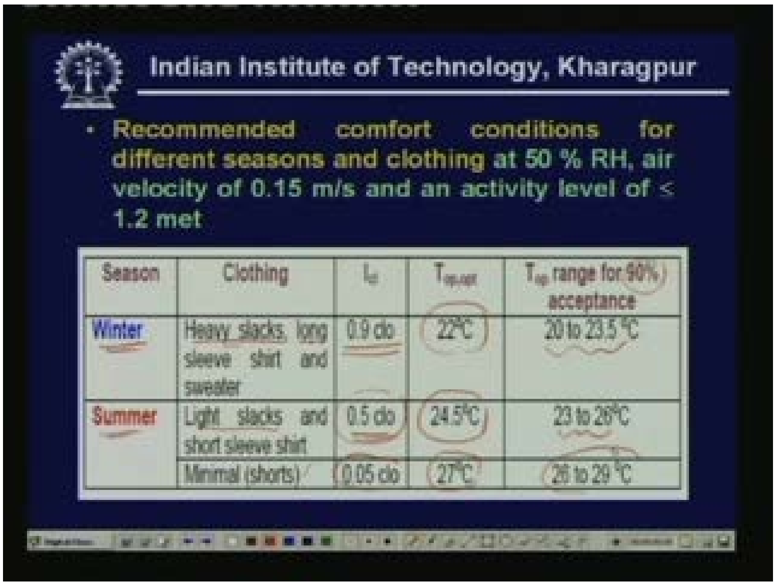

Recommended comfort conditions for different seasons and clothing at fifty percent RH air velocity of point one five meter second and a activity level of less than one point two met are given in this table for different seasons. As I said for example in winter okay, If a person is wearing heavy slacks with long sleeve shirt and sweater. That means it has clothing resistance of point nine kilo then the optimum operative temperature should be above twenty-two degree centigrade. But the temperature can vary from twenty-two to twenty-three point five degree centigrade for ninety percent acceptance okay. Similarly in summer if a person is wearing light slacks and short sleeve shirt which has a clothing resistance of point five clo. Then the optimum temperature required is about twenty-four point five degree centigrade. But this can vary from twenty-three to twenty-six degree centigrade with ninety percent acceptance.

Now you can see the affect of clothing if is wearing minimal clothes. That means let us ay shorts which has a resistance of point zero five clo then the optimum operative temperature become quite high okay. Twenty-seven degree centigrade and the range will be twenty-six to twenty-nine degree centigrade. So these are the recommendations and based on these values one can maintain or one can decide the required inside conditions for a conditioned space for both summer as well as winter air conditioning systems okay.

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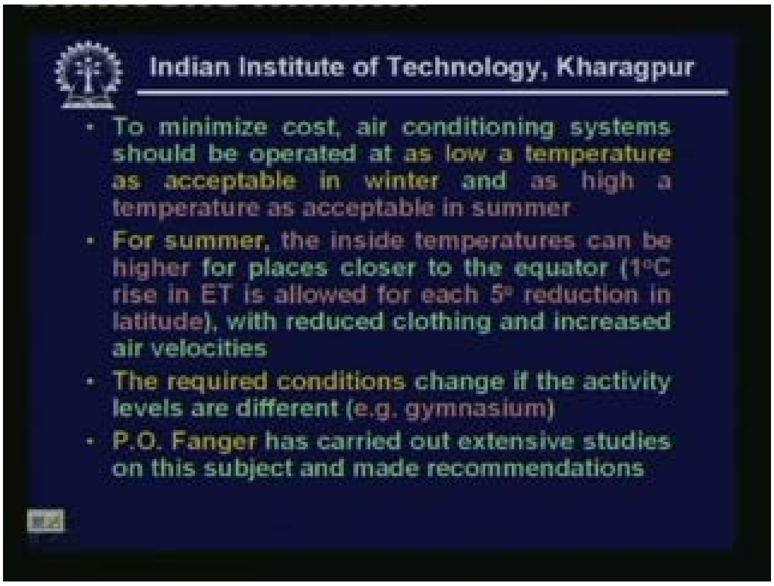

To minimize cost air-conditioning system should be operated at as low temperature as acceptable in winter and as high a temperature as acceptable in summer. For summer the inside temperature can be higher for places closer to the equator one degree centigrade raise in effective temperature is allowed for each five degree reduction in latitude with reduced clothing and increased air velocities. The required conditions change if the activity levels are different. For example in a gymnasium the required temperature may be much slower. Then what is recommender low activity and P.O.Fanger professor Fanger of Denmark as carried out extensive pioneering studies in this area. And he has made recommendations for several conditions.

So basically one thing you should keep in mind is an air conditioning system involves cost initial and running cost. So if you want to minimise this cost then the temperature inside temperature should be as high as possible. In summer and it should be as low as possible in winter okay. Of course which in the certain guidelines or within some acceptable ranges okay. So how this can be done for example in summer as I said the inside temperature should be as high as possible. So people should preferably low wear light clothes okay. If people are wearing heavy clothes in summer then required temperature in the conditions pace will be very low.

Once the required temperature becomes very low in summer then the cost of the air conditioning system becomes high okay. Similarly the required temperature can be increased by slightly increasing the air velocity. That means at higher air velocities required temperature also increases there by you can reduce the cost of the air conditioning system. Similarly the optimum temperature also found to vary from location to location. That means for people living in hotter areas the optimum temperature for summer air conditioning system can be slightly higher compared to people living in colder areas okay.

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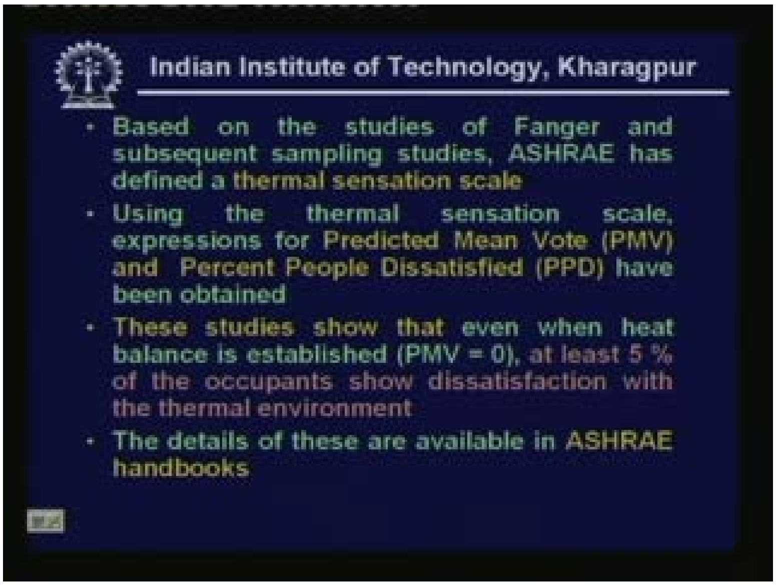

Based on the studies of Fanger and subsequent sampling studies ASHRAE has defined a thermal sensation scale using the thermal sensation scale expressions fro predicted mean vote and percent people dissatisfied have been obtained. So these are all more advanced thermal comfort indices. And these studies show that even when heat balance is established that means even when you maintain the neutral condition at least five percent of the occupants show dissatisfaction with the thermal environment. That means it shows that when you are conducting the studies with thousand people at least there will be fifty people who say that they are not happening with the surroundings okay.

That means it is not possible or impossible to satisfy all the occupants okay. Even when everything is perfect right this is based on the sampling studies obtained at several places okay. And the details of these studies and these indices such has PMV and PPD are available in ASHRAE hand books okay. One can look at ASHRAE hand book or one canread the excellent book on thermal comfort written by Professor Fanger okay. So with this i end this lecture. Let us conclude what we have studied in this lecture.

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In this lecture the following topics are discussed criteria for selecting inside design conditions thermal comfort heat balance equation for human beings factors affecting thermal comfort. Thermal comfort indices ASHRAE comfort chart and recommended inside design conditions for winter and summer. In this next lecture I shall look at how to select the design outside conditions. Thank you.