INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-37
Thermal Comfort

with
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Hello I welcome you all in this course on refrigeration and air conditioning. Today we will discuss the thermal comfort of a human being and requirement of thermal of comfort air conditioning.

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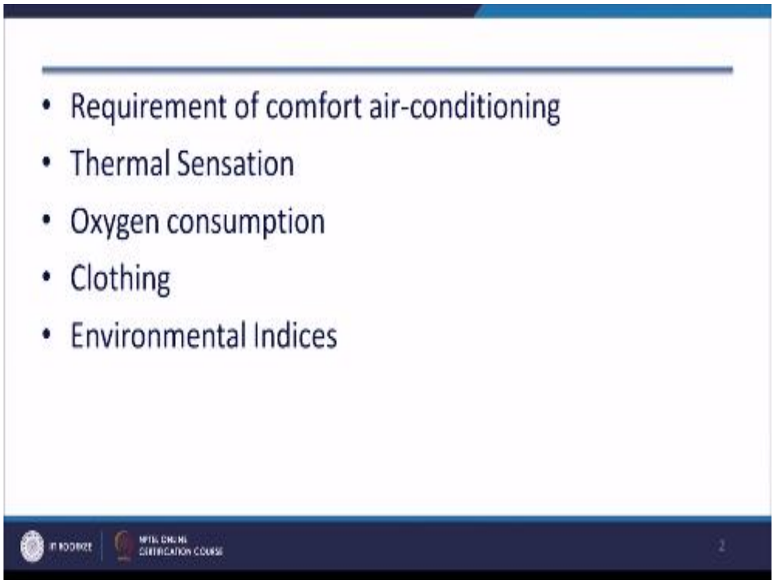

We will start with then we will talk about thermal sensation, oxygen consumption, clothing, effect of clothing on thermal comfort and environmental indices of thermal comfort. Now thermal comfort is required as I have told you in the previous lectures also to increase the efficiency of working efficiency of an individual.

If the efficiency offer individual is maintained then definitely the production in the industries will increase that is one thing even in the offices, the efficiency will increase if the offices are air-conditioned because second thing is outside environment it never keeps you in the state of thermal comfort either you have winter season or summer season or sometimes temperature is low humidity is very high in rainy season.

So that is why if somebody wants to remain in thermal comfort and an artificially controlled environment has to be created. Now in this environment ideally the temperature is has to be 25^{O}C and relating humidity of the order of 50%, but it outside in the world it does not happen. So you have some thermal sensations I mean you may feel hot, you may feel warm in the outside environment you may feel hot, you may feel cold and you may feel chill.

But say as an engineer we have to I mean quantify these things right. In order to quantify ASHRAE has quantified the thermal sensation and it has given certain points plus three is hot.

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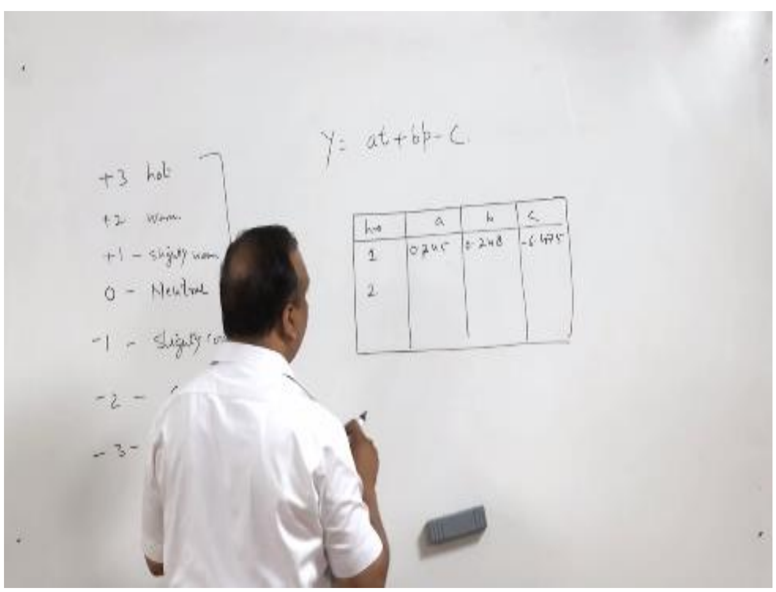

So we start with 0, 0 is neutral then +1 is a slightly warm +2 is warm, similarly -1 is slightly cool, then -2 is definitely cold and -3 is severely cold or chill. So these are the chill, so these are the indices by I mean thermal indices. And now ASHRAE has given equations for male for female generalized equation and there are number of equations, but stroker if you refer this book of a stroker you will find that it has given one generalized equation y = 80+ BP – C.

Now for A and B a table is given this is number of hours exposure for number of hours and for ABC a table is given, suppose the exposure is for 1 hour the value of 2 this value is 245 0.248-6.475. If exposure is for two hour for a particular environment.

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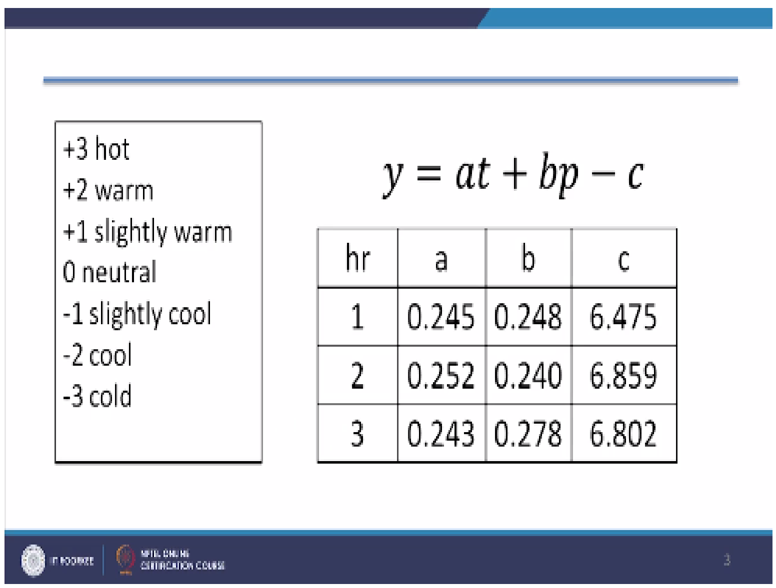

Then it is 0.25 to 0.2 40 - 6.8 59 if exposure is for three hours then 0.243 0.278 and - 6.802. So a stroker has simplified this. Now suppose somebody is exposed to an atmosphere, now we can take the conditions.

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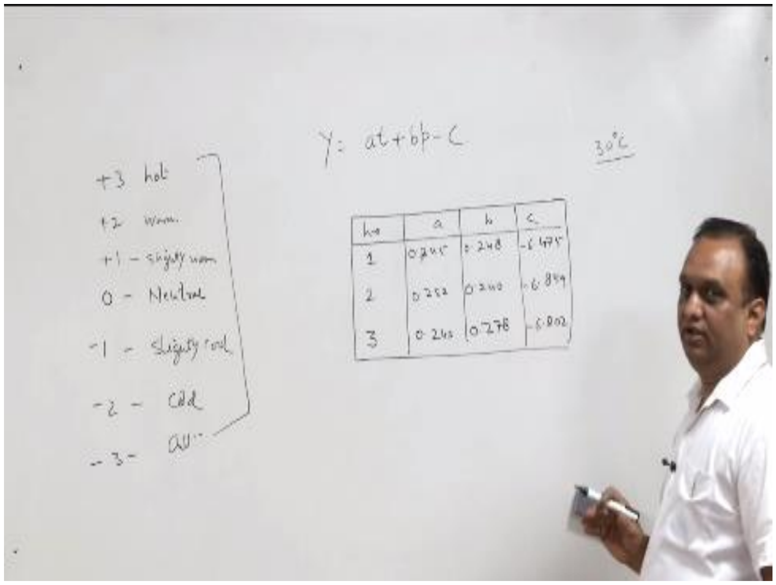

Suppose an individual is exposed to the atmosphere at let us say 30^{O}C.

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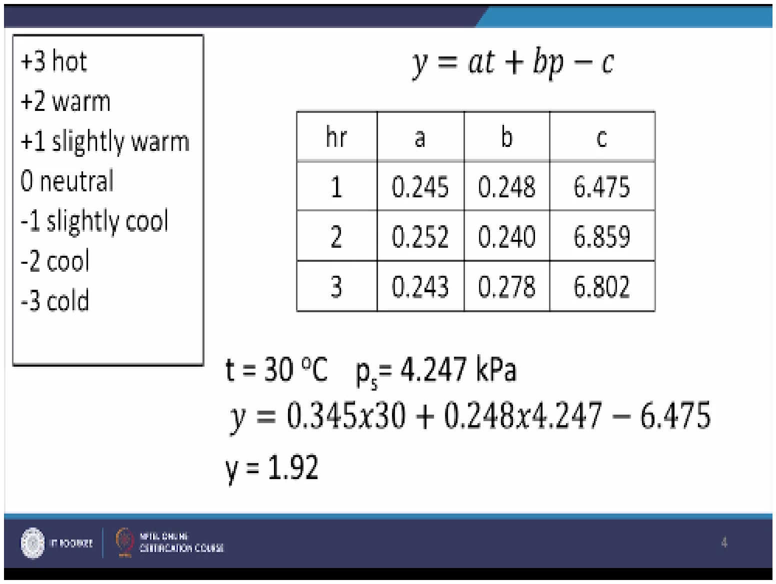

Now if somebody is exposed to 30^{O}C centigrade the feeling of firmness of coldness will also depend upon the relative humidity I mean temperature is not the only governing factor, so since it is going to affect.

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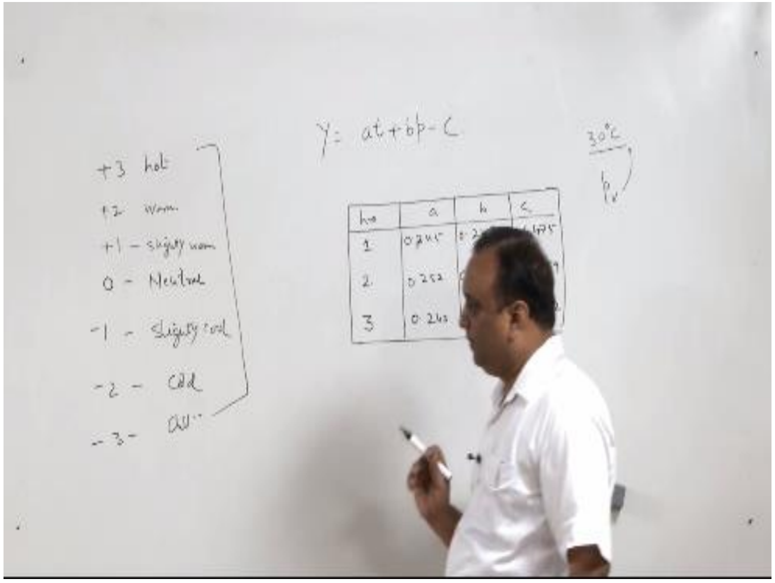

It is going to be related with the relative humidity saturation pressure of vapor saturation pressure of the water vapor at that particular temperature is also taken account here. So P is the saturation pressure of water vapor at this saturation temperature right.

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°C	p	h_f	h_{fg}	h_g	°C	p	h_f	h_{fg}	h_g
2	0.706	8.39	2496.2	2504.6	28	3.783	117.37	2434.5	2551.9
4	0.814	16.81	2491.4	2508.2	30	4.247	125.73	2429.8	2555.5
6	0.935	25.22	2486.7	2511.9	32	4.760	134.09	2425.1	2559.2
8	1.073	33.63	2482.0	2515.6	34	5.325	142.45	2420.4	2562.8
10	1.228	42.02	2477.2	2519.2	36	5.948	150.81	2415.5	2566.3
12	1.403	50.41	2472.5	2522.9	38	6.633	159.17	2410.7	2569.9
14	1.599	58.79	2467.7	2526.5	40	7.385	167.53	2406.0	2573.5
16	1.819	67.17	2463.0	2530.2	42	8.210	175.89	2401.2	2577.1
18	2.065	75.54	2458.3	2533.8	44	9.112	184.25	2396.4	2580.6
20	2.339	83.91	2453.5	2537.4	46	10.099	192.62	2391.6	2584.2
22	2.645	92.28	2448.8	2541.1	48	11.177	200.98	2386.8	2587.8
24	2.986	100.65	2444.1	2544.7	50	12.352	209.34	2382.0	2591.3
26	3.364	109.01	2439.3	2548.3	52	13.631	217.71	2377.09	2594.8

So now here we will take the value of saturation temperature from this table. So if the partial the temperature a 30^{O}C so t = 30^{O}C and partial pressure of water vapor at 30^{O}C is 4.247 right. So partial pressure of water we have also taken into account and with this if I take one hour working.

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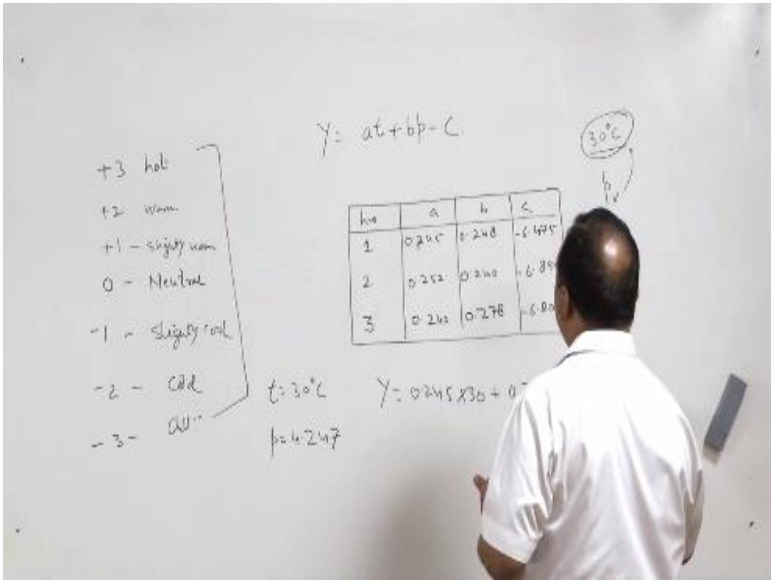

So one hour working means Y = 0.245 x 30 + 0.248 x 4.247 –

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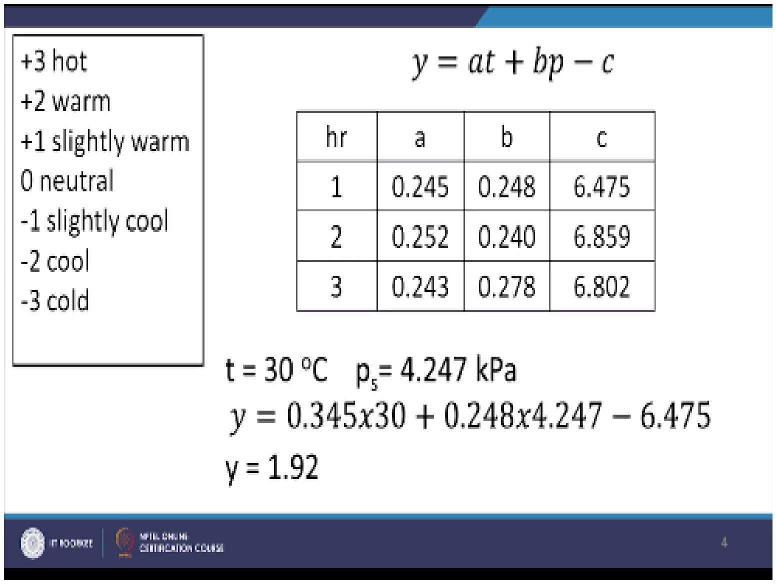

So it is - C it is already, I mean it will be -6.475. So y is going to be point 0.245 x 30 x 30 + 0.248x 4.247 – 6.475 1.92 y is equal to 1.92. So this is minus of here we will take this right.

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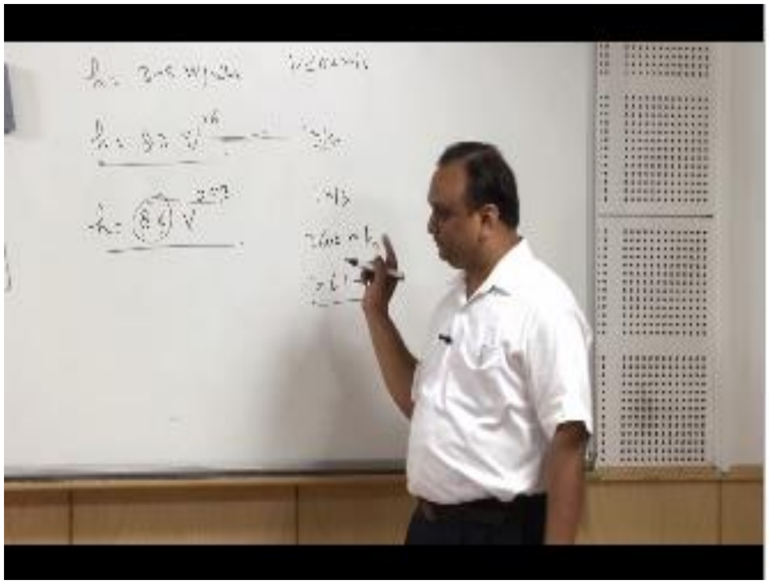

So it is y is equal to1.92, so 1.92 you feel slightly warm at 30^{O}C we can cross verify this. Now let us take let us go for three hours this is we have done for one hour. Now if we do for three hours now if you do for three hours then it is going to be 0.243 x 30 + 0.278 x 4.247-6.802 right. So here if the person is exposed to this temperature for three hours then we get 0.243 x 30 + 0.278 x 4.247 - 6.802, 1.67.

Now we can make a very interesting conclusion here y = 1.92 and where y = 1.67. So 1.92 is go towards warmer it is warm in fact and 1.6 so here the sensation of heat is less in this case here in this case it is more and it is obvious, if somebody is exposed to this atmosphere for 30 minutes definitely the body will try to accumulate ice this is the tendency of the body.

So body internal mechanism of the cooling of the body will be get accelerated and the feeling of the high temperature will be reduced if he or she is exposed to 30 minutes. And similarly we can do calculations for lower temperature you can do it yourself, by yourself temperatures and let us say 20^{O}C or 18^{O}C outside temperature let us see outside temperature is 10^{O}C.

Now outside temperature is $10^{O}C$ if outside temperature is $10^{O}C$ then partial pressure of vapor is 1.228 right, and with the help of these values point 0.245 x 10 + 0.248 x 4.247-6.475 we are getting 2.9 so outside temperature is $10^{O}C$ we will get almost chilling effect right. And chill if you look at the chilled water chilled water is approximately in a range of 4 to 7, 7 to $8^{O}C$.

So at $10^{O}C$ outside temperature you will get almost chilling effect. Now let us talk about this $30^{O}C$ we can cross verify this also our skin temperature is approximately $33^{O}C$ body temperature is $37^{O}C$ but our skin temperature is approximately plus minus $1^{O}C$ depending upon the outside temperature if outside temperature is high then skin temperature will also increase to reduce the heat flow to the skin outside temperature is low the skin temperature will go down.

And suppose evaporation from the skin that it increases the lowest of the temperature of the skin anyway so it is considered $33^{O}C$ plus minus $1^{O}C$. So it can be $32^{O}C$ or $34^{O}C$. Now if outside temperature is let us say you have to find outside temperature body temperature is skin temperature is 33. Suppose we are sitting in outside environment doing not doing any activity the heat liberated from the body will be100 watts.

There is a breeze in that case H can be taken as 10 w/m^2k area we have calculated in the previous lecture maybe you can take 1.7 or 1.8 let us take 1.8 m^2k so not m^2k. With this help suppose all the heat is dissipated by convection heat transfer, so 100 = Q, Q = $HA\Delta t$, so H is 10 for the sake of convenience I have taken these simplified values $1.8\Delta t$ is going to be 100 right.

And if this 100 is divided this is 10, 10/1.8 and that is going to be approximately 10/8, 10/1.8 5.5 approximately these are all approximate values. So Δt is 5.5 it means if body temperature is $30^{O}C$ outside temperature has to be $5.5^{O}C$ less than this is it has to be $28.5^{O}C$ $27.5^{O}C$, it if outside temperature is $27.5^{O}C$ all 100 watts of heat will be liberated.

But as we know that part of this heat is also taken away by the evaporation from the skin, so that is why you must have realized that when outside temperature is 29 ^{0}C, in the month of February or march or in the month of September you start feeling slightly uncomfortable, because convective heat transfer is not sufficient.

So either you increase the H, by blowing a air over the body, or that is one way of enhancing the heat transfer, that is why when you are sitting in the fan when you are sitting under the fan this H increases, this edge increase will reduce the ΔT, it means instead of feeling comfortable at 27.5you may start feeling comfortable at 29 ^{0}C, or for that matter 30^{0}C, that is why when the weather is extremely hot and you are coming from outside, and sitting before the fan, you feel extremely it's an extreme state of comfort, you feel very comfortable.

The reason being the value of H increases, in that case now value of H for, the air where it is less than 0.2m/sec, in that case the value of H is 3 to 5 w/ m^{2}K, the velocity of air is less than 0.2m/sec, but otherwise if the velocity is both, in that case there is a correlation 8.3 v $^{0.6}$, now using this correlation you can find the value of I.

Suppose velocity is 1 m/sec, if velocity is 1 m/sec, in that case you can find the value of H as 8.3 w/mK, right if you are walking if you're walking you about sitting, suppose you yourself is walking in that case this relation is slightly modified, it becomes 8.6 or this thought ends to be flattered 0.5.3, so if the air is blown over you with 1m/sec H is 8.3 if you are walking 1m/sec, in that case I mean 1 m/sec, is not very fast walking 1m/sec, is 3600 m/h, it is 3.6km/h, this is normal walking speed, this is not very high walking speed.

So if you are walking 1m/sec, the value of H is going to be 8.6, so instead of air is blown over you if you walk with this same speed the value of h is higher right, now in air conditioning environment, suppose am sitting in here in the conditioning environment wearing only a half sleeve shirt, another person is sitting with the suit, so the person who is wearing a suit definitely demand lower temperature, he will say that i am feeling comfortable add 22 ^{0}C.

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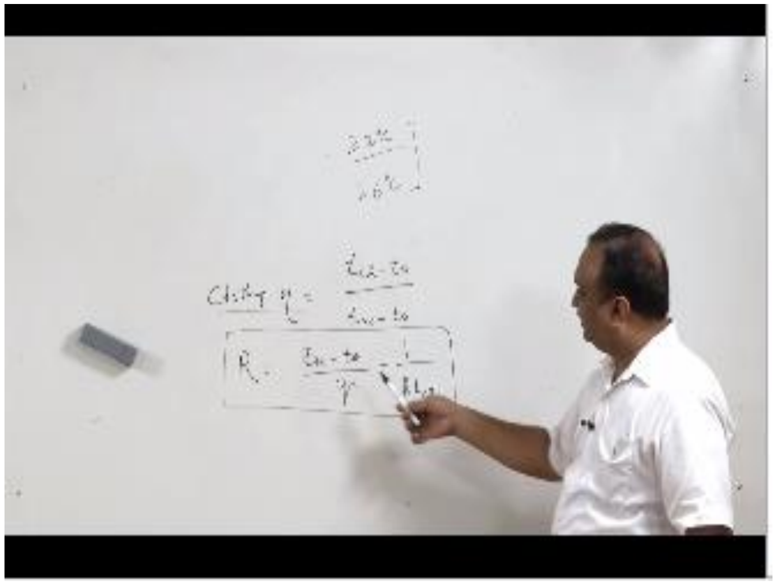

I am very half sleeve shirt, I will say I am feeling comfortable at 25 or 26 ^{0}c, so this clothing also because this these clothes X, at s a as an insulation and thermal efficiency, clothing thermal efficiency, is T CL - T 0 / t s k – tu, it means temperature of cloth suppose the temperature of this cloth outside temperature divided by skin temperature, minus outside temperature, that is clothing efficiency right.

If the cloth temperature is also a temperature, then efficiency 0, now so the clothes also offers and resistance, are thermal resistance and this thermal resistance is equal into skin temperature, minus outside temperature divided by heat flux minus 1/ h f CL. it is nothing but simple equation of conduction convection heat transfer, through that equation it has-been driven, this is the resistance offered by skin and outside, this is film coefficient film resistance because here I have when conducting heat transfer over the cloth, a film will be formed over the clothes, so that resistance has the difference of these two resistance will give the clothing resistance right.

Now this clothing resistance is expressed in terms of cl_o and 1 CL $_0$ = 0.1 55 m^{2}k/w, now I will show you one diagram, related with the comfort with clothes clothing, now these are ashtray, summer and winter comfort zone, but since inside environment is same, so it has to be same actually assumes inside temperature 24 ^{0}C, but if you look at the summer and comfort zone.

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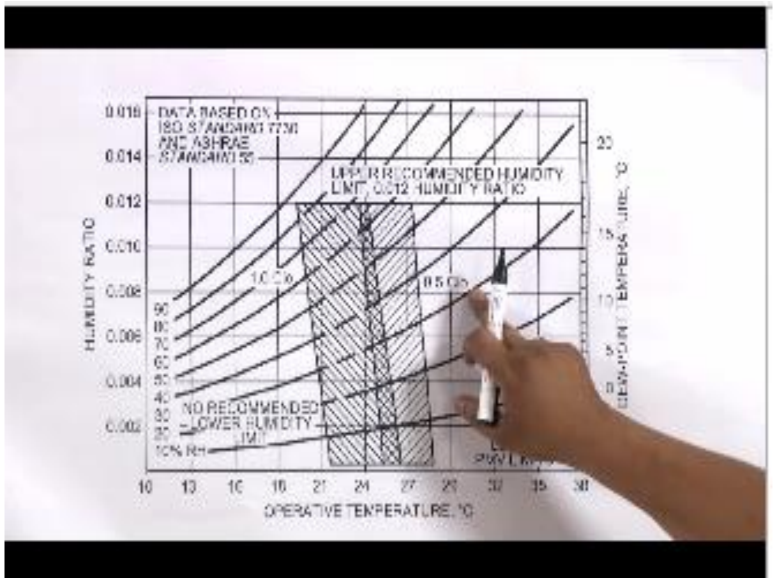

This is 0 .5 CL0,this is equal into summer clothing like my clothing, my clothing will be approximately 0.5 CL_O, now if you go to the winter clothing it even I am wearing a suit, or a coat or in that case it is going to be approximately, 1.0$CL_{O,}$ and the data are based on the ASHRAE standard 55, airspeed is less than 0.2m/sec, you can see but they have not very distinctive boundaries, operative acceptable level of operative temperature, it is safe or winters if you are have any clothes, it is starting from 21 or 21.6 or 21.7, and when the humidity ratio is increasing, the operating temperature is also decreasing, and when it comes to this, because this is the upper limit upper limit, of a specific humidity that is 12 milligrams per kg of dry air, it turns out to be around this is 18 did 18 18.5^{0}C approximately.

18.5 18 and 21, 3 so if rock separately 19.5^{0}C, then when the space k humidity or humidity ratio is specific humidity, and humidity ratio are same, when it is really reducing this temperature is also rising, and when the humidity is very this is very low, then it is approximately at 21.5 or 21.6, no here from here we can infer that for higher humidity, we can go for the lower place.

So if the temp outside temperature is low, if humidity is high the feeling of cold sensation will be less, now when this is summer clothing, and now here you can see again if the relative humidity is low, we can go up to 27, 27, 28 .5^0C, and the moment in the humidity starts increasing the temperature keeps on reducing, and this is upper limit, it comes to 27^0C, beyond it this is not a comfort zone, this is the comfort zone, this is the shaded area is the comfort zone for summer and winter as well.

But in under any circumstances or, the specific humidity is not allowed to be more than 12 milligrams, per kg of dry air so this is a restricted area, this is a restricted area here you are not supposed to design the system, and in the comfort remains is confined to only this area, and this is the operative temperature, of the surroundings.

So this is for seed entry activity, I mean seed entry activities where somebody is sitting writing or typing, when the metabolic rate is less than 1.1m, if metabolic rate is high definitely these ranges will also change, and you can find there is overlapping also, here I already told you that these lines are not very rigid lines, they also depends upon the person which geographic region, he or she is living in, or which race they are belong do it depends on many factors.

But there is statistical data, and they are widely agreed data, for internal come for the comfort of occupied space, now similarly we have another graph, for air velocities an operative temperature, now in this graph on y-axis, air velocity is taken, and on the x-axis.

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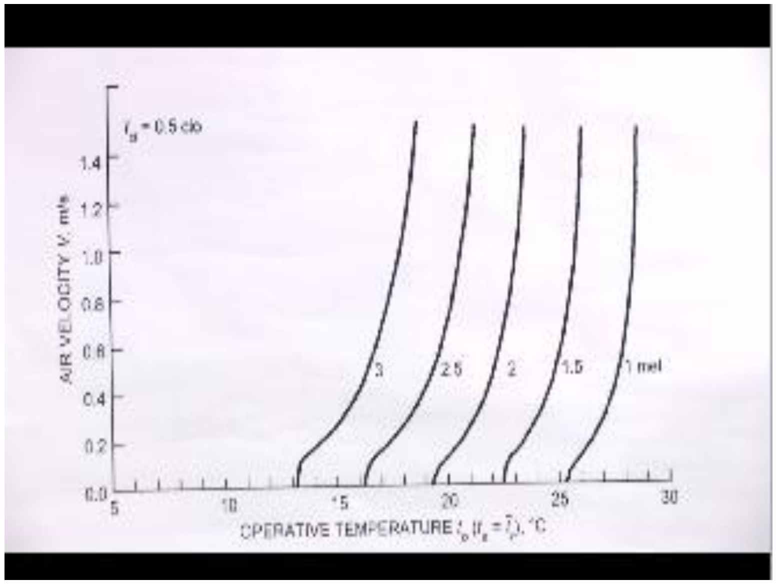

The operative temperature is taken, now activity suppose one mate activity is there, the operative temperature, where air velocity zero error loss t is not zero, if we take approximately 0.2 so operative temperature is approximately 26^0 or 27^0C 25, 26 points something, but the moment velocity increases we can go for higher operative temperature.

This fellow man I have already explained, you if you here is blowing with a higher velocity operative temperature, will increase so in this direction metabolic activities are increasing, suppose this is 3m, 3m you can find, if the air velocity is 0.2 turns per second, this is for clothing level of 0.5 with this for summer clothing.

So the temperature is going to be 13 or 14^0C, and this is letting temperature at 50%, relative humidity necessary for comfort predictive PMV, is predicted weed wood this 0 1 2 3 classification, I told you from chill to the hot climate, so predictive meet word means posted, we work means 0 means a person in this environment or a particular environment is feeling extremely comfortable okay. After this we’ll start with the last topic to be covered here, environmental indices,

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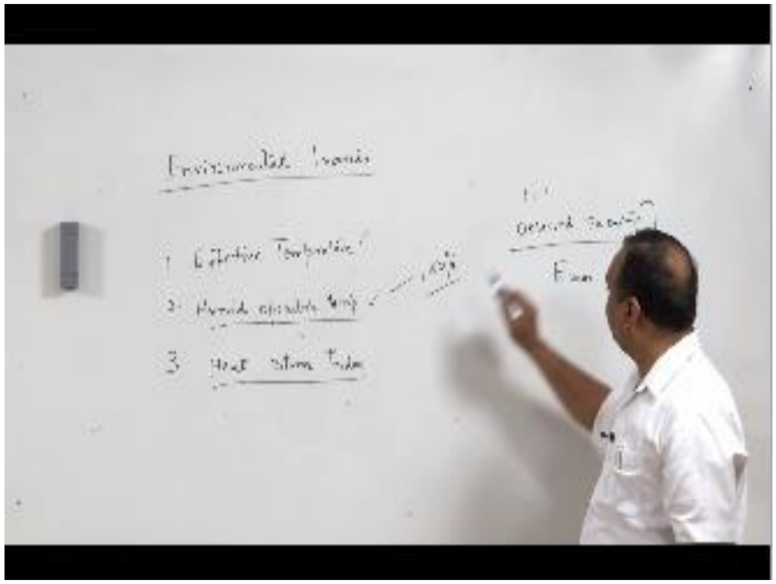

Environmental indices of two or more parameters into signal parameters, so just you look at this in this index, a particular index and you come to know about the environment. first is effective temperature, now another one is humid operative temperature, and third one is heat stress index, effective temperature I have already explained you previously, humid operative temperature is the temperature of air, which is 100% humidified or relative unity is one 100% and seem amount of heat is dissipated to the surroundings.

So that is known as humid operative temperature, now third one is heat stress index, that evaporation from the skin heat stress index is, observed sweaty from the scheme maximum possible, sweating from the skin, and this ratio is known as heat districts index, if we have the value of these if this is we can have fairly good idea, about the state of thermal comfort in a confined environment, this is all for today in the next class we will take up indoor environment health thank you very much.

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