Energy Efficiency, Acoustics & Daylighting in building
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Lecture – 28
Ventilation

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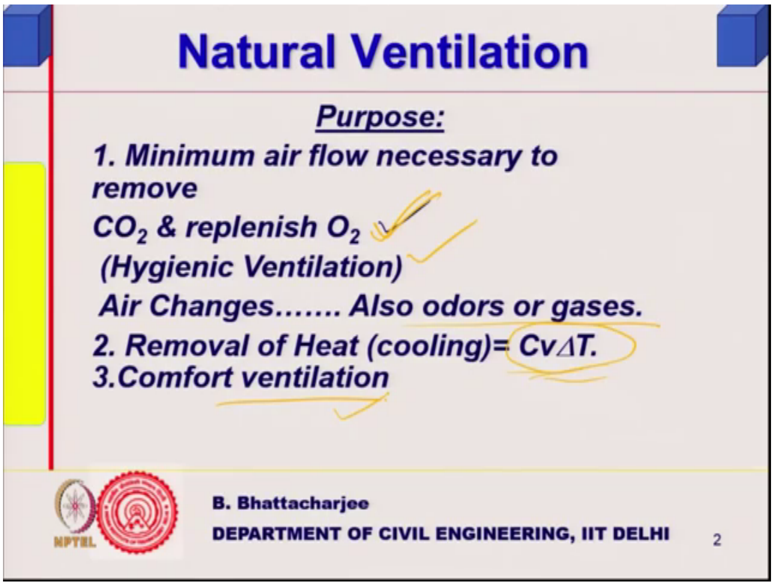

So, that is what we are saying purpose of ventilation is threefold purpose of ventilation are actually three folds; hygienic ventilation air changes right and removal of it and comfort ventilation.

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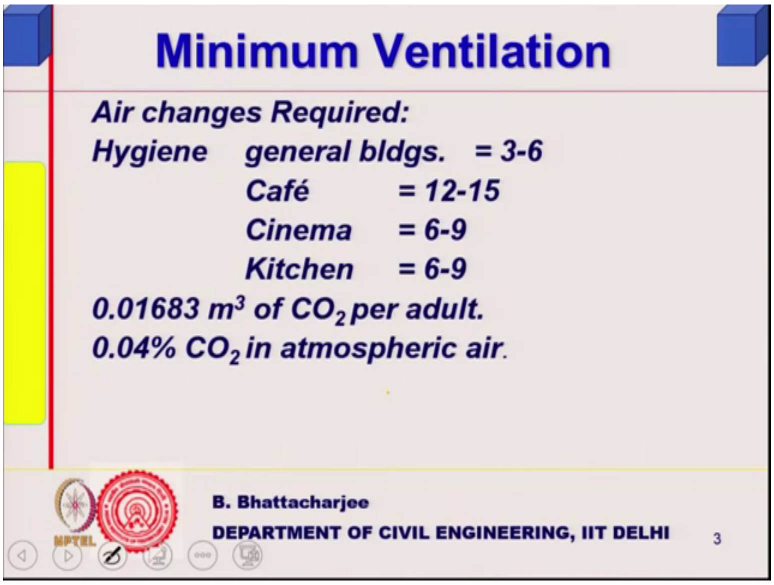

So, this is given hygienic ventilation is given, based on what this is the amount of carbon dioxide, this is the carbon dioxide oh. This is the amount of carbon dioxide you know exalted by every adult and this is what atmospheric carbon dioxide, typically 0.4 percent is a carbon dioxide you know in atmosphere right. So, how much you got to remove will depend upon number of persons. So, in a restaurant a large number of people will be sitting at a one go. I mean we are talking about one; the open air type the true scenario, so number of people will be sitting together.

So, the cafe you can see that is 12 minus 12, I mean 12 to 15, sorry 12 to 15 12 to 15 and general habitable building 3 to 6 air changes, we understand; of course, what is the air changes, this is the minimum required cinema is higher kitchen is higher, because kitchen you also got to remove the gasses you know gases coming out of the cooking, even cooking you know the food, food you know oil etcetera. So, the smoke that comes out, so therefore, this is the basis, this is given in code, this is given in code you know one can calculate this out roughly.

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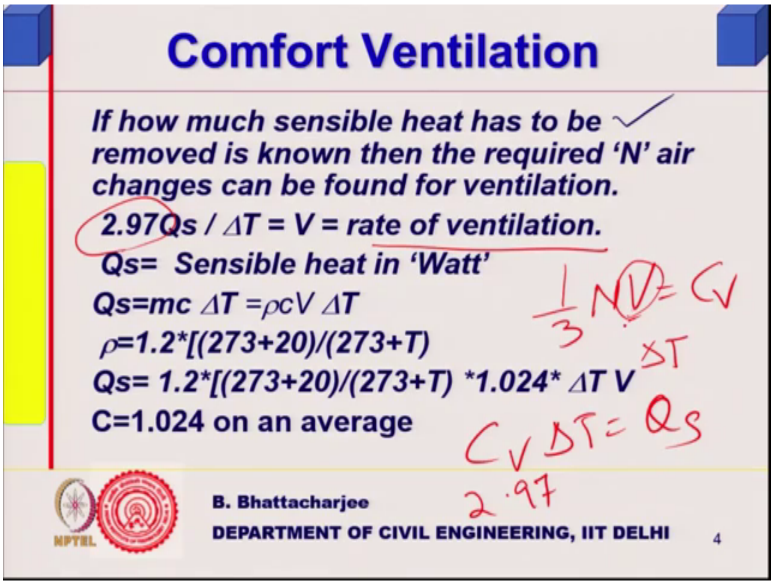

Now, how much is, you know if it is for removal of heat, then how much sensible heat is to be removed, if it is known then required air changes I can find out. We said that if you remember we said 1 3 N V; that is equals to C v approximately and delta T. So, if I know v, you know in meter cube or any y I want to find out or if that sensible heat to be remove is actually C v DT, sensible heat this equals to QS, which can be written as approximately one-third or slightly you know more accurate is 2.97 into C v, it was a rate of ventilation if I expressed, it was number of air changes in the volume of the room, but if it is in meter cube per second. If you go back to your original equation, it was you know we, how did you get this C v basically.

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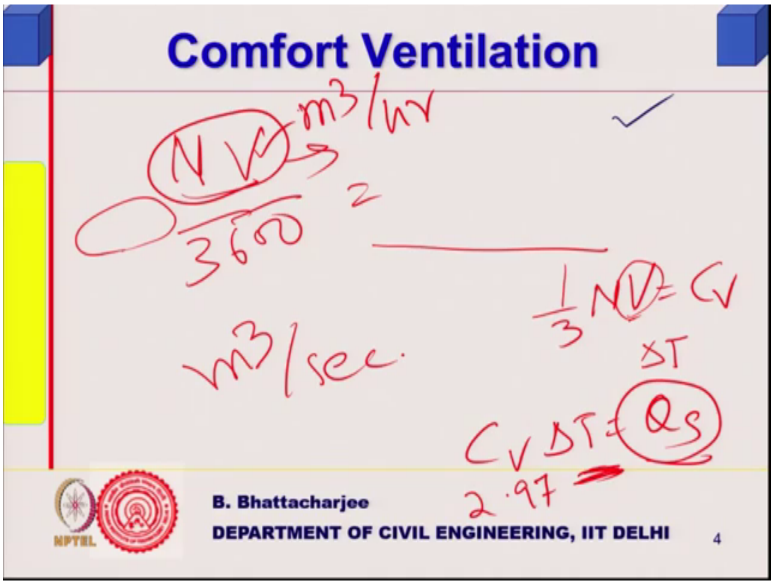

We said N is the number of air changes per hour; V is the volume of the room right. So, this is, if I want to convert this into meter cube, this is per hour this should be divided by N is the number of, N is the number of air changes per hour, so meter cube this is in meter cube, this is that many meter cube per hour, that many meter cube per hour, this divided by 3600 will give me per second.

So, that would give me you know meter cube per second. So, one third one, you know like based on this basically. So, seaweed, if the sensible heat I want to remove is known, the temp or degree if I know it or if I know the temperature difference, then I can calculate out how much QS or meter cube per second, flow rate how much, it should be based on this based on this right. So, if I know this, if I know, if I know, if I know QS amount of it have got to be removed, QS is equals to v delta T divided by 1 by 3. So, this should be you know this, what is this, in meter cube per, then the required N air changes we are in.

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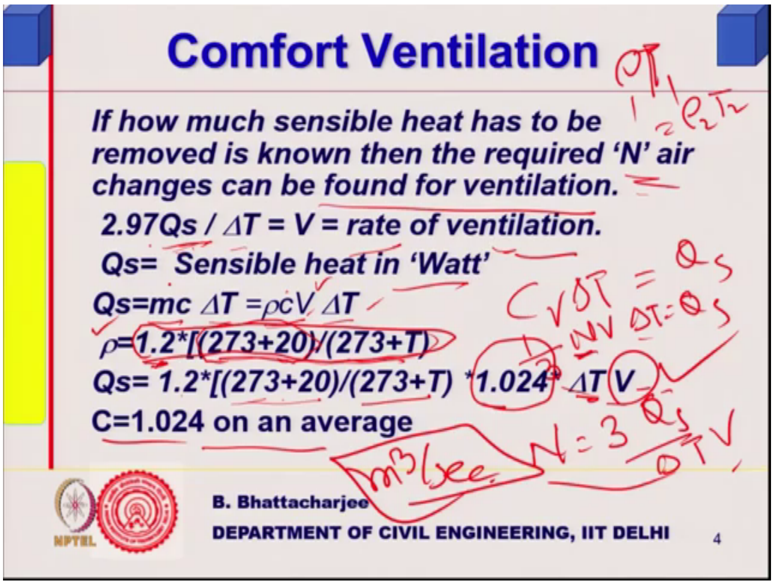

So, this basically this is what we are saying is C v delta T is equals to QS, and C v is roughly about one third N into V. So, N into V delta T is equal to QS. So, I want to find out N number of air changes that will be simply 3 QS divided by delta T delta T, where is the volume of the room must be coming somewhere. The volume of the room should have come here; delta T, delta T has come together with this issue according me, per meter cube of the per, it should be per number of air changes can be found out from ventilation from this one sensible heat and this is per meter cube of the room volume actually.

This will come out to be per meter cube of the rate of ventilation per meter cube of the room volume or you can anyway we can calculate out simply from this one how much meter cube per second, I want to find out even that I can find out, because this is what I will be using later on. So, I can easily find out sensible heat how much, depending upon how much sensible I eat I got to remove, what is the number of air changes I require I can find out. Number of air changes depends upon I know depending upon how much. So, if in my ventilation design will be based on. Ventilation design means, the required m or meter cube per second. So, I can convert it into meter cube per second and find out. Now QS is equals to m 3 delta T ok.

So, rho C v delta T mass into volume into delta T, volume of the room. Rho can be actually now I can do a little bit of more complication rho. And here you take roughly around 1, you know that we took 1300 rho C, we took 1300 remember and then we said 1300 by 3600, and you take a little bit more elaborate then, we know at 20 degree centigrade rho is 1.2 kg per meter cube. At any other temperature it will be 2 7 1.2 divided by 1.273 plus 20, you know sorry divided by 273 plus T multiplied, because rho and T rho into T rho 1 T 1 must be equals to; that is right.

So, 273 plus 20 is the temperature corresponding to 1.2 divided this will be a rho at any temperature. So, this is 1.02 is the C taken delta T into V. So, one point on an average C is taken as this. So, you can complicate a little bit more and find it out the V, instead of taking a constant rho or one third you know one, I mean that one third equation, we can make it a little bit more complicated. Also we can find out how much latent heat I have to remove.

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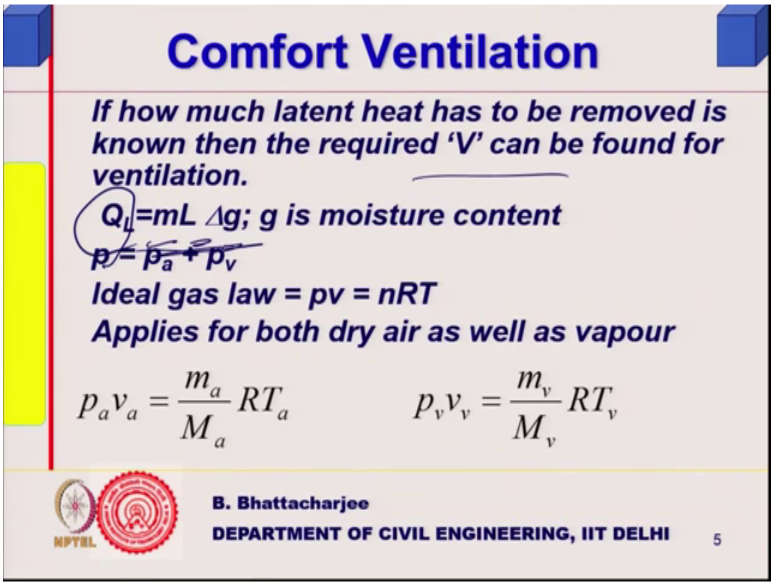

So, if I know the sensible heat I want to remove by using the formula that we have used, we can find out how much meter cube per second I got to remove. And here I can be more accurate using the density rather than simply one third NV, I can use rho as depending upon the temperature, average temperature and C as 1.024 kilo joules per kg as we have seen. I can also find out how much latent heat I want to remove, because you see it is not only the carbon dioxide, but also the vapor, moisture vapor generating out of the suet etcetera etcetera, also through our respiration process, besides if there is a process, let us say if I have a kitchen and I have hot food, I am serving hot food.

So, moisture will evaporate from the food itself, moisture will evaporate from the food itself. When cooking is usually boiling through water, so there could be some evaporation occurring and I got to remove those moisture also, some cases of latent heat removal is important. In any case latent heat removal will be there. Supposing air comes a dry air comes from outside, it will to more absorbed moisture from the room also, irrespective of whether you know you have designed it for or not.

So, latent heat has to be removed, you can find out from that considerations also, what is a required flow rate what is the required flow rate supposing you know, so to QmL the amount of heat I want to remove is mass into latent heat into delta g is the difference in the moisture content of air, dry air comes from outside, it absorbs moisture; therefore, you know it is moisture content will change, absolute humidity of the air inside and outside could be different.

So, if it is inside, you know if it comes and absorbs moisture, then it goes out together with the moisture it actually also carrying that latent heat of evaporation, latent heat of evaporation, because latent heat of evaporation is also being removed you know. So, the dry air comes it absorbs moisture. If it is in liquid form then it has to be vaporized. So, what from the heat will come, it will come from inside itself. So, this is the latent heat removal mass into latent heat into delta g and mass will be rho into volume of the room, rho into volume of the room. So, using that partial vapor pressure equation which I think I have given you earlier, applies both dry air as well as vapor, and we know that ~~p~~ P a ~~v~~ V a etcetera etcetera this we looked into earlier p v etcetera, this we looked into earlier right in the beginning we have looked into.

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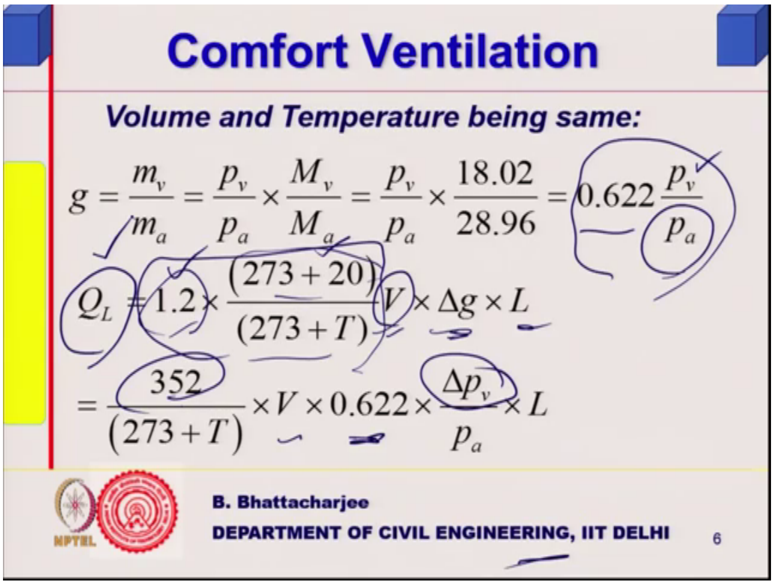

And from this one can actually find out the moisture content is 0.62 0.622 partial vapor pressure vapor and pressure of you know air. So, from that we get g is the moisture content we can relate to. Therefore, Q L 1.2 is a density, this is a temperature at 20 degree centigrade when it is 1.2, at my temperature this is the density into V into delta g and how will you find out delta g from partial vapor pressure outside and inside, because using this formula right.

So, delta g and L is a latent heat. So, this comes out to be 352 this multiplied by 1.2 is 352 into V is a volume of the room, if I am looking at or flow, directly I can look into flow 622 into vapor pressure difference between outside and inside, delta p v divided by p a into L. So, from this I can find out again V, if I know how much latent is to be latent heat, it is to be removed, how much latent heat is to be removed. You know how much moisture vapor is present inside the room and correspondingly how much latent heat removal is possible, that if I know from that I can find out the way we required.

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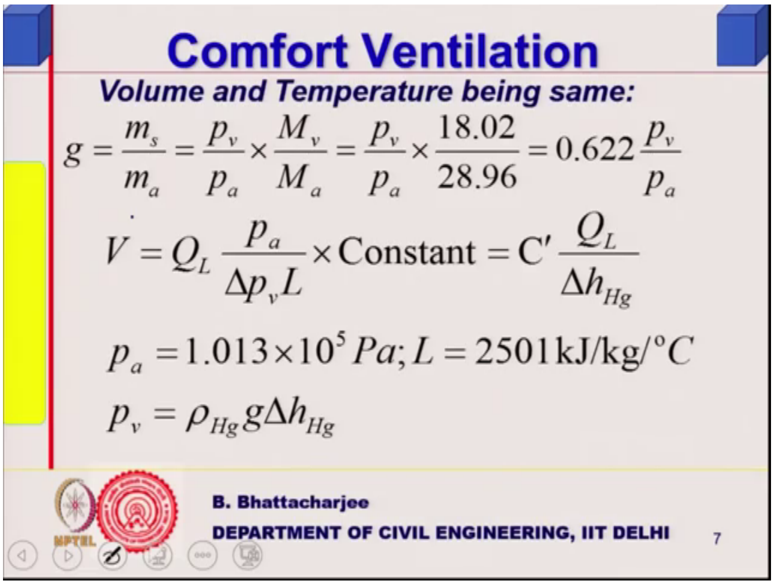

So, g, this we have seen and then therefore, V is nothing, but some constant Q L p a delta p v L from this equation simply V is expressed V is expressed from this one, you know V is equals to Q L. So, Q L by L pa divided by delta p v Q you know. So, this was V is Q QL by L pa divided by delta p v into all rest of them things are all constant. So, it will be delta this p v can be expressed in terms of mercury high to have mercury height of mercury or head of mercury.

So, delta H g vapor pressure can be expressed in the, in terms of mercury head pa is atmospheric pressure in Pascal l is 2501. So, one can get an expression for p v is equals to rho of mercury g, g delta g that is what is the p v, because it is a head difference of mercury head difference, you know manometric a difference of vapor pressure outside and inside. So, therefore, p v can be expressed in this manner, and if you do that it will give you dealt sorry delta Hg is allowable vapor pressure difference in millimeter of mercury.

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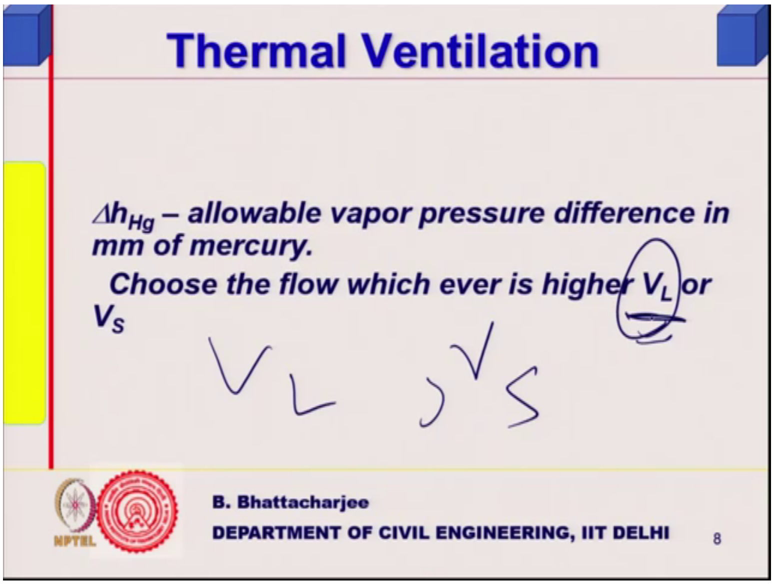

And from this we can calculate out the V values, from this you can calculate out the V, from this you can calculate out the V, C is the constant, C is a constant which will depend upon all these factors that we looked into and from this you can find out what is a V required. So, whichever is higher V, you choose that, whichever is higher V, whether V latent it removal or V for sensible removal. Sensible heat will come from where temperature difference; Cv into delta T is equals to QS. So, if I know how much heat I want to remove sensible heat I want to remove.

Some cases latent heat may be generated removal might become more important through ventilation right, usually that is not the case, usually latent heat removed to be removed is less, but supposing lot of vaporization is occurring inside, kitchen or something like that right or some processes. Not kitchen even some processes where lot of moisture is evaporating all the time. So, you got to remove that heat generated through evaporation, then latent heat might become a dominant factor and quantity of ventilation required you can find out. Because latent heat you want to remove QL is equals to the flow multiplied by the rho into L right.

So, into delta g or basically delta g is the moisture content difference, moisture content difference, how much moisture vapor, vapor is generated that is moisture you know moisture content difference. Now moisture content difference can again be expressed in terms of partial pressures. Moisture content can be expressed in terms of partial pressure;

atmospheric pressure and partial pressure difference we did not outside in inside through the formula that we I have given and if you convert them into a head of mercury, head of mercury, so delta H g, all are constants except this part of the formula that we have seen, this part of the formula C dash.

So, V can be obtained from this equation, if you know how much Q well latent heat you to remember remove in processes, but usually this will not be large, usually in room, habitable rooms residences etcetera. This will be small whichever is small you ignore it, whichever is higher out of you know meter cube per second or number of we changes you found the found out for latent heat transfer or sensible heat removal, whichever is higher you choose that, because that will ensure automatically the other one is satisfied.

So, either VL or VS, as we have calculated like VS we have calculated in, VL we calculated from this formula, whichever is higher VS we calculate from this formula, so whichever is higher that you choose and that is what is good enough for our purpose for natural ventilation. So, that is what it is that's, that is what it is. So, first is you find out you know whichever is greater. So, this is relative removal of heat, minimum is hygienic ventilation that you have to provide in any case. If this value is higher than hygienic well ventilation required then; obviously, you will provide you and this is really higher right. If you insure want to ensure some heat removal also then it has to be higher.

So, whichever is higher you will be choosing them and then what are the forces velocity aspect we are coming later, that is slightly differently looked into, but today you have got actually, if you want to go in a full analysis of a large building, large space, naturally ventilated or ventilated; otherwise you have CFD models solving draw vast equations actually. But this is simple principle I am talking about, in this class we are talking about principle you want to use it in a large building, then possibly computational fluid dynamics models one can utilize.

Otherwise largely is based on empirical results, the velocity calculation well come to that sometime later. So, the principle wise driving force. What are the driving forces for ventilation? Driving force for ventilation are, either wind or it can be driven by tunnel gradient also, that is what we have seen in when we are looking at wind tower. So, this is, this is what we call as stack effect, this is called a stack effect and wind driven is what is the common, wind driven is what is the common one right.

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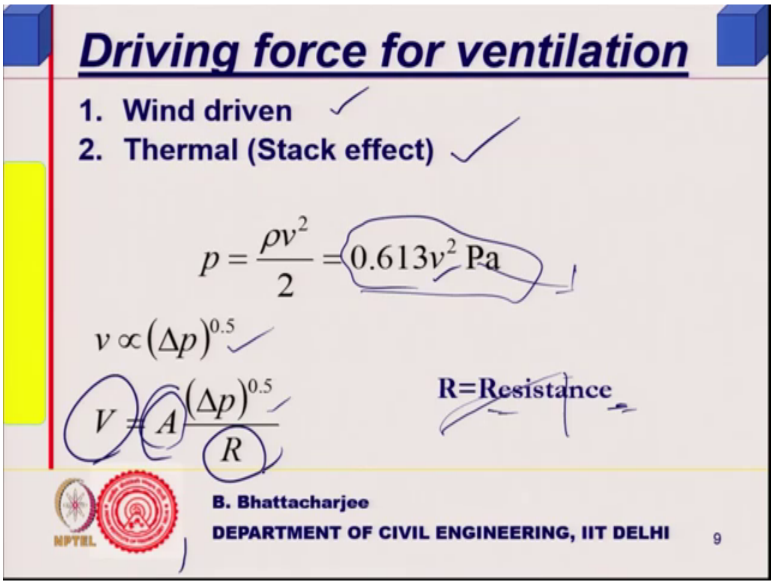

So, wind driven is a common one and you would have calculated as. You know when you have done designed for wind load pressure on a, pressure on a surface right. So, from it would come out from Bernoulli's equation actually, pressure is half rho v square and it is 0.3613 v square corresponding to right. So, what we see is velocity, wind velocity if it is v, then pressure is proportional to delta p to the power 0.5 right. So, v is proportional to delta p to the power 0.5 and flow is velocity multiplied by the area.

So, meter cube per second flow would be proportional to A into delta p right, but if I have a window or opening, I have some window or opening, it will offer some sort of resistance, some sort of resistance to flow. So, that I am calling as R. So, the you know if it is wind driven the flow meter cube per second or NV is a function of area of the opening, function of pressure difference between these two sides and of course, a resistance factor divided by resistance, because you know this, there will be stream flow even if you assume stream flow, you know the flows there we ventilation of effect and it would actually there is a resistance of, what it is not free flow right. So, this is R takes care of that.

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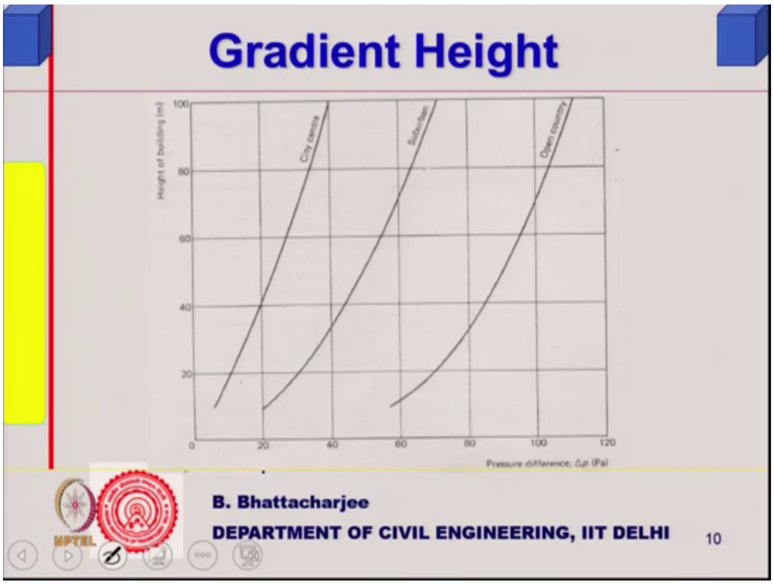

So, R is a resistance, R is a resistance right. This we have seen velocity as a function of height. Remember this we talked about, when we are talking about climatic parameters we mentioned gradient height and you can see that this is in open country, this is in city centre and this is in suburban, if you remember. I think I might have shown in this diagram or may not have shown. So, delta p is something like this velocity you know delta p or velocity both changes, velocity changes. So, delta p would also change depending upon where you are, open country, near the ground it would be, yeah it is very small or near T 0 boundary layer effect would be 0, it would be 0 actually. So, height of the building it depends upon height of the building.

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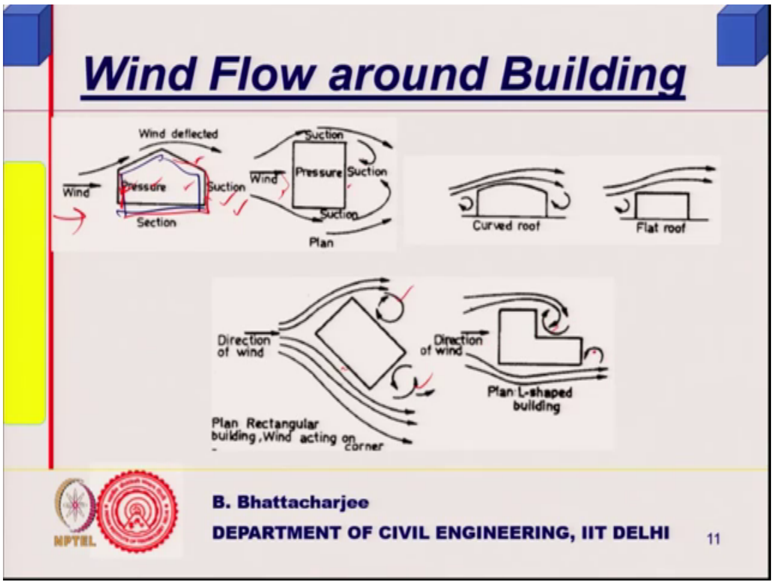

So, delta p is a function of height and if I want to find out delta p you know around, just about air opening, then I must find out the wind flow pattern around the building, because the pressure I have I have, let us say I have this building right, building, I have, I have this building. Let us say this is the building I am looking at, the wind direction is this and the moment let us assume it is normal. So, it will get stuck here, it will be obstructed. So, there will be excess pressure here right and it would flow in this manner. There will be a partial vacuum here, a suction or partial vacuum here.

So, on the windward's side you will have excess pressure. On the leeward side you will have partial vacuum or suction. So, that results in the flow through the building itself, that results in flow to the building itself. In plan if I look at a square plan let us say, so this here ill have excess pressure some suction here as well and some suction, there forming eddies, so that is how it is. So, in flow pattern around the building what we have seen so far, flow is proportional to delta p to the power 0.5, it is a function of area and divided by resistance of course, and then around in a building inward direction you will have excess pressure, on the leeward side you will have suction.

So, that creates the pressure difference delta p over the whole building, but inside there will be some pressure, outside there will be more pressure in this case. And here there is less pressure, because suction and slightly higher. So, if you have windows here and windows there, there it would actually result in cross ventilation or flow of air through the room space or building, you know space inside the building. So, that is how, that is what it is.

So, you can see different types of curved roof they look like this, flat roof they look like this. If it is at 45 degree angle, then you will have possibly excess pressure somewhere there, suction there, suction there. If it is something like this, there will be suction here, suction here and partial some suction plane L shaped. So, depending upon shape of the building and direction of the wind, you will have some inward areas and some leeward areas. Leeward areas are the areas where you will have suction and there are other areas which will have high pressure on things. So, you will have high pressure and high suction on some other places. So, that results in delta p and that results in flow.

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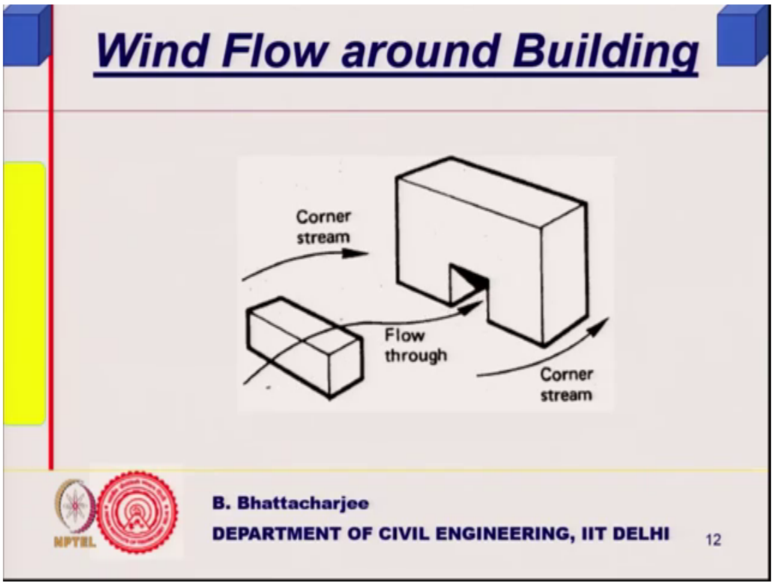

Now, if you have two buildings in series right. So, you see this, this flow through this should be, it would be, it would be suction here actually, but if the distance is sufficiently large, then there will be that there, there can be you know excess pressure here as well. If I have an opening the velocity will increase their Venturi effect right. If I have an opening Venturi effect I will have velocity higher velocity. So, corner stream will go like this, corner stream will go like this and so on.

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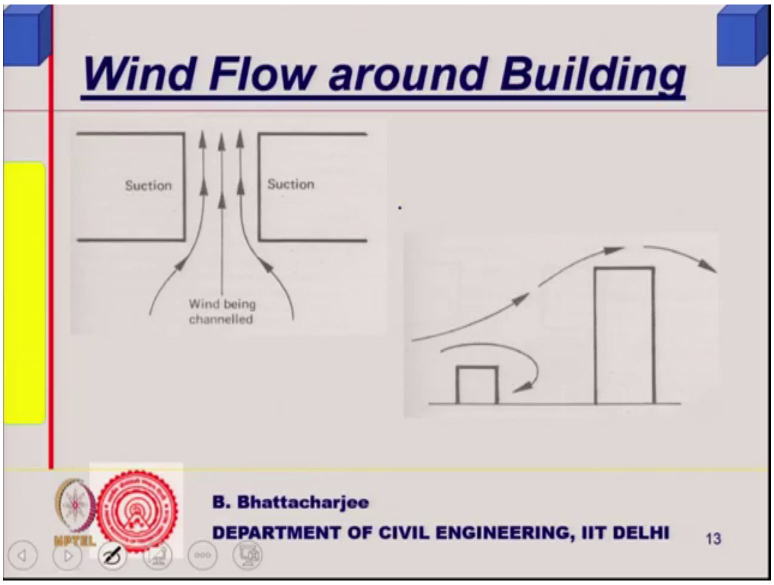

So, this for example, between two buildings I may have channel flow, flowing. So, while you know planning the building one can give this kind of these aspects in mind. As I said that you know all this issues related to a environmental design of building as we call it, it is a thermal design, acoustics ventilation, day lighting, fire. Almost all of them leaving the of course, services part of it.

For example, leaf design of lifts or plumbing system, they may not be dictated by my urban planning, but they have some role, they are also in urban planning, because your water supply system from the main municipal thing you know, it would depend upon that right. So, so urban planning dictates this and you cannot keep them away this is ignored at times, but by laws are supposed to take care of them you know. So, this, it starts all from Marvin planning. For example, two buildings, if there are too close it can simply block.

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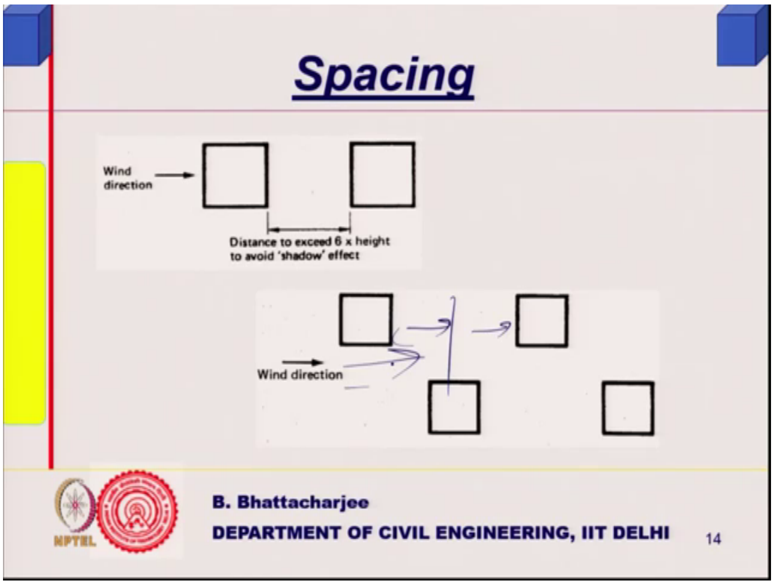

So, spacing between the building is very important right. Generally if you have 6 times the height of the building you will not have any shadow effect; like this one had some shadow effect. In fact, obstruction here and this one is driving the, you know wind flow pattern like this. So, if it is too close you might have some suction here. Although the top portion will receive some it will receive, you know it will receive the direct way, but if the tall building is on the other side or wind direction is from this side, then actually this will not, this will be totally shadowed, totally shadow.

So, this is spacing is 6 times the height to avoid shadow effect. You know height of the taller one in fact, if they are different height, height of the taller one, depending upon wind direction right, the one in the window outside 6 times the height of that one at least it should be, better would be something like this staggered it, better would be something like this stagger it. For example, this is the wind direction, better would be stagger it right stagger it.

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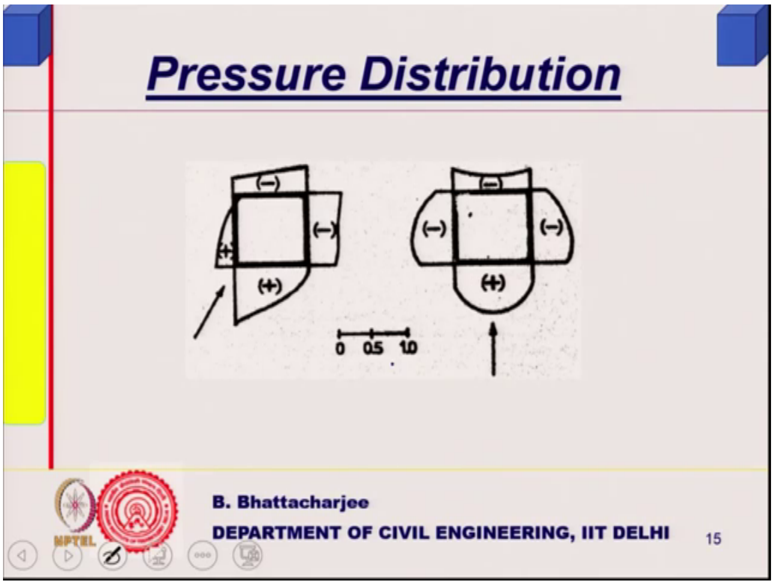

So, this could be 3 h, this could be 3 h; this could be 3 h again, depending on depending upon in direction. So, you can actually this sort of concept can be kept in mind while doing urban planning right ok. So, what we have looked into, basically the purpose of ventilation. We said there are three hygienic ventilation; ventilation for removal of heat; third aspect is comfort ventilation very close to the scheme velocity which I have not discussed over. Then we looked into for a thermal ventilation, for removal of heat, how much quantity I should select.

Quantity of you know flow that I should, I should be using in design, how much meter cube per second or how many are changes, that we can find out from latent heat to be removed or sensible heat to removed. Usually sensible heat to be remove this higher, whichever is higher you choose that. usually most of the space is sensible heat will be higher and sensible heat removal or latent heat remodel whichever is higher you choose that, and from that, that is how we find out quantity of you know we are flow rate you require.

Now to fight, ensure that that much air flow rate takes place, I got to know the driving forces and we identify two driving forces; one is the wind, other is a thermal and we have looked into the wind flow pattern around the building, which are important from our one design point of view, the spacing and we have also seen that the floor is a function of the area of the opening, pressure difference and; obviously, a resistance factor which will depend upon shape etc, but then we have all regular rectangular shape windows.

Now to identify delta p or you know, where my, I will have excess pressure, and where I will have suction, I must understand the pressure distribution around a building, you know this, this is of course, visualization, CFD can give you those ideas pretty easily, but you know, if you know that that so, but visualization is something like this, visualization is something like this. So, now, let us look at how does pressure is distributed, you know how pressure distribution occurs with if in a, I mean around a space or around a building. So, as I said depending up on the direction of the wind. See if you consider this 45 degree angle.

Now one thing I would like to highlight, we do not consider again in details; like normally in 5 degree incident will 10 degree we do not do that, because actually wind direction keeps on changing, it is not worthwhile going into so much accurate calculations. So, what we do? We consider mostly two cases; normal, 45 degree angle right. it is not worthwhile going into so much of details. So, normal or 45 degree angle, address sometime 30 degree 60 degree 90, but even not that, usually 40 degree.

So, you can see that normal wind and 45 wind we are considering, 45 degree wind you will have access pressure here, excess pressure here, negative pressure here, negative pressure here. Normal doing positive pressure here, negative pressure here, some negative suction, they will vary in this manner, so that is how it is right.

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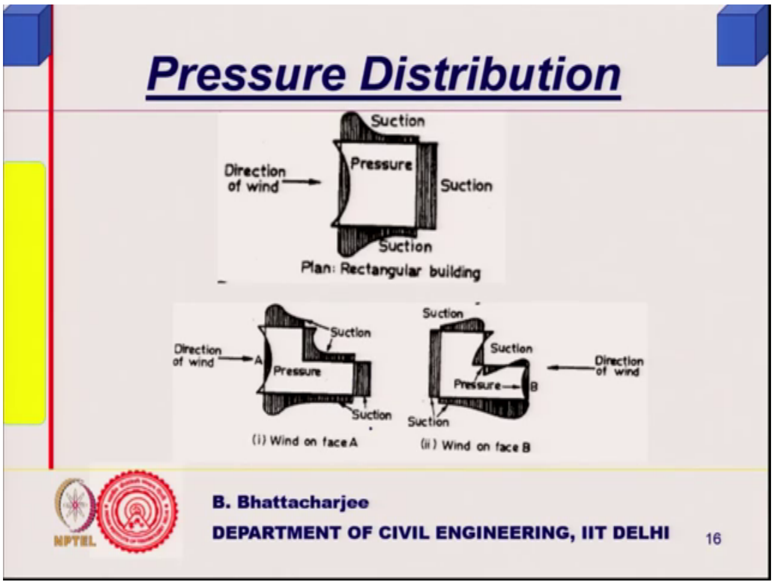

And that is another diagram showing the direction of the wind and suction etcetera etcetera. This one should be able to you know one should be able to visualize. These for L shaped building, normal the suction somewhere there and suction and if the wind direction is 45 degree suction some, you know depending upon the wind direction is something like this from this side sorry. You will have excess pressure here, and some pressure here, then suction and so on.

So, that is how one would have you know wind on face B and A separately shown. So, one should be able to visualize this aspect, that where is your, if you have manually looking at it or to want to locate your windows, you should locate your windows in such a manner I am talking of one condition building, maybe single-story or similar sort of situation. You locate your windows where there is excess pressure first of all and some windows you should be locating on the suction side, you also leeward outside also, because then only will have delta p flow. So, that is what pressure distribution look at in this way.

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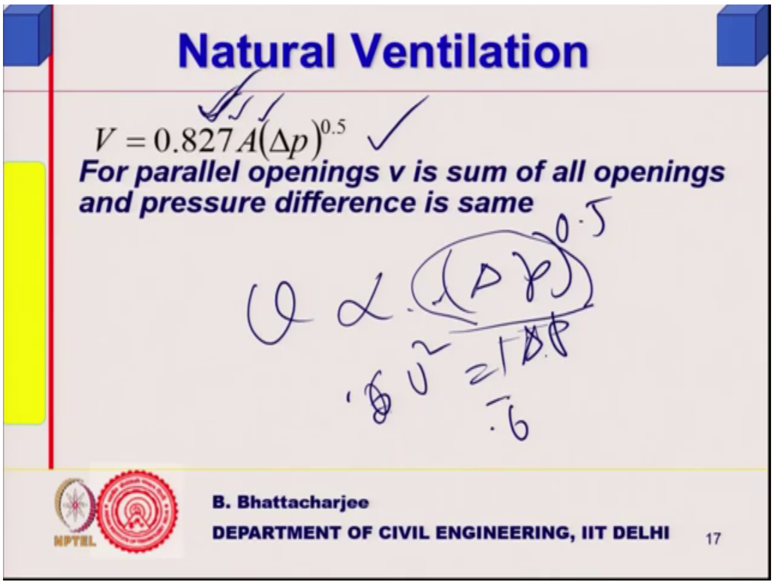

So, natural ventilation well if I calculate out you know this I suppose I have, because we said velocity is proportional to under root delta p to the power 0.5, there is a constant of proportionality, the constant of proportionality and how much this would be. It because p was related to delta p was related to point you know point 0.6 v square was equals to. So, delta p should be, you know it should be 0.6 that is what is delta p. If the delta p is 0.6 v square, so 1 by 0.6 root over from that it must be coming, it is coming there, coming from there and R also is, R also is involved, also R is involved.

So, I do not have this values derivation, but this 0.827, because it would be ye. So, then together with that would come as multiplying by R should come as, I mean divided by r that would come as 0.827. So, this is v can be related to, you know V can be related to delta p to the power half 0.827 into A, v is delta p to the power half right and delta p was0.6 v square. So, this is 1 by 0.6 right under root 0.6, how much is that? So, this is what we take for granted for the, for our purpose that V is equals to around 0.827 A into delta p to the power 0.5. Now, for openings in parallel, supposing I have got one opening here, another opening there, this is my room.

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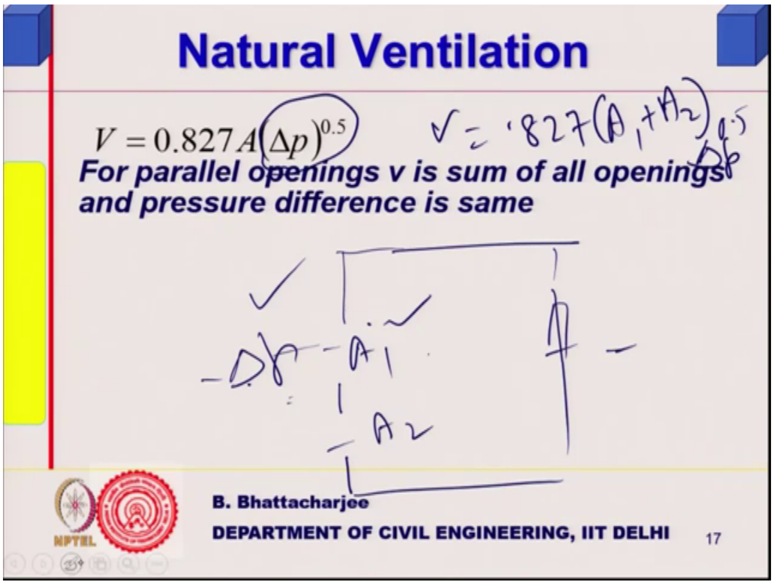

Well this side I do not talk about, two openings in parallel and the air is let us say delta p exist between this point and this point. So, there will be flow, and this then this would be A 1 let us say this is A 2, delta p is same across these 2, delta p is same across. So, delta p to the power 5 is same across. So, total flow will be equals to 0.827 A 1 plus A 2 into delta p to the power 0.5. You can sum of the areas, you can sum of the areas, but if I have another window there, another window there. I left delta p 1 here and delta p different pressure there right. So, let us see, so when they are in series think sir. So, for parallel openings v is the sum of all openings.

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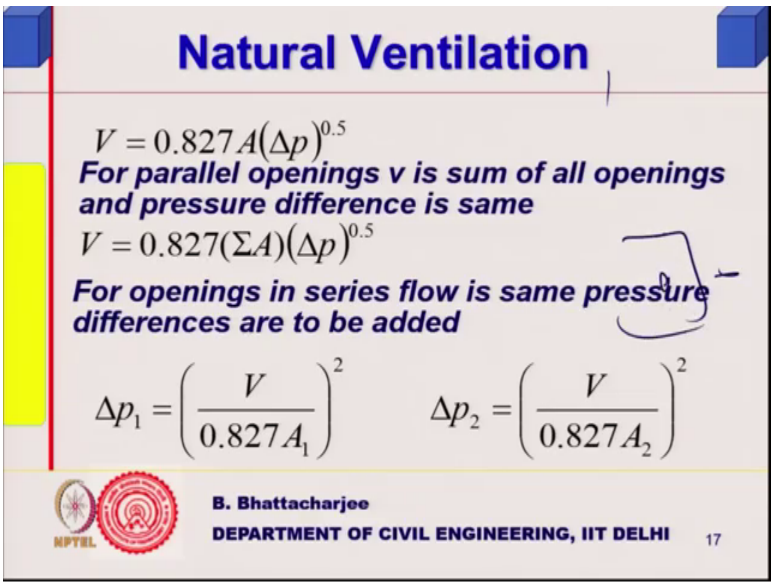

And pressure difference. So, therefore, I can write V is sigma A for in the same wall as many number of openings I have, I can simply sum up right, or for that matter, because in this room I have pressure difference across the you know all window outside, where there is excess pressure outside delta p will be by enlarge same. So, for all window are located windows, sigma A will be sum of all the areas of all window are located right. For openings in series flow is same, pressure difference is different, because whatever is coming in must will going out.

So, one window here and one window there, whatever comes in will go through. So, flow is same, but delta p s are different right. So, it is nothing, but series equation. So, delta p 1 is equals to the flow divided by area, you know because it was this one. So, delta p 1, I can find out delta p 1 of the first one. So, if I know the flow here 0.827 A 1 from this one I find out, and delta p 2, similarly same flow, but A 2 right, same flow A 2.

So, delta p 2 same flow A 2, same flow A 2 delta p it will be this, this is suction and then inside is still i. So, one window and another when doing the cross ventilation if I am talking about one window in the window outside, another window on the leeward side. So, inside pressure and the outside pressure, outside pressure and inside pressure, the two pressure differences right. So, delta p 2 is something like this delta p 2 something like this.

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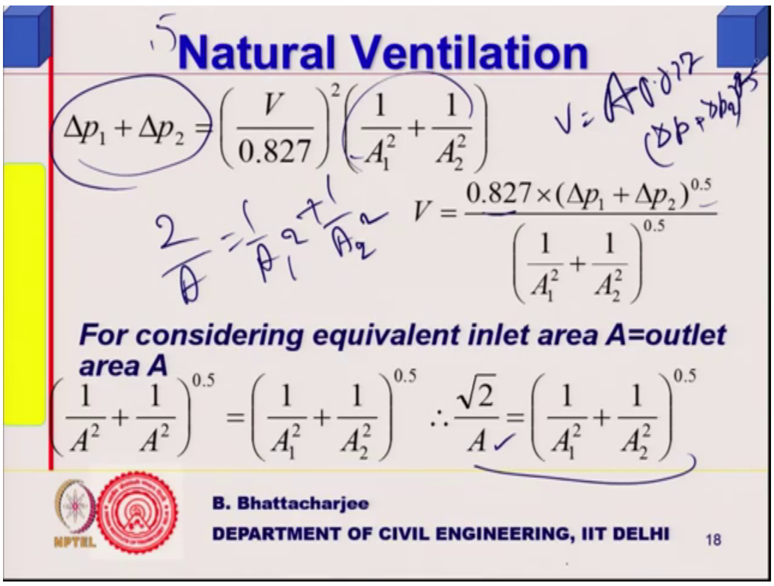

So, then I can sum up delta p 1 and plus delta p 2 and then it will be getting given as V by 0.827, it follows from there only, it follows from there only delta p 2 delta p 1 V square I can take it out V by 0.827 I can take out. So, I will have one, who I 1 square plus 1 by A 2 square right and therefore, V can be written in this manner delta p 1, you know I just square it up, I mean take under root of everything, so this is 0.5 and then 827 goes there divided by this 1 to the power 0.5, because this 1 to the power 0.5 right, 0.827 multiplied by 0.827 divided by this whole thing to the power 0.5. So, if its, it is equivalent to, it is therefore, considering the inlet area you know.

So, it is basically equivalent area is given as equivalent area then we can find out. Supposing my equivalent area, inlet area is A, outlet area is A, both are equal let us say, then if they are equal then 1 by A square plus 1 by A square to the power 0.5 is equals to this. So, root over 2 A. So, actually equivalent area for inlet and outlet being area being different, I can find out from this formula, I can find out from this formula. In this case you know like 1 by root over root 2 by A is equals to 1 by A 1 square. In other words if I square up both the sides I will get 2 by A is equals to 1 by A 1 square plus 1 by A 2 square A 2 square

So, V can be written as pressure difference, total pressure difference existing between outside; you know in window outside. Some of the pressure difference is actually window outside minus the inside and then inside difference between all of them come to the power 0.5 anyway comes in into the area is, area is equivalent area is A. So, V is equals to A 0.827 any area moves remains and delta p 1 plus delta p 2 to the power 0.5 to the power 0.5 to the power 0.5 to the power 0.5. In other words I can consider the equivalent areas as by using this formula, equivalent area of inlet and outlet I can find out by this formula right.

So, I think we will just stop here, and then putting everything into account we can actually get an expression. We look into this in the next class.