BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 01

Lecture - 04

Lecture 04: Ventilation and Air Properties

Welcome to the course on building energy systems and auditing. So, today we are in module 1 and lecture number 4. So, today we will discuss ventilation and air properties. If you remember the earlier two lectures, we have properties of material, particularly the thermal properties of material. So, today

In the ventilation and air properties, we will go with the requirements and the types of ventilation. Then we will discuss something about the design guidelines of natural ventilation, the heat gain in the buildings, and the air and its properties. So, in the requirement point of view, why is ventilation required? Ventilation is required for two reasons: one is human health. Because, you know, indoors we sometimes need a periodic intake of fresh air to maintain the level of carbon dioxide and oxygen balance. And also, we require it to remove odors, remove some of the gases, and all the kind of products that may give some kind of odor or something. The second requirement of ventilation is for human comfort. Human comfort because of sweat, because of heat, and sometimes because of cold.

So, we have to maintain a particular temperature that actually soothes a person based on their health, clothing, etc. So, we require some kind of periodic ventilation. Now, if I say the types of ventilation, it is broadly classified into two ways. One is natural ventilation, which, as we all know, is through the air and through fenestration. It is the outdoor air that comes through because of the typical placement of the inlets and outlets of the fenestration.

And the second one is mechanical ventilation. It is due to some kind of fan. The air conditioner, etc. So, by virtue of these two types, we can say that natural ventilation is energy efficient, whereas in the case of mechanical ventilation, you need electrical energy to do that. So, now what are the different factors for natural ventilation?

So, we see the first factor is orientation. The orientation is that a building is oriented, in some direction, maybe this is the north, and maybe this is the wind pattern or so. So, what is the orientation of my inlets? That is going to be one of the factors. Then, the external features: is there any kind of building or some kind of external element, like trees or something, or not? Externally, that will also create some kind of barrier to natural ventilation. Then, the position of the window: the position of the window is definitely the inlet, and where is the outlet? Is it on the cross side or just the opposite side? That will also demarcate what the type of ventilation will be because, in the case of natural ventilation, you know on one side, positive air pressure will be created, and on the other side, negative air pressure will be created. We call that the windward side positive pressure and the leeward side negative pressure.

So, as and when this negative and positive pressure difference occurs—it may be a very small difference, but still, there should be a difference—to maintain an ample amount of flow. The size of the opening is definitely one of the criteria: is it a small opening, or is it a large opening? Also, the controls of the opening: if there is any kind of fin, in case of any kind of chhajja, those are also going to play a vital role in the amount of ventilation prevailing indoors. So, let us first discuss some of the guidelines. I have taken those guidelines from the National Building Code 2016. So, first of all, they say that the fenestration should be oriented at an angle between 0° to 30°.

Please remember that 0 to 30° is this angle or the orientation is based on the prevailing wind direction. It is not with the north or north, not with the east or west, or any chordal direction; it is all with the prevailing breeze. In the case of the east or west side, it can be oriented at 45° to get a higher velocity inside the room; that is also one of the issues. Then the inlet opening in the building should be well distributed, so it is always better on the windward side to provide the inlet openings, and they should be well distributed. Maybe the same amount of area but well distributed, and the outlet opening should be located on the leeward side.

Just now, I have discussed that because we need to create a kind of pressure difference between the inlet and the outlet; otherwise, there will not be so much wind flow inside. The maximum air velocity at a particular plane is achieved by keeping the window following these recommendations. So, if your building has some kind of level of occupancy, if it is sitting in chairs, maybe it is a classroom scenario, then 0.75 meters is the lowest level of the opening that can be considered. If it is sitting on a bed or something like that, we can lower the sill level a bit to 0.6 meters or so. If it is a sitting-on-the-floor kind of scenario, maybe some primary school or something like that for the kids.

So we can further lower the sill level a bit, such that the inlet level starts from 0.4 meters or so. For a room of normal size, we know we can go for some kind of windows in the opposite direction or maybe the cross direction. Or the adjacent directions. So what we can say from here is that if we want to have good ventilation. So the width of the window can go up to two-thirds of the wall.

Two-thirds of the wall. So one-third may be the solid wall and two-thirds may be the window. So that is the maximum we may go. Beyond that, there will be no such increment. And the greatest flow per unit area will definitely be obtained if the inlet and outlet are of nearly equal area.

So, that will create a kind of good pressure difference. The last one maybe we can say that in case of the rooms or maybe in case of any kind of room having only one side wall, one wall exposed to the outside, and we can give only one side windows. So we should give at least two windows, that kind of a. So, circulation may be obtained. Suppose this is the only one room.

So, I want to give at least two. Some kind of circulation may be attained in the room also. So, that is the recommendation. The last one is that because of the sash, because of the canopies, because of the louvered or sometimes we put some kind of net to prevent the entry of mosquitoes.

So, all those additional attachments with the windows will change the amount of natural ventilation and also that will change the pattern of the ventilation airflow inside the room. So, now as per that NBC and also SP41, So, this is an interesting curve; on the x-axis, it mentions the fenestration area in percentage, how much percentage of the fenestration area is based on the floor area. So, that is one of the very good measures when we design any kind of building. So, we can say that tentatively, we can keep 20 to 30 percent of the window area

as per the floor area point of view. Beyond that, if you increase the window area to more than 30, maybe around 40, it may not go that sharp increase; we are not going to see that much of which we can get from 20 to 30 percent. But below 20 percent, that is very, very poor. So, 20 percent to 30 percent of this floor area, sorry, the fenestration area with respect to the floor area, is good or optimum, we can say. So, that is one of the points, and the next point is we have seen that in the kind of the size of the inlet.

How much will be the size of the inlet and all? The size of the inlet should be kept around 30 to 50 percent. Of the total area of the openings. So, that means there are two fenestrations, we may say. Some will be actually on the windward side.

Which I can say is the inlet. And one will be on the leeward side or maybe the adjacent side. Which I will call the outlet. So, the total area of the windows will be the area of the inlet plus the area of the outlet. But the area of the inlet should be 30 to 50 percent of the overall area.

In such a way that it will increase the efficiency of the pressure, the velocity, or the total intake of the ventilation. So, we will do a small problem on that. This problem was asked in the 2018 GATE examination air paper architecture paper. So, it was given that there are two such openings, P and Q, which are on opposite sides, and those are the inlet and outlet, each with an area of $2m^2$. So, there is a total of $4m^2$ of area, 2 for the inlet and 2 for the outlet. So, this is your $2m^2$, and this is your $2m^2$ of area.

The outdoor wind speed is almost about 5m/s. The coefficient of effectiveness, which we have just mentioned here, which is the efficiency, is 0.6, 0.9, or whatever. So here it is given as 0.6. So, the rate of ventilation through the enclosure due to the wind condition we have to find out in cubic meters per hour. So, per hour, how many cubic meters can flow?

Inside the room, based on the average wind speed of 5 m/s outside and a $2m^2$ inlet area, $2m^2$ outlet area, and effectiveness is 0.6. So, as effectiveness is 0.6, I can say that the Even though there is a wind speed of 5 m/s outside, only 0.6 times 5 m/s will be taken into the inside. So, the inside velocity, which will actually pass through the inlet, will be almost about 3 m/s because 0.6 times 5. And now I know the area, so if I multiply the area by the velocity, I know how many cubic m/s is the entry.

So, I can now find out that because I know the area is 2 meters square, that is only the inlet area. Don't take both areas because the flow is from the windward side, which is 5 m/s. So, here it will actually go with 3 m/s because of the ratios or whatever, so 3 into 2, 3 is the velocity, and this is the area, and this is from second to hour I have converted, so the answer will be almost about 21,600 cubic meters per hour. Very easy, but you need to know what to do and how to actually deal with this kind of problem. So, now the convection is, as we discussed in the very second lecture, in the very first slide, there are three types of heat transfer: one is conduction, which we have discussed; we also discussed radiation in the last lecture, and that is convection.

Convection is the way a fluid, particularly in our building, the air, actually takes the heat from one place to the other. It may be from natural ventilation, so the place is outside to inside, or maybe it is the air conditioning, that is from the air conditioning plant where the chilled air is actually going to create it, or maybe the AHU where it is created, and from there it is inside, so there is a change of the state or the temperature of the air from one side to the other side. The rate of ventilation, if I know as V That is the ventilation rate, if I know as V, that is m^3/s. How many meters m^3/s the air is entering in a particular space, if I want to know that. If I know that and if I know what is the delta T, that means the temperature difference between the outside air and the inside air, or maybe the treated air and the outside air, whatever it may be, there is definitely a temperature difference because I do not want to take the outside air temperature the same inside; we have to chill it down, cool it down, so there is a delta T.

So, if I know these two values, ventilation rate and the amount of temperature change, I can directly multiply them with 1300, which is the volumetric specific heat of air, given as J/m^3 °C. So, I can find out how much heat comes in for this particular rate, I mean, for the heat flow rate due to convection. So, number of Air exchange is another issue. So, we have been told that we need to have some kind of air exchange per hour or so, and if I know the volume of the room, I can find out this rate of air exchange as the number of exchanges per room multiplied by the volume of the room and that is divided by 360.

Here, some of this SP41 also states that the same thing has been given in the NBC. The air exchange per hour is recommended for various spaces. Suppose it is a classroom like your classroom, or maybe a laboratory or somewhere, it is 3 to 6 air exchanges per hour. That means 3 to 6 times the whole volume of your classroom has to be changed with fresh air 3 to 6 times in an hour. So, you need to know the volume of your classroom.

You need to multiply that with 3 or 6, whatever the exchange rate may be, and divide that by 3600. So, you can get how much m^3/s is your V. In bedrooms, it is again 3 to 6. In the case of bathrooms, the toilet is a little higher, 6 to 12. In the case of cafeterias and restaurants, there are a lot of Smoke and all those things.

So, the air exchange is too high. 12 to recommended is too high. 12 to 15. The cinema is 6 to 9 like that. So, a small problem we can solve.

Suppose a room is measuring 12 meters by 25 meters by 4 meters. And it is mechanically ventilated through accreted outside air. And you see this, the outside air temperature is 38°C, whereas the room needs to be at a temperature of 24°C. So, I want to drop the particular outside air temperature from 38 to 24, almost like 12 to 14° or so. If the room needs 3 air exchanges per hour, then I have to find out the energy requirement.

So, air exchange per hour is 3, and I know this is the volume: 12 multiplied by 25 into 4 and divided by 3600, the total number of seconds per hour. So, I know V, this V is your 1 m^3/s. And then I will apply the second formula, which is Q into V into del T. Q equals 1300, that is the specific value. Volumetric specific heat, one is your V, air exchange rate, and this is the del T. So, I will find, I got 18.2 kilowatt-hours as the energy required for this particular ventilation. Now, let us go to the heat gain in the building.

So, buildings will get a lot of ways of heat gain. We can actually say there are two major ways. One is the external heat gain. Those we have just now discussed. Conduction, convection, and the radiation through.

And also due to the internal occupancy, internal instruments, some lighting, etc. Also... Provide some kind of the heat gain. We will discuss in the next module those heat gains and those kinds of the internal heat gain. So, those are the typical some of the parameters for the internal heat gains also.

So, we can see those changes there are a lot of other changes, but if you see the internal heat gain we have two types of the heat, one is the sensible heat and one is the latent heat, both have to be added together to see the space is how much is the total heat gain or so now what is the sensible heat it is the heat which actually absorbed without change of any kind of a state so it increases the temperature because of the sensible heat okay it is some object some solid object is increasing its temperature because of the convection conduction and the radiation there is some change of the temperature we notice so due to that it is the converted sensible heat we will just see the change of temperature in the sensible heat if there is any increase or decrease or we can see that is a change of temperature so the sensible heat loads are based on actually basically for the from the wind link envelope due to the infiltration of the Of the outside air, there may be you have a totally concealed area, but there is slight infiltration of air from outside.

There is solar heat gain through the glass and windows, appliance loads, and the occupancy of body heat. So, those are also present. But what is latent heat? Latent heat is actually due to the moisture, the water vapor that is also present in the air. And that is because of this content, some kind of latent heat, because it is in a vaporized state.

So, from one state to another, you require latent heat for any kind of liquid, maybe if it is water. So, from liquid to vapor, there is a kind of latent heat, but latent heat cannot be actually measured by a thermometer or temperature increase or decrease; it cannot be seen. Latent heat, how it will actually come in or increase the internal load of a building or a space, is due to moisture. Definitely, when air comes in, there is some kind of moisture coming. There is occupant respiration and activities that also produce some kind of sweating, breathing, and all those that also have some kind of moisture. And also, there is some moisture from the equipment and appliances.

Suppose you are cooking something or doing some kind of washing, like clothes in a machine. So, definitely, there is moisture coming out of it. So, that also increases some of the load, some of the heating load in the particular space. So, in the air and air properties, what is air? Air is a kind of mixed gases.

It has nitrogen, it has oxygen; almost 78% of the air is nitrogen, and 21% is oxygen. It has some amount of argon, some amount of carbon dioxide, and also some amount of water vapor and dust particles. So, these are actually the components of air. So, in the air, I can actually visualize the air in this diagram where these green dots represent some of the air molecules.

So, the green dots represent nitrogen, oxygen, carbon dioxide, or dust particles. And there are some white-colored dots which represent space for moisture. So, you may fill all the spaces with moisture or you may not. And those yellow dots represent water molecules, which are moisture molecules. So, within this three-phase diagram of air, there are air molecules, some space for moisture, and some space that will be filled with water. So, at this point, if I say this is a Temperature is actually measured as, not defined as, two types: the dry bulb temperature.

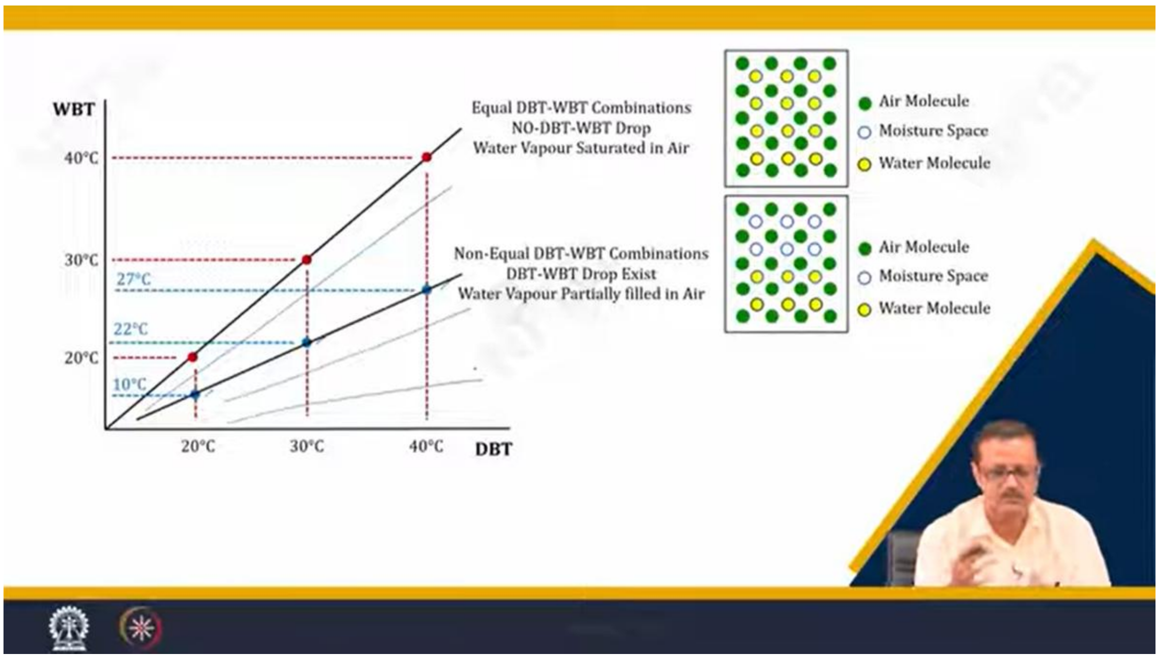
So, I take a particular thermometer, and there is a bulb where the mercury or all these things are present. So, that bulb is dry; nothing is there. So, whatever air passes through that particular dry bulb, it actually measures that temperature and causes the mercury to rise to a certain level or height. So, from there, I can find out the temperature of the airflow. Similarly, if I want to find out the wet bulb temperature, what will I do?

I just put that particular bulb in a wet cloth or clothing or something. And if there is an air flow through it, the air will actually take out some kind of moisture from those wet clothes, which is in and around that particular area. That particular bulb, so what happens is that evaporative cooling will occur, and gradually there will be a drop in temperature with respect to the DBT. So, DBT is maybe 40°, but when the other temperature device is having some kind of wet clothing, because of the evaporative cooling, this will drop. So, the wet bulb temperature is because of this particular phenomenon. This particular phenomenon of the temperature reduces because of the evaporative cooling.

The last line is very important. The wet bulb temperature is always less than the DBT. Definitely, that is because of the evaporative cooling effect. Now suppose, the air is very dry, so there is not much humidity or moisture content in the air. So, if I just pass through a particular dry air through the wet bulb thermometer, there will be a huge amount of drop because the Air will have a lot of vacancies, I may say, a lot of vacancies. So, it can actually absorb a lot of moisture from that particular wet cloth, and gradually the evaporative cooling amount of cooling will be increased, and there is a drop. So, we will have a higher drop. But if the air is humid, if it is moist air, then that particular air does not have that much number of vacancies. So, it will pass through and will take a minimum amount of moisture, whichever is available or required to fill that particular excess amount of the vacancies.

So, the drop of the wet bulb temperature will be a little less or less compared to the dry air. So, we can say that this is the DBT WBT drop. It will be very high if the air is dry, so that means we can say dry air has very low humidity, a low amount of relative humidity. So, in the case of a low amount of relative humidity, this drop is very, very high, whereas if the air is already very humid, if the relative humidity is very high, more than 80 percent or so, there will be a very little amount of drop between the WBT and the DBT. So, by virtue of this drop, how much is the drop between the DBT and WBT?

I will say this RH is low, and I can say this RH is high, isn't it? This RH, and I can actually figure out what will be the relation between this DBT WBT drop with this RH. So that also can be figured out in the way that I can find out this particular RH from these two kinds of scenarios also. So, I have told you that in general, DBT is higher than WBT. So, that is fine, and this DBT WBT drop will give you a kind of understanding of how much moisture a particular air is containing, that means how much. Relative humidity is having that particular state of the air, and that will be beneficial for us to know two very important parameters of the air.



One is the temperature, and one is the relative humidity. Now, suppose this DBT and WBT are the same. I am going to suppose I am finding both temperatures, this temperature, the instrument, both are supposed to be the same. That means the air is fully saturated. So, if the moisture is passing through, it is not at all even taking even one molecule of the moisture into the airspace because there is no air vacancy, no airspace vacancy.

So, it is fully saturated. So, the RH is almost 100% or so. So, we will discuss that particular diagram. So, we have already discussed that one. Suppose on the x-axis, I have plotted the DBT.

The y-axis is WBT. Suppose these are the values. So, both the DBT and the WBT are the same. So, that means it is a case of full moist condition. So, there are no such vacancies left.

So, I can plot a line. Of course, generally, the line is not a straight line. It is a curved line. So, we will discuss it in the next lecture. So, but theoretically, we can say that there can be a line.

So, in that line, what we can say is it is equal to DBT and WBT. Number one, number two, there is no drop between the WBT and DBT because both are the same. So, water vapor is saturated. So, if I see my three-phase diagram, no moisture space is vacant; all are filled by yellow water. Thus, yellow means the water molecule, right? Now, in some cases, we may say these blue lines are there, blue dots are there. So, that means, for the DBT 20°, WBT is 10°.

So, WBT is less than DBT, and there is a little bit of a gap, not exactly the same. This is 22° and 30°; this is 40° and 27°. So, we can say that in this scenario, in this scenario, The DBT and WBT are not equal, number one. There is a DBT-WBT drop that exists, number two. And number three is that if there is a drop that exists, even if it is the smallest amount of drop, there are some vacancies there.

So, that is why there is a drop. So, water will—sorry, the air will try to collect some of the molecules of the air from this WBT, these wet clothes. So, the three-phase diagram will look like this. There are some spaces available. Of course, some spaces are also filled.

So, any such lines can be drawn from here, and from that, we can find out the relative humidities and all those scientific things. Then, if you go away from this 45° line, your RH is low, and if you go higher, RH is high. But one thing we can say is that DBT cannot be more than WBT, though there cannot be any line on the upper side of the 45° line or so. So, that is all for today's lecture. These are the references. So, what we understand is that natural ventilation is an important feature and that can be adopted for energy conservation.

So, there is a typical ratio and the total area versus the floor area parameters of the inlet and outlet. Two types of heat exist normally: one is called sensible, and one is called latent heat. Dry bulb temperature and wet bulb temperature give you an indication of the relative humidity, which is one of the prime factors to understand ventilation, particularly mechanical ventilation. Thank you very much.