Energy Efficiency, Acoustics & Daylighting in building
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Lecture - 27
Design for Thermal Efficiency

So, now last time we looked into some of the passive features right, like vary thermo wall and roof pond system and also we talked about earth sheltered structures, below the earth the temperature does not change so much. So, now, overall let us look into design for thermal efficiency.

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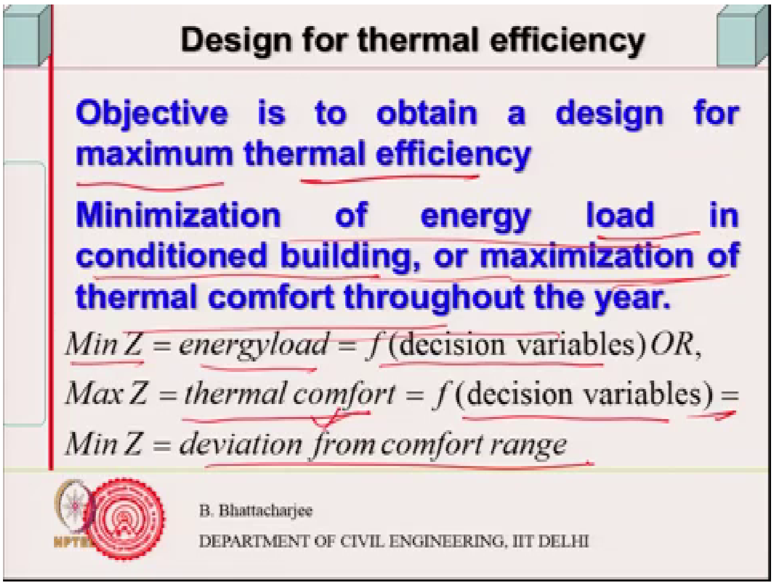

Generally objective is to obtain a design for maximum thermal efficiency right. So, that is what would be our energy efficiency of building you know. So, thermal efficiency we are talking about which should accurate translate into minimization of energy load in conditioned building, minimization of energy load in conditioned building right or maximization of thermal comfort throughout the year. That should be our objective translate into this, either minimization of because you know we want to maximize the thermal efficiency which would mean minimization of energy load in conditioned building or maximization of thermal comfort throughout the year.

So, which actually would be something like you know mathematical optimization process and I can write it like this minimized z which is equals to energy load, energy load z equal z equals to energy load. Which is a function of decision variables, if you have been associated to any kind of them optimization process decision variables are basically on which on which you want to take the decision on which you want to take the decision right. It will match through more or maximized thermal comfort which is also a function of decision variable right. In other words this can be equals to minimization of deviation from comfort range minimization of deviation from comfort range. So, that is what is our objective, that is what is our objective right that is what is our objective all right.

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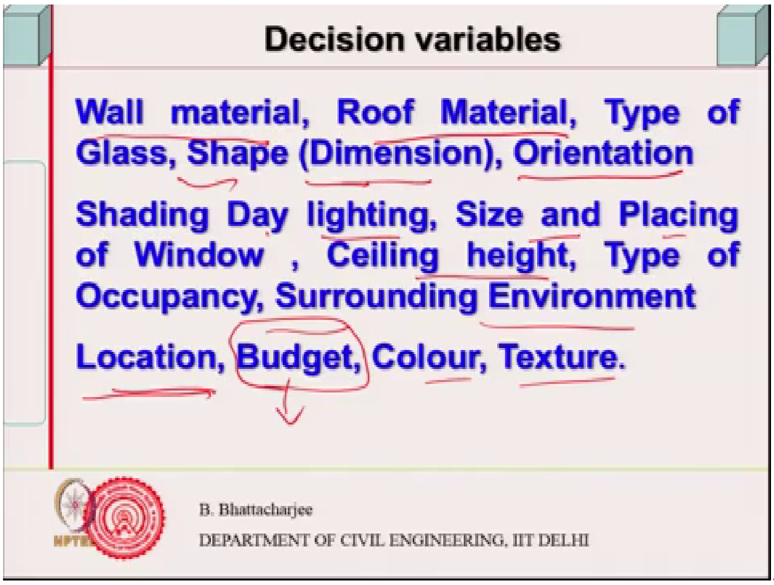

So, decision variables are materials in the wall or construction in the wall these are decision variable I can I can take you know I can choose this. So, decision variables are chosen at their optimal level such that my objective function is maximized or minimized. So, wall construction I choose in such a manner similarly roof construction, type of glass shape orientation you know dimensions etcetera, these are these are shading day lighting size placing of window ceiling height type of occupancy surrounding environment all these are decision variables all these are decision variables right, all these are decision variable.

Location budget colour texture, now budget normally would not be a decision variable, but might be a constraint what you called it can be it can be you know it can that you want to do within a given budget you might maximize your life cycle cost, you know minimize life cycle cost, minimized life cycle cost or life cycle maximized life cycle performance, location is also a constraint these are given to you location budget etcetera given. So, these are kind of decision variables you encounter in thermal design a building.

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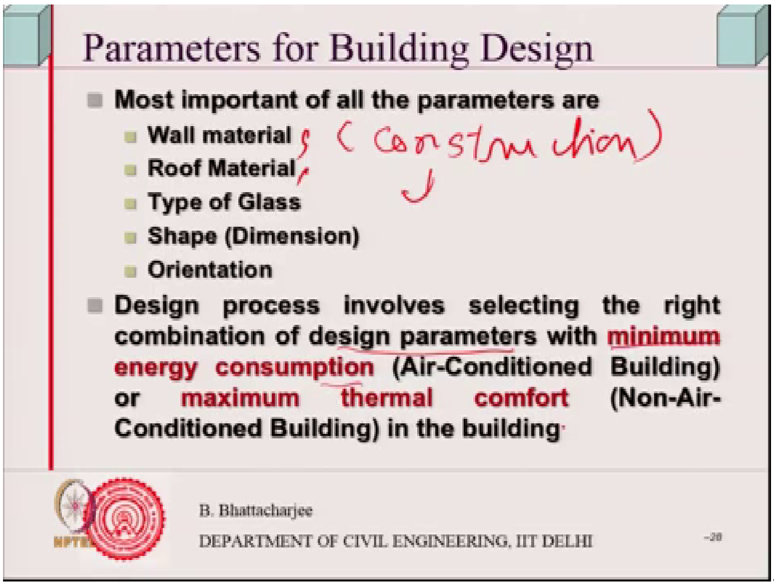

So, most important of all these parameters are wall material, roof material or construction I will say I rather like to call them construction there will not be one material roof construction. So, not material, materials many of them may be there because it can be layered contractions, type of glass that you are using shape, orientation therefore, decision design process will involves selecting the right combination of design parameters or values of the decision variable for with minimum energy consumption or maximization of thermal comfort right, so in the building.

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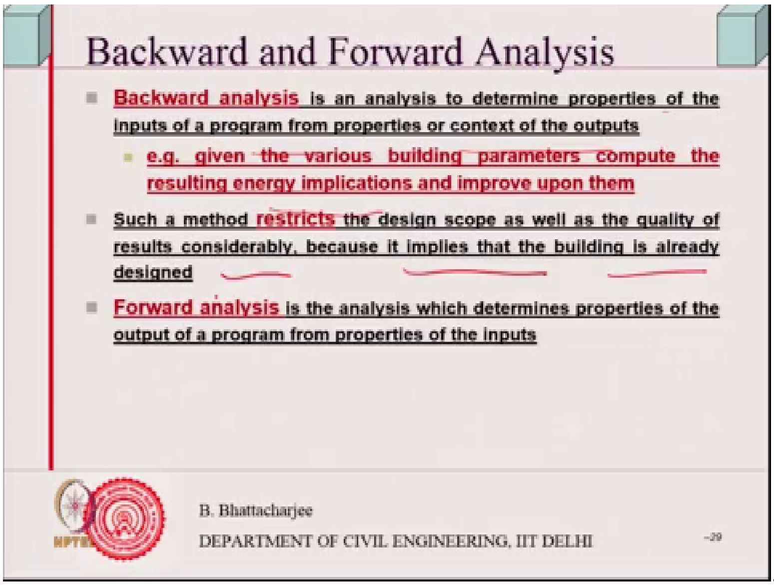

So, that is that is actually your design process should be, now generally we define something called backward analysis. Backward analysis is first determine the, you know first basically you find out choose a solution then analyse it right. So, first you chose a solution and then find out and you repeat this process to get the best. So, is an analysis to determine properties of the inputs of a program in the in the properties or from the properties or context of the outputs.

Basically, well I think I will not complicate it in by this kind of statements it is given various building parameters compute the resulting compute the resulting energy implication and go on improving upon them that is what is the statement is you choose something backward analysis. You know backward analysis first you choose, find out the performance, then change your choices repeat this performances right and try to find out come up to a optimal level from there or best from there.

Such design of course, restricts because you see in many of our design process actually involves, even your structural design for example, you first choose a section, but that must be based on constraint also for example, very simple case of rain force concrete beam designed. The height you know the architectural requirement might specify the clear height from floor to the ceiling level therefore, beam depth is actually there may be constraint, but you design you decide the beam depth right in the beginning then you find out through analysis the amount of reinforcement do you require. So, see is a kind of somewhat backward analysis, but supposing I know I know for the given load. Now, supposing I know the load and from there directly I was able to calculate out their enforcement and the size given the constraints also that would have been forward analysis right, at the moment we have to because is dependent on density properties of the material. So, first you choose because mass it will depend upon you know size of the section e I etcetera whatever it is.

So, therefore, we do a part you know sort of a backward analysis in many design. So, such a method, but it restricts, it restricts basically depending upon how large is your problem, simple archi design it may not be that complicated but, in a in a system where you have very large amount of parameters not only the amount of reinforcement and depth.

Here the d you know fixed cover etcetera, etcetera depth effective depth of the beam and enforcement quantity that is our, that is our variable design variable v v in fixed. So, if there are too many of them then doing this backward analysis might take a lot of time and it will restricts the scope as well as the quality of results considerably because it implies that building is already designed, you have already designed it then you are analysing it, finding out the performance time and again.

So, forward analysis is something different, in this one which determine the properties of the output that is your performance straight away, from the properties and input sequence for example, you know if you are able to find out the wall choose the type of wall that is best suited. You have you have you know like say let us in case of reinforcement concrete design same example that I was talking about, supposing I give you the load combinations all that and just you know that and constraints are also given the depth, the depth cannot exceed this much right.

Because of the architectural results supposing a procedure is there which will straight away directly calculate out the size of the section you know or size of the section or amount of reinforcement etcetera, etcetera then that is a forward analysis. You do not have to assume anything in the beginning in that case, but conventionally we do assume. So, backward analysis will assume the design first, analyse it find out whether it satisfy the performance then change the design again if required and go on doing this forward analysis on the other hand should be able to find out straight away the solution.

So, that is what it is; that means, determine the levels of decision variable from minimum energy consumption in this context, minimized the energy consumption and what is the values of the decision variable. What is the type of wall I should choose? That is what is backward analysis such backward analysis process, I mean forward analysis process would always require you know is done testing a number of design alternatives and computing the thermal performance of each one, find out the best. So, that that you know that you can be inbuilt in a optimization problem that becomes much better.

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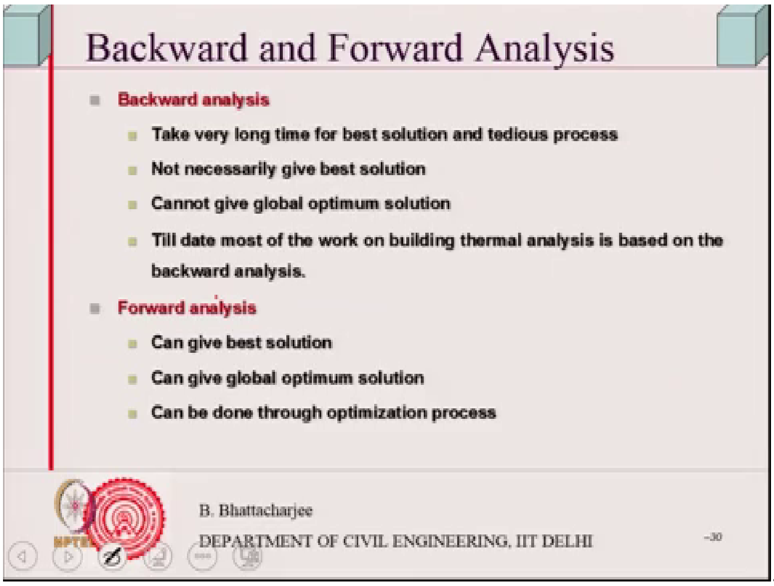

So, backward analysis take very long time for best solution, tedious process, not necessarily give the best solution cannot give global optimum till date most of the work on building thermal analysis based on that is not really of our interest. Forward analysis can give you the best solution, can give global optimum solution if you are using a optimization process can be done through you know only through optimization process. In fact, it is possible to structural optimization also, but anyway that is not concerned here.

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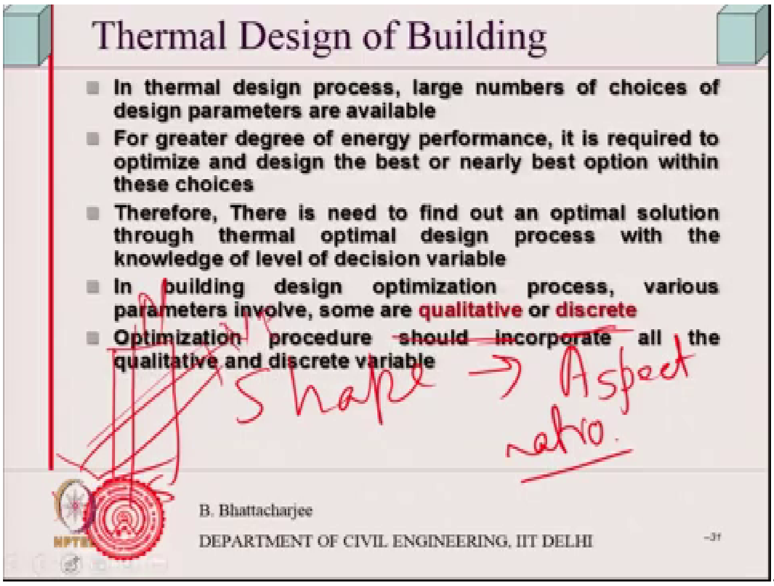

So, thermal design process large number of choices of design parameters, for greater degree of energy performance it is required to optimize and design the best or nearly the best option right of from these choices actually within these choices therefore, there is need to find out optimal solution. So, optimization can give you best thermal design, optimization can give you best thermal design, right.

So, in building optimization process various parameters are qualitative and they are discrete of course, for example, shape also you can talk in term of aspect ratio you can talk in terms of aspect ratio. But supposing I have mixing of rectangular and l shaped or t shape in that case they are basically qualitative, you cannot quantify you can call them shape number 1, shape number 2, shape number 3, but in a given rectangular type you might vary with aspect ratio even then some sort of quantification may be possible.

But very easily we can understand that they are actually qualitative, you know. So, you can call shape number 1 you can quantify them, shape number 2, shape number 2, shape number 3, shape 4 n etcetera. So, you see there, many of them could be qualitative and remember the discrete also aspect ratio you might vary from 1 to 2 to say 1 to 2.1 to 0.2 etcetera in a continuous manner, but still it will be discrete actually, usable it will be only discrete, because aspect ratio 1 2 you know 1 is to 2 or 1 is to 2.1 does not make any sense fairly.

So, these are discrete and many a times they can be qualitative, orientation similarly you might define the major axis with respect to due north and south. So, you can change in angle may be made it even continuous, but really practically practical situation it will be discrete, long axis parallel to north south. So, this could be orientation 1, orientation 2 could be same 1 is parallel you know parallel to north east to south west no. So, orientation one, also these are qualitative you can codify them may be possible to use them in continuous manner, but not really practically usable. So, basically the qualitative and discrete some of the you know some of them are qualitative and discrete.

So, optimization procedure incorporate that qualitative and discrete variable right.

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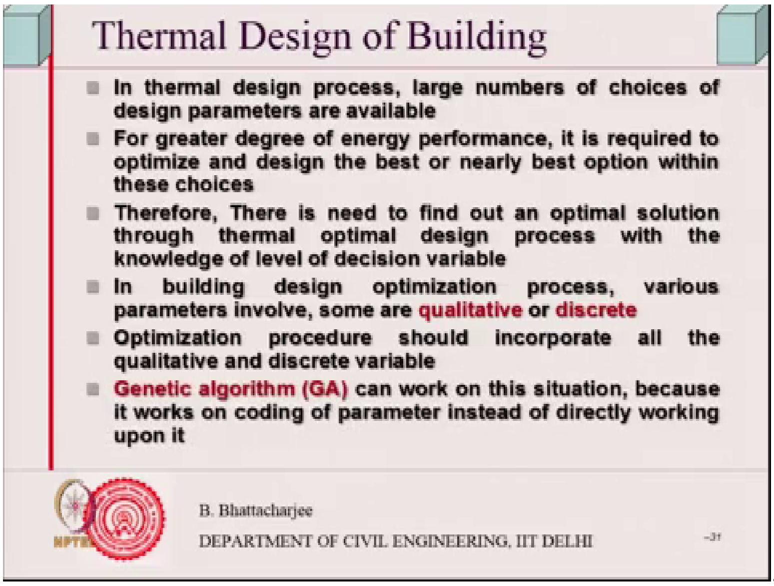

There should qualitative in discrete variable, like any kind of a evolutionary algorithm helps their best. So, I will not discuss about this algorithm. So, tools which are there now there are so many of them. So, that I will not talk about, but I will just talk about possible alternative. So, that you understand that this process can be fairly involved process.

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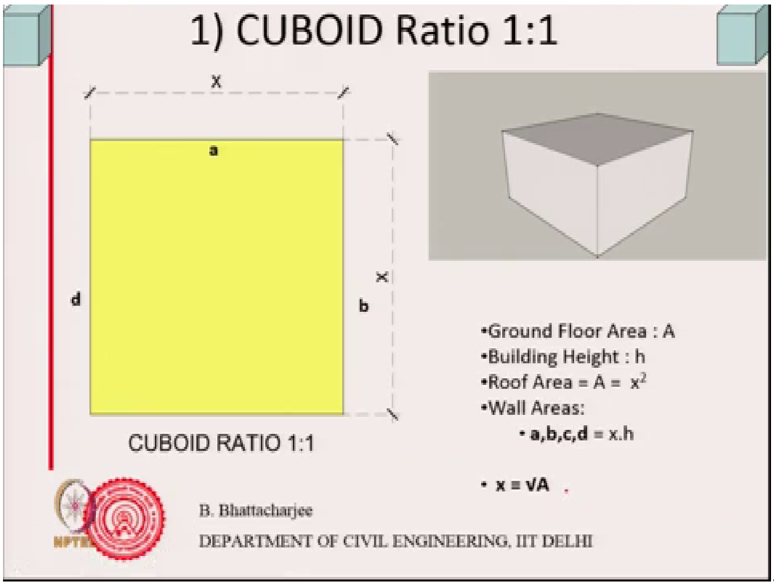

For example form alternatives I can have rectangular with the ratio of 1 is to 1 cuboid right. So, ground floor area building height roof area a is roof area is x square and wall areas then x into any wall would be x into h, h is the height. So, x is root over a I know is the same I can do some geometrical things which you did earlier. So, this is one kind of shape 1 is to 1, cuboid I can have 1 is to 2 and then again similar sort of thing I can do right. Some relationship I can obtain with respect to x supposing h is being constant number of story height is constant.

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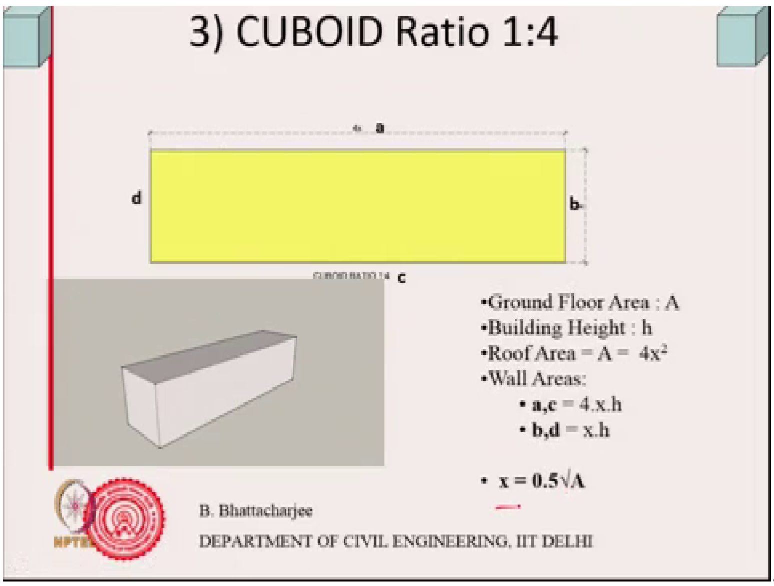

Then x can be a variable which can vary in this manner depending upon. So, 3, 1 is to 4 then this you know subject could be 0.5 under root a x that is this dimension, the dimension and everything else can be explained in the term of x. So, this sort of, but then there you can see the discrete actually, first one had x equals to under root a right, if it is a square in plane if it is 1 is to 2 then it is 0.70 under root a this is 0.5 root a. So, there are discrete steps. So, that discrete t shapes.

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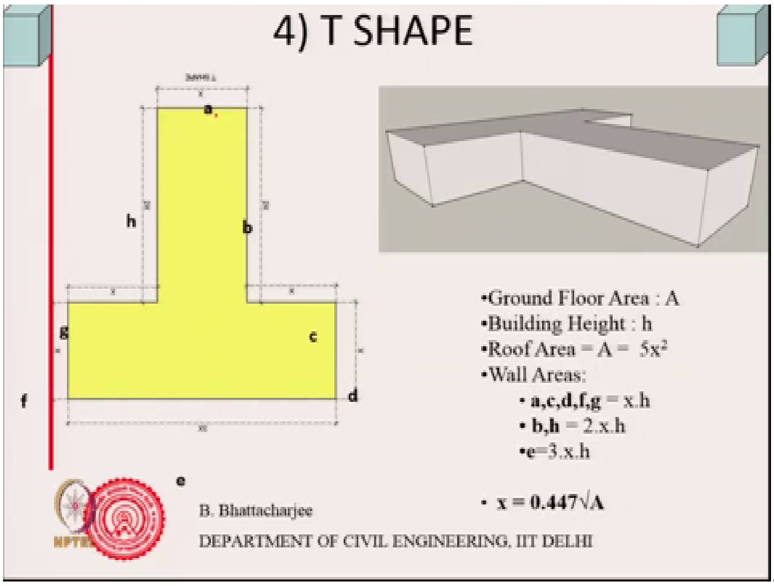

Similarly, we can talk about some area related to x, x is the smallest dimension or dimension shown here this is x. So, you know this is x this is x. So, this is x this is the dimension this is x this is x. So, actually you can actually you know.

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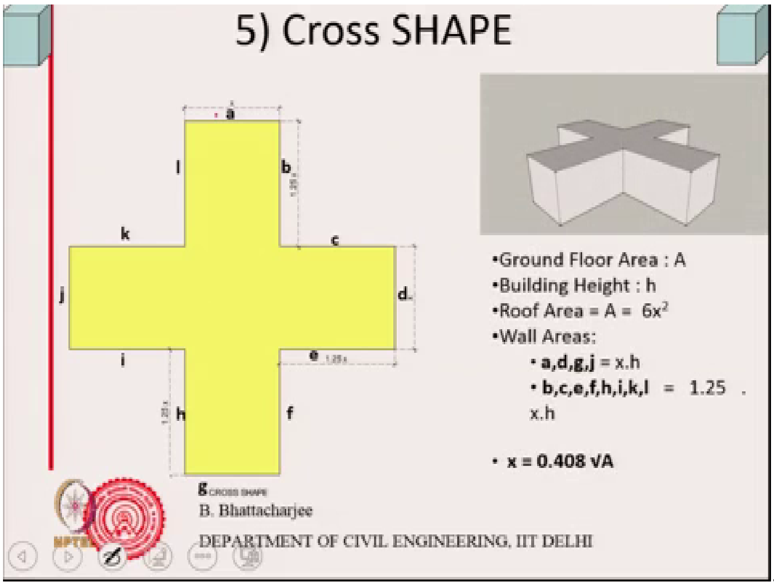

It can take several sort of shape, we can take cross shapes and some basic relationship you can obtain as.

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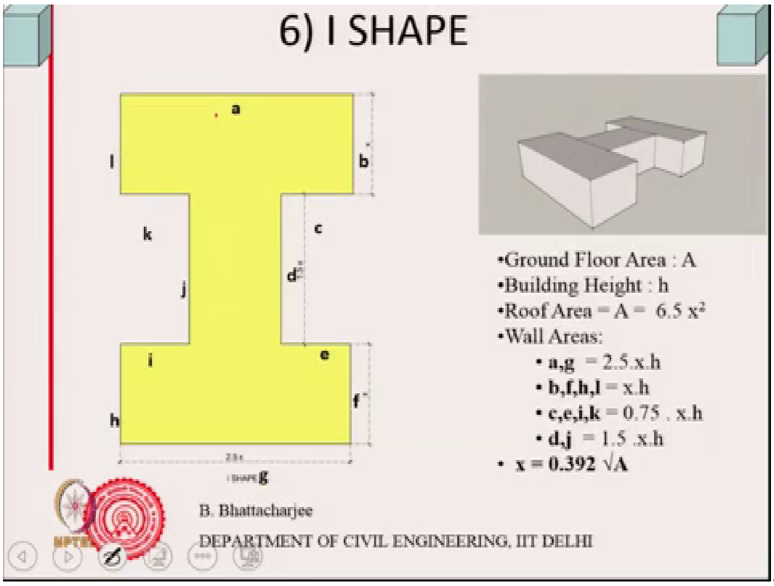

So, therefore, that you know the variations you can understand this is as you can take this sort of shape 0.392, but will be constrained by side constraints will be constrained by side constraints also by loss.

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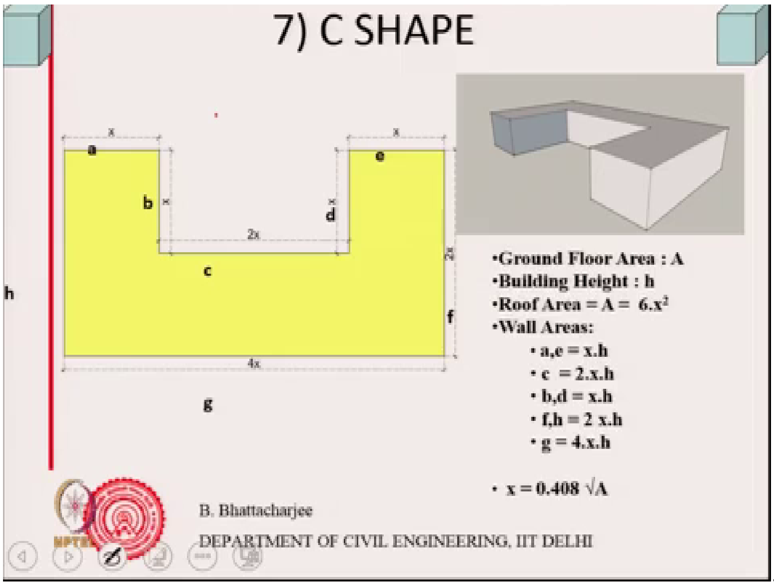

So, the constraint because you may not be able to use all the space in a plot; according to the floor area ratio or such restrictions.

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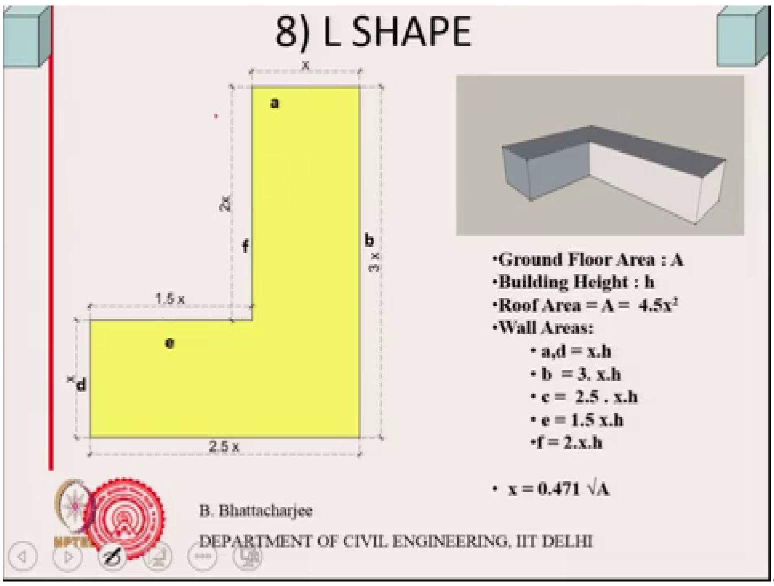

So, they will form again constrains, but shapes should be chosen you know various shapes one can take, one can take all these shapes all this shapes and you can see the relationship of the smallest dimension to the floor area you can obtain.

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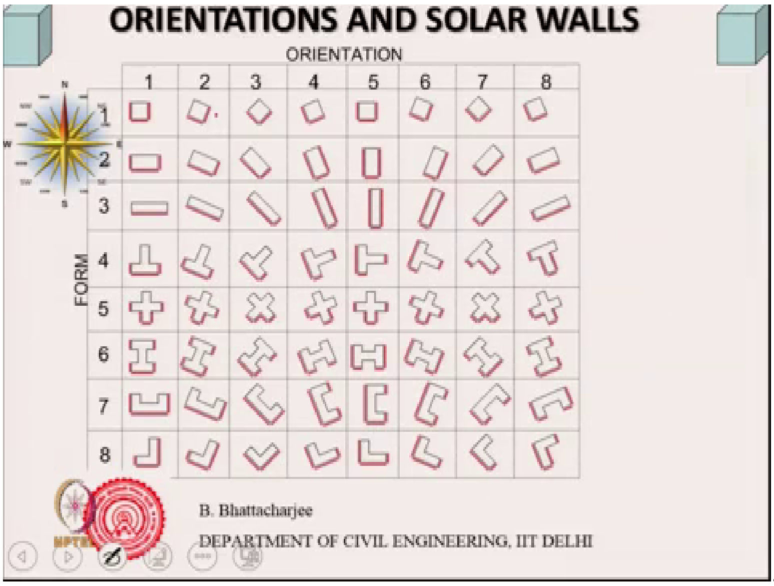

So, for example one can choose this 8 shapes right, 8 shapes one can choose and one can choose orientations several of them. So, I choose 8 orientation again this for the cuboid right, north and south in climb 45 degree right. So, I can have various kind of orientation. So, I have now 64 possibilities, out of which I will be choosing the a most the best. In fact, I should be choosing best, but I have taken only 2 variable right.

So, unshaded it could be shaded or unshaded there could be more comprehensive involved. So, unshaded for major part of the day oriented towards the etcetera, etcetera east west and so on so, we can choose that way.

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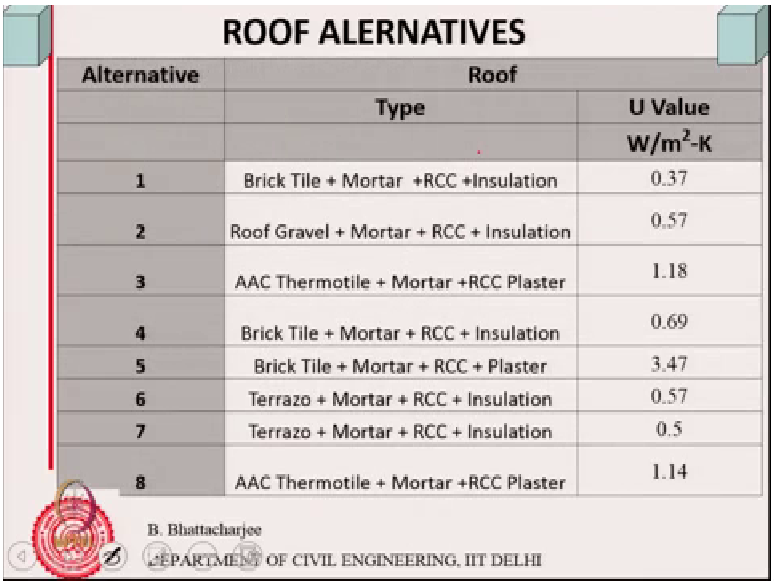

ROOF ALERNATIVES

Alternative	Roof	
	Type	U Value W/m^2-K
1	Brick Tile + Mortar +RCC +Insulation	0.37
2	Roof Gravel + Mortar + RCC + Insulation	0.57
3	AAC Thermotile + Mortar +RCC Plaster	1.18
4	Brick Tile + Mortar + RCC + Insulation	0.69
5	Brick Tile + Mortar + RCC + Plaster	3.47
6	Terrazo + Mortar + RCC + Insulation	0.57
7	Terrazo + Mortar + RCC + Insulation	0.5
8	AAC Thermotile + Mortar +RCC Plaster	1.14

Roof there can be several constructions, I can choose here I am showing 8 only there can be n number of them. So, u values are known all other properties actually I can determine and find out brick tile mortar RCC plus insulation ACC thermo thermotile mortar RCC plaster etcetera.

And wall similarly there can be large number of options available, typically this is shown just 8 of them are shown brick 200 millimeter thick brick this is modular brick we thought to you know that showing in that way, but one can choose what is available in the market.

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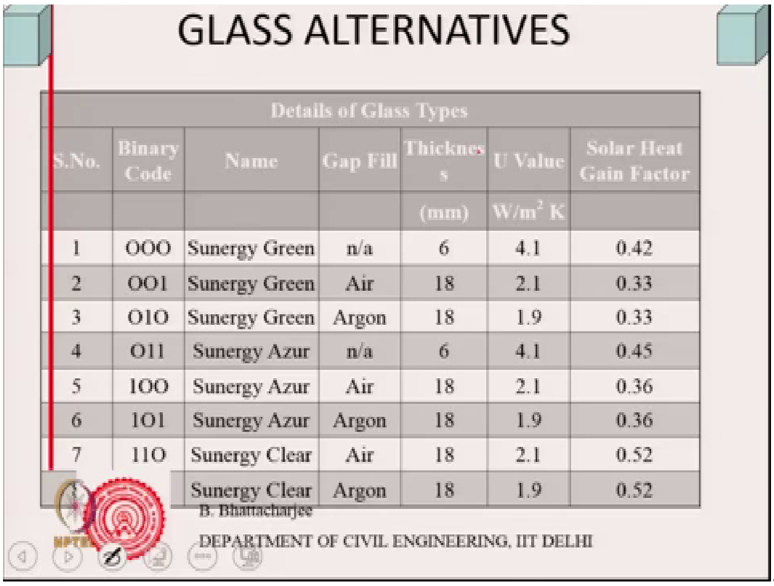

Details of Glass Types						
S.No.	Binary Code	Name	Gap Fill	Thickness	U Value	Solar Heat Gain Factor
				(mm)	W/m^2 K	
1	000	Sunergy Green	n/a	6	4.1	0.42
2	001	Sunergy Green	Air	18	2.1	0.33
3	010	Sunergy Green	Argon	18	1.9	0.33
4	011	Sunergy Azur	n/a	6	4.1	0.45
5	100	Sunergy Azur	Air	18	2.1	0.36
6	101	Sunergy Azur	Argon	18	1.9	0.36
7	110	Sunergy Clear	Air	18	2.1	0.52
		Sunergy Clear	Argon	18	1.9	0.52

So, you see glass alternatives, glass alternatives various as you know sun energy green is from commercial ones there is no gap fill thickness 6 millimeter, u value solar heat gain factor, this property should be known to me. So, I can choose some 8 of you know 8, 9, 10 or 12 as many number of them.

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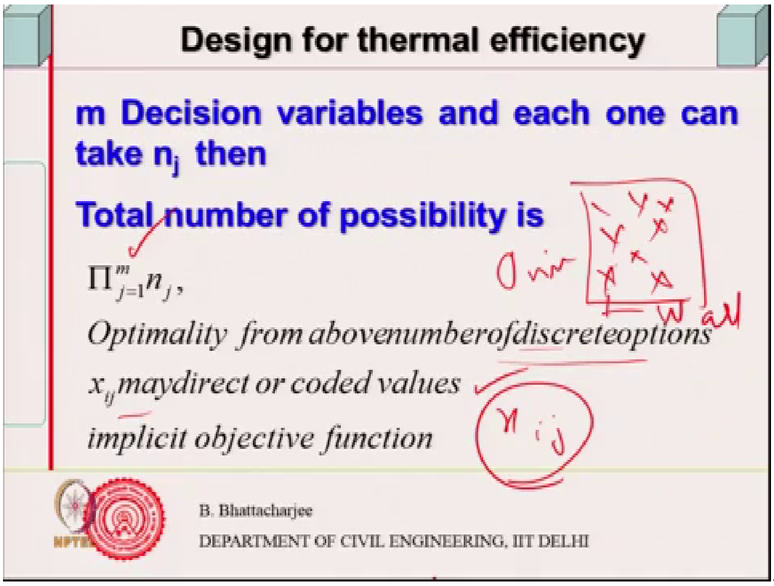

Therefore m decision variables and each one can take n j values, 18 you know I have shown shape, orientation, wall, roof, glass 5 it could be m number of them I have not taken many, I have not taken many actually right.

So, there will be m number of decision variables 5 decision variables I have taken, m number of decision variables and each one can take supposing n j values then total number of possible is product of n j this is this is the product, this is you know sigma is a sign for summations this is for product. So, you will have n j; that means, in our case it was 8 into 8 into 8 into 8, but supposing you know I am varying for example, wall construction each layer variation it is possible.

So, the m can be very large in facts somewhere people have recorded wall to window area, window to wall area ratios I have not taken many. It can be 20, 25 or such kind of decision variables or 20 you know 30, 30, 40 wherever it goes now just imagine I am getting 8 of each one of them 8 into 8 into 8, m 40 that many number of possible options I have available.

In my case it was you know combinations if I see, wall I can choose 8 ways roof I can choose 8 ways therefore, totally I can choose from 64 solutions shape eight. So, 8 into 8 into 8 orientation another 8. So, 8 to the power actually 4 in my case if I am taking 8 of each n j of each m such cases that may became turn to very huge number and there are discrete values.

You know discrete points for example, the domain would be I mean if I draw it will be m dimensional hyper space, you know if there are 2, it will be 2 dimensional space. So, 2 dimensional space I would have points like this, some points discrete values where this let us says wall construction just where I have fixed and this is orientation I am just saying these 2 or shape in orientation you know I have fixed rest all are all fixed.

So, there are 64 possibilities, I choose the best out of them right. So, 2 dimensional if in our case in general case it will be m dimensional hyper space, m dimensional hyper space with this many number of options. So, optimally, optimality from above number of discrete options right and this x I j values value taken for example, this is you know x, value x is the value orientation I can take x I stands for ith value, it will vary from 1 to n and j stands for 1 to m.

So, any value x I j x I j is any value there may be direct or coded variables for example, u values that will be direct value. So, orientation will be some sort of coding you can do direct value sometime may not be possible may be possible may not be possible. So, this is what is the scenario and second thing is our objective function is also implicit, it is not straight away like I have written earlier the function of decision variables.

But this is not explicitly define, I cannot write you know this energy load.

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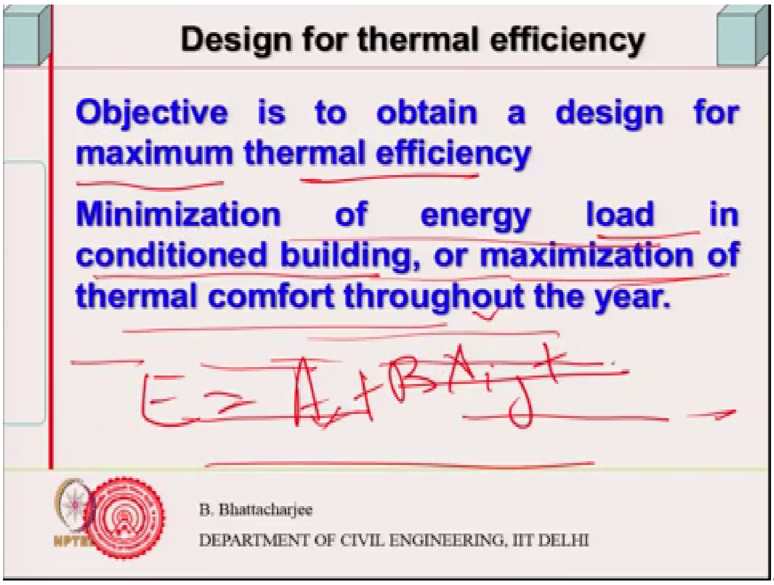

If I call it e, if I call it e it is not very easily I cannot write it like you know some constant into b into x I j plus or square even in non-linear form I can just write them because it involves the complex say simple admittance procedure mean calculating the cooling load or finding out the internal temperature, finding out deviation of the internal temperature from comfort range. So, this is only implicit, this is not explicit. So, I you know my objective function calculation would be implicit and.

So, many decision variables and therefore, one is to resort to actually you know. So, is actually implicit that is what I said, this implicit objective function which you can calculate out. So, you all have m dimensional hyper spaces out of which you go to fix out find out the best and your objective function is actually implied.

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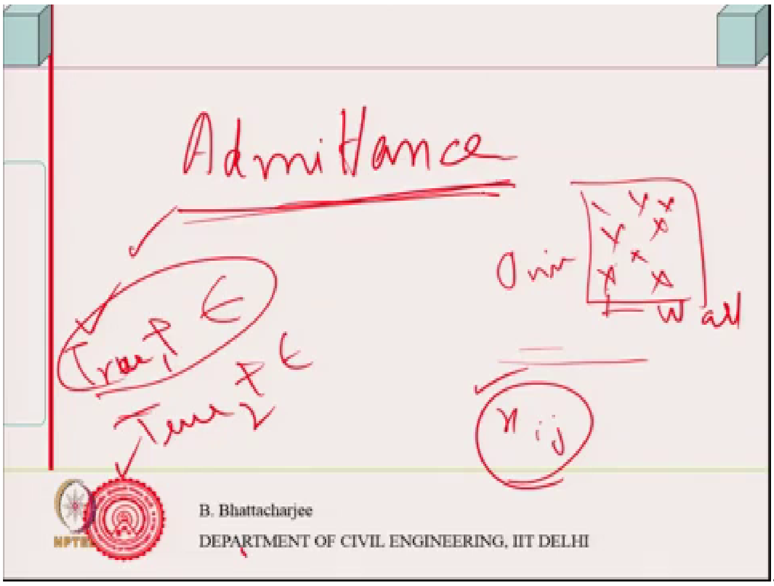

Either you calculate out through admittance procedure, through admittance or similar procedure anything which is there available to you admittance is easily programmable; remember it will have lot of errors in real.

But if you are comparing from one set of solution one solution to another solution, if the errors are similar comparatively the one which is said to be better will still remain better, even if the error is same. So, you can use this admittance or similar procedure which may not be very robust for optimization purpose because as long as my epsilon error, you know error relative error from one solution to another solution is similar. The error do not is not percentage error is same then actual true value plus, true value true plus error true 1 plus true too plus epsilon error is same. If I say that the true 2 is better than true one solution 1, 2 is better than 1 by an approximate method and if I use a robust method and then still get the same answer it is fine.

So, this should be used, one can use this for calculating or objective function for example, find out the energy low or find out internal temperature and find out the deviation of this internal temperature from the comfort zone. Either plus or minus which I have mentioned earlier to you and that is how one can actually do the design right, if initially we looked into each component how do they effect that is what was purpose of our course optimization process is not part of this course, but this is how one can do if you want to do you can do it that way.

So, I think this is what our discussion about thermal design, our discussion about thermal design I mean to look at the natural ventilation first you should know, what is the purpose of natural ventilation? What is the purpose of natural ventilation? There are 2, 3 purpose right.

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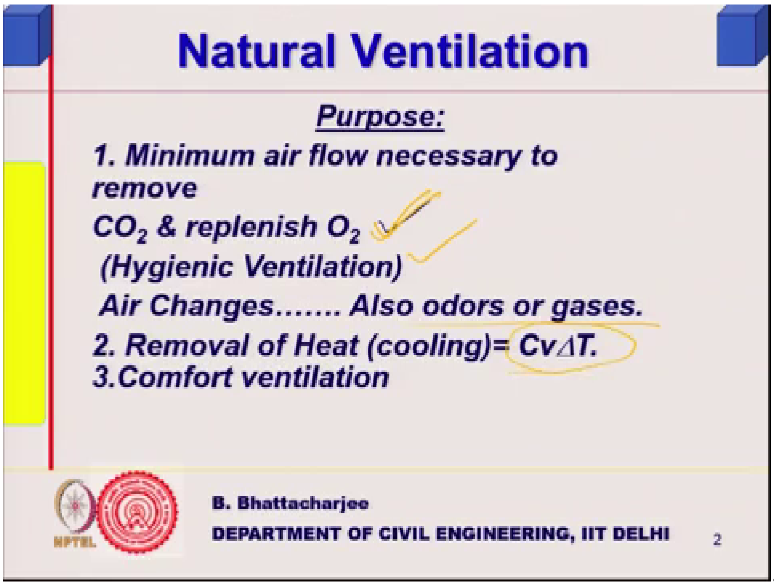

First one is minimum air flow necessary to remove carbon dioxide and replenish the oxygen right minimum needed to remove the carbon dioxide and replenish the oxygen this we call as hygienic ventilation, right. So, also in kitchen you might have to remove the smoke and some gases. So, therefore, you know these are also important then if you want to remove some heat, if you want to remove some heat then we have seen that c v delta t is the amount of heat that can be removed for constant number of air change c v is one third and v approximately you said.

So, this is amount of heat it will remove if the outside temperature is lower it will take away the heat from inside through air exchange. So, that is c v into delta t, then lastly we have seen that if the velocity of air around the skin is high it can remove heat by heat by convention as well as evaporation therefore, comfort ventilation this is called comfort ventilation.

So, there are 3 purposes first one is most important hygienic ventilation right, that is a minimum that is you have to have in any space, fresh air requirement is hygienic requirement otherwise suffocate suffocation will occur. So, that is we called as hygienic ventilation the second part is on top of that I might you know use it. So, for example, in the night time when the outside air is cool I might use it to remove the heat right and like mean scenario, mean temperature remember c v delta t. So, outside mean is usually lower.

So, I might you know ensure that I am talking only natural condition building not air condition building at all in air condition building; obviously, the air will be supplied through the duct cold cool air and that will mechanically you remove the heat through air. You know, you know like supplying cool air which will get heated up and it will it will be removed. So, that part we are not discussing here, natural ventilation I might if I ensure that there is sufficient ventilation then mean temperature might you know like cooling might occur through that depending upon the situation.

Then comfort ventilation means distribution of air velocity within the room because I might have a flow, inflow you know ventilation you know inflow of air into the room an; obviously, equal amount of outflow from the room equal you know the volume of the room remains constant. So, there can there will be an outflow cross ventilation as you call it from the room, but that may not ensure sufficient air velocity in all corners of the room. So, air velocity is important and therefore, that is related to comfort ventilation.