Sustainable Materials and Green Buildings
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Lecture 31
Building Design Optimization using Genetic Algorithm

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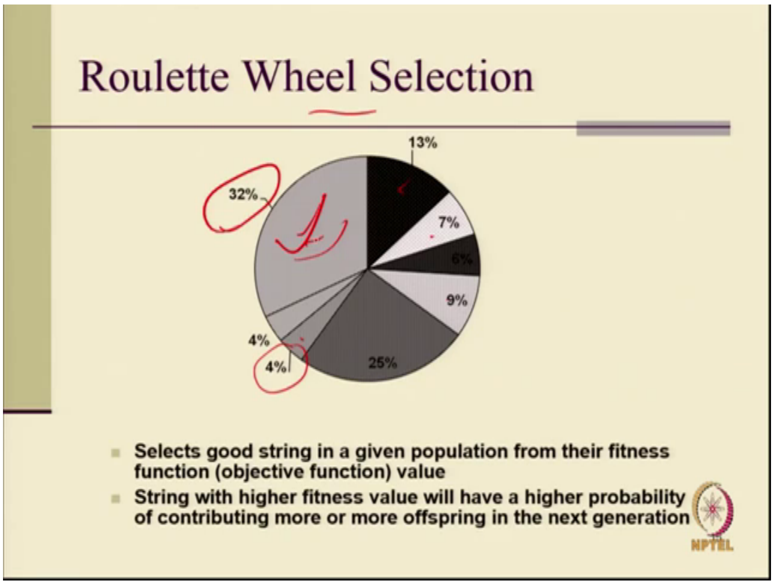

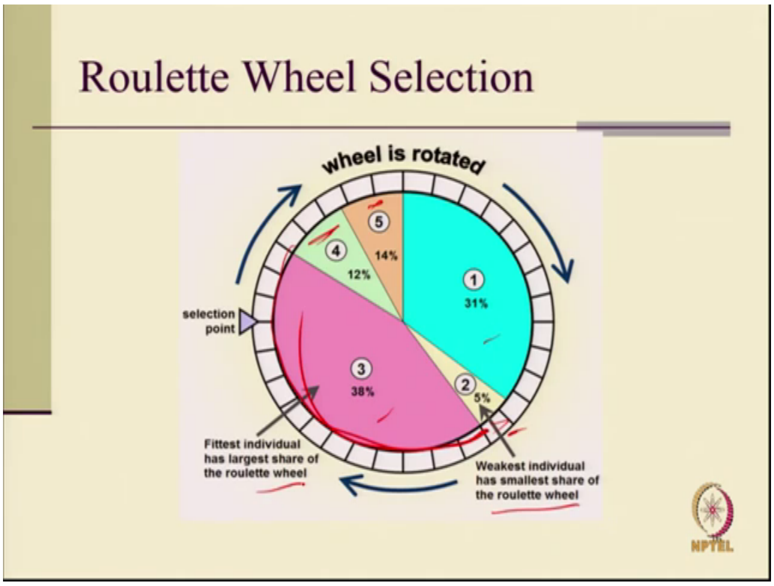

So, we will follow from where we stopped actually. So, this particular corresponding to this option there will be you know it would be repeating 32 percent of the time. So, this is how you can get is actually a question of Roulette Wheel Selection because as if we have got this pie diagram, this is 38 percent, 5 percent etcetera for that simple algebraic problem that I took.

So, as if you are rotating and more probably that it will actually, the wheel will stop here. Wheel is rotated and obviously less number of time it will stop here or stop there or stop there and so on. So, this is how it is done. So, weakest individual has smallest share roulette wheel and fittest individual.

So, there are other ways of doing it, there are advanced ways of doing it also. But my purpose here is to tell you that this type of algorithm is best suited for energy efficient building design or energy efficiency in building where you have discreet variable and qualitative variable. Because you are operating on coded variables.

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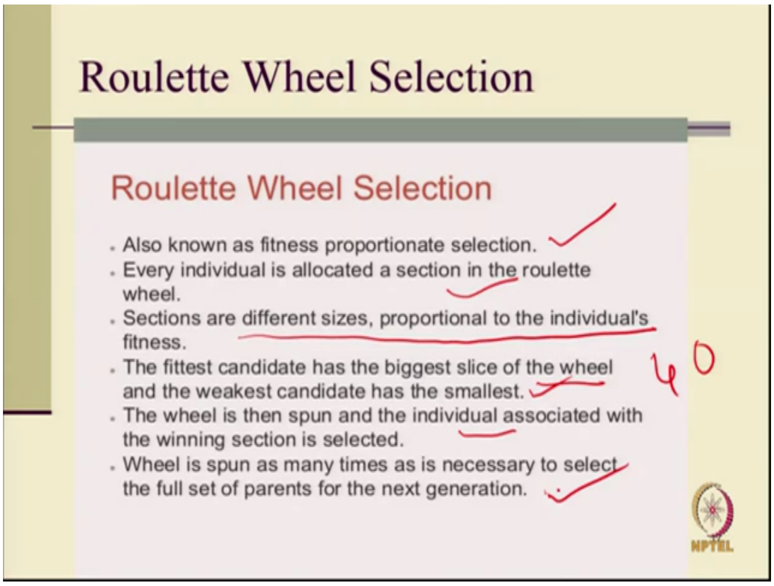

So, basically roulette wheel selection is fitness proportionate selection. Every individual is allocated a section in the roulette wheel of course. Sections are of different size proportional to individual's fitness that is what it is. The fittest candidate has got the biggest slice in the roulette wheel and the weakest candidate has a smallest slice. The wheel is then spun and the individual associated with the winning is selected.

So, that is basically generating random numbers. Wheel is spun as many times as it is necessary. So, you had original population 40, if you check their fitness, then after that when you want to skip them. So, this is what you will be doing.

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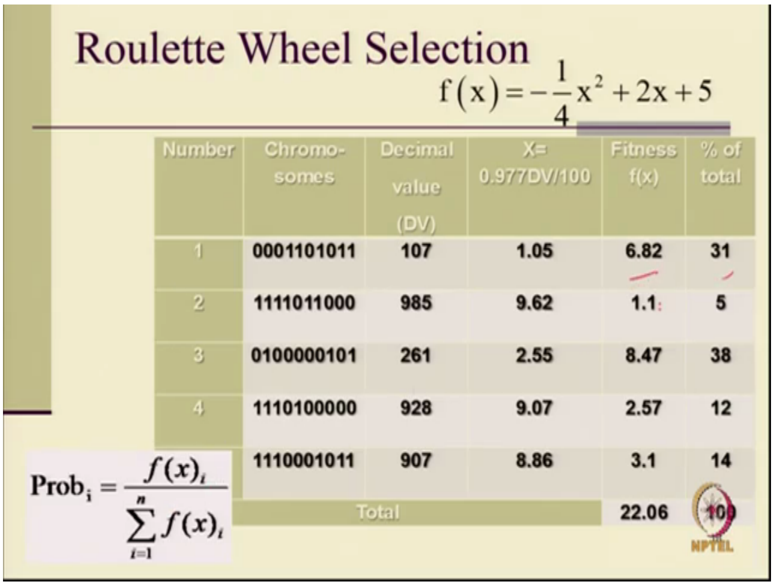

So, this is how it goes about. So, example problem was there very much. So, this is how we do it, so probability of been selection is given by (fxi) fxi divide by sigma fxi.

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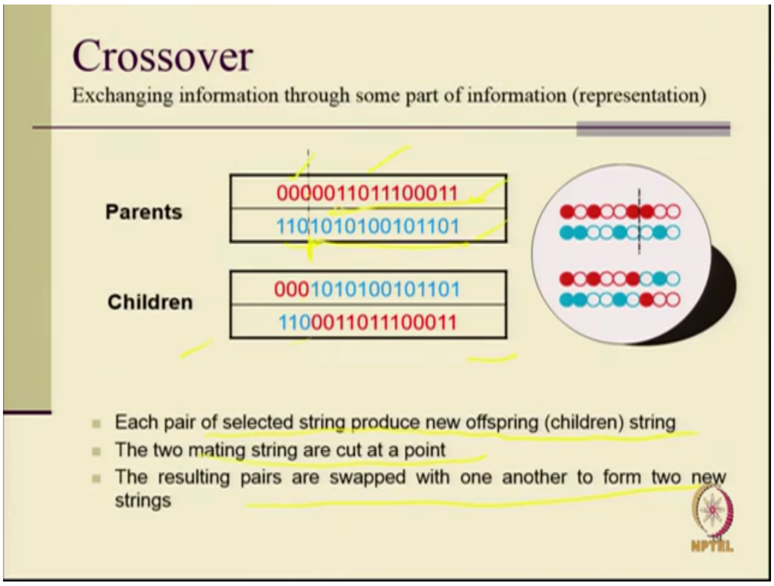

So, then we do what we call crossover. From 2 parent population, I want to generate new children, new generation. So, what is done, you do the procedure called crossover. Crossover is the thing, suppose this is my (())(02:54) and this is the 1 pair is the parent pair and I generate new children out of those.

Now, how do I do it. Basically, I will generate again a random number and this time it will be random number of this many digits. I had how many digits here? 16 digits here. In this one the chromosomes string is 16 digits.

So, I generate a random number, 2 digits random number, but divided by 1 by 16. For example, if I find it between up to 0 to 06, then this is the point. If it is 7 to12 this will be you know; so basically 0 to 16 and 16 to 32 etc. so, I can divide by 16 to get 1 by 6 here. So, 1 by 6 etc. So, suppose I found out, it is somewhere between 18 to 24, the random number is. Then this is the position which I have selected for crossover.

So, what I do? I take these 3 strings of this one and these 7 strings of (this was how many) 16. So, this 13, now I make a crossover, these goes here and this goes down here. So, this goes here, so this one is 0, 0, 0, 0, if you look at this the colour is disturbing, this colour is not the right one, so I use a colour is something like this colour.

This is a crossover location. So, 0, 0, 0 and rest all from here. And in this case, 1, 1, 0, and rest all from there. So, I have generated new population from the fittest population itself. First step is (to find the fitness and generate the) to have randomly your choice. Your choice might generate a random number and generate a population size of even population size, find out the fitness and from that you generate your new 40 population.

So, 40 times you generate a random number, which are fitted, that you will keep and then do a crossover. Crossover means, from the parents you will generate new children. Both are relatively fit, because you have selected that fit 40 population. From there you are doing the crossover, which means that, you know currently the new orientation that I am likely to get, the shape I am likely to get, they are only from the fittest ones.

So, new children you have got. So, out of 40 you will generate, randomly you will generate 40 children. A new generation has come. So, there are 40 parents from that you will generate 40 children, because you will do crossover. So, each pair of selected string produce new offspring and the two mating strings are cut at a point, the resulting pairs are swapped with one another to form the two new strings.

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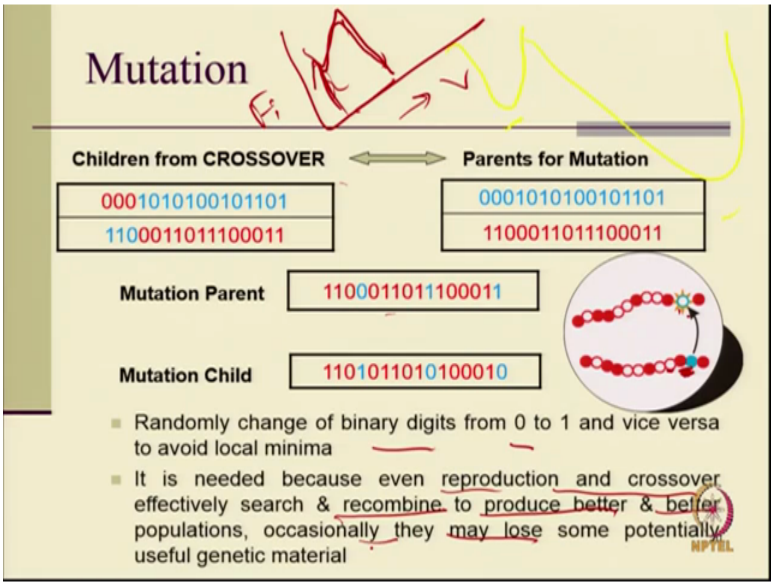

So, this new string now you evaluate again. So, then once in a while this might lead to, what is called local optima. Sometimes, you might get stuck local minima (or something like that) And leaving the global one, bigger one. Supposing something like values are, fitness values are coming something like this. You will obviously maximise the fitness, so it is all fit for only maximisation, as you can see. And sometime you might find it, where is the variable let us say, decision variable like this.

You know, you are trying to maximize it. There is a small maxima, then there are global maxima is much higher. You might get stuck here, because you will be operating around those population. So, what is done? Sometime you do, what is called mutation. So, in mutation what you do, randomly you change, again generate random number and randomly you change at one location, change 0 to 1 or 1 to 0. Because here are only two cases.

Supposing, you know the; suppose the this was green. Now here, you suddenly change it to the, green standing for this particular one, I mean this was, blank is 0. Red one is 1. So, let us say this was in the new population everything will remain same, but this was red, now it becomes blank. That means, 1 2 you have changed. So, randomly you change 1 to 0, so that it can come out from. Now, this probably itis very less, you do not do it every time. You do it in, once in a while.

So, you do the mutation. So, randomly change the binary digit from 0 to 1 and vice versa to avoid local minimum. But this is not done every time, it is done once in a while and probability such thing is also fixed. You already decide, possibly 1 in 1000 times you will do this or something of that kind.

It is needed because, even reproduction and crossover effectively search and recombine to produce better and better population, occasionally they may lose some potentially useful genetic material. So, this is actually a kind of (())(08:47) the natural evolution process. Sometime you may have.

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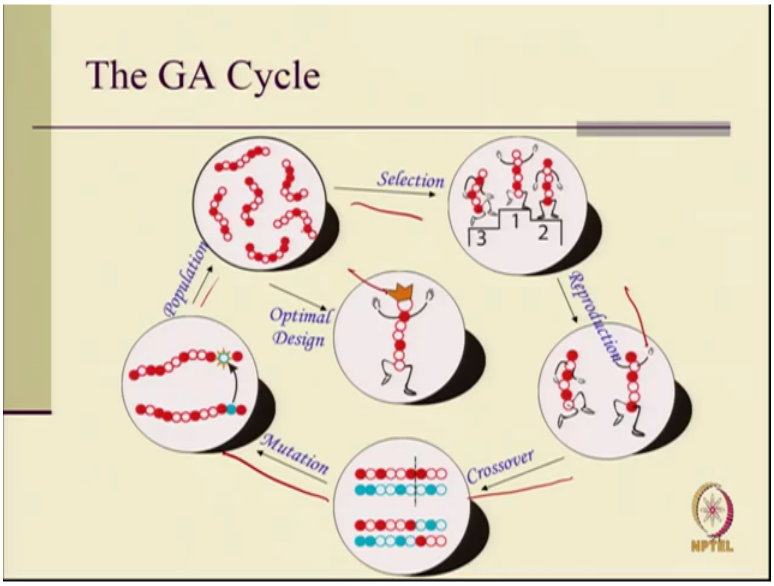

So, basically the GA cycle would be what then? To start with, you have a population, from there you are selecting, keeping the bests and then reproducing through crossover, mutation once in a while. Look at this population, find out the best.

So, this process continues, till you do not improve upon the fitness value. Now, what will happen, after sometime, you know fitness value of all the members in the population are same. That means, there is no scope of improvement further.

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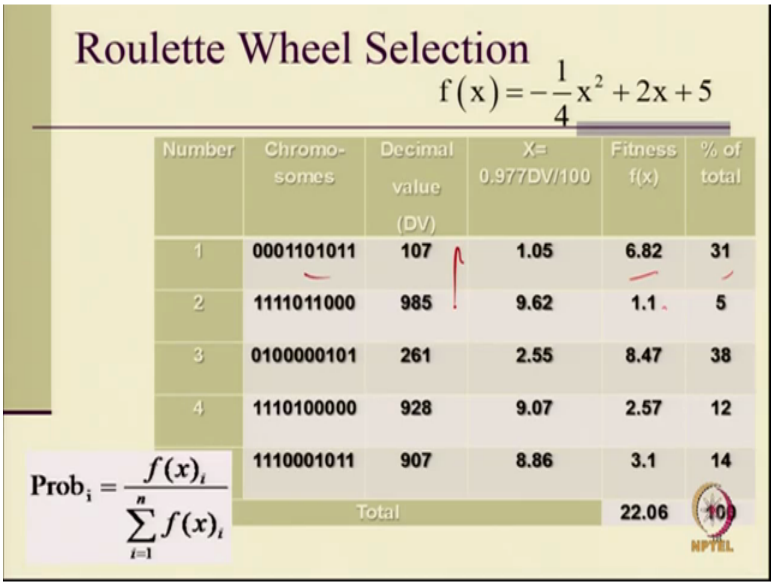

So, in our case, if you take this example and now, you go on doing this process, you will find that, algebraically whatever is the fitness value of this one, you will arrive at that. and all this members of the population will have the same fitness value.

Because you are combining and recombining, doing also something crossover, same orientation will come, you know they will repeat and finally all population will be same values. That is the idea. This is what is done.

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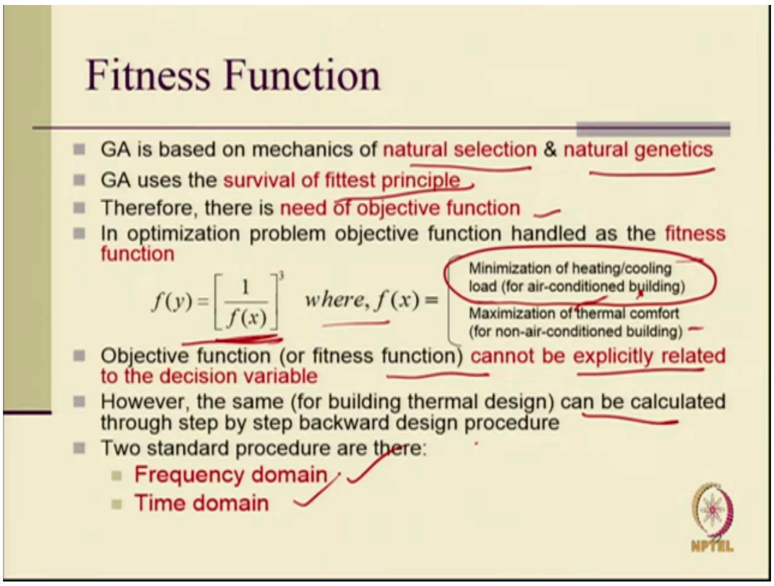

And now here, there is one problem, because this is always maximisation. And survival of the fittest principle is adopted. Therefore, the need for objective function. So, fitness function maximises. How do you minimise it? Because we have minimisation function, minimise the cooling load might maximise the thermal comfort but minimise the cooling load.

So, therefore you can use function like 1 by fx, where fx is the cooling load or one can use 1 by fx to the power 3, various one's can be use. Fx is minimisation of heating or cooling load. And if it is maximisation of thermal comfort, then obviously you do not write, maximisation from deviation, maximization of thermal comfort, which it means, the deviations from the comfort zone is minimise.

So, you can do its objective function cannot be explicitly related to the decision variable in our case, cannot be explicitly related. However, it can be calculated by step by step design procedure. So, as I said, frequency domain and time domain solution procedures are there, which am not going to discuss here, I just told you, that you can use GA together with such procedure, to come out to the best solution.

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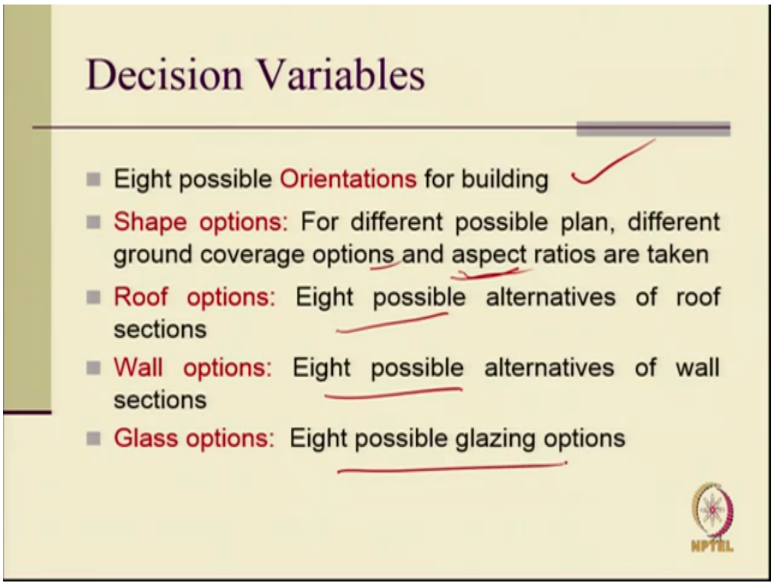

So, this is eight possible orientations of a building, for different possible (())(11:52) aspect ratio one thing. Roof, (eight) this 16 as I said. And this is 8 possible and 8 possible glazing, examples are been shown here.

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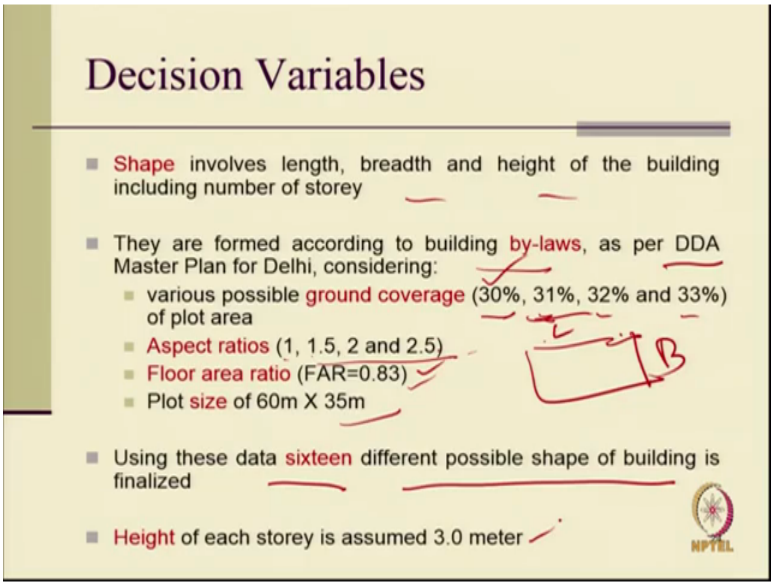

Shape involves, length, breadth and height of the building, which I showed earlier. They are formed according to the building by laws. For example, you can take DDA master plan of Delhi. And ground coverage 31 percent, 32, 33 percent. Aspect ratio, 1, 1.5, 2 and 2.5. Floor area ratio you take fixed, plot size is fixed.

So, you are actually getting 16 cases. 31 percent ground coverage, aspect ratio 4, 31 percent ground coverage, aspect ratio, what is aspect ratio? L by L and B. So, this ratio is 1 is been square, 1.5 longer dimension 1.5 times then the shorter dimension and then 2, 2.5, etc. and ground coverage, so you can get 16 variables, that is how you get 16.

And plot size is fixed and these are constant, this also fixed, one can keep them constant. So, using this data 16 different possible shape of the building can be finalized. Height you can keep as fixed. If you vary, you can vary the number of variables and increase only.

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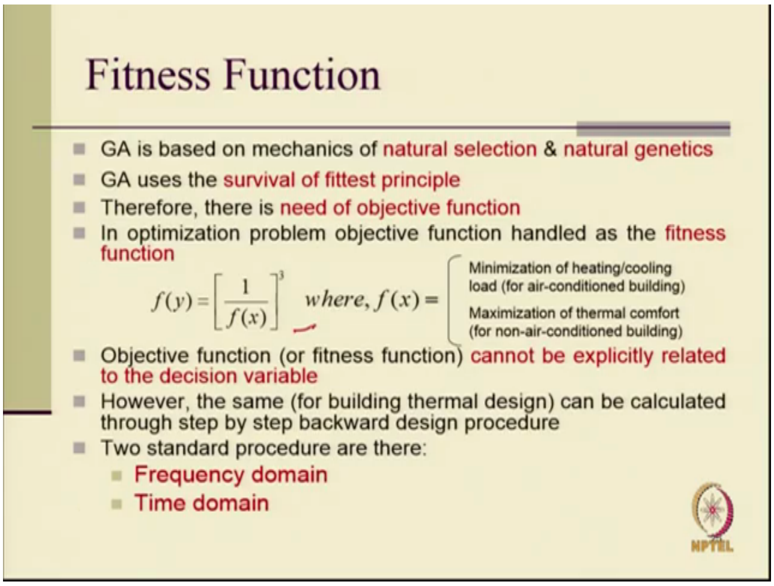

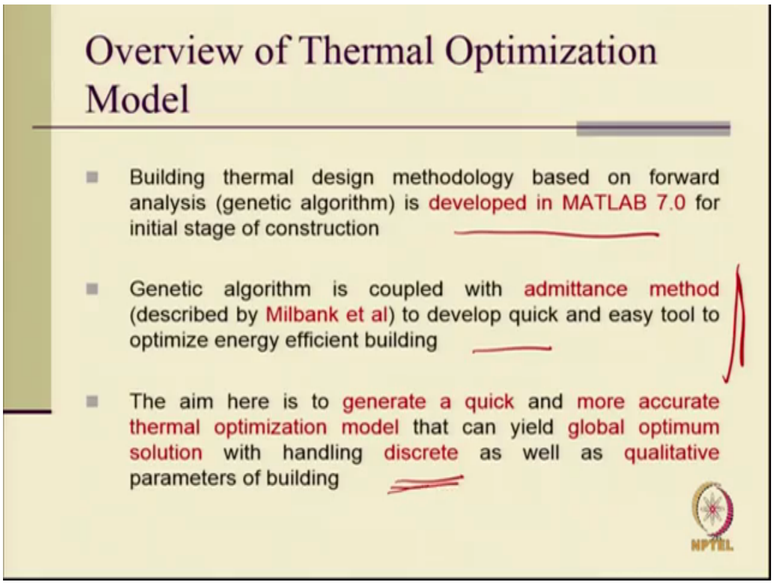

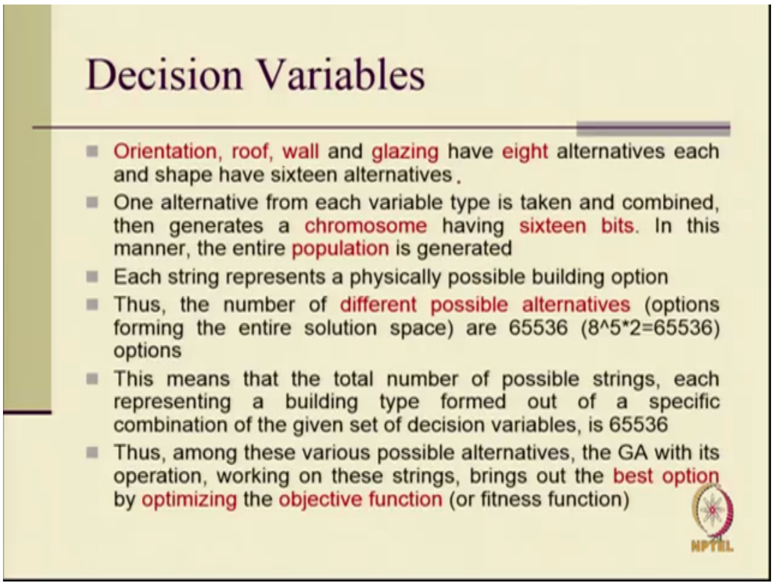

So, fitness function, something like this one can use. And then, one can write it in some programme. But for the class purpose, you do not have to really write the programme. But one simple method is using admittance procedure, which I am not teaching you in this class. In building science class of course we have covered. And generate in a quick and more accurate thermal optimisation model you can generate based on this. So, this is what I said.

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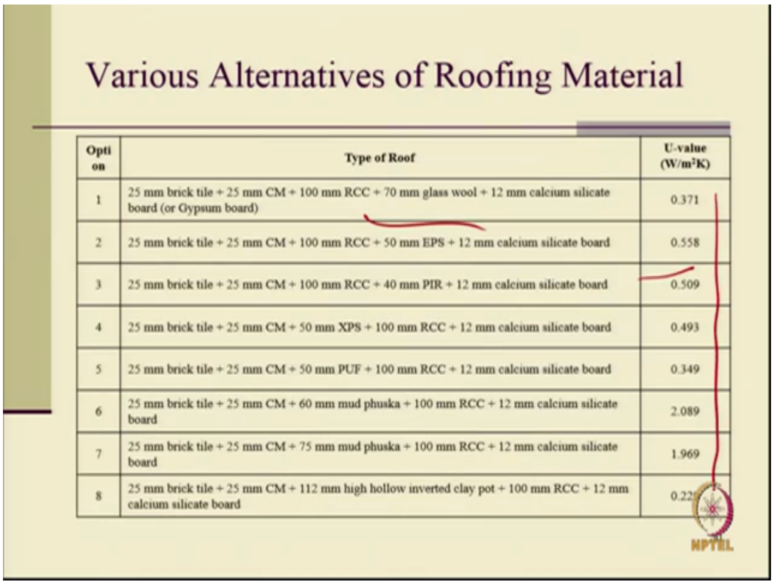

Option	Type of Roof	U-value (W/m²K)
1	25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum board)	0.371
2	25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board	0.558
3	25 mm brick tile + 25 mm CM + 100 mm RCC + 40 mm PIR + 12 mm calcium silicate board	0.509
4	25 mm brick tile + 25 mm CM + 50 mm XPS + 100 mm RCC + 12 mm calcium silicate board	0.493
5	25 mm brick tile + 25 mm CM + 50 mm PUF + 100 mm RCC + 12 mm calcium silicate board	0.349
6	25 mm brick tile + 25 mm CM + 60 mm mud phuska + 100 mm RCC + 12 mm calcium silicate board	2.089
7	25 mm brick tile + 25 mm CM + 75 mm mud phuska + 100 mm RCC + 12 mm calcium silicate board	1.969
8	25 mm brick tile + 25 mm CM + 112 mm high hollow inverted clay pot + 100 mm RCC + 12 mm calcium silicate board	0.22[illegible]

Various Alternatives of Walling Material

Option	Type of Wall	U-value (W/m^2K)
1	12 mm PL + 220 mm AAC + 12mm PL	0.915
2	12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	0.404
3	12 mm PL + 200 mm AAC + 30 mm PUF + 12 mm calcium silicate board	0.464
4	12 mm PL + 230 mm brick + 50 mm PUF + 12 mm calcium silicate board	0.431
5	12 mm PL + 230 mm brick + 30 mm XPS + 12 mm calcium silicate board	0.651
6	12 mm PL + 230 mm brick + 50 mm EPS + 12 mm calcium silicate board	0.540
7	12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL	0.563
8	12 mm PL + 230 mm brick + 50 mm glass wool + 115 mm brick + 12 mm PL	0.502

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Various alternatives of glazing material

Option	Type of Wall	Gap Thickness (mm)	Gap Gas Fill	Total Thickness (mm)	U value (W/m^2.K)	Solar Gain Factor
1	Sunergy Green	-	-	6	4.1	0.42
2	Sunergy Green	6	Air	18	2.1	0.33
3	Sunergy Green	6	Argon	18	1.9	0.33
4	Sunergy Azur	-	-	6	4.1	0.45
5	Sunergy Azur	6	Air	18	2.1	0.36
6	Sunergy Azur	6	Argon	18	1.9	0.36
7	Sunergy Clear	6	Air	18	2.1	0.52
8	Sunergy Clear	6	Argon	18	1.9	0.52

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Parameters of GA

Number of Generation	50
Population Size	20
Probability of Crossover	0.6
Probability of Mutation	0.03
Selection Method	Roulette wheel Selection
Crossover Method	Single Point Crossover
Mutation Method	Uniform Mutation

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These are the roofing materials, 8 roofing materials. I can show you similar examples earlier, there U-values are like this. Then various walls and their U-values could be something like this. Various glazing material, they could be something like this.

And number of generations, so population size has been taken 20 here. Crossover probability is 0.6, probability of mutation is 0.3, procedure is roulette wheel selection, single point crossover and uniform mutation, you know you can also have double point crossover and all, here is single point crossover and uniform mutation.

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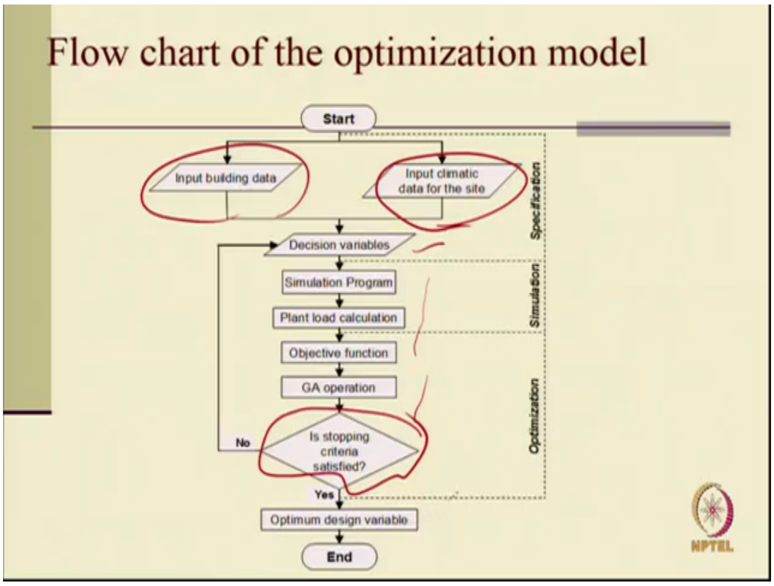

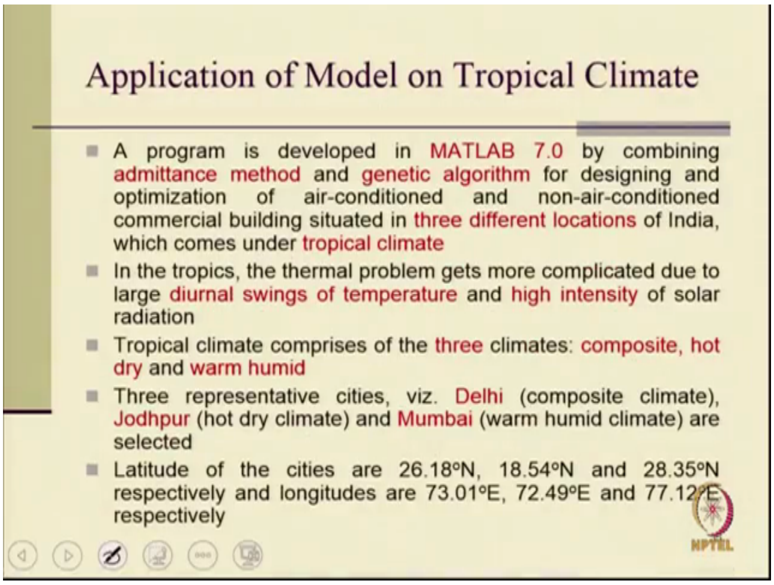

So, that would be the start. Give the input building data, obviously the climatic data is needed for the building. Then decision variables, then program, plant load calculation, GA operations and the stopping criteria is well, let us say, 90 percent of the values are all same, fitness values are same, that could be stopping criteria and that is the end of it. So, this is what it is.

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Inputs for Thermal Optimization Model

- Plot area = 60mX35m
- FAR = 0.83

(as per DDA, 1996. Master plan for Delhi: Perspective 2001)

- Ground coverage = [30, 31, 32, 33] (max is 33.33%)

(as per DDA, 1996. Master plan for Delhi: Perspective 2001)

- Aspect ratio = [1, 1.5, 2, 2.5]
- Height of each storey = 3m
- % of glass on front wall =25%
- % of glass on other wall =15%
- hig = 10 W/m^2K, hog = 23 W/m^2K
- hiw =10 W/m^2K, how = 23 W/m^2K
- hir =15 W/m^2K, hor =23 W/m^2K
- alpha(w) = 0.6, alpha(r) = 0.6, alpha(g) = 0.4
- Set temperature = 25°C
- Working hour = 9:00 to 18:00 hr
- No. of air changes per hour = 0.6 (infiltration)

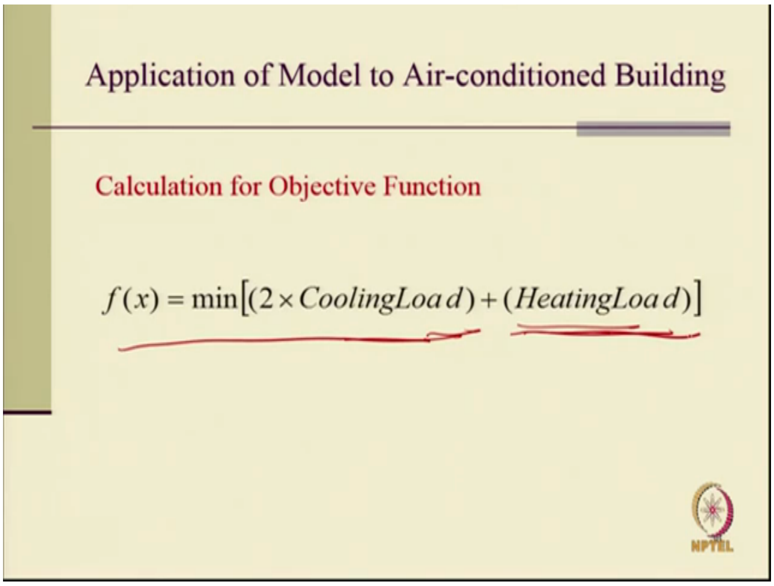
  = 1 (ventilation for AC building)

  = 5 (ventilation for Non AC building)

Building bye-laws from Master Plan of Delhi

Area of Plot (m^2)	Max. ground coverage (%)	FAR	Maximum height
Below 32	75	1.5	8
32-50	75	1.5	8
50-100	66	1.8	12.5
100-250	60	1.6	12.5
250-500	50	1.4	12.5
500-1,000	40	1.0	12.5
1,000-1,500	33.33	.83	12.5
1,500-2,250	33.33	.83	12.5
2,250-3,000	33.33	.83	12.5
3,000-3,750	33.33	.83	12.5
Above 3,750	33.33	.83	12.5

DDA, 1996. Master plan for Delhi: Perspective 2001. New Delhi



Supposing I take an example, plot area, etc which I gave you. And you can take even building master plan into account in this one. So, for this kind of plot areas, if you have taken, these sum of this maximum height and all those as prescribed then objective function is minimised, two times cooling load plus the heating load. You are minimising, therefore two times cooling load. Minimising the heating load, cooling load is taken twice the weightage is given because the cost and heating load is just once, that is what I said.

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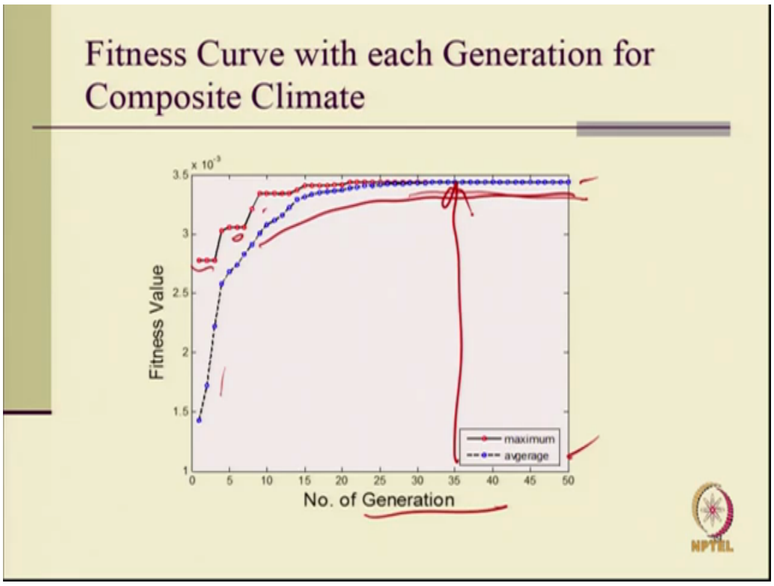

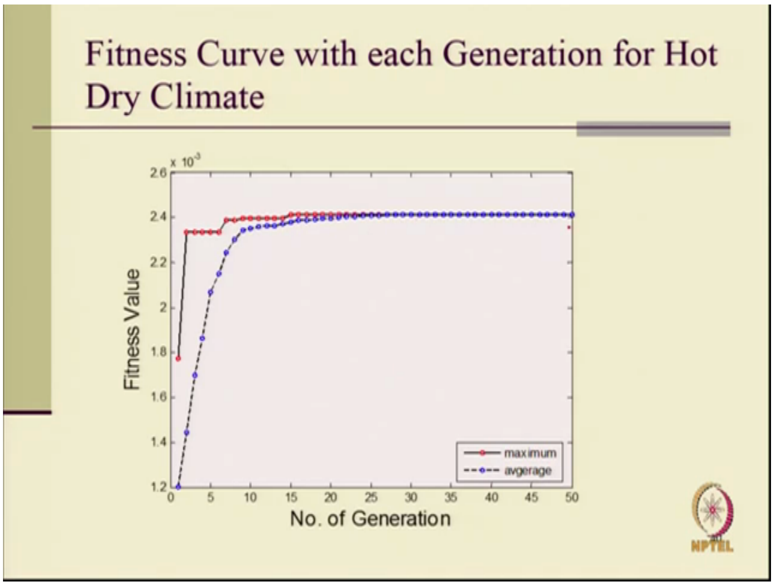

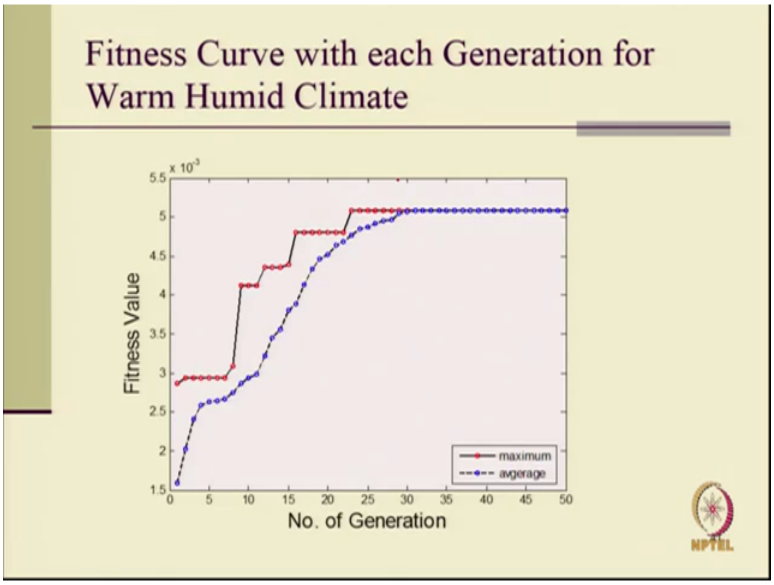

And if you see that, after number of generations, the fitness value is average fitness value. Average fitness value becomes constant, that means all of them have got same fitness value. So, this is the average fitness value, the blue one. And maximum value is here this much, then it is this much, then this so maximum and average, they all become same when after that you need not.

So, therefore we can actually do an exercise initially, you say that after 35 cycles, I will not do further or depending upon your case, sometimes it may be around 50 cycles, which when it will tell you that it is (())(16:38) optimisation.

So, this is for a given climate let us say, in composite climate something the Delhi kind and this is something of the kind of Jodhpur- hot dry desert. So, after some period you find it all becomes same. Warm humid climate something like Chennai, Mumbai, Kolkata is similar. So, there you can find something of this kind.

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Rectangle Building (Optimum Solution 1)

	Composite climate (Delhi)	Hot dry climate (Jodhpur)	Warm humid climate (Mumbai)
Orientation	North	North-east	North-east
Shape (dimension)	27mX27mX6m	27mX27mX6m	27mX27mX6m
Roof	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 2) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board	(Option 2) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board
Wall	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 4) - 12 mm PL + 230 mm brick + 50 mm PUF + 12 mm calcium silicate board	(Option 6) - 12 mm PL + 230 mm brick + 50 mm EPS + 12 mm calcium silicate board
Glazing	(Option 3) - Sunergy Green (Argon)	(Option 2) - Sunergy Green (Air)	(Option 2) - Sunergy Green (Air)
Cooling load (kW)	82350	92875	72675
Heating load (kW)	925	500	0

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Rectangle Building (Optimum Solution 2)

	Composite climate (Delhi)	Hot dry climate (Jodhpur)	Warm humid climate (Mumbai)
Orientation	North-east	North	North
Shape (dimension)	27mX27mX6m	27mX27mX6m	27mX27mX6m
Roof	(Option 2) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)
Wall	(Option 3) - 12 mm PL + 200 mm AAC + 30 mm PUF + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board
Glazing	(Option 2) - Sunergy Green (Air)	(Option 2) - Sunergy Green (Air)	(Option 3) - Sunergy Green (Argon)
Cooling load (kW)	85300	91450	70525
Heating load (kW)	1200	425	0

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Rectangle Building (Optimum Solution 3)

	Composite climate (Delhi)	Hot dry climate (Jodhpur)	Warm humid climate (Mumbai)
Orientation	North	North-east	North-east
Shape (dimension)	33mX22mX6m	33mX22mX6m	33mX22mX6m
Roof	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 2) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board)
Wall	(Option 3) - 12 mm PL + 200 mm AAC + 30 mm PUF + 12 mm calcium silicate board	(Option 3) - 12 mm PL + 200 mm AAC + 30 mm PUF + 12 mm calcium silicate board	(Option 4) - 12 mm PL + 230 mm brick + 50 mm PUF + 12 mm calcium silicate board
Glazing	(Option 3) - Sunergy Green (Argon)	(Option 3) - Sunergy Green (Argon)	(Option 2) - Sunergy Green (Air)
Cooling load (kW)	78325	92850	73425
Heating load (kW)	1000	675	0

And you find, that this is your finally optimum solution 1, for such kind of situations. So, you know the orientation for each climatic situation you can get, you can get the best solution. You can get the best solution using such kind of optimisation process. And optimum solution 2, that is the next to the best, if you look at it, that also you can look into. And next, 3rd best also you can look into. For shape of the building was considered to be the rectangle one and another L-shaped.

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L Shaped Building (Optimum Solution 1)

	Composite climate (Delhi)	Hot dry climate (Jodhpur)	Warm humid climate (Mumbai)
Orientation	North	North	North
Shape (dimension)	33mX22mX6m	33mX22mX6m	33mX22mX6m
Roof	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)
Wall	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board
Glazing	(Option 2) - Sunergy Green (Air)	(Option 3) - Sunergy Green (Argon)	(Option 3) - Sunergy Green (Argon)
Cooling load (kW)	57475	63625	53650
Heating load (kW)	375	75	0

L Shaped Building (Optimum Solution 2)

	Composite climate (Delhi)	Hot dry climate (Jodhpur)	Warm humid climate (Mumbai)
Orientation	North-east	North	North
Shape (dimension)	27mX27mX6m	27mX27mX6m	27mX27mX6m
Roof	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)
Wall	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board
Glazing	(Option 3) - Sunergy Green (Argon)	(Option 2) - Sunergy Green (Air)	(Option 2) - Sunergy Green (Air)
Cooling load (kW)	56500	62575	52800
Heating load (kW)	475	75	0

L Shaped Building (Optimum Solution 3)

	Composite climate (Delhi)	Hot dry climate (Jodhpur)	Warm humid climate (Mumbai)
Orientation	North-east	North-east	North-east
Shape (dimension)	33mX22mX6m	27mX27mX6m	33mX22mX6m
Roof	(Option 2) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board	(Option 1) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 70 mm glass wool + 12 mm calcium silicate board (or Gypsum borad)	(Option 2) - 25 mm brick tile + 25 mm CM + 100 mm RCC + 50 mm EPS + 12 mm calcium silicate board
Wall	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board	(Option 2) - 12 mm PL + 200 mm AAC + 50 mm glass wool + 12 mm calcium silicate board
Glazing	(Option 3) - Sunergy Green (Argon)	(Option 3) - Sunergy Green (Argon)	(Option 6) - Sunergy Azur (Argon)
Cooling load (kW)	58650	62750	57875
Heating load (kW)	650	150	0

Comparison of Optimized Building With Conventionally Designed Building

Parameters for conventionally designed building

- **Orientation:** Same as optimized solution
- **Dimension:** Same as optimized solution
- **Roof:** 12 mm PL + 100 mm RCC + 25 mm mortar + 25 mm brick tile
- **Wall:** 12 mm PL + 230 mm brick + 12 mm PL
- **Glass:** 5 mm single clear

So, separately for L-shaped building, with different aspect ratios. And L-shaped building and optimized building with conventionally designed building, then one can compare by using software or using the same basically, you can calculate the cooling load.

(Refer Slide Time: 18:06)

Comparison of optimized and conventionally designed Rectangle building

	Solutions	Orientation	Shape (dimension)	Optimized		Conventionally designed	
				Cooling load (kWh)	Heating load (kWh)	Cooling load (kWh)	Heating load (kWh)
Composite	1	North	27mX27mX6m	82350	925	168281	5044
	2	North-east	27mX27mX6m	85300	1200	169500	5465
	3	North	33mX22mX6m	78325	1000	168863	5081
Hot dry	1	North-east	27mX27mX6m	92875	500	192488	1613
	2	North	27mX27mX6m	91450	425	191419	1594
	3	North-east	33mX22mX6m	92850	675	194625	1613
Warm humid	1	North-east	27mX27mX6m	72675	0	183844	0
	2	North	27mX27mX6m	70525	0	181594	0
	3	North-east	33mX22mX6m	73425	0	183863	0

Comparison of optimized and conventionally designed L-shaped building

	Solutions	Orientation	Shape (dimension)	Optimized		Conventionally designed	
				Cooling load (kWh)	Heating load (kWh)	Cooling load (kWh)	Heating load (kWh)
Composite	1	North	33mX22mX6m	57475	375	119456	3525
	2	North-east	27mX27mX6m	56500	475	118556	3825
	3	North-east	33mX22mX6m	58650	650	122006	3844
Hot dry	1	North	33mX22mX6m	63625	75	135113	1238
	2	North	27mX27mX6m	62650	75	132750	1238
	3	North-east	33mX22mX6m	62750	150	133931	1256
Warm humid	1	North	33mX22mX6m	53650	0	130519	0
	2	North	27mX27mX6m	52800	0	127931	0
	3	North-east	33mX22mX6m	57875	0	133706	0

You will find that, you will get much better cooling load for conventionally designed as practiced. It would give you something of the kind of let us say kilo-watt-hour 168281. In this case, is nearly half. This is the 3rd best solution, even that is nearly half of this.

So, you can look at, heating load is this much, heating load here was 1000, here was 5000. So, you can see that, best even 2nd best or 3rd best solutions are much better than just using arbitrary solutions. And L-shaped building also similar sort of thing one can see.

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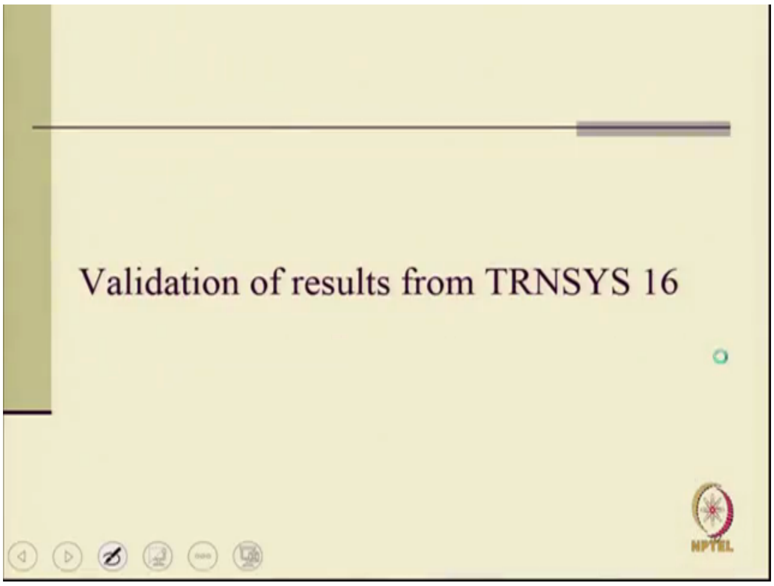
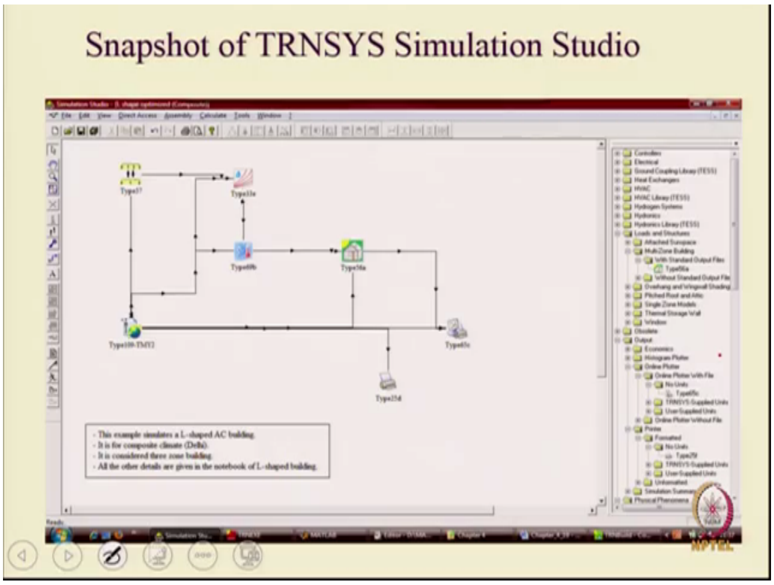
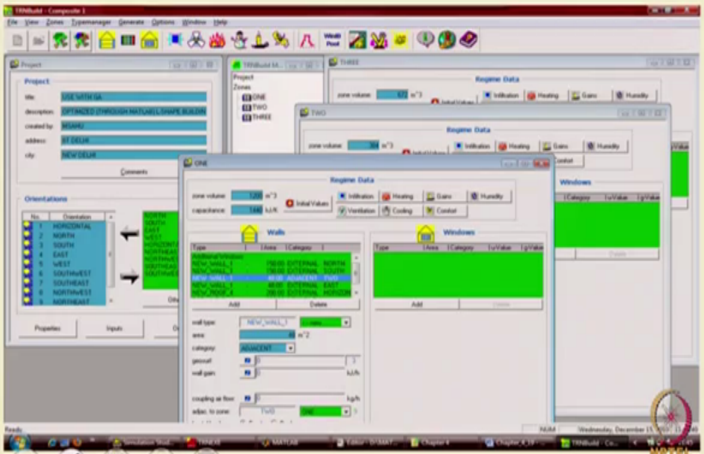
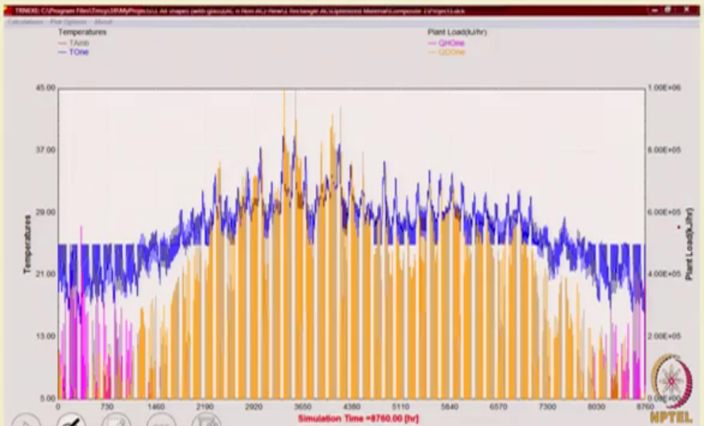




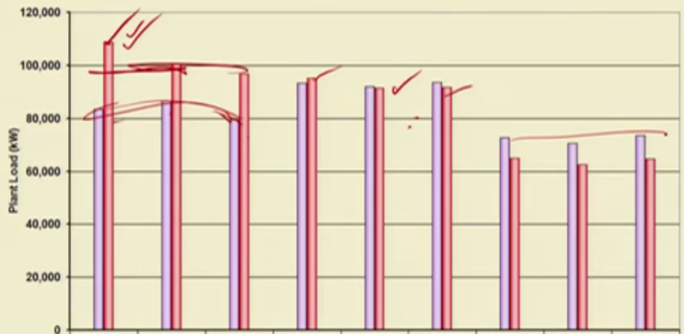
Snapshot of TRNBuild



Snapshot of the Annual Results Obtained from TRNSYS



Comparison of Plant Load of Optimized Rectangle Building (All Climate)



	Solution 1	Solution 2	Solution 3	Solution 1	Solution 2	Solution 3	Solution 1	Solution 2	Solution 3
	Composite			Hot dry			Warm humid		
GA Model	83,275	86,500	79,325	93,375	91,875	93,525	72,675	70,525	73,425
TRNSYS	108,704	100,600	96,840	95,056	91,520	91,696	64,922	62,450	64,766

And if you use a software, to see the value. For example: TRNSYS is one of the software. So, if you, these not requires snapshot, unless you know TRNSYS or no. So, you will find that, this is solution one, this is from TRNSYS and this is from GA model using a procedure of calculation which is much, you may available to hand calculation.

Relative results are more or less same. This was the best, well this near best. So, if you are selecting between this three, this also says that, this best. If you compare the conventional, you will find the difference, you know the best, if you calculate them out, so they are something like this.

For example, these 3 are from the best 3 for optimisation and they give similar result, based on the software, any software. So, since I am selecting relatively best one., a very sophisticated (()) (19:58) software may not be needed. Relative result will still be same. To start with design, you might verify this, but if you are interested in calculating or estimating annual energy load, then you have to use the software to verify the same.

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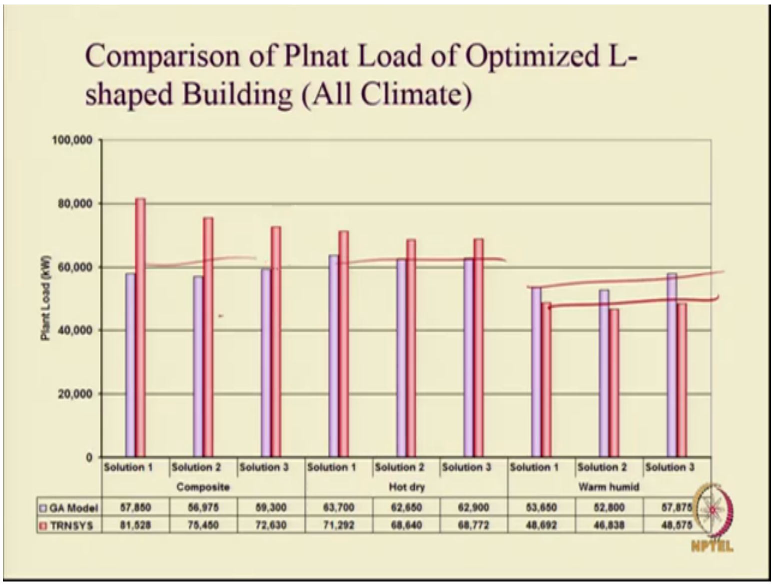

So, L-shaped building also it will show you similar, this is from admittance procedure, optimal once and this is from the software, this is from similarly again from the software and this one.

(Refer Slide Time: 20:30)

Comparison of optimized and conventionally designed Rectangle building

Climates	Solutions	Proposed GA model: Annual plant load (kWh) Optimized building (a)	Proposed GA model: Annual plant load (kWh) Conventionally Designed building (b)	Ratio = (b)/(a)	TRNSYS model: Annual plant load (kWh) Optimized building (c)	TRNSYS model: Annual plant load (kWh) Conventionally Designed building (d)	Ratio = (d)/(c)
Composite climate	Solution 1	83,275	173,325	2.08	99,952	227,476	2.28
	Solution 2	86,500	174,956	2.02	100,600	209,660	2.08
	Solution 3	79,325	173,944	2.19	96,840	209,792	2.17
Hot & dry climate	Solution 1	93,375	194,101	2.08	95,056	199,756	2.10
	Solution 2	91,875	193,013	2.10	91,520	199,756	2.18
	Solution 3	93,525	196,238	2.10	91,696	199,360	2.17
Warm & humid climate	Solution 1	72,675	183,844	2.53	64,922	137,255	2.11
	Solution 2	70,525	181,594	2.57	62,450	137,255	2.20
	Solution 3	73,425	183,863	2.50	64,766	136,686	2.11

Comparison of optimized and conventionally designed L-shaped building

Climates	Solutions	Proposed GA model: Annual plant load (kWh) Optimized building (a)	Proposed GA model: Annual plant load (kWh) Conventionally Designed building (b)	Ratio = (b)/(a)	TRNSYS model: Annual plant load (kWh) Optimized building (c)	TRNSYS model: Annual plant load (kWh) Conventionally Designed building (d)	Ratio = (d)/(c)
Composite climate	Solution 1	57,850	122,981	2.13	54,376	112,550	2.07
	Solution 2	56,975	122,381	2.15	51,410	101,040	1.97
	Solution 3	59,300	125,850	2.12	54,310	103,000	1.90
Hot & dry climate	Solution 1	63,700	136,351	2.14	67,185	138,542	2.06
	Solution 2	62,650	133,988	2.14	65,825	136,421	2.07
	Solution 3	62,900	135,187	2.15	68,872	139,937	2.03
Warm & humid climate	Solution 1	53,650	130,519	2.43	59,957	120,507	2.01
	Solution 2	52,800	127,931	2.42	59,955	120,271	[illegible]
	Solution 3	57,875	133,706	2.31	60,845	117,438	[illegible]

Comparison of EPI from proposed model with GRIHA benchmark (Rectangular building)

Climates	Solutions	Floor Area (sqm) (a)	Annual Plant Load (kWh): Optimized building (b)	Annual Plant Load (kWh): Currently practiced building (c)	Annual Lighting Load (kWh/sqm) (d)	EPI (kWh/sqm/yr): Optimized building [(a)*(d)+(b)]/(a)	EPI (kWh/sqm/yr): Currently practiced building [(a)*(d)+(c)]/(a)	EPI (kWh/sqm/yr): GRIHA specified
Composite	1	1458	83,275	173,325	31.5	89	150	140
	2	1458	86,500	174,956	31.5	91	151	140
	3	1452	79,325	173,944	31.5	86	151	140
Hot & dry	1	1458	93,375	194,101	31.5	96	165	140
	2	1458	91,875	193,013	31.5	95	164	140
	3	1452	93,525	196,238	31.5	96	167	140
Warm & humid	1	1458	72,675	183,844	31.5	81	158	140
	2	1458	70,525	181,594	31.5	80	156	140
	3	1452	73,425	183,863	31.5	82	158	140

So, in all cases, it would give a much better than a conventional design buildings. So, this is fine.

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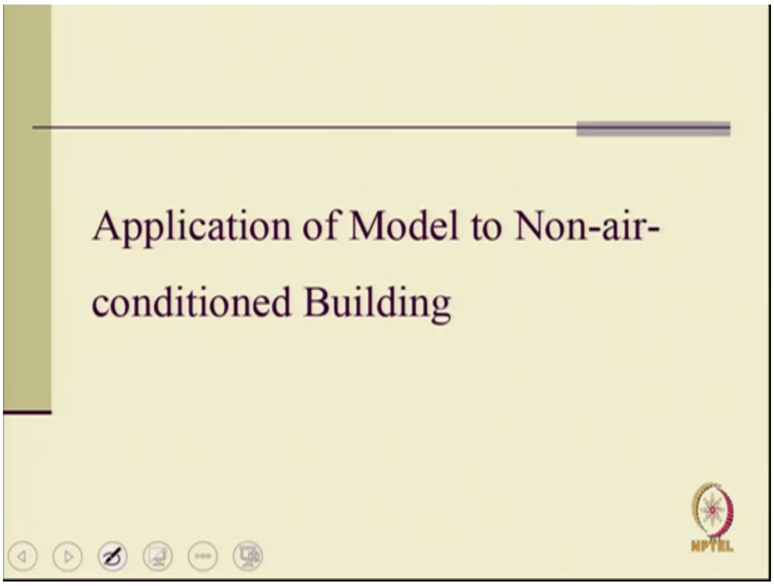

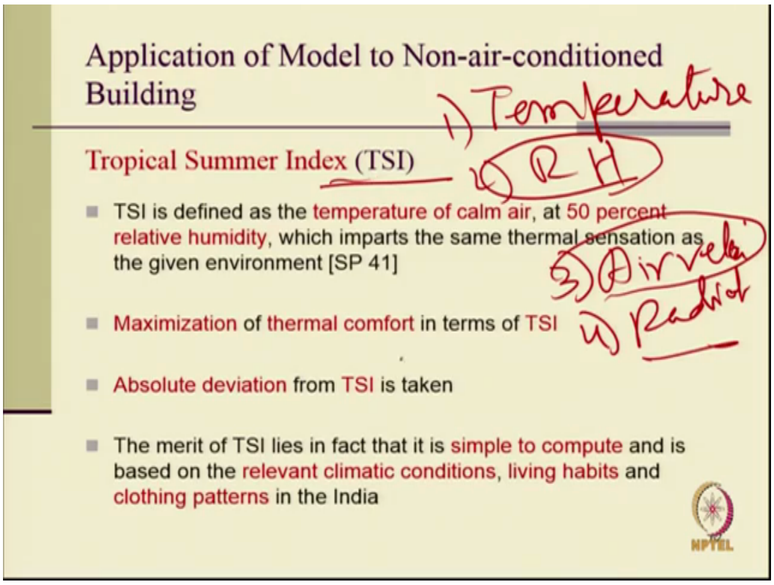

But I think, I will just tell you about non-air-conditioned building at the last part of it. Now, in the non-air-conditioned building, cooling load you do not calculate. We calculate what is called (()) (20:54). Now, there are various (()) (20:58). One which is simple and suitable for country like India, tropical countries is called tropical summer index.

These are actually developed by selecting healthy individuals, between the age group of 20 to 60, putting them into the given environment and asking their subjective response. There are other ones, there are improved ones, also there are modern ones, some software also can give you some idea. But this is a classical one, and it has got its simple algebraic. So, it is pretty useful in that sense.

Now, what is the factor which governs your thermal comfort? Number one, it is a temperature. Number two, relative humidity. Number three, air velocity, fan etc. Number four, radiation from surfaces. What I mean to say is, the temperature inside the room, if it is high you start feeling uncomfortable. So, there is an, temperature is aspect. But even the temperature is low, relative humidity is high, you start feeling discomfort, why? Because body can cool itself by evaporative cooling. From the scheme, sweat can evaporate and cooling occurs.

In still air this cooling will depend only on the relative humidity. If the relative humidity is high, this cooling will not occur, evaporation cannot take place. But supposing I have a fan, then that will remove some of the heat from my skin. If the surfaces are very hot, they would also radiate heat into my body.

So, temperature, relative humidity, air velocity, local air velocity from fan or something of that kind, it was naturally ventilated, even if you can design from natural ventilation air coming from outside, if it is cool air, then that can actually remove some heat from your body and radiation from the surfaces. So, all these are combined in tropical summer index or for that matter any thermal comfort index.

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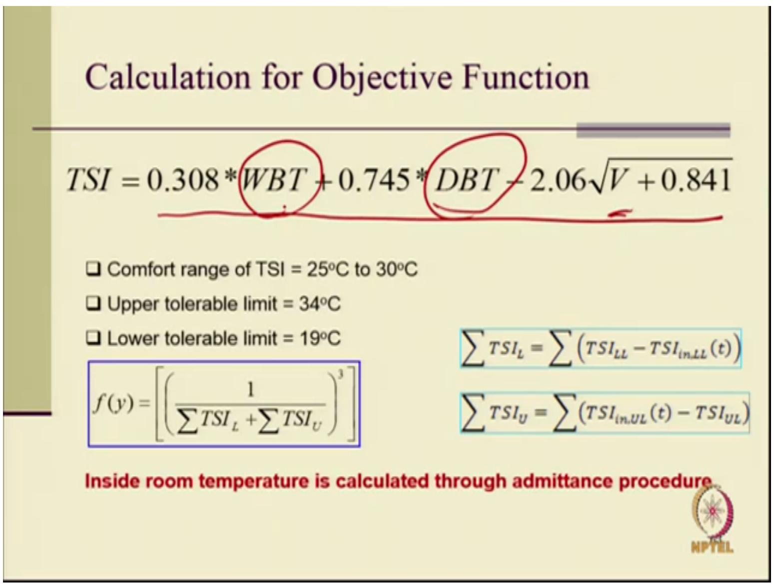

So, this is given by this formula, tropical summer index is given by this formula. DBT stands for Dry Bulb Temperature, temperature inside the space. V stands for air velocity. WBT is called Wet Bulb Temperature, thus actually related to relative humidity. Difference between DBT and WBT gives me relative humidity. Just let me now explain what it is actually. So, let me just explain what is, because some of you may not have been exposed to cyclomatic chart or similar thing.

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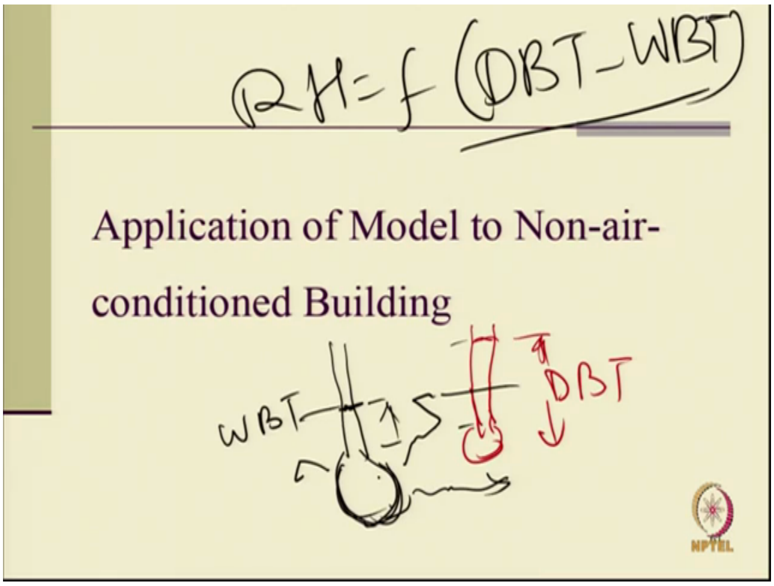

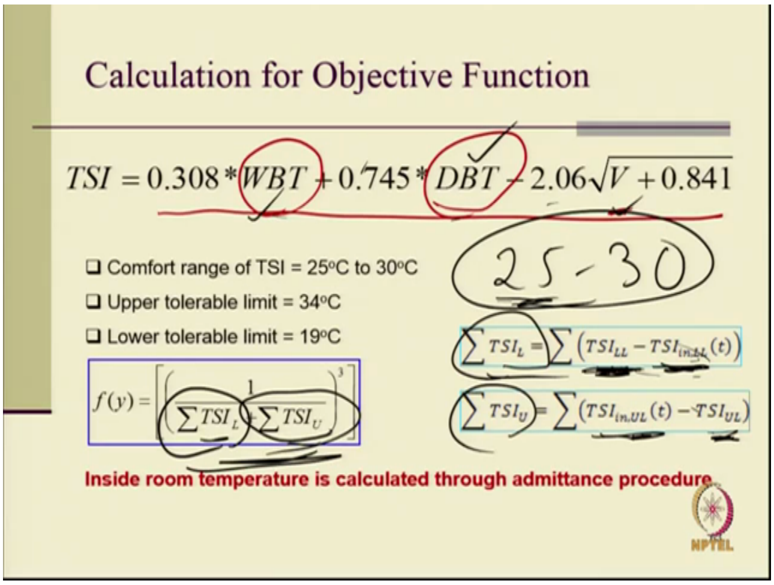

What you do is, when you want to find out relative humidity this is if I have a thermometer, you know mercury thermometer, if I measure the temperature, that I called it DBT, Dry Bulb Temperature.

Now, supposing same thermometer, now this bulb is kept wet by putting wet jute. Evaporation will occur from here; evaporation will occur from here. So, this height and height here would be less, there will be difference in this height, this is called wet-bulb thermometer temperature, Wet Bulb Temperature. And WBT will be less than DBT, except for the case, where it is, relative humidity is 100 percent. Where no evaporation can take place from here and therefore relative humidity is 100.

So, relative humidity is a function of DBT minus WBT, this will call as wet bulb depression. So, therefore in this model as you have seen, WBT is directly taken, which is a measure together with the DBT, is a measure of relative humidity. So, this is the formula. Now, this easily you can calculate out. Now, the range of, comfort range for this one is also given, 25 to 30, these all expressed in degree centigrade.

These is an empirical equation. So, simple way is to, if you know the air velocity, inside the room there may not be any air velocity, you might assume to be 0 or whatever it is, if there is no air velocity. So, you can find out and if it is within 25 to 30 it is comfortable. So, what we can do is, we can actually find out the deviation from this. So, lower limit of this is 25, tropical summer index lower limit is 25 and upper limit is 30.

So, the value which is there at a given time, lower limit minus this TSL lower and TSL upper, which is 30, this is negative. So, both will be negative. Actually, lower limit is less than the room temperature, upper limit is also less than the temperature, this will be negative. This one, the deviation from this I can actually minimise or negative deviation I can maximise. So, these are negative values as you can see and I can maximise.

Now, how do I find out this T, this has to be again calculated through the admittance procedure or some such procedure. The inside room temperature every hour has to be calculated, knowing the outside condition and all, using the same procedure that I talked about.

So, once you know this, deviation from this one can minimise or if you have to maximise negative deviation from this one you can maximise or you can use a fitness function like this. One over this deviation, simply absolute value of this solution. One over this deviation and this is summed up for 24 hours and this is maximised, fitness function, because minimisation of a negative function is equivalent to maximisation, negative values maximisation. So this is how, what we do.

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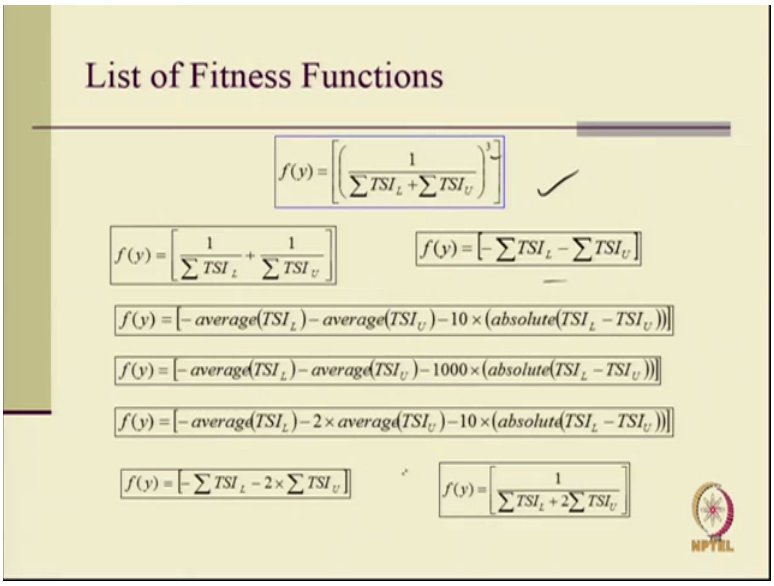

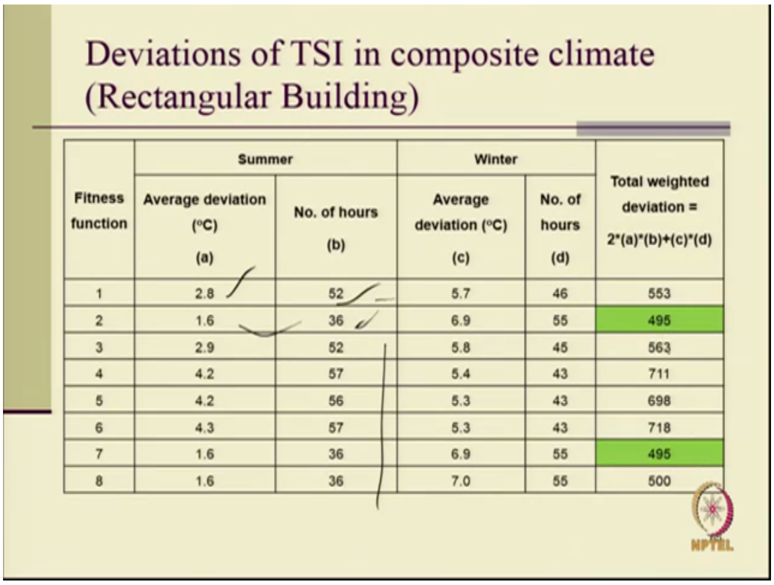

Fitness function	Summer		Winter		Total weighted deviation = 2*(a)*(b)+(c)*(d)
	Average deviation (°C) (a)	No. of hours (b)	Average deviation (°C) (c)	No. of hours (d)	
1	2.8	52	5.7	46	553
2	1.6	36	6.9	55	495
3	2.9	52	5.8	45	563
4	4.2	57	5.4	43	711
5	4.2	56	5.3	43	698
6	4.3	57	5.3	43	718
7	1.6	36	6.9	55	495
8	1.6	36	7.0	55	500

So, fy is this, sometime one may use a power and so on so forth. And therefore, you can find out which is better. So, rest all remain same, average deviation we can find out, number of hours etc. And you can find out the best selection, total weighted, you know you can use some weighted function. For example, deviation is 28 for 52 hours, for 1.6 is the deviation for 36 hours and so on. So, you can actually find it out this deviation.

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Deviations of TSI in hot & dry climate (Rectangular Building)

Fitness function	Summer		Winter		Total weighted deviation = 2*(a)*(b)+(c)*(d)
	Average deviation (°C) (a)	No. of hours (b)	Average deviation (°C) (c)	No. of hours (d)	
1	2.2	47	4.8	42	408
2	1.9	29	5.3	51	381
3	2.2	48	4.6	43	409
4	4.0	62	4.0	36	640
5	3.6	56	4.0	41	567
6	4.0	62	4.0	37	644
7	2.0	29	5.4	49	381
8	2.0	33	5.0	47	367

Deviations of TSI in warm & humid climate (Rectangular Building)

Fitness function	Summer		Winter		Total weighted deviation = 2*(a)*(b)+(c)*(d)
	Average deviation (°C) (a)	No. of hours (b)	Average deviation (°C) (c)	No. of hours (d)	
1	0.8	16	0.7	16	37
2	1.1	53	0.3	4	118
3	0.8	13	0.9	13	33
4	0.8	28	0.8	14	56
5	0.7	21	0.7	16	41
6	0.8	22	0.7	13	44
7	0.6	10	1.0	23	35
8	0.5	11	1.1	20	33

Deviations of TSI in all climate (L Shaped Building)

Fitness function	Total weighted deviation		
	Composite climate	Hot & dry climate	Warm & humid climate
1	554	392	19
2	502	379	289
3	528	528	22
4	761	761	42
5	740	740	61
6	744	744	63
7	497	497	20
8	493	493	21

Rectangle Building (Optimum Solution)

	Composite climate	Hot dry climate	Warm humid climate
Orientation	North	North	South
Shape (Dimension)	43mX17mX6m	40mX16mX9m	40mX16mX9m
Roof	(Option 8) - 25 mm brick tile + 25 mm CM + 112 mm high hollow inverted clay pot + 100 mm RCC + 12 mm calcium silicate board	(Option 8) - 25 mm brick tile + 25 mm CM + 112 mm high hollow inverted clay pot + 100 mm RCC + 12 mm calcium silicate board	(Option 8) - 25 mm brick tile + 25 mm CM + 112 mm high hollow inverted clay pot + 100 mm RCC + 12 mm calcium silicate board
Wall	(Option 7) - 12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL	(Option 7) - 12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL	(Option 7) - 12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL
Glazing	(Option 3) - Sunergy Green (Argon)	(Option 3) - Sunergy Green (Argon)	(Option 7) - Sunergy Clear (Air)

L Shape Building (Optimum Solution)

	Composite climate	Hot dry climate	Warm humid climate
Orientation	North	South	South
Shape (Dimension)	43mX17mX6m	43mX17mX6m	43mX17mX6m
Roof	(Option 8) - 25 mm brick tile + 25 mm CM + 112 mm high hollow inverted clay pot + 100 mm RCC + 12 mm calcium silicate board	(Option 5) - 25 mm brick tile + 25 mm CM + 50 mm PUF + 100 mm RCC + 12 mm calcium silicate board	(Option 8) - 25 mm brick tile + 25 mm CM + 112 mm high hollow inverted clay pot + 100 mm RCC + 12 mm calcium silicate board
Wall	(Option 7) - 12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL	(Option 7) - 12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL	(Option 7) - 12 mm PL + 115 mm brick + 50 mm EPS + 115 mm brick + 12 mm PL
Glazing	(Option 2) - Sunergy Green (Air)	(Option 3) - Sunergy Green (Argon)	(Option 6) - Sunergy Azur (Argon)

And thus you can select the best one, who gives you the best value, based on least deviation in a way. So therefore, same procedure follows for all kind of building that there.

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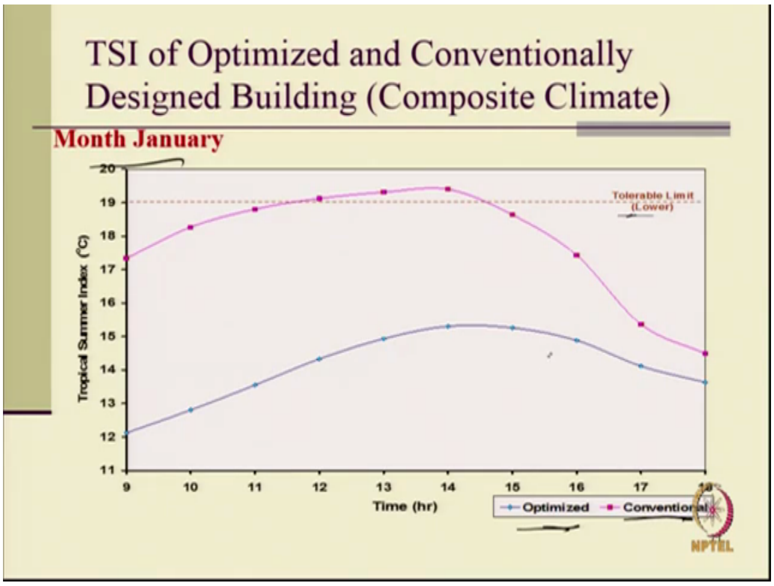

And you can find out optimised building and conventional building. So, conventional building for month of January, it shows beyond tolerable lower limit, sometime it is above this. So, this is conventional is, optimised building sometime it could be below or depending upon composite monsoon climate.

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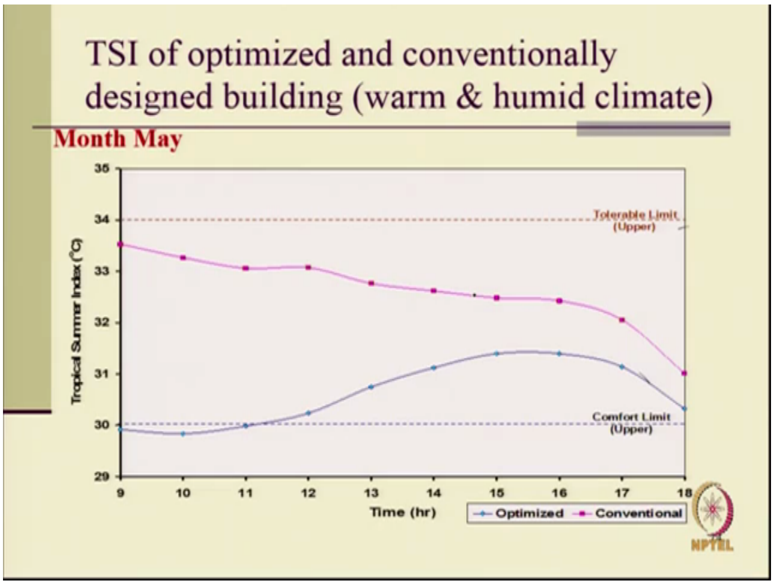

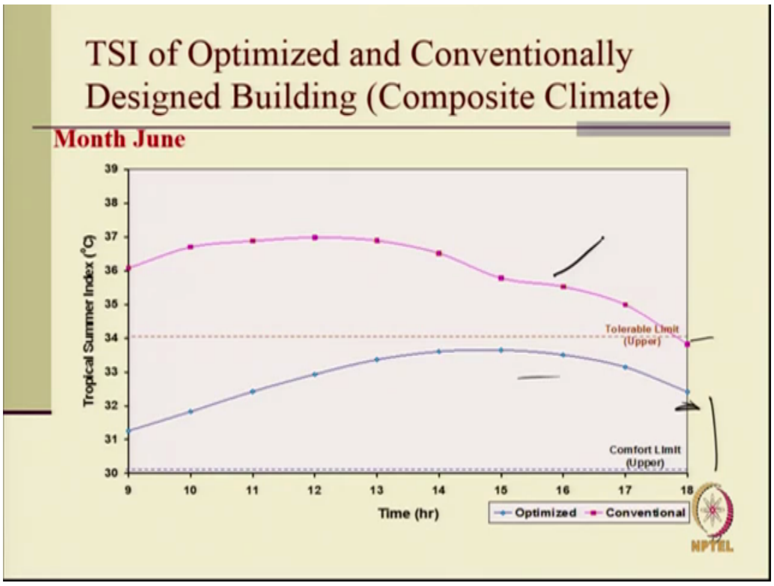

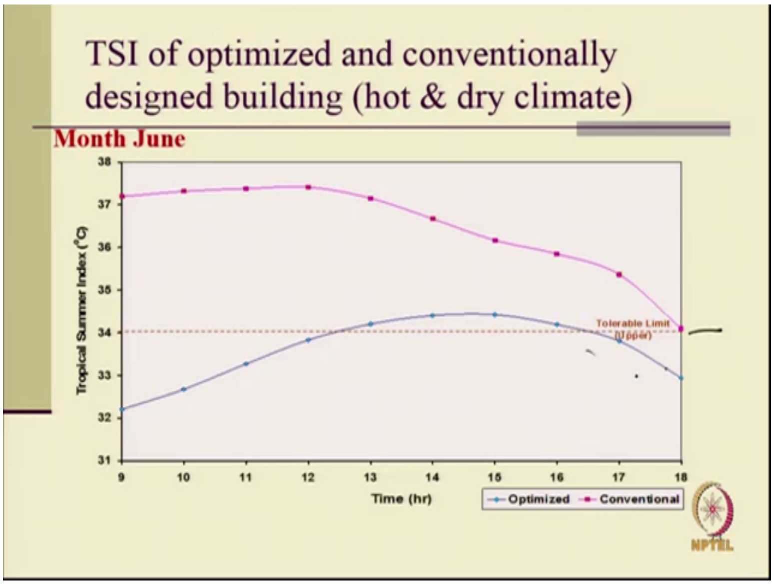

So, this is what it is, upper limit, this will be cooling it, comfort limit, it was not comfortable for a given type of building. Month of June. For each month, one can look into this upper limit, so most of the time this is below lower limit, these above. So, one can find out in this manner. And upper limit, lower limit, this is also here.

So, it has a tendency, if you use 2, that factor 2 times, depending upon the type of objective function you are using, if you use a weightage function, for the summer heating and you think that summer discomfort is more important than winter discomfort. Then you can put a weightage factor or appropriately one can do.

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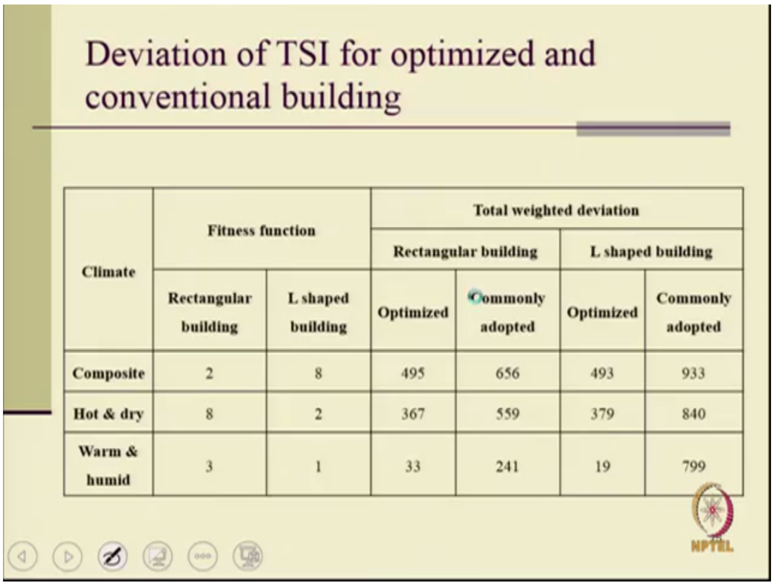
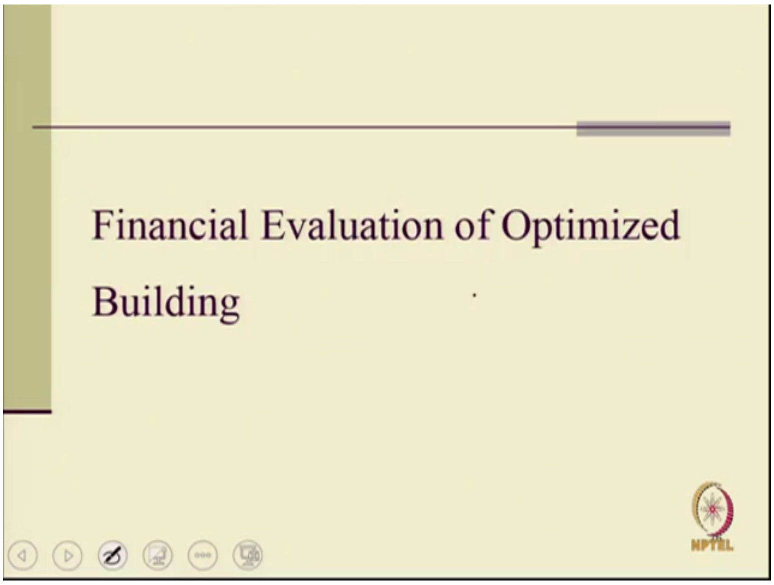


Climate	Fitness function		Total weighted deviation			
			Rectangular building		L shaped building	
	Rectangular building	L shaped building	Optimized	Commonly adopted	Optimized	Commonly adopted
Composite	2	8	495	656	493	933
Hot & dry	8	2	367	559	379	840
Warm & humid	3	1	33	241	19	799



So, this procedure can be used to actually find out both for conditional and unconditional. And if you are using financial evaluation, then you can calculate it out the energy load, and cost of the energy and so on. Operational cost, that we talked about in the beginning, operational energy.

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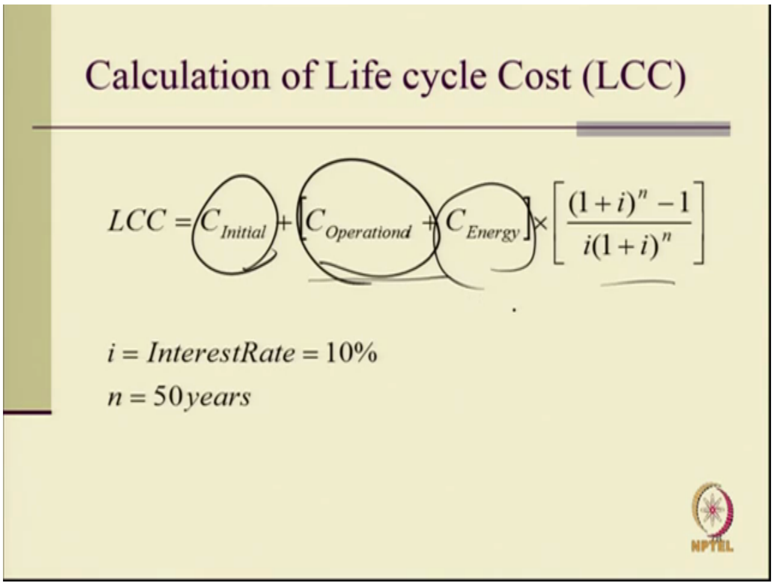

So, economical, you can use something like this. So, initial cost of the envelope, operational cost you can look into and energy cost and then put the present worth with some interest rate and you can check.

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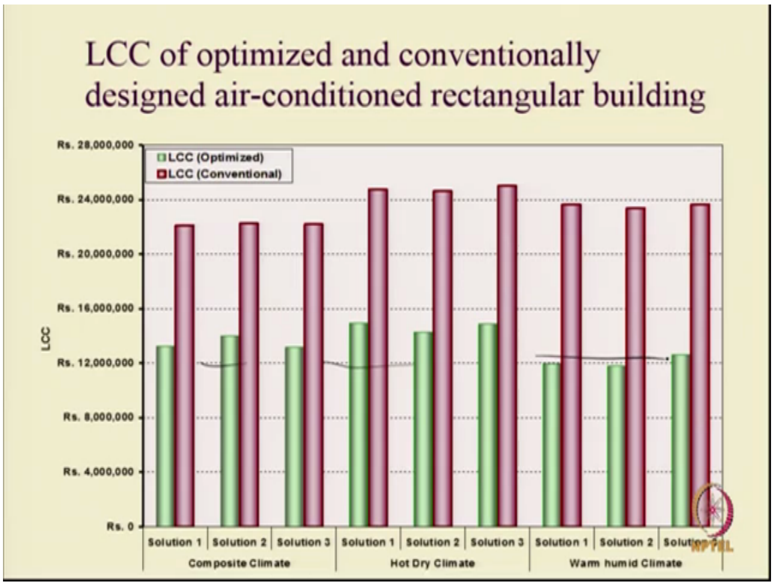

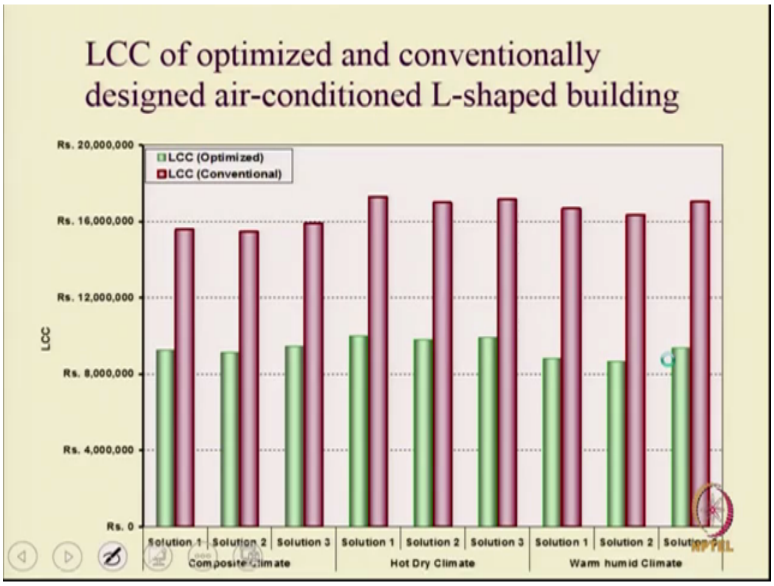

Percentage reduction in LCC (Conventional to optimized building)

		Rectangular building	L-shaped building
Composite Climate	Solution 1	40%	41%
	Solution 2	37%	41%
	Solution 3	41%	40%
Hot Dry Climate	Solution 1	40%	42%
	Solution 2	42%	42%
	Solution 3	41%	42%
Warm Humid Climate	Solution 1	49%	47%
	Solution 2	50%	47%
	Solution 3	47%	45%

And that is what it would show that, even life cycle cost wise optimised one will have much less life cycle cost. Considering operational energy and energy cost it will be much less. So, this is what it is for L-shaped building, for conventional and optimized that, we saving an energy and that is it.

So, I think that, this is an optimisation process which you can adopt for minimising your operational energy, which is important. Although the procedure for calculating the energy load, I have not discussed. But the optimisation process that can be used for such a situation, where your variables are qualitative and discrete, that is what I have discussed.