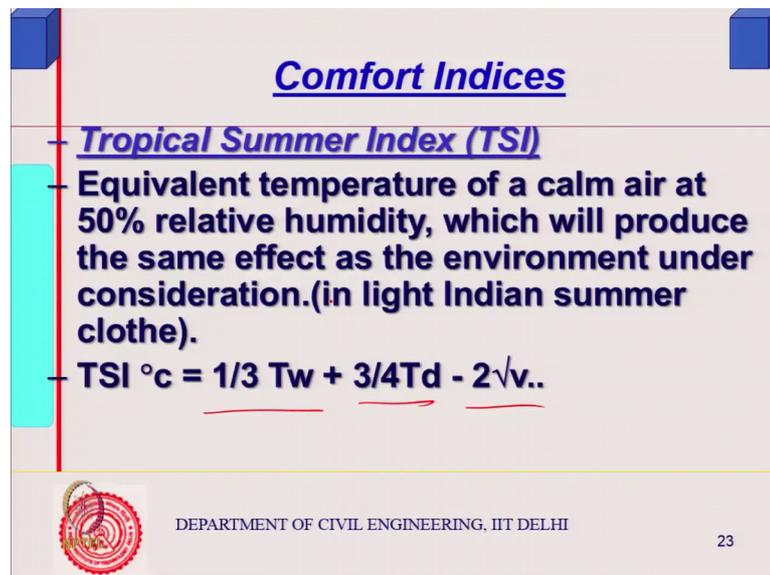


**Energy Efficiency, Acoustics & Daylighting in building**  
**Prof. B. Bhattacharjee**  
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**Indian Institute of Technology, Delhi**

**Lecture – 21**  
**Comfort & Thermal Design of Unconditioned Building**

So, this is what we are looking at in the last class, Tropical Summer Index.

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**Comfort Indices**

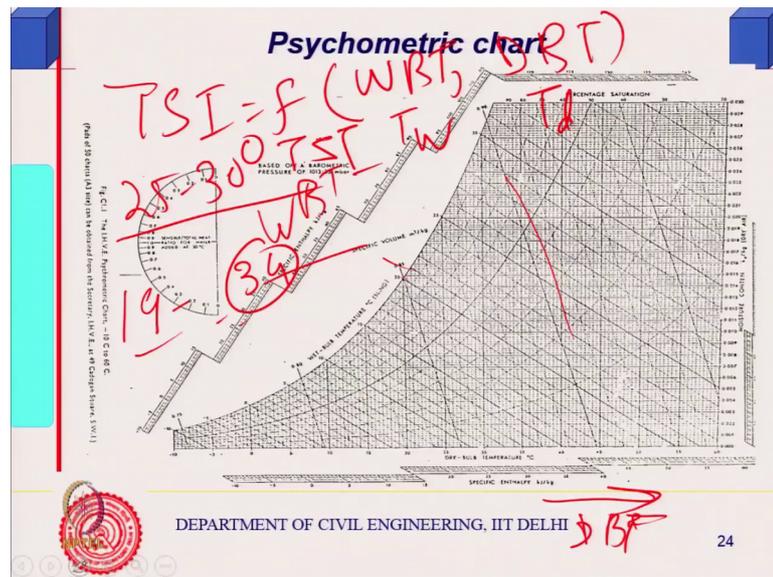
- **Tropical Summer Index (TSI)**
- **Equivalent temperature of a calm air at 50% relative humidity, which will produce the same effect as the environment under consideration.(in light Indian summer clothe).**
- **$TSI \text{ } ^\circ\text{C} = \frac{1}{3} T_w + \frac{3}{4} T_d - 2\sqrt{v..}$**

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And, I think I gave you the formula, I mean the formula associated with this. This was approximately one third wet bulb temperature, three fourth dry bulb temperature, 2 under root v. This slightly more original empirical equation or slightly more elaborate, but this is good enough for our purpose.

So, that is what I said this equivalent temperature of calm air at 50 percent relative humidity, which will produce same effect as the environment under consideration.

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So, you can plot it on psychrometric chart, because remember psychrometric chart has dry bulb temperature DBT here, then there are wet bulb temperature WBT here. So, since it is a function of DBT and WBT, you know TSI is a function of wet bulb temperature and dry bulb temperature DBT,  $T_d$  and you know that  $T_w$  and  $T_d$  and velocity, assume velocity equals to 0 then TSI can be for 0 below air velocity TSI can be plotted here.

So, these are the TSI values vertical TSI values are there TSI values. So, wet bulb temperature is there then TSI values you can actually plot it here and then identify the comfort condition which would be 25 to 30 degree. As I said 25 to 30 degree TSI and slightly tolerable is 19 to 34, so, 30 to 34 is one situation which is tolerable, 19 to 25 cold situation which is tolerable. So, this is how anyone can plot them actually, one can plot them.

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**Psychrometric chart**

$$\phi = \frac{P_w}{P_s}$$
$$P_s = \exp\left(14.481133 - \frac{5333.3}{T_d}\right)$$
$$P_w = P_s' - 6.66 \times 10^{-4} P_b (T_d - T_w)$$
$$P_s' = \exp\left(14.481133 - \frac{5333.3}{T_w}\right)$$

*$P_b$  is atmospheric pressure*

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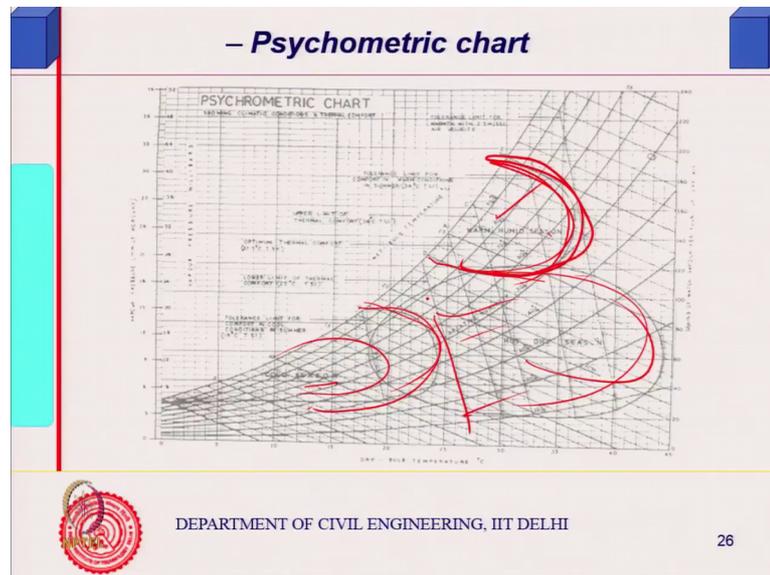
So, this I think I have given you this expression earlier. Relative humidity can be you know obtained from this kind of expression this is a saturated pressure at  $T_d$  dry bulb temperature empirical equation fitted from the psychrometric chart only and  $P_w$  is basically the vapor pressure associated with wet bulb depression this is atmospheric pressure.  $T_w$  is the wet bulb temperature,  $P_s'$  is here. So, once you find out the  $P_s'$ ,  $P_w$  we can find out the wet bulb pressure corresponding to current situation.  $P_s$  is the vapor pressure corresponding to saturated, so,  $\phi$  can be found out. To find  $P_w$  you need  $P_s'$  which is given by this and this is the wet bulb depression.

So, through this empirical equation you can find out the relative humidity you know. First you find out  $P_s$  14.48 etcetera, knowing the dry bulb temperature then you find out  $P_s'$  depending upon the wet bulb temperature and this  $P_w$  is found out knowing  $P_s'$  and wet bulb and dry bulb temperature. So, if you know dry bulb temperature wet bulb temperature there is atmospheric pressure you can find out  $P_w$  and once you have found out  $P_w$ ,  $\phi$  can be obtained.

So,  $P_b$  is the atmospheric pressure as I said. So, based on this you can actually calculate out. I did not do a calculation earlier, but now you know supposing it is 25 degree centigrade or whatever 30, 35 degree centigrade, relative humidity is 40 percent or 50 percent corresponding to this I or rather wet bulb temperature is known then you can find out the relative humidity.

If relative humidity and dry bulb temperature is known then it is of course, calculating its (Refer Time: 04:15) situation you will have to obtain the wet bulb temperature accordingly.

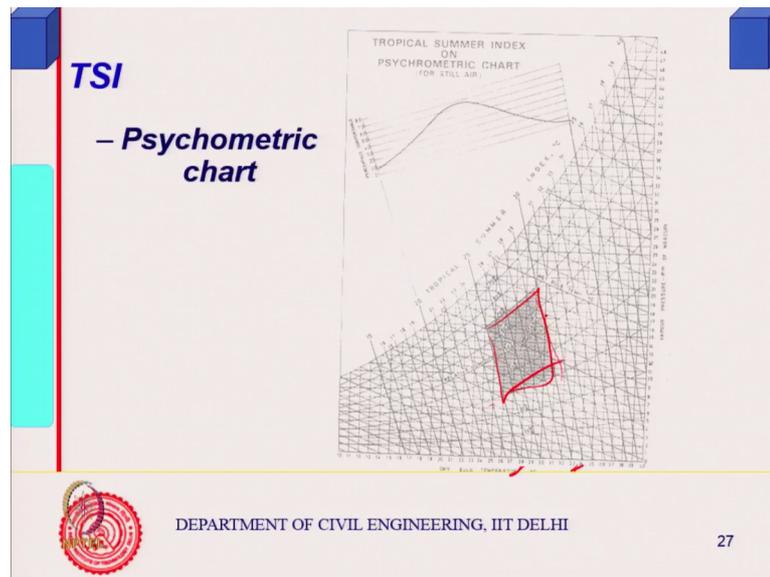
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So, in the psychrometric chart, again, now coming back though you know we can plot this TSI values and for various season for example, warm humid situation where relative humidity is very high TSI values actually you can obtain for various situation for hot dry climate because we know that I am range of temperature and relative humidity and we can plot and this is the you know this is a another situation. Basically, this is warm humid hot dry and this is this sorry this is hot dry situation, this is cold dry situation.

So, that is how one can actually identify in a psychrometric chart TSI values and if you know comfort zone is known for example, comfort zone is somewhere here, so, what is uncomfortable, you can actually estimate.

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So, this is the comfort zone you know this is the comfort zone. TSI comfort zone is this one, dry bulb temperature I mean a TSI value corresponding from 25 to 30 and relative humidity range etcetera is known. So, one can actually obtain these values in psychrometric chart, anyway that is alright. So, I mean there it is you find out in psychrometric chart or otherwise what we know is that comfortable situation is 25 to 30 and slightly stretchable situation is 30 to 34 and 19 to 30. So, deviation from that at any time will cause kind of discomfort. So, we can, knowing the dry bulb temperature, wet bulb temperature and air velocity, your design condition should be basically maintaining deviation from TSI minimal, either way from the other side [FL] ok.

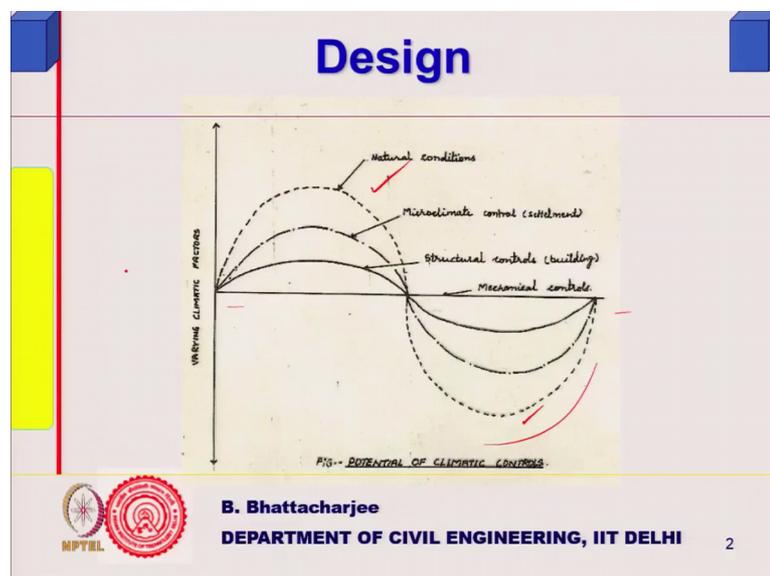
So, that is what it is. So, now, we can look in the next scenario, thermal design of unconditioned building. We can look into now having understood the thermal requirement of an unconditioned building, now we can think in terms of how do you design the envelope or you know building as a whole. Internal distribution of heat is a secondary issue, but the internal I mean distribution from one point to another, one room to another, but overall if you are looking from you know overall your envelope is about which controls are heat gain or heat loss.

Therefore, thermal design when you are talking of largely we are talking of the design of the envelope including shape, orientation etcetera. So, you cannot fully design by passive

means; what are passive means, I think in the beginning I said something related to passive means.

Passive means are those ones which are permanently there in the building and do not consume any energy. For example, even though fan is an active device, but we still consider it a part of the passive device because it does not consume large energy, but air conditioners they consume a lot of energy, you need energy input. So, they are active devices. So, with pure passive devices you should know you would not be able to control the condition or you know thermal condition of the space within fully.

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So, natural conditions I mean if I assume it to be you know there is some sort of mean value and there is a perturbation purely (Refer Time: 08:01) is for the schematic purpose drawn. So, variation would be something like this there will be lower side and higher side natural, but the first stage of any design is actually at the urban design level. You know you can modify the microclimatic situation.

As I talked about earlier, when I was talking of site climate I said, for example, if you have a lot of clusters of buildings then they would have a tendency to increase the temperature because they will reduce down the evaporation loss that the ground runoff will be higher, losses will be less and thermal mass of the buildings they will try to store the heat, it can even result in what is known as urban heat urban heat climate I mean you know urban heat island.

So, this kind of situations could be there. So, so in the beginning itself not only that you can also plan the buildings in such a manner that one building shades another etcetera. So, while designing the urban stage itself you can control something; plantation of trees, obviously, increases evaporative cooling which means that relative humidity will increase, but temperature will come down. So, trees would actually bring down the temperature, but it will increase the relative humidity.

So, microclimatic through microclimatic modification done in a not in half resort manner and just by anytime you do not change you know once you have decided in the planning stage you have to look into and with sufficient flexibility of course, for future changes, but by and large you know what is likely to happen with the current knowledge. If the knowledge base changes new technology comes thing could be different, but still the flexibility would care could be there in the planning stage itself.

So, design urban planning can be done in such a manner that you can actually get some modification like planting tree will bring down the temperature, but increase the relative humidity, spaces around the building everything put together green areas and so on so. This will reduce down the perturbation somewhat, then you have structural control that is your envelope design and all that, structural control. It is best if you can actually use multifunctional system, that means, you have an envelope which not only provides comfort against thermal issues temperature changes and you know climatic thermal climate, but possibly if it can be also coupled together to perform for structural purpose also then it is 2 functional, multifunctional you know.

So, there are various kind of modern buildings coming in for example, you do not have I mean you do not have you know you can have precast elements, box element or tunnel form of construction. Now, there are many other form works where the concrete goes as wall as well as roof and acts monolithically for a structural element. So, the just trying to give an example therefore, the wall itself will perform should perform for 2 functions at least structural function and also the thermal function might be acoustics and etcetera.

So, multifunctional will of you always be economical, should not looked in isolation. Then, you have once you have done that you have come to this, but finally, if you want to bring it to over a very small perturbation, no changes, and then you need mechanical control. So, that is your mechanical control.

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**Design**

- ❖ **Design/ Decision Variables**
- **Envelope**
- **Orientation**
- **Shape**
- **Fenestration & Glass**
- **Shading Devices**

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So, it is you know is essentially optimizing the deviations naturally conditioned building deviations from the TSI values or similar temperature humidity combination you know thermal index values. So, in our case could be deviations from TSI could be our one of the objectives. So, whenever you do an design, is essentially optimization process. For example, structural design is minimizing the material to perform you know withstand the loads forces which in terms of stress we talk about and strain or deflection or whatever it is some way you defined. So, it is usually an optimization process and thermal design is no different. So, in this one objective function nor first purpose the objective is to minimize the deviation from tropical summer index or something similar deviation from the comfort condition minimize the deviation from comfort condition in unconditioned building.

If it is conditioned building it will be minimize the thermal load one can obviously, also look into the cost part of it now if you are improving the comfort you know minimizing the deviation from comfort conditions then budget may be a constraint that you do not cause, should not be more than this. So, in optimizing optimization process you know numerical or mathematical optimization process usually you have constraint situation any other separate not part of this course actually.

So, here also optimization or somebody might minimize the total lifecycle cost for energy efficient building. So, there could be various, but there has to be some sort of cost

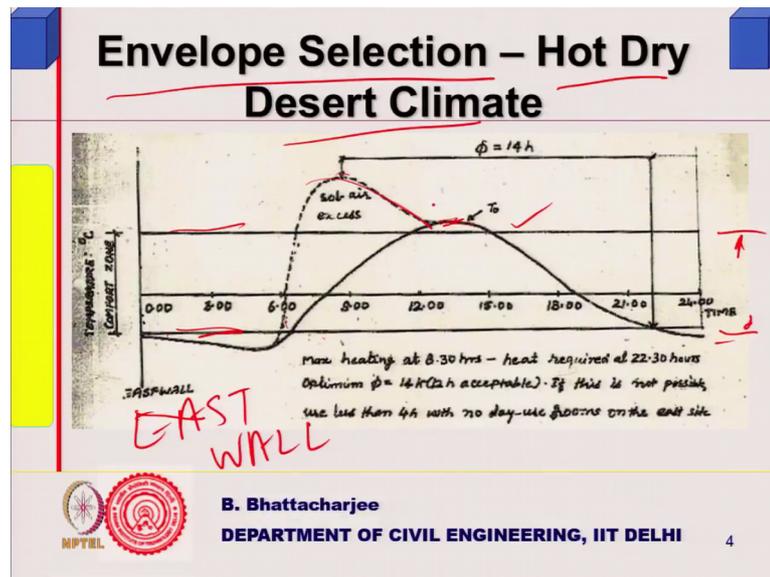
minimization, deviation minimization or energy load will mean. In case of naturally condition building it is deviation from the comfort condition which you would like to minimize.

Now, in such situation you have something called decision variables or design variables. Decision variables are what which you can change and you find out their value for example, thickness of the wall or they revalue, find out the value which will optimize the performance. These are called decision variables u value of the wall or construction of the wall etcetera, which will actually govern new value. So, you might have in form correct you know some form these are called either design variables or decision variables. When you do a course on operation research optimization he will come across this.

So, in our case the design or decision variables at the envelope; wall, ceiling you know sun shades etcetera, orientation shape window to wall area ratio or fenestration area, type of glasses, if there are shading devices then shading devices. There could be any number of them I have just listed the few main ones.

You know because they will get for example, envelope can be divided into several numbers you know envelope can be divided into I mean it would be it would be thickness of the envelope, thermal conductivity of the component of the envelope layer, each one can be decisions there can be n number. So, there are very large number of decision variables actually in thermal design and we look into some thumb rule sort of thing actually we want to do you all have to optimize it and use some optimization tool now we are not doing that.

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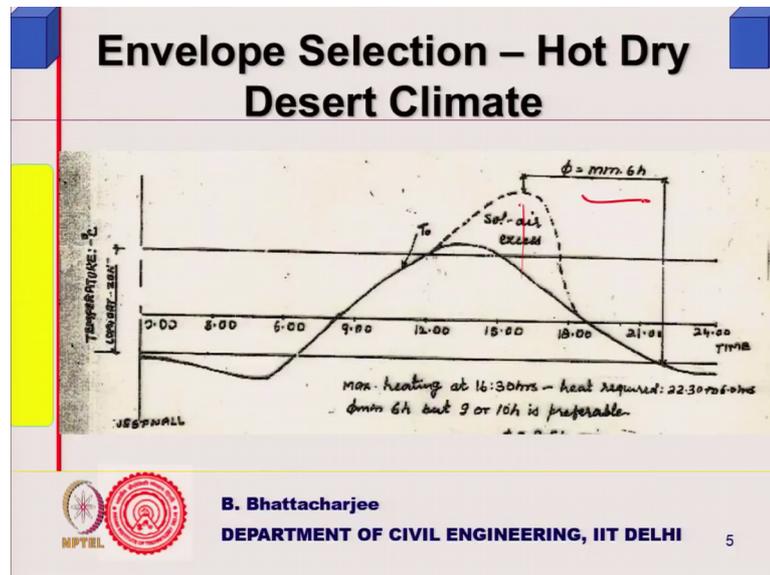
In this class we are just telling you how which factors how they affect. For example, you want to select the envelope parameters in hot dry desert climate, now this is your comfort zone. As I said in the unconditioned building this is a comfort zone let us say this is a comfort zone temperature you will find that outside air temperature actually sometime early in the morning you know it is up to 6 am or so, it will be lower than the bottom of the comfort zone; that means, you feel cold in the morning those who come from desert areas early morning you start feeling cold, but in the during you know daytime it goes beyond the you know it becomes uncomfortable because of the warm condition.

So, that is typically hot dry desert climate because you know diurnal variation is large. Now, solar excess over it could be something like this, if it is you know if it is east wall, east facing wall. So, morning the sun's radiation comes in the morning it is peak would be somewhere around 8 - 10 am or something like that. So, if you superimpose the solar access you get something like this.

So, your peak temperature or peak which you like you know peak will come somewhere there, but then sometimes at night it goes below it, becomes cold and goes below the comfort condition. So, your time let could be something like 14 hours because this peak the outside pattern of temperature variation is something like this should bring in the heat into the room when outsiders become cold. So, you need large time lag 14 hours. So, your wall thickness east facing wall thickness typically could be something like 14

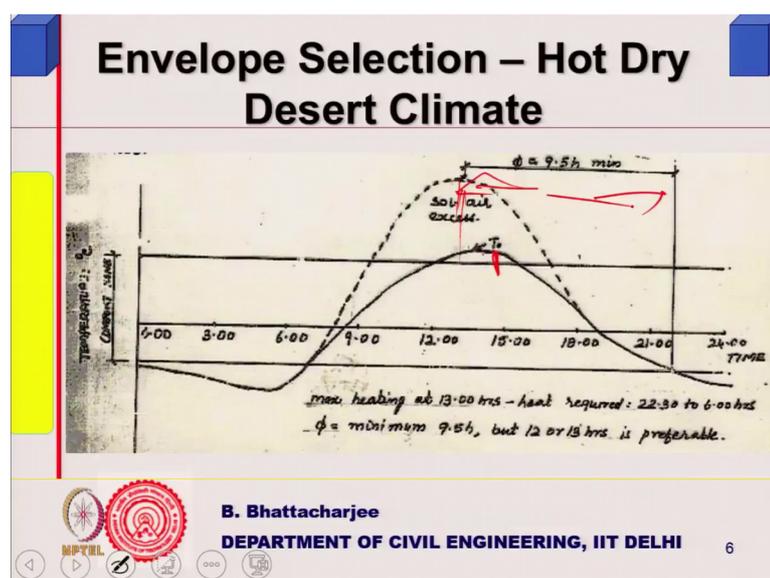
hours, but this is not I mean this is just a way how you find it out one might look into actual scenario and then find out. So, this is for east facing wall for hot dry desert climate.

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For west wall, the solar excess goes somewhere there you need much less time. Lag decrement, anyway will recur same, pretty low as low as possible. So, this is for you know this for west facing wall.

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This is for actually roof. So, this is more or less at the day you know the peak temperature and slightly peak temperature will be somewhere there solar radiation is slightly earlier. So, you need possibly somewhat less time length then the west facing wall I mean east facing one, but slightly more than the west facing wall.

So, this is how we can get some idea these gases. So, hot dry desert climate we need these because diurnal variation is very large. We meet climate really you do not need all that because the diurnal variation temperature variation is not very large.

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Warm Humid  
Climate -  
High Ventilation  
- fenestration

Days chosen are 16th May & 22nd December.  
Check for various orientation and choose best.

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More important thing is actually ventilation. You would like air movement to be high because relative humidity is high. So, forced evaporation from the body should be high. So, in warm humid climate naturally conditioned building high ventilation. So, you need large openings, fenestration should be designed accordingly large. So, these are some kind of guidelines. Now, orientation how did I decide, this was this was related to the wall thickness u values are important, but you see decrement and time lag is important in hot dry desert climate and in warm humid climate perhaps you do not need much thickness of the wall, but what you need is lot of openings in the you know in the you know envelope I mean; obviously, not the ceiling.

So, orientation let us say I am just giving some examples actually, but if you want to do a rigorous one, you have to resort to an optimization procedure, but otherwise you can get ideas typically I should be using this much for east wall, west wall etcetera and

accordingly, obviously, you cannot vary too much. You know another analogy with respect to structural engine structural design is normally column sizes even though some column is taking more load some other column is taking less load you keep them same you group them actually otherwise shuttling cost will increase the other implications are there.

So, you cannot vary east wall or west wall, but you know this idea you got to have. So, that kind of choice you can make orientation if you have to do orientation one way is to minimize summer gain minus winter gain particularly in composite climate.

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**Thermal design (orientation)**

Minimize ( 2 x Summer gain - Winter gain)

For an envelope with  $A_1$  to  $A_n$  surfaces (walls)

$\Sigma(I_T)A_i =$  Total radiation on  $A_i$ .

Take one representative summer day and one representative winter day.

Minimize

2 (summer gain) - winter shading

Days chosen are 16th May & 22nd December.

Check for various orientation and choose best.

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When you have a severe winter and also a severe summer of the 2 kind, now why twice summer gain because removing heat from space is costlier heating is cheaper cooling is costlier at least 3-4 times costlier than heating is. Heating is much easy directly you heat removing it we do work and to remove the heat actually. So, it is costlier process and in this process therefore, well at least a weightage factor of 2 should be taken. So, what do you do minimize twice summer game minus winter game you would like to have winter game. So, the envelope should be such that or orientation should be such that it should allow for summer, lowering the summer gain, minimizing summer gain, but then it should not block the winter gain.

So, your objective function could be something like this supposing I have got an envelope of area  $A_1$ , you know with area  $A_1$  to  $n$  surfaces are there, then what I do is, I

find out I T. I T is the intensity of radiation on total radiation on involve multiplied by A i sum up. So, total radiation on A i. So, sum it up for all the ones. Take one representative summer day and one representative winter day this is for pure we have hand calculation, but if you have written a program then you know you can take for many days because you will just simply put it in what you good old days used to call as do loop repetition.

So, you can repeat this procedure you repeat it so, but hand calculation if you are doing take one represent is in summer day and one representative winter day and then minimize twice summer gain minus winter shading minus, you know winter minimize the summer gain minus winter gain otherwise it would have. Days chosen are 16 May and 22nd December in sp 41. 16 May stands for typical summer day and 22nd December this Indian condition elsewhere it could be different. So, 16 May and 22nd December because you know that radiation is a function of the latitudes and. So, therefore, this is. So, check for various orientation and choose the best you can find out the areas of all the walls and corresponding radiation falling on 16th May at different times, sum them up.

Sigma this is some sum up the total radiation falling on each surfaces multiplied by the surface area sum it up for all the as you change the orientation for example, if this is your orientation or otherwise this is your orientation radiation falling onto this area would be you know multiplied by this area, radiation falling on to this area multiplied by area on 16th May similarly, for this case again you can find out minus that will would should have come you know that would come on 22nd December.

So, whichever gives you minimum summer gain minus winter gain that is what it should be choosing. That is how you can choose the orientation by simple hand calculation itself by simple hand calculation you can choose.

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**Thermal design (orientation)**

Summer gain =  $\sum_{i=1}^n (I_T)_i A_i$  Summer

Winter Loss =  $-\sum_{i=1}^n (I_T)_i A_i$  Winter

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So, that is it summer gain something like this  $i$  goes from one to  $I_T i A_i$  winter loss because if you have you know if you have designed it in such a manner the orientation is such that it does not allow winter heat to come in. So, that is we are considering winter loss actually otherwise it would have come. So, radiation falling during winter that should be minus subtracted, so, this minus this you should minimize.

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**Shape**

(Total surface area / Volume) \* Radiation governs shape

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Then shape; now, shape basically per unit volume is what you should be considering because after all the internal space should be same internal you know habitable room

heights are fixed or any functional building for that matter the heights are generally fixed. So, the shape is to do the layout in plan and total volume. So, shape is a total surface area. Now, what is relevant for us because if I change the shape external surface facade surface area will change. So, what we do is total surface area per unit volume multiplied by the radiation total external surface because supposing I choose a cylindrical shape height is same or the same volume if I consider I can have a rectangular shape.

Now, cylinder will have cylindrical circular has got the least surface area. So, the radiation coming onto would be different in these 2 cases. So, shape will govern the heat gain again because the surface area is like the orientation. In fact, orientation and shape should be seen together. The combinations of orientory their cylindrical buildings even residential buildings there get cylindrical buildings are there would be you know may not be very good unless there is something else is done because it will always receive lot of radiation from where surface etcetera anyway one can see that. So, total surface area per unit volume multiplied by radiation governs the shape.

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### Shape

(Total surface area / Volume) \* Radiation governs shape

**Winter condition:**

$$(\Sigma UA + C_v) (T_{ia} - T_{oa}) = \text{Heat loss}$$

C<sub>v</sub> NV

$$\text{Loss per unit temperature} = \Sigma UA + C_v$$

$$= \Sigma UA + NV / 3$$

To compare different shapes, heat loss per unit volume is required.

$$\therefore \text{Loss per unit temperature per unit volume} = \Sigma UA/V + N/3.$$




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Winter condition then if it is winter heat loss you want to minimize, then heat loss will be given by  $UA C V T_{ia} - T_{oa}$  this will be actually summer scenario. We will come to that, but supposing I am not bothered about heat have any cooling, I am bothered about heating in that case the heat loss is a function of inside temperature and outside

temperature and I would like to minimize that loss per unit temperature therefore, is given by this what degree temperature difference is given by this. To compare differences you know different shapes heat loss per unit volume is looked into. So, UA because C V is nothing, but NV by 3 remember C V is equals to NV by 3. So, I am just writing that. So, UA by V number of air changes divided by 3, loss per unit temperature per unit volume can be written like this.

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**Shape**

For minimum heat loss, minimum  $\Sigma UA/V$  (i.e. least surface area per unit volume)

$L = \alpha B$

$B = \beta H$

$L = \alpha \beta H$

$V = \alpha \beta^2 H^3$

$\alpha = \text{aspect ratio } L/B.$

Cube has the least surface area to volume ratio, hence most efficient  $V=H_0^3$

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And, for minimum heat loss UA by V per unit volume you know surface area list the least surface area per unit volume. So, one can consider. So, one can minimize this because n would not be in your hand n depends upon changes and that will depend upon outside air velocity etcetera and related more to the opening areas. So, that is you know outside we can just. So, if you minimize this we will have least heat loss. So, that is actually in no tropical condition, that would be you know shape should be based on the shape should be based on this and then you can actually write it in terms of aspect ratio L by B, L is a length this aspect ratio L this is B length and width. So, L by B is aspect ratio and B can be related to height, B can be related to beta H. So, therefore, L is equals to alpha beta H. So, volume is alpha beta square H cube. Beta is ratio between width and height.

So, everything is expressed in terms of height actually you know everything is expressed. So, volume we can express in terms of height and surface area also you can express in

terms of height and heights have generally you know like that is that is I will not really our concern because they will remain by and large same. So, you can actually cube has the best surface you know cube amongst the rectangular parable sort of shape cube has a least surface area to volume ratio. I am leaving out sphere because buildings are unlikely to be sphere.

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**Shape**

For minimum heat loss, minimum  $\Sigma UA/V$  (i.e. least surface area per unit volume)

$L = \alpha B$                        $\alpha = \text{aspect ratio } L/B.$   
 $B = \beta H$   
 $L = \alpha \beta H$   
 $V = \alpha \beta^2 H^3$

**Cube has the least surface area to volume ratio, hence most efficient  $V=H_0^3$**

**For identical volume  $V=H_0^3 = \alpha \beta^2 H^3$**

**$H_0/H = (\alpha \beta^2)^{1/3}$  ; *1 is best,***

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Hence most efficient is V equals to H 0 cube. V H 0 cube had it been H 0 cube that will be in the most efficient and for identical volume I can just say H 0 cube. So, H 0 by H, 1 is the best I mean H 0 by H as close to one that will be this that will be best. Let us see we will look into it just will have a break.