Principles and Applications of Building Science

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Lecture – 09
Thermal Performance of Building Envelop – Indices and Measures – 2

In previous session we stopped looking at decrement factor which is the outside surface. Now inside surface delta T T i max minus T i min by outside surface delta T T o max minus T o min which is the number between 0 and 1. Then whatever Indian codes, national building codes talks about it is about thermal damping it has delta T o which is outside air temperature range it is not surface temperature, it is outside temperature amplitude versus the inside temperature air temperature drivel temperature amplitude.

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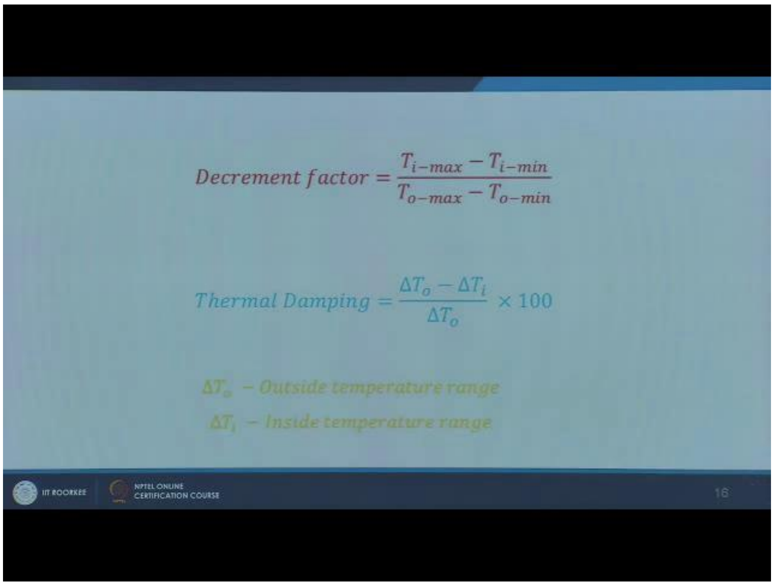

So, we said if the ambient temperature diurnal variation is delta T is 20 degrees versus indoor 10 degrees then you will get a thermal damping of above 50 percentages. National building code tells you how much is the minimum required thermal damping for you know places where diurnal variations is quite high, then you will need more thermal damping. Whereas, places where you have less diurnal variations like humid areas coastal areas where the amplitude of variation diurnal cycle variation about say 6 to 7 degrees or some cases lesser than that, where you will need or you will may not need much of thermal damping they may not be use to you.

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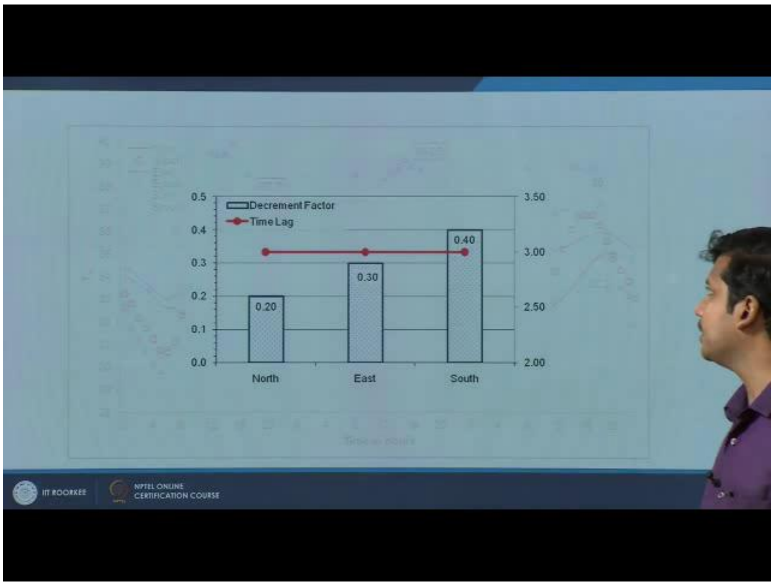

To continue with some examples thermal damping and the time lag also varies with respect to orientation of the particular room or the space. Say for examples, for a north versus east versus south exposed wall surfaces the time lag and decrement factor in this case time lag remain the same, but there can be differences also. The decrement factor considerably varies because it is a surface temperature value, so the ambient outside surface solar temperature can go peak at a particular time cycle and it may vary little bit between one side to the other orientation; one orientation to the other orientation.

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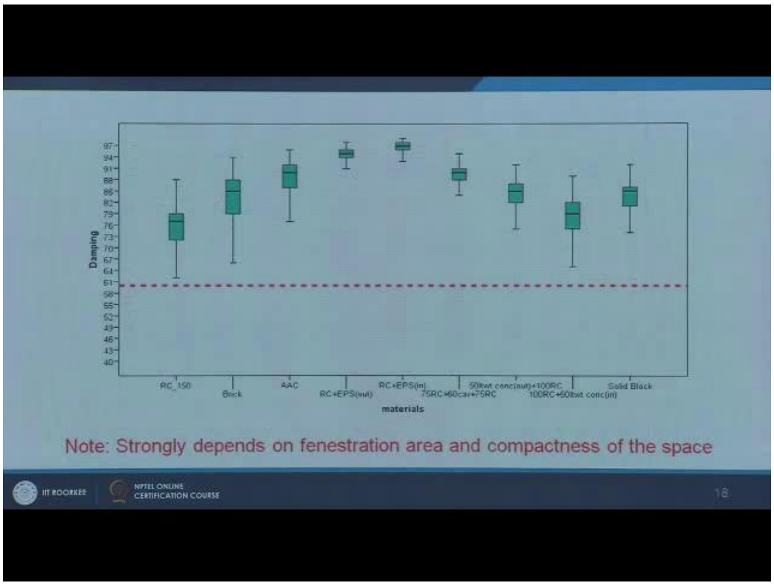

It strongly depends on a fenestration area on the compactness of the space. Thermal damping especially if you look at what you know our national code talks about I have drawn a line here, because for this particular climate it is hard and dry climate which we did the assessment the minimum required thermal damping was 60 percentage. It said minimum you are enveloped should give 60 percentage thermal damping, below which it says it is not compliant to the national building code.

So, most of the materials that we tested this is a concrete wall 150 mm, brick wall, aerated concrete, you have a insulated wall, outside versus inside insulation, you have cavity wall system, you have a solid blocks cement block system. Most of them had thermal damping which is above the prescribed limit, but please make a note of one thing it is very critically or strongly dependent upon the fenestration area. So, you take a room at 10 foot by 10 foot or 12 foot by 12 foot room which has very large window surface which is open, then the damping is going to be really low.

Naturally the convective mechanism sets in and the indoor is more closely connected or closely correspondence with the ambient temperature cycle. So, in that sense it depends on the fenestration area number of surfaces exposed and the overall compactness of the space. If the space is more compactly design you know three sides are enclosed, just one side is exposed or partly exposed which is also shaded a small window. Imagine a case of how traditional buildings were built in hard dry climates or even colder climate. We looked at some examples. Connecting those examples if you look at these things are compact with very low fenestration area, they used to have high thermal damping. That is the indoor cycle of variation was much lesser come back to the compare to the ambient diurnal cycle.

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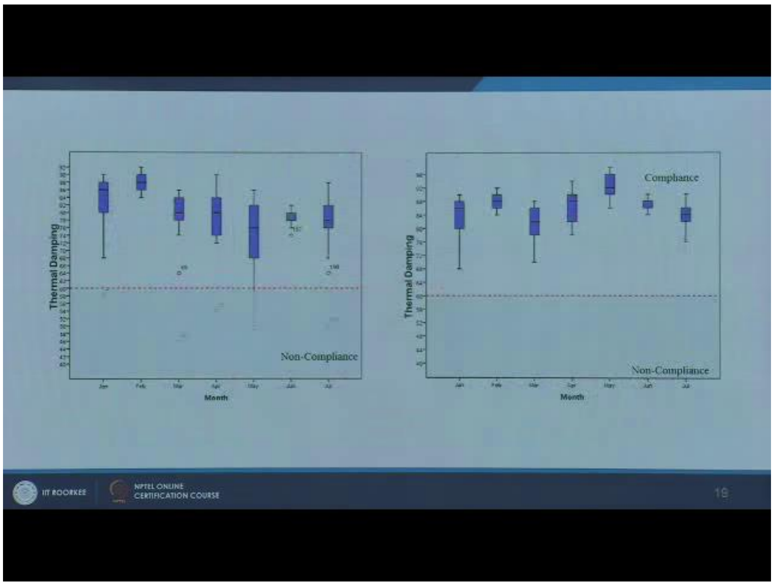

So it depends on the material, it depends on where you put your insulation and whether you have insulation or not, thermal damping considerably varies. Apart from this it varies from month to month day to day, because precisely day to day that is what we have shown in this box in (Refer Time: 04:30). The main value lies somewhere around 85, in this case 80 it goes as high as 88 then it drops down, but there is also a considerable variation across. You know it ranges somewhere from 68 to 88 and all the way to height 90.

So, 20 to 25 percent difference can be observed, because it is daily phenomena. What is a delta T today may not be there tomorrow and the wall has to respond to it or the space rather has to respond to it. So, thermal damping though national building code draws line at 60 for this particular climate zone it does not mean it is going to remain a single number all through. You may have to representative day and then calculate this thermal damping as a number. If it is above 60 which means it is compliant.

Before getting into the next thing another important factor that we have to understand here, thermal damping requirements. Whether all the climate require thermal damping as I said when the diurnal temperature variation are much lower you may not need thermal damping at all or another tricky case is the case of composite climates there for the extreme dry spells of summer where have more or less it is (Refer Time: 05:40) hard dry climate diurnal variation are much high solar radiation is also high, in that case you will require thermal damping.

Again during extreme winter you will require thermal damping. But there are other two spells where you have the monsoon seasons which is really sultry, the diurnal variations are not that high as summers and winters you will need more breezy less damped surfaces as well as the moderate season where you do not need the thermal damping effects in the building. So, design has to take into account these factors.

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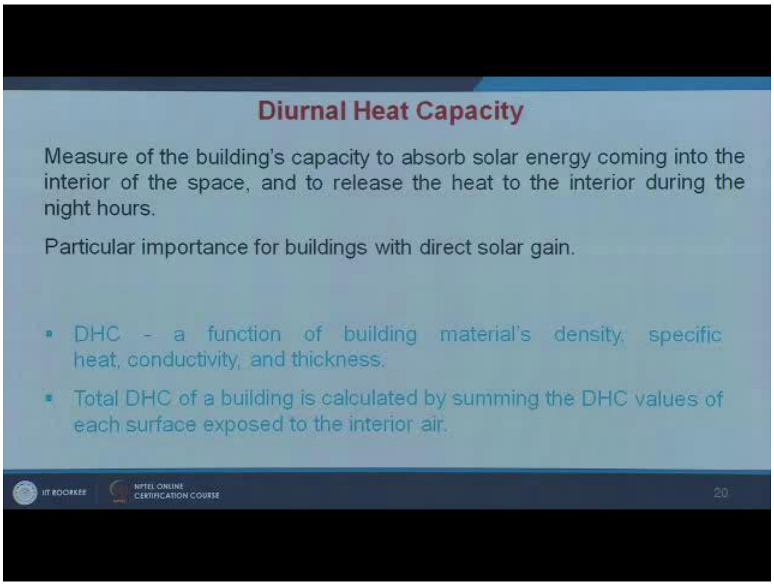

Another term which is commonly in use is the diurnal heat capacity or the DHC. It is also indicator capacity insulation; I am not getting into the formulas because in during this course I do not want to put too many equations or numbers here. To develop a fundamental understanding it is a function of building material density, specific heat, conductivity and thickness. If you have to calculate the diurnal key capacity of a particular build form or a space you have to calculate it by talking a sigma or summing of the DHC values of each surface which is exposed to the interior air. It is like a representative of a how much thermal mass is available for heat storage. That is why we are talking each surface expose to the interior surface, indoor air, for heat gains and losses heat takes into take place.

In this there is a small equation which gives you the required heat capacity. We have been talking about capacity insulation, so let us also try to understand how much we will require for a particular location. You are building in a place, so you are building your house in Delhi where you are building your house in hard dry place like Jaisalmer, then how much amount of thermal capacity you have to build in into your envelop. So, what capacity should the wall contain? There is a simple equation, of course this is not physically validate for Indian contexts it is developed in some other country, but still it gives you a very good or fair indicator.

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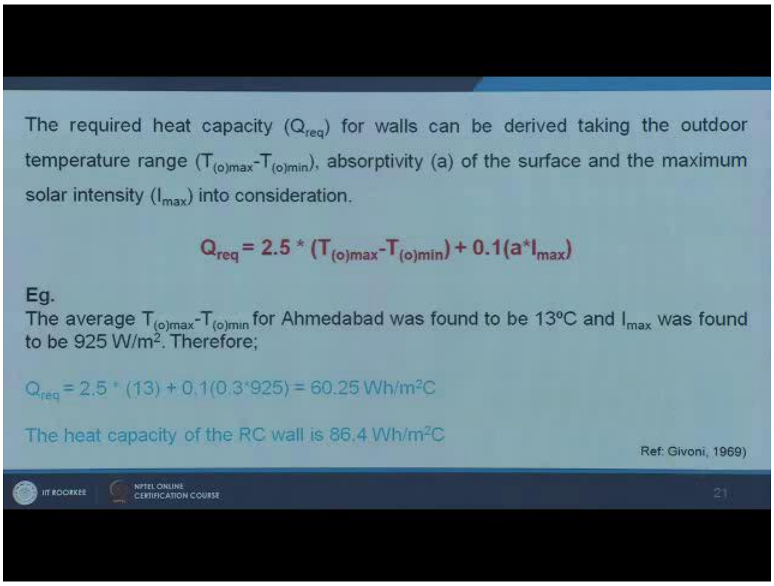

There are follow ups which are available in improved versions for different climatic zones are also available, but to give you a basic understanding of it this is Q require that is the heat capacity required is a factor of the outside delta T T o max that is outside temperature air temperature drivel temperature maximum minus temperature minimum this give you the ambient delta T plus it also includes the absorptivity of the surface and the solar intensity; that is the solar radiation here.

So, what happens when the delta T is high? You are in a hard dry climate in summer the ambient delta T goes as highest 20 22 degrees. So, when this is high the heat capacity requires going to be high. Take a coastal region where the delta T is of the order of 6 to 8 degrees relatively the Q is going to come down much considerably because this is a crucial factor 2.5 into delta T. So, this crucial factor determines how much increase or decrease is required in terms of your required heat capacity. I have you know substituted this in the case of Ahmadabad hard and dry climate as per our national building code.

We took one particular day where the ambient temperature delta T was to be found to be 13 degree and the solar radiation I max was 925 watts per meter square. We have taken a wall surface which is you know the absorption is 0.3. That it is more or less is white painted glassy surface which is reflecting enough amount of solar it is only, 30 percent absorptive. In that case you get a Q required that is solar sorry, the heat capacity required is around 60 watt per hour meter square degrees centigrade. Imagine solar radiation is going to go up again it will have some implication on the required heat capacity this will go up as solar radiation intensity goes up.

What if the wall gets more absorptive? Instead of a white painted surface which is 30 percent reflective that is 0.3 absorption coefficients inside of this I am substituting say a mat black surface which is 0.85 or 0.9 absorption. Then as a consequence the Q required is going to go up. Say dark surface versus light surface, dark surfaces requires became more thermal capacity whereas a light surface this will come down as a diurnal deference in delta T increases this will go up and as the intensity of solar radiation increases the required heat capacity will go up.

As I said this is not a prissily validated equation for Indian contexts, but it is gives us a fair idea about where thermal capacity or the heat capacity comes to use and to what proportion we need or we do not need in specific seasons and locations.

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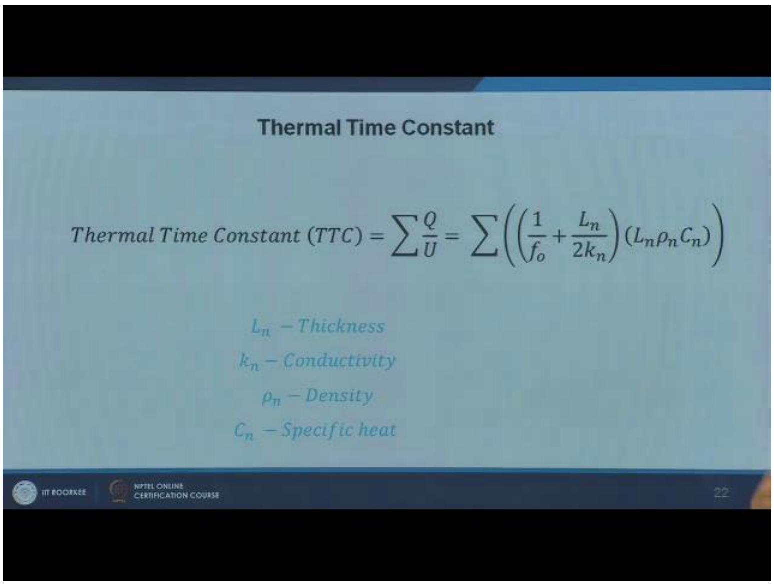

The next factor which national building code talks about is a thermal time constant; TTC. Simple term it is sigma Q that is a heat gain the total by the thermal transmitters U value. To get it more in detail this is the surface coefficient which we looked at in the last class sigma so as many layers are there. For a single homogeneous layer it is just 1, but as many layers this will be calculated and then totaled out. Where you have other things like thickness so it is a factor of thickness, it is a factor of conductivity.

Effectively this gives you the thermal conductance value resistance value, so then you also have the density as well as specific heat into peaks in the pictures. As the density and specific heat increases your thermal time constant value is going to go up. As the thickness of the wall increases, thermal time constant is going to go up. As the conductivity of the wall increases, thermal time constant is going to get down further.

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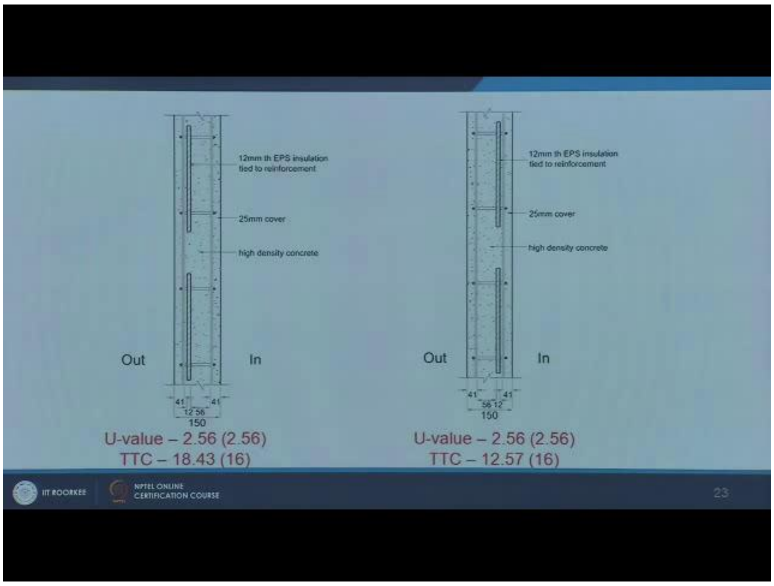

Take two examples, this is the same wall system thickness is same 150 mm, 150 mm I am going to introduce a very thin slender insulation system here it is a just a 12 mm thin insulation sheet. If I am introducing this on the outside surface versus the inside surface the U value or the thermal transmittance will remain the same. It is coming close to 2.5 or 2.6 watts per meter per Kelvin. So, this is the restive or conductive heat flow which is accounted in the U value.

So, you may not know the different between an outside insulation versus the inside insulation, whereas where will you find the different you will find the difference in terms of thermal time constant. If it is put in the outside surface you get thermal time constant of 18.4, whereas if you put it inside you get a thermal time constant of 12.5, 16 I put in brackets because 16 is what national building code recommends for this location. There is a considerable variation depending on where you put your insulation. It has an impact on heat gain and loss where you may not be able to understand it if you look at the U value.

This is where I said there are technical data sheets available, but if you do not have a fundamental understanding of which number to choose look at and what to choose we will not be ending up with the right product most of the time. So, apart from U value we also have keep a tag of the thermal time constant which is a crucial indicator of the heat transfer between outside to inside. The next indicator is thermal performance index.

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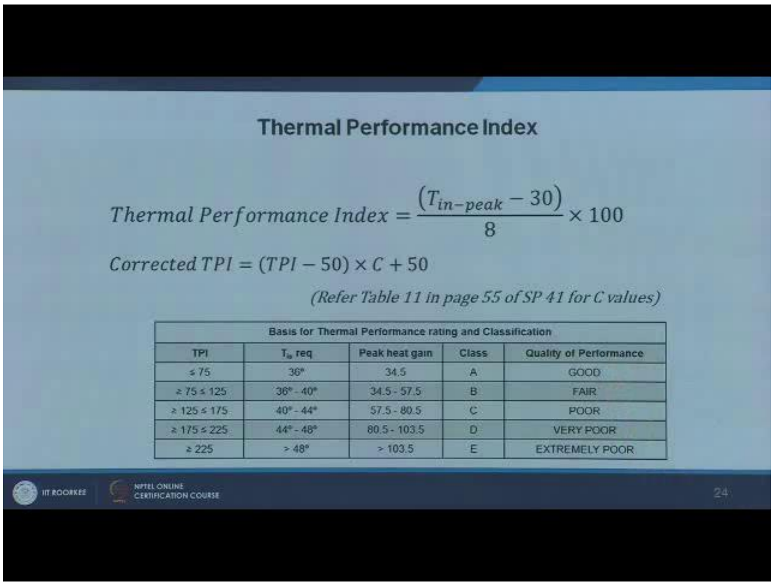

This equation thermal performance index gives you T in peak that is inside peak surface temperature. So, if this is a wall surface the peak surface temperature says it may go to 35 degrees minus 30, I will explain what 30 and this 8 means, minus 30 by 8 into 100. This 30 comes from a series of calculation it goes all the way to the next index that is the building index it is also accounts for the maximum heat gain and it is done for a specific wall system say brick wall and a standard compliant wall system under room space along with the given amount of fenestration area.

Then they found 30 degree as the comfort temperature in that range that is the maximum allowable temperature 30 degrees and 8 because they found that when the wall surface temperature rises above 8 degree say it can go up to 38 degrees then it will be not causing you discomfort. So, 38 minus 30 this gives us 8 as a number so this particular thing again expressed in percentage. Now getting little back to one of the previous module where we talked about thermal comfort, we talked about radiant asymmetry. We talked about what is the horizontal radiant asymmetry permitted, that is what is cold wall versus hot wall there also the IS code that is the recent ISO codes international code as well as ASHRAE they specify what does the allowable increase in the surfaces temperature of wall compared to the air temperature. Say air temperature is the 25 degree up to what to extent the surface temperature of the wall can go so that the maximum beyond which you will start feeling the radiant discomfort.

So, this exactly was being talked about in our national code. This was developed somewhere in the 70's and 80's, where you know they have estimated that up to 38 degrees this component of radiant discomfort will not be much impact full beyond which say when the wall temperature touches 39 40 degrees then this going to cause more problems. Based on this there is a limit which is set. They are basically classified the wall system into good, fair, poor, very poor, and extremely poor. If the thermal performance rating is less than or equal to 75 in this particular context you require 36 degrees peak surface temperature or lesser. The peak heat gain will be 34 and half you know watts per meter square. This is termed as class a building are good performing system. This primarily now you will understand since we talking about the peak inside surface temperature we are you know actually talking about a particular wall system.

Now, you know to brush up little bit more we talked about element level property, we will talked about component level property and we also talked about assembly level property. Here, this thermal performance index more closely talks about the whole wall system or the assembly level property. When the wall is in place it is plastered it is painted it is put in place it is not a static indicator, it is a dynamic indicator. The peak surface temperature is obtained as a part of different sets of phenomena. Finally, the result is ts surface inside peak, so you substitute this if you are able to get less than 75 it means you are peak heat gain will not go above 34.5 watts per meter square. Then your wall system the total assembly is deemed to be performing good.

On the other hand, if the TPI is greater than 225 which mean the inside surface temperature goes above 48 degree. That means, if you touch the wall surface if you measure the surface temperature inside it is going to as high as 48 or above which is really not comfortable. As a consequence you have a very high heat gain more than 103.5 watt per meter square heat gain will be there which is extremely poor. Imagine a thin metal sheet what will be the inside peak surface temperature it may go as high as 50-52 degree, outside of course will be much higher; gets heated up then it is extremely poor thermal classification.

So, this is developed, apart from this there are correction factor I am not presenting all the table I will recommend you to read st 41 that is the hand book of functional efficiency in buildings special publication 41 of national building code. There they have also cited a set up correction factors where you can substitute this and find out location specific. Say if you are climate zone is different or if your wall surface absorptive is different then there is a correction factor which is given substituting that you will get that actual thermal performance index. What you need to understand here? Thermal performance index in this case essentially takes conductive capacitive as well as reflective insulation in picture.

Since, they are given correction factors for absorptivity it takes the reflective component also. They have taken inside peak surface temperature which is a factor of here conductive heat flow as well as it gives you the capacity storage and limiting capacity of the wall. So, effectively this gives a comprehensive idea about the whole wall assembly.

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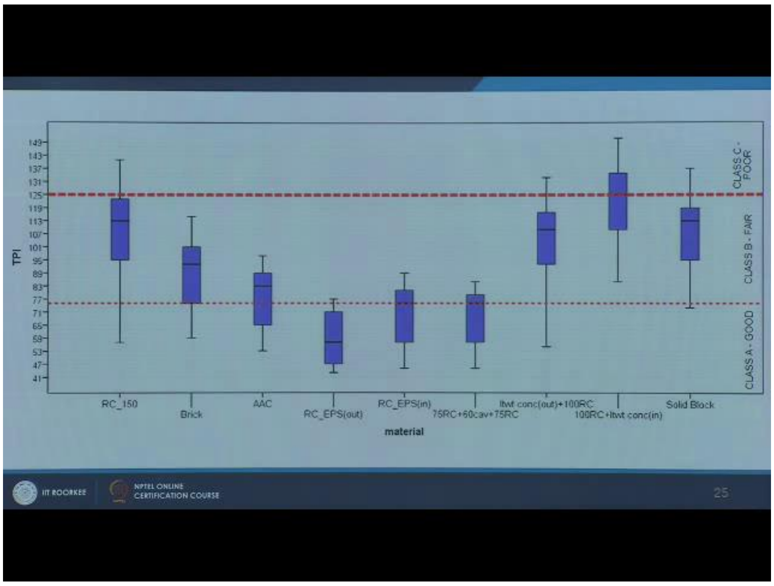

Some examples; most of the materials were fair performing material you can take a brick wall, you can take a aerated concrete, you can take a cement block wall, some insulated wall system, most of them are lying somewhere between the band of a fair performing or (Refer Time: 18:32) material further you insulate it or improve upon it you may be able to get a classy or good performing material. This is for a naturally ventilated building.

In case of air condition building, you have another version of TPI; thermal performance index. Inside of these peak surface temperature and this temperature numbers here you get the peak heat gain that is Q and the maximum allowable heat gain so which I am not presenting here, but there is an alternate version for air condition building where again you have a classification between good and poor.

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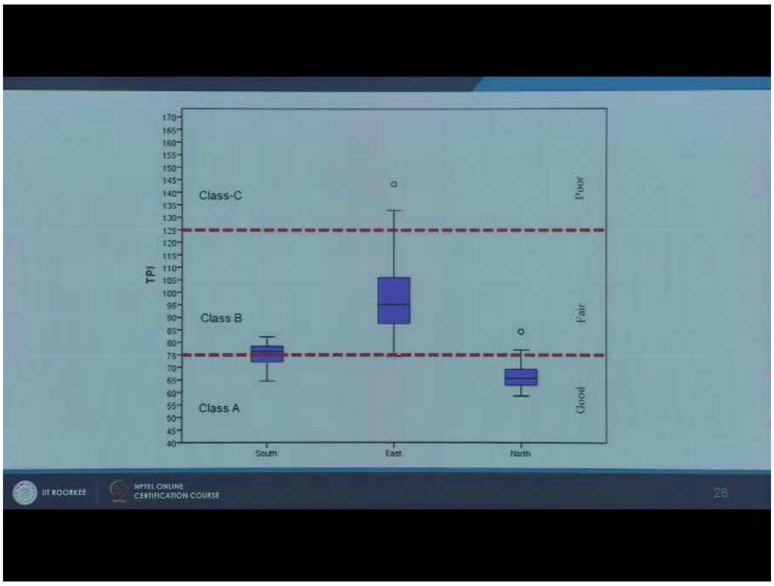

It also varies from orientation to orientation. This we tested for three different orientations, the same wall performs differently in 3 different orientations. To some up this is what national building codes give you.

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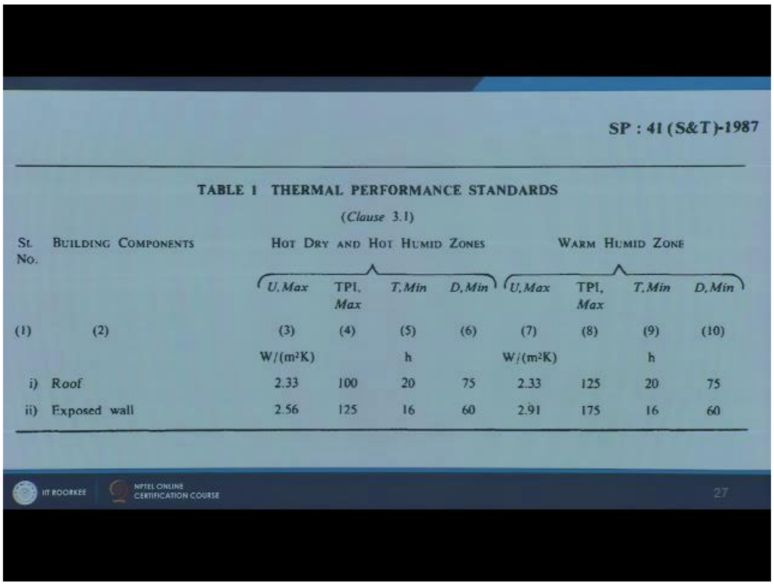
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TABLE 1 THERMAL PERFORMANCE STANDARDS

(*Clause* 3.1)

Sl No.	Building Components	Hot Dry and Hot Humid Zones				Warm Humid Zone			
		U, Max	TPI, *Max*	*T, Min*	*D, Min*	*U, Max*	TPI, *Max*	*T, Min*	*D, Min*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		$W/(m^2K)$		h		$W/(m^2K)$		h	
i)	Roof	2.33	100	20	75	2.33	125	20	75
ii)	Exposed wall	2.56	125	16	60	2.91	175	16	60

It gives you standards for exposed wall as well as roof for different climatic conditions. Say let us take exposed wall first if it is a hot dry or hot humid climate then you have a maximum U value of a 2.56 so your wall or a system that you choose should have a U value less than 2.56. Now, this is not end of the story.

The next thing is the TPI; thermal performance index maximum of 125 if you recollect it, 125 here means above in this range. So, they say that at least the wall should be a fairly performing wall. So, 125 gives you a cutoff that is where they have given here TPI maximum of 125 it should not exceed it then T this is the thermal time constant they have given a 16 this is minimum, so thermal time constant should be higher than this. Here you also get where to put your insulation and how to place your system, shaded wall versus unshaded walls orientation everything affects both TPI as well as thermal time constant. Then they also give you another clause for damping where we saw minimum of 60 percentage this is where they give for harder regions they say at least you need 60 percent thermal damping.

Apart from this if it is warm humid zone or a moderated zone there is there is relaxation U value you can go as high as 2.9. You can also have higher TPI value; thermal performance index can be 175. Thermal time constant is retained it is 16 and thermal damping is retained to 60 which actually varies day to day as I said. Next is the building index building indexes cumulates the heat gain from various surfaces, fenestrations, wall roof put together they calculate what is the overall watts per meter square that is the heat gain through the overall building system into a particular space.

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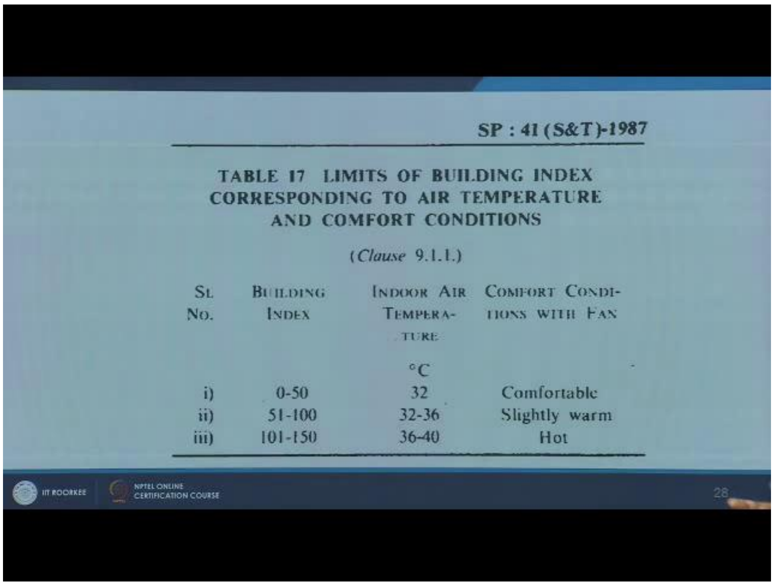

So, there is range which is given building index from 0 to 50 you can expect an ambient you know indoor air temperature of around 32 degrees or lesser deemed to be comfortable. 51 to 100 you can expect 32 to 36 degrees slightly warm condition. If it goes above 100 you can have a very high indoor air temperature which is pursued to be hard.

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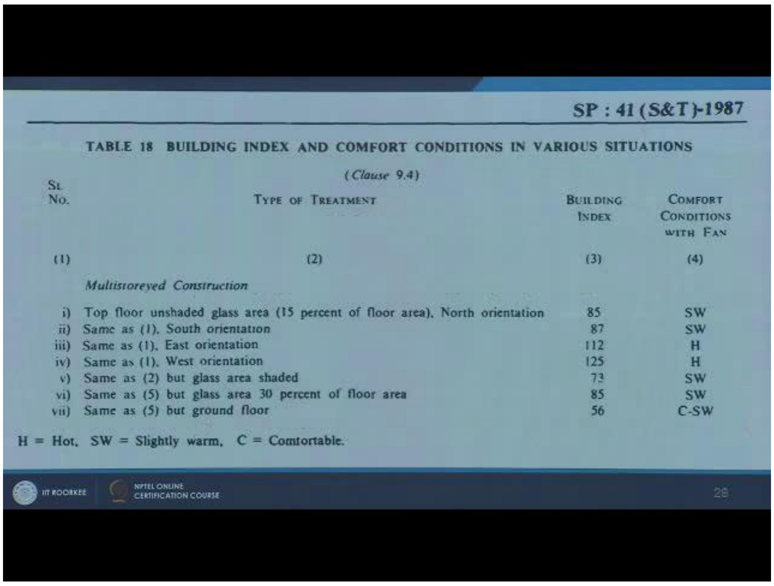
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TABLE 18 BUILDING INDEX AND COMFORT CONDITIONS IN VARIOUS SITUATIONS

(*Clause* 9.4)

Sl No.	Type of Treatment	Building Index	Comfort Conditions with Fan
(1)	(2)	(3)	(4)
	Multistoreyed Construction		
i)	Top floor unshaded glass area (15 percent of floor area), North orientation	85	SW
ii)	Same as (1), South orientation	87	SW
iii)	Same as (1), East orientation	112	H
iv)	Same as (1), West orientation	125	H
v)	Same as (2) but glass area shaded	73	SW
vi)	Same as (5) but glass area 30 percent of floor area	85	SW
vii)	Same as (5) but ground floor	56	C-SW

H = Hot, SW = Slightly warm, C = Comtortable.

They also worked out some examples. Take a multistoried construction you take you know top floor unshaded glass area 15 percent of the floor area. That is you know floor area to fenestration that ratio you know fenestration to floor area ratio is 15 percent, it is north orientation. The building index is 85.This is straightly warm condition, but then getting here with a south orientation and the glass area shaded you can bring it down to 73 which is again slightly warm. Further same as 5 that are 15 percent shaded window south facing, but it is on the ground floor.

Now, the roof is not exposed then your building index drastically drops down. From 85 we have come all the way to 56 where it is comfortable and slightly warm. Based on this what inference we draw we have a building index and we tentatively know as a designer this space is going to be partly comfortable and slightly warm then we can try adjusting the orientations. We can try adjusting the shading systems, we can try and enhance the shading system provided or we can try insulating the roof system. If you are not able to get to a lower floors, naturally you have a top floor you can try insulating it minimize the heat gain so that you can bring the building index value down and improve the comfort indoor.

To get a quick recap of the indices that we looked at what they actually mean.

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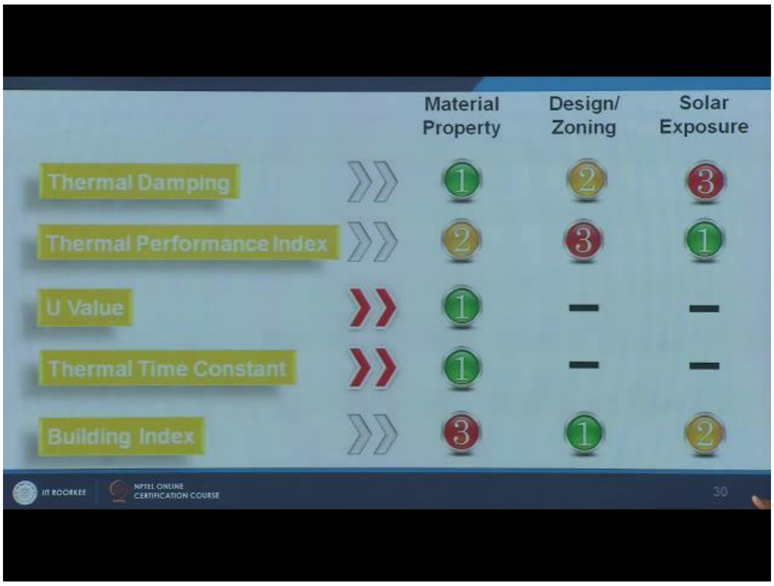

First we looked at U value, what I have here is the material property the impact on design and zoning and the impact of solar exposure. What I am trying to present here, whether these indices take into account these three things or not and to what extent. For example, a value like simple value like thermal transmittens or U value it only takes into consideration the material property it takes the density of the material, it takes the thickness of material and the surface property. It takes into account only the material property it does not really give importance as there is no weightage for which orientation where you put your material, what is your window area, what is your wall area these things are not accounted this is a basic material property.

Similarly, thermal time constant is a material property. Apart from there is the conductivity it also includes the density as well as the thermal capacity of the material specific heat, capacity is also included but still this is also only the material property two things are there. Next when you talk about thermal damping it has importance for material property, but it also gives importance for design and zoning. So, moment you change the design compactness your zoning is different thermal damping is going to vary. It also gives weightage for solar exposure that is orientation of the particular space, one side versus two sided oriented or north versus south orientated space will have an impact on thermal damping.

The next important thing thermal performance index it gives you know weightage to the solar exposure that is the orientation to which the particular wall is facing and whether it is shaded or not, because if the solar temperature or the outside surfaces is getting higher the inside surface is going to go high. Because of this thermal performance index might considerably vary. The next weightage is given to material property followed by design and zoning.

Building index again gives more importance to the design and zoning. How do you reshape or reconfiguring your building (Refer Time: 25:05) then it gives weightage to solar exposure and at last to the material property.

So, you know to get a consolidated idea we might need U value which is critically essential, but we also need 2 or 3 other numbers minimum to take a proper decision on which material to choose and actually how to design our building by itself. Let us you know take peak at what other countries are doing before getting into the slide. We talked about thermal capacity, use of thermal mass we have been traditionally doing, but most of the existing practices we do not look at thermal capacity as a crucial indicator. But recently you know few years back Australia introduced a new substitute or an (Refer Time: 25:49) for U value they have a stringent U value requirement for their buildings. They introduced the new factor that is thermal mask enhanced U value. For example, if you have a thin wall system your wall system.

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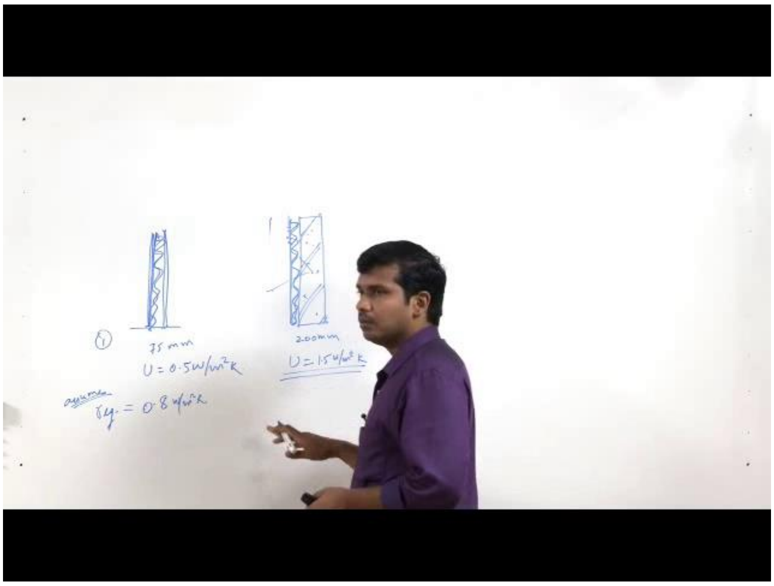

For examples has the thin gypsum board and thermal insulation (Refer Time: 26:10) plus inside finish, so overall wall thickness probably would be say 60 or 75 mm wall. These are two thin sheets; if you look at the U value probably you will get around say 0.6 or 0.5 watts per meter square Kelvin. This will be wall system 1. The next wall system for examples you have a sheet this is the outside facing for example, then you have the insulation, then you have a inside block work or say brick wall, any masonry construction or concrete anything if you have a wall system. Here you may have overall thickness might be say 200 mm, your U value could go up to say for example 2 watts per meter square Kelvin or say let us say 1.5 watts per meter square Kelvin.

As per the regular code if they say minimum required U value is say 0.8; required value is 0.8 for example assume this wall system is meeting the code, whereas this wall system is not meeting the code. As per the new enhancement which they have introduced they found that though this wall system does not have the resistive insulative property this has a crucial factor of capacitive insulation. Once you have capacitive insulation, this is storing heat, it is re releasing heat, it can be inside, it can be outside, it is varies considerably of course your thermal constant or damping values will considerably vary but apart from that this has capacitive insulation.

So, to give this allowance for using capacitive material like dense concrete blocks or a concrete masonry wall system itself, the code says mass enhanced U value. If you have thermal mass they give you relaxation in terms U value. Of course, you cannot go as high as you know 33.5, but still you have a consideration for introducing thermal mask into the wall system. Similarly there are other countries Brazil which also have relaxation in U values if you using thermal mass material.

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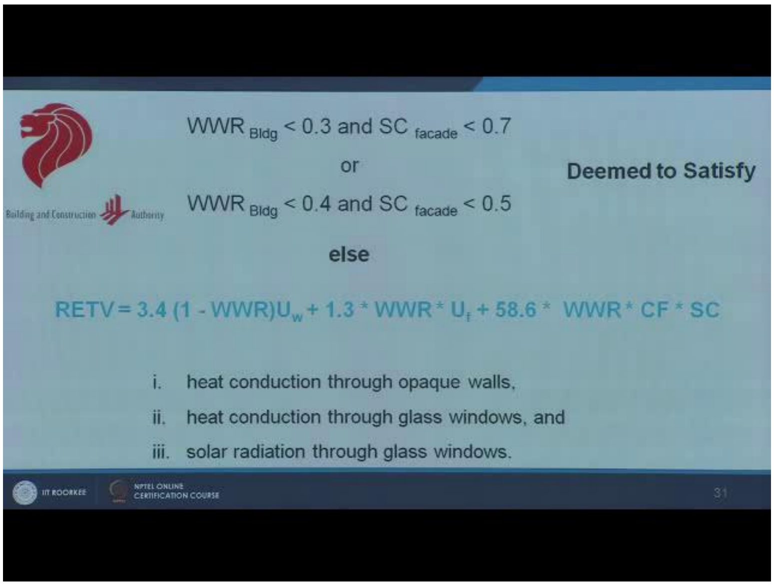

Let us take peak at what Singapore does why closely because it is a tropical country more so they have been rigorously working on the thermal codes on building performance standard. They have been realizing at quiet you know consistently. They talk about a number called RETV; that is effective thermal transfer value. Earlier it is OTTV; overall thermal transfer value.

First cut they say that if the building window wall ratio that is the size of windows are less than 30 percent and the shading coefficient. We will talk about shading coefficient little later in next session less than 0.7. Then you have satisfied the coddle requirement. But in case if it is more then they give a empirical formula which is essential contains U value of the walls, the window wall ratio U value of fenestration, then certain correction factors to be included. Overall you will get the net heat gain through the building envelope watts per meter square.

Now the current code is around 22 watts per meter square is permitted. So, you can have a larger window they say that you have to have smaller window, but if you have to meet the code your overall heat gain should not exceed 22 watts for meter square. Now think back with our building index example, what did our code say; it says that building index between 0 to 50 watts per meter square is deemed to be comfortable.

Similarly, in terms of the other factors like thermal performance index when they say 125 is allowable they also said the peak heat gain will be 32 to 40. In this slide when you have a TPI of less than or equal to 75 peak heat gain is 34.4 watts per meter square which is a good quality construction. So, our standard also says critical gives critical weightage for the maximum heat gain and allowable heat transfer through the particular system. So, we essentially looked at 3 different levels, element level, component level and assembly level. We primarily looked that what our national building code says part from just one or two examples are brought.

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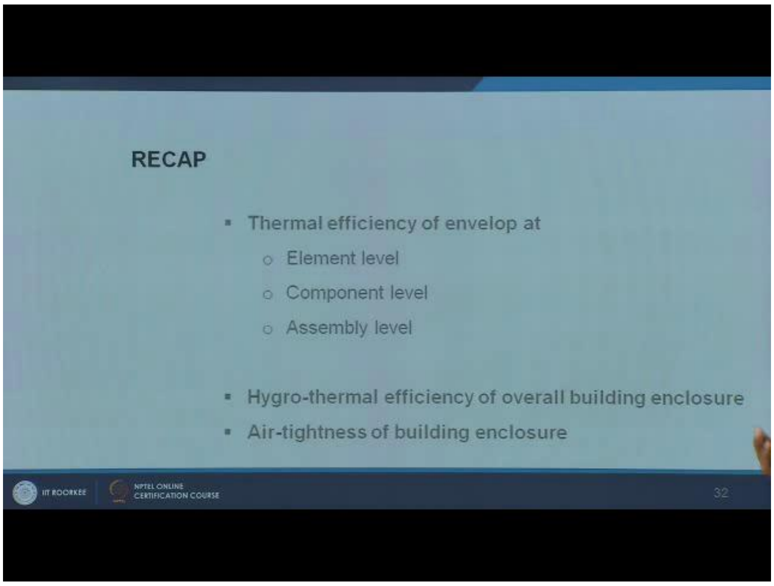

As I said there are two other important things that is a (Refer Time: 30:52) transmission through building envelope or the enclosure and the air tightness of the building enclosure. As a part of this module we are not looking at it, but essentially they play an important role or a significant role in the overall performance or thermal performance of the building enclosure.

Thank you.