**BUILDING ENERGY SYSTEMS AND AUDITING**

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**Week - 01**

**Lecture - 03**

# Lecture 03: Thermal Properties of Material-I (Contd.)

So, welcome to the third lecture, and this is the continuation of the second lecture on thermal properties of the material, part 2. So, we will discuss in this particular module, in this particular lecture. Three things: one is the heat gain through radiation. If you remember the last lecture, we discussed conduction, and we will also discuss the solar heat gain factor and the solar temperature. This radiation, if I see, we get the solar radiation, and that solar radiation is actually going to be involved in heating the different objects.

It will first, this radiation heat, which actually falls upon the building surfaces, roofs, different walls, the windows, and due to that particular radiation, some of the radiation may penetrate through the windows, the glazing, or the skylight. And finally, it will accumulate inside the room, and that will cause the room temperature to increase, and the total thermal gain, the heat gain, will also be increased. This particular solar radiation is different on different surfaces. So, if I see, what are the factors that actually cause the variation in the solar radiation in different parts of the globe? First of all, the latitude. So, from the latitude point of view, if you go to the higher latitude zone, the inclination of the sun's angle is

not perfectly 90°, or it will be much more, and that is why the amount of radiation will be low. The time of the day. So, it is the daytime when the solar radiation is exposed to the portion of the earth, and which time are you considering? Are you considering the very early morning? Are you considering the late evening, or are you considering the afternoon time?

So, that is another point. Then the altitude, then it is at sea level or maybe it is the same latitude, but not at sea level; it is in a hilly area. So, that is also going to be a deciding factor for seasons. The same location, same time, maybe you are calculating at around 12 in the afternoon. Same latitude but on a different day in a different season, not in the month of May or maybe it is the month of December.

So, things will change; the amount of solar radiation that comes to you will change, and also the amount of cloud cover. So, if you see the NBC, the National Building Code 2016, it was also given in 2005 with the same chart. It has given the solar radiation in summer and winter in different orientations. So, that means, as you know, in the northern hemisphere, the sun moves from near about northeast or maybe around east, and then it follows the southern path and the southern side, and then the west. So, there is a variation in the south intensity, variation in the east intensity, variation in the west wall intensity, also in the north, and also in the horizontal.

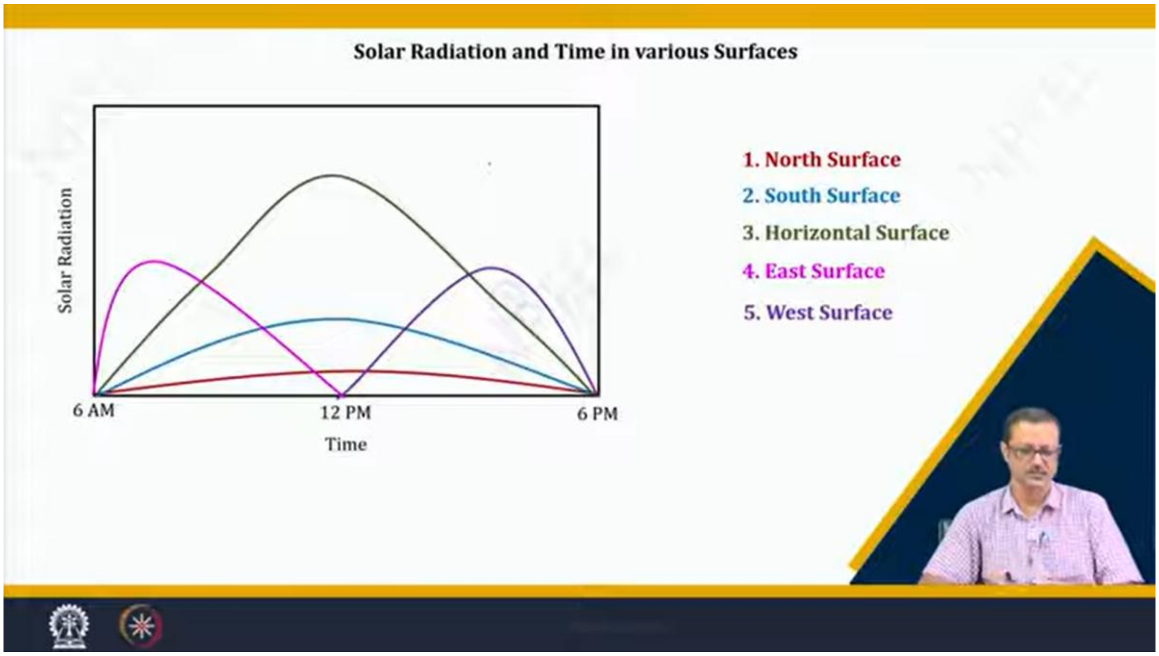
So, here north, northeast, east, southeast, south, southwest, west, northwest, and horizontal, all the 9 surfaces. Eight cardinal surfaces and one horizontal surface, both in summer and winter, and in this 1, 2, 3, 4, 5, 6... 6 latitude, 9° north to 29° north, it was listed. So, this is very helpful data. So, we can take this data if my city is nearby or may not be exactly at 13°, but we can see that yes, it will be approximately in that area. So, we can actually see my southern side; I have this much area.

So, how much is the per day $W/m^2$ per day again? So, here we can understand one thing: the solar radiation is given with a unit of $W/m^2$. How much $W/m^2$ of the area is falling? I mean, how much joule per second or something like that. So, that is one of the points.

So, now, the solar radiation, the variation in the various surfaces, if I want to see. So, this is the north surface. We are in the northern hemisphere. North is not at all directly exposed to the sun, maybe in some part of the morning or some part of the evening, or whatever. Maybe it is under diffused kind of radiation. So, it is a very minimal kind of thing. So, from morning 8, sorry, 6 am to the evening 6 pm, if I want to see. So, this is the south surface, which is potentially high because the predominant time of the solar path actually follows the south, or the incident radiation will be on the southern surface.

The next one is the roof surface, which is horizontal, is the maximum peak because the horizontal surface, from the morning 6 to the evening, whatever may be the sunset, sunrise to the sunset, it is always exposed to the sun. But if you see all three, it is not constant; it increases and then there is a decrease. So, there is again a periodicity. Again, there is a periodicity. Now, the east surface. The east surface, you see, it is the morning sun. So, by around 12 or so, it vanishes. That particular sun rotates and then it is gone to the west side or so.

Similarly, the west surfaces are some other type of hump on the other side of the




afternoon side. But what I see is that all the five sides are horizontal, including the horizontal. There is a time dependency if the solar radiation is not fixed. So, we will discuss how to tackle that because if I want to actually accumulate how much heat is penetrating. Because of the temperature difference, we have seen in the last lecture that there is a periodicity in the outdoor temperature also. And now we are seeing that there is again a kind of periodic phenomenon in the solar radiation also because solar radiation is also going to impart a lot in the heat penetration or the total cooling load calculation.

These two periodicities are different. The east wall periodicity type of periodic changes and the west wall is not the same, and east-west is not going to be the same with the south and the roof. So, how to tackle that, we will see. Of course, it requires a little bit of higher mathematics, but we will not go into that much detail. We will just see how easily we can develop some kind of approximate model that will actually calculate my heat gain through a building in maybe the third phase or the fourth phase of our lecture. So, a pyranom is another instrument that is actually used to estimate this radiation. So, nowadays, digital pyranoms are available.

Now, when a particular glass or maybe a particular glazing or any kind of transparent material is exposed to solar radiation, there is some incident solar radiation that is going to be incident upon the glass. Some of the portion, I must say, will be reflected back, some will definitely be transmitted, some of the portion will actually be absorbed inside the glass, and after absorption, an amount will be transmitted and an amount will go out. So, by virtue of this, if I see what my total incidence is and what my total gain inside is, that is direct transmission, which is this arrow, and the second is absorption, which means this red arrow is my actual gain inside the building. So, this ratio is very important because this ratio will give you a kind of character of the glass that how much amount of radiation is actually transmitted in and also absorbed in.

So, how much is my gain inside the building, inside a particular room? How much is this? So, this particular ratio is called the solar heat gain factor. I am sorry, the solar heat gain coefficient (SHGC) is sometimes also called the solar gain factor (SGF). So, the solar heat gain factor is a unitless quantity that gives you a particular ratio. If the ratio is, suppose, it definitely fluctuates between 0 and 1. If everything is blocked, nothing is transmitted, and nothing is absorbed, it is 0.

And if everything comes in, nothing is reflected, and nothing is absorbed, then it is 1. So, both may not occur; it may occur in between. Suppose it is maybe 0.6, which means that 60% of the incident radiation actually comes in, and 40% is whatever, right? So, if the SHGC values are very high, definitely it will admit a lot of radiant heat, and vice versa. If it is low, then it will be very good, as it will not admit much. So, this is what I have already discussed.

So, now if I see heat conduction through the window, how is it happening? So, it is happening in two ways: one is through conduction, and definitely one through radiation. So, there is a temperature gradient that exists. So, this glass, the window glass, or maybe the glazing, is also having a material envelope material with some thickness, maybe very low, but still some thickness.

So, there is a temperature gradient that exists, and this particular material has a U value. So, based on that, I can easily calculate the conduction, how much is that? We have seen in the last lecture that we have calculated if I know the area of the exposed window, if I know the U value of the window, and if I know the temperature difference. Similarly, I can also find out how much is the radiation heat gain because the wall and the opaque surfaces will not allow any radiation; only the transparent surfaces like the glazing or the window will allow. So, in that case, my equation will be (the area x SHGC x I), where I is the amount of incident radiation. Now, you see that incident radiation is nothing but your $W/m^2$. If your window is in the southern face at some time, some date, it will have some kind of incidence. So, you have to see how much is the I value, and this I value is ever-changing in a day; it changes from morning to evening. Seasonally, it is changing. So, this I value is a kind of fluctuating value.

So, we can take an average and we can do something like that, but if I have a window and if I want to use that in my particular heat load calculation, I have to use that particular window because it is in the envelope surface. I have to take two types of heat that come through the window: one is conduction. So, I have to use this equation, and I have to use this equation also. So, these are some of the U values and the SHGC values mentioned for tinted glass and some of the clear glass. So, if it is single glazing, that means only one sheet of 6 mm glass, the SHGC is 0.76, which means 76% of the radiation is actually transmitted in and also absorbed in.

Whereas, a clear glass of double glazing, whether two glazing with some air gap. So, it is 64% or 0.64. Now, if I go with the body-tinted glass or the surface-tinted glass or the reflective glass, I have given the definitions of those. So, the values dropped So, from 0.76 to it is 0.6, 0.5 to 0.18 as in when the SHGC value drops below or drops below maybe 40% below that, this is always going to be good because in the case of the reflective glass, you see it is 0.18, that is 18% is admission or transmission in and the rest is going out.

So, here in the double glazing, surface-tinted plus clear. So, there is a double glazing, one is surface-tinted and plus one is clear. So, one is body-tinted and one is clear, and one is reflective glass and one is clear. So, like that, I have taken those values from this particular source. So, you see when there is radiation, and through this radiation, when it actually falls from the sun, the sun rays come with only shortwave radiation.

What is shortwave radiation? If you see the electromagnetic spectrum, there is visible light that will come to that just maybe two or three slides after. So, this radiation is infrared radiation. Infrared has a very broad band. So, out of that, the short wavelength actually comes from the sun and it actually falls into the glass.

Now, short wave radiation goes in, and this long wave radiation, the other part of the IR radiation, does not actually come from the sun, but it is emitted by the glass. This is because the glass becomes hot due to the short wave radiation or so. So, that is why I have written over long wave radiation that it is not the original because the glass has been heated up. The temperature of the glass surfaces has been heated up, or any surfaces if they are heated up, you will get the radiation that is the long wave radiation. So, the long wavelength part of the infrared spectrum.

So, we can stop that one, we can manage somehow to stop that one, and in this long wave radiation, it stays indoors because it cannot go out. It will be reflected inside the indoor, and that is why if there is a glass building or so, we say it is a greenhouse effect. It is going to be gradually heating up, and the temperature is increased to be very high because it cannot go out, and this long wave radiation, which is trapped in it, cannot go out. So, somehow we can actually do something by virtue of some material science way that some coating can be given on these particular surfaces, glass surfaces, in such a way that this emissivity, what is emissivity? Emissivity is a property of a material to radiate heat energy. So, if I put some protective layer or some kind of other material that will not emit or radiate that much.

So, automatically the long wave radiation will be less. So, that kind of low emissivity material we can think of, and it is available in the market. So, that is called the low e-glass. So, low emissivity glasses are a little bit high cost, of course, but they are available, which actually allow the short wave radiation, but they will stop the emissivity of the glass itself. So, that it cannot or it will not radiate long wave that much.

So, now let us see with the help of these equations how I can find out some of the heat gain or so. So, I have a wall whose dimension is almost 60 $m^2$, 15 by 4. WWR is 15%; the window-to-wall ratio is 15%, and the wall U-value, window U-value, and window SHGC values are also mentioned. The wall does not have any U-value, as you know, it is opaque. The outdoor temperature and the indoor temperature are also given, and the solar radiation I have mentioned is 150 $W/m^2$.

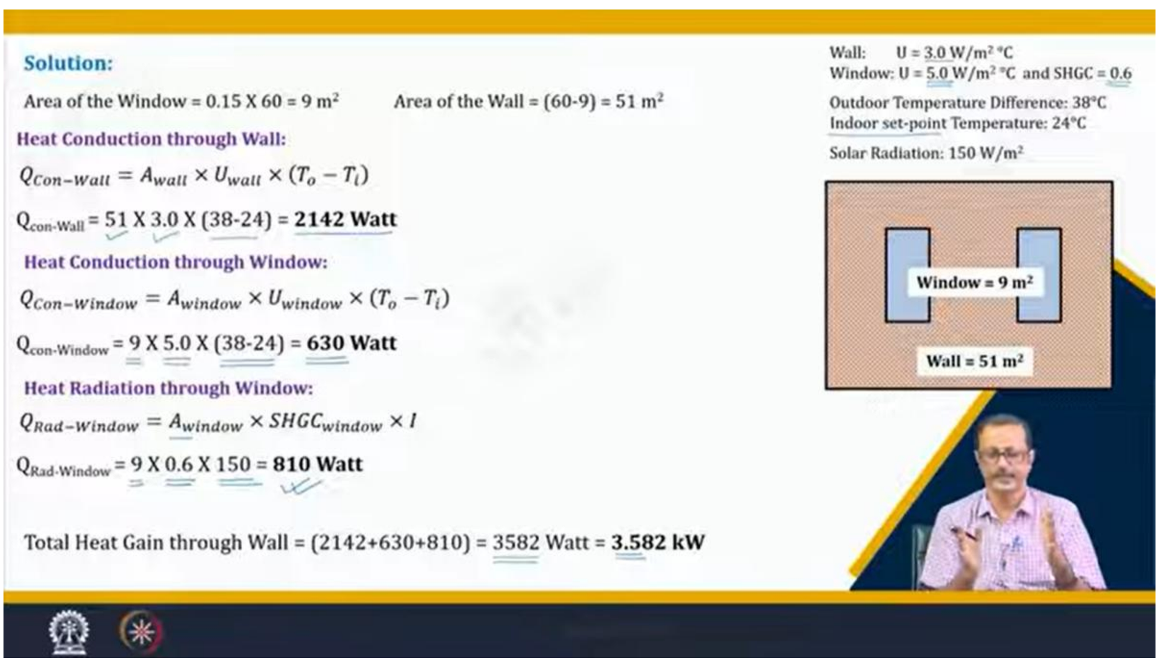
So, first of all, I need to know how much is the wall area and how much is the window area. This window-to-wall ratio is going to help me. So, I found out that 9 $m^2$ is the wall area and 51 $m^2$ is the window area, fine. So, I take it to the next slide. So, the wall area I know, the window area I know.

So, now, I will take the first equation to see how much heat is conducted by virtue of conduction through the wall. So, I have that old formula which we discussed in the last lecture. The area of the wall is 51, the U-value is 3, which I have mentioned over here, you see, and the temperature difference is this. So, it is 2142 watts. Then, similarly, I do the same; I use the same equation for the window because the window now has two components: one is through the conduction of heat, and another one is the radiation.

So, here, very simply, A is 9. The area is 5, the U-value of the window has been given in the problem, and the ΔT remains the same, which is 630 watts. And then, the last part, the other part of the window, the radiation part of the window, where In this new equation, I have to place the area of the window as 9, and the SHGC of the window as 0.6. You see, the SHGC of 0.6 has been taken here, and there is no question of ΔT.

Instead of ΔT, the outdoor temperature is naturally given. So, here, I have taken another naturally given param, which is the solar radiation of 150, and this is 810 watts. So, now, I have to add it up. So, if I add it up, I get the value as 3582 watts. So, it is 3.5, almost 3.6 kilowatts, which is the total.

That means, for that particular situation, when the temperature is 38° outside, and you want to keep it at 24°, which is why I call that the indoor set point temperature, I want the indoor temperature to be 24° Celsius. At that particular moment, the solar radiation is 150, and you have a wall of 60² ms with 2 or 3 windows, whatever it may be, but only 15% of the area is windows. And the rest, 85% of the area, is your wall, I think. So, I just go back, yes, the WWR is 15%. So, 15% is your window, and the rest of the area is your




wall. So, at that snapshot time, 3.582 kilowatts will be the energy transmission.

Next is a very important thing: the sol-air temperature. See, because of the solar radiation which actually strikes the surfaces, the surface temperature increases. If you just touch a wall which is under solar radiation and another one of the same material, same color, same thing, but it is under shade, definitely the wall which is under solar radiation will be higher in temperature. So, we have to take that particular factor into account because of the conduction of the heat from one surface of the wall to the other surface of the wall.

So, this surface wall condition has to be considered; it is not only the outdoor temperature but also the temperature of the wall surface. So, is it under shade? Or is it under direct solar radiation? That has to be considered. So, we have to find out this sol-air temperature, which we will determine with this particular formula. You see, this is the outdoor temperature, To, and an additional extra amount of temperature can be found out by the solar radiation, which is I, then the absorptance of the surface

which is small a, which indicates how much it is going to absorb because of the color. If you see both walls under the sun, but one is black in color and one is white in color, definitely the black color surface will absorb more and you will see a little bit of extra temperature. So, the value of the absorptance fluctuates from 0.1 to 0.9. So, that is also there, and also the surface conductance. How the surface is conducting the heat is also a very interesting phenomenon because of the thin layer and some of the air or so, it also has an effect.

So, that value also depends upon the material. So, that value is given in $W/m^{2\circ}C$ and that value comes from 15 to 25 around to 15 to 25 $W/m^2 \,^\circ C$ depending upon different types of material. So, now suppose the wall is under complete shade. So, then the I is going to be 0 and as and when I is going to be 0 you will have the sol-air temperature equal to the outdoor temperature 38° whatever we have seen in the last example.

But if there is a 150 or something is there some solar radiation is there because of your color and all this thing there is an A and F not exist because of those params and if some increment of the temperature and these two temperatures will add up the increment plus the outdoor temperature and that should be you should take that for your calculation. So, let me see with the same problem which we have solved just now I have just given two more data that the surface absorbance is 0.4 which is A which is this is your A and the surface conductance is 20 which is your F not. So, the same problem so, that this area calculation remains same. So, we will go back to this we have now have to calculate how much is your sol-air temperature.

So, your radiation is 150 the same which we have taken in the last problem that this is your A value this is your F not value. So, almost about 4°. So, this if you see there is a 4°. So, this is 38 plus 4° centigrade is increment because of this solar radiation. So, if you have to take as outdoor temperature 41° not 38°.

So, if you take 41° because it is under solar radiation, your calculations will be much more accurate. So, based on this again, I am calculating the heat gain through the wall, which here I have taken the solar air, not outdoor. So, now, it is not 38 minus 28, and it will be now 41 - 24. So, this is the value in the conduction of the wall, conduction of the window again, this is 48, sorry, 41 - 24, that 18° or so. And your other values remain the same, the area remains the same, your U value remains the same, only the solar air temperature changes if it is under the sun.

And the last one, that 810 will remain the same because, in this particular equation, the radiation equation, there is no question of any temperature difference or so. So, I will get almost about 4.1, if you remember, the last one was 3.5, this is 4.176 kilo or so. It has been a kind of increment; definitely, it has to increase because you are, we are considering the solar radiation, we are considering the extra temperature raising in the outdoor wall and outdoor window surfaces, which actually contribute to the transmission of the heat. So, we have different types of protective material. We can use those protective materials; we have insulative EPS covers or sometimes some hollow concrete blocks or some kind of layers we can use for the protective material.

So, we can use that in our building; there are some cases, this is the EPS, this is the EPS, and sometimes we also put some kind of protective materials in the rooftop also; we will try to put the roof. light in color. So, that the reflectivity is increased, the absorptivity is decreased, and the solar air temperature decreases. You see, on a hot sunny day, you cannot walk on the roof terrace barefoot probably because its temperature is much higher; the solar air temperature is much higher. Maybe the temperature outside is 38, 39, 40 maybe, but you cannot walk in the afternoon, maybe 2 o'clock or so, on the terrace because the surface temperature of the terrace is maybe around 55° or so, 15° higher because of those params; solar radiation is very high, maybe 800 watts per m².

So, that particular temperature has to be taken, and that particular temperature will be killing you. Because of the heat transfer kind of thing. So, how that can be reduced down may be shading or some kind of insulative material. So, those are some of the EPS, the expanded polyurethane material, which is very useful for this purpose. So, now how I can use it, suppose I have two materials, one is the combination, suppose the UA is your RCC slab.

Which is suppose your U value is 3, and Ub, you know, the new material you are putting up, and that is your next new material, which is 1-inch expanded polystyrene, having a U value of 1, then what will be the combined U value? Of these two layers. So, you can use this equation, which is also a very approximate equation, but holds very good. So, the combination of the U values of material A and material B will be reciprocal added and then reciprocal again. So, 1/Ua + 1/Ub. So, 1/3 + 1/1, and then see, actually, if you want to use an RCC roof.

That U value is 3, and it is dropped down to 0.75. So, instead of 1-inch EPS, if you use 2-inch EPS, then the U value of 2-inch EPS is 0.6, which is further dropped. So, you will get a maximum benefit by virtue of this insulative material, as insulative material increases the thickness and all. The decrease in the U value will be helpful. So, here it is the energy-efficient glazing, as I told you, the glazings are there, the window glazings are also required for the daylight.

So, the solar radiation also takes care of your visible light as well. So, if you see the band, this is the band for the solar spectrum. It has an infrared portion, a visible light portion, and a UV portion as well. So, out of that, 44% is the visible light, and 53% is the infrared, which is actually heat. So, out of any, we will first see that particular glass or some transparent material, how much is the visible light transmission which I want to improve.

So, we will see how much is this visible transmission, what percentage, and out of that, how much is your SHGC? SHGC will increase your temperature. So, this LSG ratio, light to solar gain ratio, how much is your light, and how much is your solar, what is the ratio between them? So, I want more light, but I do not want the solar gain. So, if this ratio is high, if somebody can give me a glass material which has a high VT value, but a low SHGC value, I will be very happy because I will have a lot of daylight. The visible spectrum will be much more, which will not increase my temperature and also has a low SHGC value.

So, the temperature increase will be low. So, we can have reflective glasses or clear double-glazing glasses that will follow this 45° path. So, both are equally increasing. Suppose a kind of glass which has a high SHGC and also a high VT, which is very normal, but some glasses may show a very high SHGC with a very low VLT, visible light transmission. So, we should not actually take those glasses because that will unnecessarily increase my heat gain, but it will not give me any kind of daylight. The low VLT, but I will be very interested if I get some kind of glass in this zone where I have a very high VLT, a very high value of VLT, and a very low value of SHGC, okay.

So, that high VLT gives me more ray light penetration. I will be very happy because my artificial electrical lighting load will be less, and I will not have that much heat gain because of the low SHGC value. So, there are some high-performance tint glasses, and there are some low ones. I just want to talk to you regarding the low emissivity glasses that I can think of. So, it is another graph where we can see from the wavelength point of view. The visible portion and the infrared.

So, if you take a double-glazed window glass or whatever. So, it has good visibility and also good infrared penetration. So, both are good: both VLT and the SHGCs are good, which is not going to bother me because I am going to have a lot of heat gain, but I can actually go for this kind of curved one where we have a good visibility or the visible spectrum penetration, but very low kind of the infrared penetration.

So, those are the low-e glasses. Also, see the red color pattern is very high visibility or the low kind of a thing. So, these are the references for this lecture. I have used the same references, and what we understand from here is that solar radiation plays a very important role, as you know, it has a periodicity. So, we need to see that one in the following lectures: how you can tackle that one, and it increases the surface temperature of the wall and also penetrates through the window. So, the transparent things like the window glazing and skylight have to be designed accordingly. Thank you so much.