Course Name: Bioclimatic Architecture: Futureproofing with Simple and Advanced Passive Strategies

Professor: Dr. Iyer Vijayalaxmi Kasinath

Department of Architecture,

School of Planning and Architecture, Vijayawada

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Lecture 02

PCM with Glazing

Hello students, Welcome to another class on an advanced passive strategy. Today we will look at a strategy, which is PCM-enabled glazing. So today we will see in this class on advanced passive strategy about PCM integrated windows. PCM is phase-change material. So PCM means phase change material. So in the construction and architecture industries, PCM is becoming generally applicable to materials and products that can be used as temperature-regulating media.

For example, latent heat storage media for the regulation of temperature. Increasing the thermal storage capacity of buildings can increase human comfort by decreasing the frequency of internal air temperature swings so that indoor air temperature is closer to the desired temperature for a longer period of time. This system provides a valuable solution for correcting the difference between the supply and demand of energy. A phase change material is a substance that absorbs and releases thermal energy over a period of time.

So phase-change materials work by undergoing the processes of melting and solidifying to store and dispense the heat. Thermal energy storage in the wall, ceiling, and floor of a building can be enhanced by encapsulating or embedding suitable phase change material within these surfaces. They can either capture solar energy directly or thermal energy using natural convection. The use of phase change materials as latent heat storage material is an efficient way of storing thermal energy. So, as the temperature rises, the phase-change material starts to absorb the heat and slowly change its phase.

When it changes its phase, it stores the energy, and vice versa is true when it cools. As the temperature drops, the PCM begins to solidify as it gives away, and then the temperature still remains constant. So, when the temperature rises, the PCM will melt, but its temperature will still remain the same. When the temperature drops, the PCM will solidify, and the temperature will remain constant. So, phase-change materials, or PCMs, can give out latent heat at a wide range of temperatures, from sub-zero to several hundred degrees.

This heat-on-demand requirement is satisfied by phase-change materials that work at specified temperatures. A phase change from a solid to a liquid or liquid to a gas and vice versa occurs at precise temperatures. Thus, where energy is absorbed or released can be predicted based on the composition of the material. So, a phase-change material has a lot of latent energy storage in it. They use the chemical bonds to store and release the heat.

The thermal energy transfer occurs when the material changes from a solid to a liquid phase and to a solid state again depending upon whether heat is supplied to it or removed from it. So phase change processes invariably involve the absorbing, storing, or releasing of large amounts of energy in the form of latent heat. So phase-change materials such as inorganic hydrated salts absorb and release large amounts of heat energy, and these processes are reversible. It's a reversible process. What do you mean by reversible? From a solid state, this material becomes liquid when it gets heated.

And from liquid it again becomes solid when it is cooled. So this keeps on happening. This cycle keeps on happening. And just to show you how it would look. I have put this.

It can be in crystalline form, amorphous form, or an intermediate form. So, PCMs absorb and emit heat while maintaining a nearly constant temperature. Within the human comfort and electronic equipment tolerance range of 20 degrees to 30 degrees centigrade, latent thermal storage materials become very effective. These solid liquid phase change materials perform like conventional storage materials. then temperature rises as they absorb solar heat.

Unlike conventional heat storage materials, when phase change materials reach the temperature at which they change their phase, which I will call the melting point, they absorb a large amount of heat without getting hotter. When the ambient temperature in the space around the phase change material begins to fall or drop, the phase change material again solidifies, releasing the stored latent heat, and this cycle keeps on continuing. So, when the environmental temperature rises, the phase change material becomes a liquid and stores the heat that it gets from the temperature rise, and it manages to keep the temperature by changing its phase from solid to liquid. So a phase-change material absorbs heat and retains its solid phase. It becomes liquid and starts storing the heat. So from solid it becomes a liquid storing the heat and vice versa.

When it cools, it again becomes a solid. So, this is the principle of phase change material. Because phase change materials are substances that can absorb and release thermal energy. during the process of changing from one phase to another, say from solid to liquid or vice versa at specific temperatures. So phase change material incorporated glazing units refer to innovative building materials that combine phase change materials with glazing systems in order to enhance the energy efficiency of buildings.

These units aim to address the challenges of regulating indoor temperature by leveraging the latent heat absorption and release properties of the phase change materials. So, there are numerous passive solutions that lessen the indoor heat gains and losses in. These have been developed to increase the energy efficiency of the windows. Reducing or postponing heat flow through the window is the primary goal of using new materials or designs to improve the thermal performance. By managing the energy flow between the interior and outside environment and limiting the amount of solar radiation that enters the building through the windows. The integration of these technologies results in a decrease in energy usage, which is our main aim.

We need to reduce energy use in buildings in order to design sustainable buildings. So this is our aim. and PCM-integrated windows help us in this. So, this is a promising technique to improve the thermal management of transparent facades. PCM controls the energy flow between indoor and outdoor environments dynamically.

The efficient regulation of interior temperature and reduction of heating or cooling load can be achieved by phase change material windows through the storage and release of thermal energy during phase transitions. The usage of phase change material can play a very crucial and important role in managing the indoor temperature. By transferring the peak load to off peak hours and reducing the energy required for space cooling or space heating. The movement of heat storage and release within the phase change materials is the fundamental idea behind phase change material windows. This is the primary aim or motive.

Phase change materials experience a phase transition from solid to liquid when subjected to substantial heat gain which includes incident solar radiation. During this process, phase-change materials absorb a significant quantity of thermal energy. The phase-change material re-solidifies as the surrounding temperature drops, releasing the stored energy back into the environment. By regulating the amount of solar radiation that enters the structure, phase-change material windows can help to lower the requirement for cooling or heating and thus lower the energy used by the air conditioning system. Despite being a relatively new technology, phase change material windows represent an exciting advancement in sustainable building design, and further research is necessary to fully grasp their potential benefits and their limitations.

So, one of the efficient ways to enhance the thermal capacity of a glazing system is the double-glazed window filled with phase-change material, which can be very useful. What this means? Double-glazed window filled with phase change material we will see in the subsequent slides. By regulating the amount of solar radiation that enters the structure, the phase change material windows can help to lower the requirement for cooling or heating and thus lower the energy used by the air conditioning system. Despite being a relatively new technology, PCM windows represent an exciting advancement in sustainable building design, and further research is necessary to fully grasp the potential benefits and their limitations. So, what do you mean by double glazing? Double-glazing, double-plane, or triple-plane glass windows are also called insulated glass units.

So in this class you will be listening to these insulated glass units, IGU, double pane glass, and double-glazing units very frequently. So, what are the components of insulated glass units? First is glass. The glass in IGUs or insulated glass units can be a range of thicknesses or types. Laminated or tempered glass may be used in areas where safety or strength is an important criterion. Insulated glass units can contain up to three panes of glass where extra heat and sound insulation is required.

Thicker glass is more expensive, but it is more efficient. The second component is the spacers. Insulated glazing units utilize a spacer that separates two glass panes. So you have to separate these two glass panes. So, this is a glass pane, and this is another glass pane of this double-glazing unit.

You need a spacer, and this spacer usually has some sort of desiccant to absorb the moisture between the panes and prevent fogging. The width of the spacer depends on the gas used for insulation and the window type. Generally, the wider the spacer, the more efficient and expensive the window will become because the space between the glazing will increase. And that will also mean more infill material, more insulating material. And therefore, this can become more efficient as well as expensive as compared to the first one.

The third component is the window frames. Insulated glass is used in many different types of windows where efficiency is required. Double-hung windows, picture windows, casement windows, and skylights use insulated glass to prevent heat loss. The fourth component is a gas or something to fill in between. The gas used between the glass panes will vary with each manufacturer.

In general, inert gases such as argon, krypton, or a mixture of both create the insulating barrier between indoors and outdoors. In our case, we are trying to look at translucent PCM as the filler or replacement for the gas. So, phase change materials are these substances that will absorb and release thermal energy during the process of changing from one phase to another. For example, from solid to liquid or vice versa at a specific temperature. Phase change material integrated glazing units operate based on the principles of latent heat storage and release during phase transitions.

The primary goal is to enhance the energy efficiency of buildings by utilizing the thermal properties of PCM in combination with glazing systems. So the first step is the selection of phase change materials. So, this first step involves choosing the correct kind of PCM. So choosing an appropriate PCM with the phase change temperature that aligns with the desired thermal comfort range for the building is important. So PCM can be designed to undergo phase change typically from solid to liquid or liquid to solid within a specific temperature range.

Second is incorporation in glazing units. The PCM is then integrated or incorporated into the glazing units, which can include windows, skylights, or any other transparent building materials. This integration can take various forms, such as encapsulating the PCM within the glass or applying a coating with PCM properties on the surface of the glass. Here I have shown the picture of a PCM integrated window with various levels of transparency based on how much exposure it has had to heat. So, during heating periods, what happens is that sunlight that makes it through the outer insulating glazing unit, which is the IGU, which we saw last time passes through the inner IGU that is filled with sealed polycarbonate channels into which the translucent salt hydrate PCM is encapsulated.

So there is an outer insulated glazing unit, say this one, and this has suspended prismatic filler. like a fresnel lens between the panes of glass that reflects higher-angle sunlight back out while transmitting low-angle sunlight. aSo, this during summer is designed in such a way that when the sun is high in the sky, greater than 40%, the solar radiation can get reflected away. Whereas during the shallow winter sun, when the sun angle is less than 35, the solar radiation manages to get inside. So, this offers a passive solar control mechanism for south-facing glass to keep out most of the high summer sun while benefiting from the lower angle of winter sun.

And then the PCM stores a lot of heat as they change from solid to liquid. So, as they change their state because of absorption, they release that heat as they cool off. The salt hydrate melts and freezes in the temperature range of 26 to 30 degrees Celsius. So here we have an example of three windows. This first one has the TCM incorporated in one of the cavities, which is towards the indoor, and here you have in one of the cavities, which is exposed to the outside, and this is a reference window.

So two separate low-emissivity coatings and low-conductivity glass fill in the outer sealed spaces. So the outer sealed spaces have gas filled into them that helps to push heat from the PCM inward while slowing outward heat loss. The direct beam light transmission, assuming that the sunlight isn't blocked by the prism layer, is about 45% when PCM is liquid and is 28% when PCM has crystallized. Along with doing a remarkably good job at blocking heat loss, the glazing stores the heat like a trombe wall or thermal storage wall, which we have already seen, offering a heat storage capacity of 1,185-watt hours per square meter. This is as much heat as a 9-inch or 24-centimeter layer of concrete.

So how does the energy storage work? PCMs store a lot of heat as they change the phase from solid to liquid by melting over a narrow temperature range. Then they release that heat as they begin to cool off. The salt hydrate that is used in PCM glazing will melt, and it freezes in the temperature range of 79 to 86 Fahrenheit or 26 to 30 degrees Celsius. So too low a temperature. Separate low emissivity or low E coatings and low conductivity gas fill in the outer two sealed spaces of the glass that help to push heat from the PCM inward while slowly outward heat loss.

And along with doing a remarkably good job of blocking heat loss, the glazing stores the heat like a trombe wall. This 16 mm of PCM is equivalent to 25 cm of concrete when it comes to storing the energy. And you can see how it looks when it is solid at the time of phase change and when it becomes completely liquid. So this is how the window will change its opacity based on how much heat the PCM has stored. What happens during the cooling period? When the external temperature decreases, such as during the night or cooler period, the PCM begins to solidify, and it releases the stored latent heat back to the indoor environment.

This process will help to regulate the internal temperature, keeping it within a comfortable range. This leads to reduced energy demand by effectively managing thermal loads. PCM integrated glazing units contribute to reducing the reliance on the grid or traditional heating and cooling systems. This in turn leads to a lot of energy savings and a more sustainable and cost-effective operation of buildings.

Then it also leads to enhancing comfort. The use of phase change material in glazing units helps to maintain a more stable and comfortable indoor temperature throughout the day. improving the overall comfort of occupants. Also, PCM-integrated windows offer environmental benefits. The reduction in energy consumption contributes to environmental sustainability by lowering greenhouse gas emissions associated with heating and cooling systems. In summary, PCM integrated glazing units leverage the latent heat properties of phase change materials to store and release thermal energy, effectively regulating indoor temperatures and enhancing the energy efficiency of buildings.

The most common way that PCMs are added to windows is by packing them into space between glass panes. The uncomplicated production process and ease of maintenance make this technique very popular. PCMs can be arranged in a comparatively large space within the window cavity, increasing the amount of thermal energy that can be stored and released. The manufacturing technique of inserting PCMs into window cavities is rather straightforward. So PCMs have also been used in triple glazing or quadruple glazing windows.

But these are not used much in practice because of their cost, and especially in the Indian context, we have still not found their use to be that rampant. So what is this triple-glazed light-insulating PCM? glazing system with micro-encapsulated PCM. So, an insulation glazing system consisting of four panes is positioned one behind the other. So, there are four panes, one, two, three, and four, giving us three cavities, one, two, and three cavities. So, these four panes are positioned one behind the other with external integrated light-directing prismatic plastic panels and internal integrated transparent plastic containers filled with salt hydrate.

So this one on the outside has a light-directing prismatic plastic panel, which we saw in the previous few slides, which I said behaves like a Fresnel lens, and this internal integrated transparent plastic container has the PCM integrated in it. This system provides passive climatization of the facade and can be used in almost the same way as the conventional insulation glazing system. So, it also has a higher replacement cost of defective panes and PCM containers, which is relatively heavy with consequences for installation cost and high manufacturing and installation cost compared to conventional insulation glazing. So, how does it effectively look? So, a PCM in a solid state will look like this. So a solid-state PCM because of exposure to heat will look like this, and a PCM in a liquid state becomes translucent to transparent.

And it can become vice versa. It keeps changing from completely opaque to translucent to transparent. A study has found that, with reference to a reference pane using PCMs, various types of PCMs in windows during the summer have caused a lot of reduction in transmitted energy. Similarly, even in winter it has caused a lot of decrease in transmitted energy. So, the energy flux through this glazing system during summer and winter days has been found to be very beneficial. There are other theoretical variations of how PCM-based windows can be.

So you can have a glass pane, this glass pane here, and then we can also have an air cavity, which is this air cavity, which can be about 20 millimeters, and then you can have a solar cell here. So this next glazing has a solar film to it, and then again, you can have this glazing here, and you can have an air cavity again here, or a PCM, or it can only be an air cavity, and then you can have the glass pane. Then you can have a single air gap, which is this. You have an air gap here. If this is the basic, if this is the basic type, this can be an alternate one where the first you have a glazing, then you have an air gap.

Then you again have the solar cell or solar film attached to glass. And in this space, you can have your phase change material filled in. Then you can have another glazing and a vacuum-insulated panel.

And then the next glazing. So, you can have a glass pane. You can have a glass pane 1, 2, 3, 4. You can have an air gap. You can have a solar PV. You can have phase change materials and further a vacuum gap here.

This is a vacuum gap. Then, to make the you know, PCM integrated windows more efficient, you can have further variations, like you can have the glass here, you can have the air gap, the solar film, the solar film, after that another glass, then the phase change material, and just the glass pane. In the second variation, we saw there was a vacuum and another glass. So this we are eliminating now. There is no vacuum or glass. Then you can have another variation where this I will call alternate 2 and this as alternate 3.

Where you are completely removing this. That is one glass and one air gap you are removing. So you directly have a solar panel. or a film, and then you have the glass pane, then you have the phase change material, but here you have glass, a vacuum, and another glazing. So you can have multiple variations; these are all theoretical variations to assess, which is very effective. And the other theoretical variation is this: You have a system where instead of the air gap, you are permitting ventilation through this.

So you have a glass pane, and then you have the solar film, and to prevent overheating of this air gap, you are kind of allowing ventilation through this place. Then you have the film, solar film. Then again glazing, then a vacuum space, and then another glass. So you can have multiple designs or options of PCM-encapsulated windows.

So these windows are essentially building elements. So, this will allow visual contact between internal and external ambience. as well as impose a pleasant aesthetic building appearance. Because of the small thermal mass and physical properties, they are considered as a barrier for heat loss and heat gain depending upon what all layers you add, whether it is just two glasses with phase change material or you can have single glass pane in section or you can have a glass pane with a PCM. Or you can have a glass pane with a solar PV film and PCM.

Or you can have a solar film glass pane with PCM. Vacuum. And then another glass pane. So, this is a vacuum.

Then you can also have a glass pane. With an air gap. And then a solar film. Then another glass pane. Then a gap, which will have PCM.

Paste change material. Then vacuum. and then a glass. So, what you want to do and how you want to design these sections is entirely up to you based on the requirement of how much heat you want to hold back or how much heat you want to release. Now, we will look at a small case study of a senior citizen's apartment with a latent heat-storing glass facade in Switzerland. So, the Swiss architect Dietrich Schwarz has shown in several office buildings how, in addition to their latent heat-storing properties, the ability of PCMs to change their optical appearance can also be used in a facade. The initial solution involved pure paraffin in transparent hollow plastic blocks used as latent heat storage facade elements in the south side of the building for the zero-energy house. In contrast, for this project, salt hydrate was used as a PCM due to fire safety reasons.

So, in another project, the same architect had used paraffin, and that was a zero-energy house, and Ednard Kappel, again, was also in Switzerland. But to reduce the risk of fire in this building, he has used salthydrates. So, the architect has placed a brand new 148-square-meter latent heat-storing insulating glazing system on the south side. This is filled with salt hydrate. The 78 mm wide glass crystal system is built similar to a standard triple glazing unit.

We have already seen triple glazing units with four glass. But it has a PCM panel inside and a light-directing prism panel outside. The PCM panel is made of polycarbonate containers that are filled with salt hydrate mixtures and retain heat at 26 degrees to 28 degrees Celsius. So during the winter, the lower sun angle allows the solar radiation to pass almost unimpeded into the facade construction, where it hits the PCM panel. This is converted into thermal radiation and stored by the melting of the salt hydrate, which is a PCM. If the room temperature falls below 26 centigrade, perhaps at night or on cloudy days, the salt hydrate crystallizes and releases its stored energy into the room. If the facade looks opaque, as seen from outside through the prismatic panels or from the inside, then the salthydrate is uncharged.

If it appears translucent as seen from outside through the prismatic panels or transparent from the inside with no printed pattern, the salt hydrate is assumed to be charged or is fully charged. So in summer, the solar radiation is reflected back outside by the prismatic panels. During the winter, the lower sun angle allows the solar radiation to pass almost unimpeded into the facade construction. The charge state of this latent heat-storing glass facade can be observed directly from its optical appearance, which is determined by the different phases of salt hydrate.

If the facade looks opaque, then the salt hydrate is uncharged. If it appears translucent or transparent, the salt hydrate is being charged or fully charged. In this case what happens is the daylight concept Compared to massive walls, the rooms receive much more daylight through the glazing elements. It also uses the climatization concept, where small-sized air conditioning and passive cooling elements are used. The installation encompasses PCM integrated glazing elements, which are mounted at 5 to 10 centimeters behind the curtain wall. And the architect has full freedom to design the outer facade because this PCM integrated window is, you know, it is towards the inside, and on the outside there is a curtain wall.

Then the ventilation system consists of grills in the floor that release air that streams along both sides of the glazing element. So this is a passive cooling element for curtain wall construction. So it contains a translucent TCM layer on both sides, which is protected by toughened safety glass. This system extends from floor to ceiling and is mounted a few inches behind the actual facade.

During the day, the PCM absorbs both solar radiation and internal heat load. So, it absorbs solar radiation as well as the heat that is generated from inside because of human activities, human beings, as well as apparatus like computers and things like that. Leveraging this thermal capacity, the conventional HVAC system can be significantly reduced in size, or sometimes it can be eliminated completely. Since it is mounted on the interior side, the architect says that he has full freedom to design whatever he wants on the outside of the glass facade. So what happens, or how did it finally look? So as you can see in this graph, this is the outside temperature.

The outside temperature is about 34 degrees centigrade. Now. When you. When the room temperature. Without PCM.

Just with the glazing. The maximum room temperature is 32 degrees centigrade. And with PCM. The indoor temperature remains at. 25 degrees centigrade. So you can imagine how much the load on the air conditioner can get reduced when we use PCM integrated windows. So, this is the PCM integrated Windows temperature graph from 6 am to 12 am.

Similarly, you can also see, the outside can get very cold. It can be about. So, this is about 10 degrees. So, this will be about 8.

Minus 8. So this will be about 10 degrees centigrade. 10 to 11 degrees centigrade. So the outside is about. 11 to 12 degrees centigrade. At that time. You can see that when you do not have a PCM, it reaches up to 14 degrees Celsius, and with a PCM, about 17 degrees Celsius.

Whereas this is your desired temperature. So the load on the air conditioner with phase change material is only this much. Without a phase change material, and with regular glazing, the load on the air conditioner is this much. And when you don't have any air conditioning system, then this is how much heat has to be thrown out. So what was found is in this building when it was practically seen when the outside temperature was 12 degrees.

I will just take some other color so that we can see clearly. So when the outside temperature fluctuates at 10 degrees and goes maximum up to 19 degrees centigrade. This is the outside temperature. The room temperature is 21 degrees.

And moves maximum up to 25 degrees Celsius. From 21 degrees to 25 degrees Celsius. And we also saw that this can be. This is very much in the desirable or comfort band range. So this is very much within the comfort range.

Because of which there is a dramatic reduction in the use of. air conditioning of the building. So, when no PCM is used, you can see the ventilation heating is required, and there is cooling also required during the afternoon period. But with PCM, the load on air conditioning is reduced dramatically. This clearly shows the benefit of using phase change materials in this building. I will just quickly, for the sake of your imagination, tell you that we can have other theoretical variations of phase change material-based windows that can act as a trombe wall as well as this can act as a PCM integrated window.

So PCM-integrated windows can be used as solar walls and trombe walls. The combination of a trombe wall and a solar photovoltaic panel is a viable combination to generate electricity and supply heat simultaneously. The thermal performance of the trombe wall depends primarily on its mass. since it stores sensible heat. More mass means more capacity to store solar energy and fewer temperature fluctuations.

But it may increase the building's dead load and cause structural problems. So phase-change materials can provide an appropriate solution for massive mass problems. So many variations of the trombe wall were introduced over the years to reduce its weight, improve its thermal performance, extend its range of application, and integrate it with other systems to generate electricity. Other systems means photovoltaic systems, PCMs, etc. These variations were investigated to extend its use to lightweight buildings. Irrespective of the volume of research reported in the literature, there are still gaps and technical and thermal problems, and future trends and studies of the trombe wall should be addressed by incorporating phase change materials.

So, here you have a system that can independently work like a PCM-encapsulated window, this one. But as a whole, this unit can function like a trombe wall. So this is, this A is a picture of a regular trombe wall where you have a massive wall that will aid in absorbing the heat radiated through the glass. And here you are using a phase change material-encapsulated window integrated with the trombe wall. So my role here is primarily to tell you that you need to be as creative as possible in order to integrate all these technologies, not just see these technologies in isolation, so that the outcome brings out a more energy-efficient building.

Suppose you have a PCM-encapsulated window with a trombe wall. How will it function? Now what happens is that during winters, the solar energy falls on the PCM-encapsulated glass, and this heats up this place gradually because the PCM is storing the heat and it releases it gradually, and you are able to use this to draw the cool air outside, make it warm, and throw it inside. During summers when you don't want the indoors to be heated, you need to just close these vents and open these two vents, and you would still have a good amount of visual connection to the outside because you no longer have a solid wall as you normally would have in a trombe wall. So how does a PCM integrated brick look? So PCM integrated walls are like, now this is a passive cooling element for curtain wall construction. So it consists of a translucent PCM layer. So what all options are available? We can use it more like an element with a curtain wall, and both sides can be protected by toughened safety glass.

So this system can extend from floor to ceiling, and it can be mounted a little behind the actual facade. Now this system using PCMs can also be part of the opaque walls. So here are various four sections. The first is a primary section where you are not using PCM. Section B uses PCM along the outside. C uses PCM on the outside and inside cavities, and D uses PCM on all three cavities of this brick, which would probably look like this.

So, you can also have construction bricks with microencapsulated PCMs. Though this topic is primarily on PCM integrated glazing, I thought I would open up because I am not going to take a separate class on this. So, I have. I am just trying to tell you that we can use this even in bricks. And then you can use it with, you know, finishes like plasters or mortars.

You can have paraffin enclosed in stainless steel boxes and so on. Then you can also have roofs, composition of roof with PCM. So you have the RCC, or reinforced cement concrete, after which you can have thermal insulation. Then you can have PCM. You can have a water barrier or a water insulation.

And then you can have concrete, and then you can have the regular weathering course. So these are all theoretical and not yet used, but you can think of how we can use them. Then you can also use it like you know in lightweight construction, where you have the micro-encapsulated PCM within the internal plaster of the wall. of a lightweight wall. So you can have it in a concrete floor roof slab where you can fill the holes with PCM.

You can also have a flat container installed under the roof like this. So there are various options. We have seen phase change materials incorporate glazing. How does it actually work? We have seen the theoretical considerations and how we can have various designs. We have seen its application also.

And we also saw various elements of architecture where you can use them. You can use it as glazing. You can use it in blocks. You can use it as part of the roofing material and flooring material along with plaster for a lightweight wall. So today we saw phase change materials integrated in windows and a little on how it can be integrated in the other building components also. With this, I will stop today's class. And we will continue our next class with another topic on an advanced passive system. Thank you.