Course Name: Building Materials as a Cornerstone to Sustainability

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Lecture 02

Thermochromic

Hello everyone, welcome back to another class on smart materials. Today let us look at the control of solar radiation transmitting through the building envelope with a special emphasis on thermochromic and thermotropic materials. So, what is the difference between photochromic and thermochromic glass? In terms of its working mechanism, photochromic glass darkens when exposed to sunlight or UV light, returning to its clear state when the light source diminishes. In terms of its energy efficiency, by automatically responding to sunlight intensity, photochromic glass can help control glare and reduce cooling loads in buildings. Let us look at what are thermochromic glass. Its working mechanism is that changes in temperature causes the glass to alter its colour or opacity, regulating heat and light transmission.

In terms of thermochromic glass energy efficiency, this helps in passive solar heating by allowing more sunlight in during colder periods and reducing solar gain in warm winter months. So, what is the control of solar radiation transmitting through building envelope? High performance glazing using advanced glazing materials with specific properties such as spectrally selective coatings can help in controlling the transmission of solar radiation while allowing visible light to pass through. So this is just for a perspective to tell you the endless possibilities of controlling heat and light as per varying user requirement. It can be done by using low E-coated triple glazing glass, by using vacuum glazing, aerogel filled glazing, in general highly insulated glazing.

It can also be done with electricity generated glazing, using PV, using concentrating PV. Then it can be done by optically switchable glazing which is thermochromic glazing. thermotropic which is currently what is of importance to us as we will see the other materials slowly one after the other. We have already seen SPD and PDLC. So, now SPDs.

SPD technology involves the use of suspended particles within a film that can align or disperse when an electric field is applied. This can change the transparency of the material allowing for dynamic control over solar radiation. Suspended particle devices or SPDs they change from clear to dark in a matter of seconds. SPD light controlled windows are made of two panels of glass or plastic conductive material. Now this is used to coat the panes of glass.

The suspended particle device comprises of millions of these black particles that are placed between the two panes of glass. The liquid suspension or film allows the particles to float freely between the glass. Whereas the control device could be automatic or manual. In an SPD window, millions of these SPDs are placed between two panels of glass or plastic which is coated with a transparent conductive material. When electricity comes into contact with the SPDs through the conductive coating, they line up in the straight line and allow light to flow through.

In the absence of electricity, they move back into a random pattern and block light. When the amount of voltage is decreased, the window darkens until it's completely dark after all electricity is taken away. The windows can be controlled manually with a rheostat or remote. or photocells and other sensing devices could be used to control the level of light automatically. Let us look at the low E coatings.

This is another way of control of solar radiation transmitting through a building envelope. Low emissivity or low E coatings are thin metallic layers applied to glass surfaces. They reflect a significant amount of solar radiation while allowing visible light to pass through. This helps in reducing heat gain and maintaining natural light. Low E coatings are typically made from a thin metallic layer such as tin oxide or silver.

These metallic particles are dispersed within layers of a transparent oxide creating a microscopically thin coating that alters the behavior of light passing through the glass. What are the advantages of low E coating glass? First is it is energy efficient. Low E coatings significantly reduce the transfer of heat through windows keeping indoor spaces cooler in hot climates and warmer in cold climates. This leads to reduced reliance on artificial cooling and heating systems resulting in lower energy consumption and utility bills. It also gives enhanced comfort.

The ability of low E coatings to minimize infrared radiation transfer helps maintain a more comfortable indoor environment This can also be a way to stop the annoying hot spots and cold drafts. This can also enable preservation of interiors. Ultraviolet radiation, a component of sunlight, can cause fading and damage to furniture, flooring, artwork, etc. Low e-coatings help to block a significant portion of UV rays, thus preserving the beauty and longevity of your cherished possessions. It can help reduce glare.

Certain low-E coatings can decrease glare by reducing the amount of visible light reflected from the glass, leading to a more pleasant and comfortable viewing experience indoors. In terms of environmental impact, with reduced energy consumption, low-e-coated windows contribute to a greener future, reducing the carbon footprint associated with heating and cooling systems. Let us now look at thermochromism. Thermochromism is change of colour and thermotropism is change of transparency with respect to temperature change. While thermochromism is rare, it has been observed in a variety of material classes and has several distinct origins.

Thermochromic material can be single or multiple component systems, organic or inorganic systems, monomers or polymers. Temperature related changes in optical appearance could be reversible or irreversible. abrupt or persistent and caused by modifications in the characteristics of light absorption, reflection or scattering. Now, what are thermochromic materials? These materials darken and reduce transmittance when heated above a critical temperature. Ranging from sophisticated thin films to everyday items like color-changing bowls, they can be used.

They are normally used in automotive windows to darken when internal temperature rises. They are commonly employed in transition metal oxides, with vanadium oxide showing excellent performance. Vanadium dioxide or vanadium oxide undergoes semiconductor-to-metal transition around the transition temperature. This is promising for thermal control in space structures exposed to intense solar radiation. Let us look at the working mechanism of thermochromic materials.

Thermochromic materials are substances that change colour in response to changes in temperature. The working mechanism typically involves a reversible molecular rearrangement that alters the absorption or reflection of light as the material undergoes a phase transition with temperature variations. A compound's thermochromic transition temperature can be chosen based on its intended use. The temperature at which the solar reflectance changes is called the transition temperature. With the transition temperature between 20 and 30 degrees Celsius, thermochromic materials are ideal for thermal roof performance in a variety of climates.

They are brighter in the summer at higher temperatures, which lowers cooling loads in the winter at lower temperatures. They are darker which increases energy absorption and lowers heating loads. So, here you can see an example of colour change occurring due to thermochromic materials. What are the energy-efficient properties of thermochromic materials? So, first is solar heat gain control. In warm conditions, thermochromic materials can darken, reducing solar heat gain and lowering the need for air conditioning.

When it comes to daylight optimization, thermochromic windows or films can dynamically adjust transparency based on temperature, optimizing natural daylighting and reducing the demand for artificial lighting. Insulation enhancement can happen by changing their properties in response to temperature. Thermochromic materials can contribute to improved insulation and thermal regulation in building components. Although it has several advantages, it also comes with its own limitations. First is the limited reversibility.

Some thermochromic materials may experience a decrease in performance over multiple cycles of temperature changes. Specific temperature range. The colour change of thermochromic materials is often tuned to a specific temperature range, limiting their effectiveness in extreme conditions. Durability The durability of thermochromic materials, especially in outdoor applications, can be affected by factors such as UV exposure and weather conditions. Some of the other examples of use in construction industry.

Smart windows. Thermochromic coatings on windows can dynamically adjust their tint based on temperature, controlling solar heat gain and optimizing daylighting. Temperature sensitive paints. Thermochromic paints applied to building surfaces can act as temperature indicators, helping identify areas with inefficient insulation or potential issues. Next are thermal comfort applications. Thermochromic materials integrated into textiles or surfaces can provide visual feedback on temperature changes contributing to occupant comfort.

Smart roofing materials Thermochromic coatings on roofing materials can contribute to temperature regulation reducing heat absorption during warm periods. Next is its energy efficient facades. Thermochromic materials in facade elements can adapt to temperature changes contributing to energy efficient building envelopes. What are the characteristics of thermochromic materials? First is temperature responsiveness. thermochromic materials exhibit a change in colour or transparency in response to temperature variations.

Second is its reversibility. The colour or transparency change is typically reversible, meaning the material returns to its original state when the temperature changes again. Third are various activation temperatures. different thermochromic materials have specific activation temperatures at which the color change occurs. This allows for customization based on application requirements.

Then mechanism of action. The color change often results from alterations in the molecular structure or arrangement of the material when exposed to different temperatures. Fifth is the dynamic and passive property. Thermochromic material can be dynamic, changing colour in real time with temperature fluctuations, or passive, maintaining a specific state until a threshold temperature is reached. Sixth is diversity of forms. Thermochromic materials come in various forms, including inks, paint, films, and particles, providing versatility in applications.

They are a broad color range, which means the color palette of thermochromic materials can cover a broad spectrum, allowing for the creation of diverse visual effects. What are the applications of thermochromic materials? First is, temperature indicators. They are used in temperature-sensitive labels, inks, or paints to indicate temperature changes in products or surfaces. The second is smart textiles. integrated into fabrics for applications like color changing clothing or textiles that provide visual temperature cues.

Third is food packaging. Applied to packaging materials to indicate temperature changes in food products ensuring proper storage conditions. Next is mood rings. Traditional application in mood rings where the color changes are associated with body temperature and purported mood shifts. Fifth is smart windows. So, these are utilized in smart windows or glazing systems.

to control light transmission and heat absorption based on external temperatures. Sixth is architectural coating. These are applied to surfaces such as walls or roofs to regulate building temperatures and enhance energy efficiency. Seventh is educational tools. These are used in educational materials, toys, or displays to demonstrate principles of temperature change in a visually engaging way, more as an experiential education tool.

What are the applications when it comes to control of solar radiation transmission through building envelope? Improved lighting performance in terms of energy-efficient lighting, visual comfort, and color management are expected by spectral and angular selective glazing in solar control windows utilizing nanoparticles. When nano rods of gold, silver and some other elements are aligned with the preferred orientation with respect to light, their optical extinction characteristics become dependent on the polarization and angle of incidence of the light. This effect could potentially be exploited by producing a color-change coating. Hydrogel-based smart windows have potential but are not commercialized due to high technological and economic manufacturing effort and problems to seal the double glazing. We will not go into the depths of hydrogels now, as it is a complex area of research and application.

What are the other ways of solar control through the building envelope? Smart glass technology. So, using electrochromic glass technology. photochromic glass. Say when it comes to electrochromic glass, this glass can change its tint dynamically in response to an electric voltage by adjusting the tint. It can control the amount of sunlight and heat entering the building, whereas photochromic glass darkens when exposed to sunlight and returns to its clear state when the light decreases.

It provides passive control over solar radiation. We can also have a look at the shading systems. So, there are many external shading devices, such as louvers, shades, sunshades, and vertical fins. etc. that can be installed to block or redirect sunlight before it reaches the building envelope.

These systems can be adjustable to allow for flexibility in controlling light as well as heat. So, what are the other control of solar radiation transmission through building envelope? Daylight harvesting, incorporating a daylight harvesting system with sensors, can control artificial lighting based on available natural light. This helps optimize energy usage by reducing artificial lighting when sufficient daylight is available. Second is-ventilation and passive strategies. Incorporating natural ventilation strategies and passive design principles can contribute to controlling indoor temperatures by using building orientation, natural airflow, and other architectural features to manage solar radiation.

Third is external reflective surfaces. Applying reflective coatings or materials to extend surfaces can help in reflecting a portion of the solar radiation away from the building. And then there are photochromic, thermochromic, and thermotropic effects that can be combined in one material system. For example, the polyalkyl oxide lithium chloride bromothymol blue hydrogel for the course of color and transmittance shows thermochromic properties. So, today in this class we have seen the various methods by which we can control solar radiation inside the building, and with this as the main topic we saw what are the other smart materials. that can be used for us to reach this aim, which is thermotropic and thermochromic materials, and we touched upon slightly on hydrogels.

Let us now look at a real-world example and prototyping using thermotropic material, or rather, here we will see thermochromic glass. So, first we will see the Clemson University, College of Business, South Carolina, USA. This is designed by LS3P. The dual-tall, five-story building provides students and faculty with a modern, technology-driven space for learning and collaboration. The five-story atrium soaring 90 feet serves as a bright, airy communal space and focal point with smart windows installed throughout.

These windows tint throughout the day in response to sunlight, ensuring the atrium remains cool and comfortable while maintaining views of the campus's historic old main clock tower and the blue ridge mountains in the distance. The second example we will see is Nashville International Airport. This is a major thoroughpoint and economic engine for the Middle Tennessee region. One phase of the project focused on BNA's Concourse D while including over 1,15,000 feet of space. The concourse has high ceilings and a large western exposure, which can lead to unwanted heat and glare from the windows.

The programmable glass auto-tints based on the amount of sunlight throughout the day. It helps reduce glare and heat and is a key component of the modern relaxed environment in the concourse. The use of this glass directly impacts sustainability too. The reduction in glare and heat improves the concourse's thermal efficiency, contributing to the project's LEED silver certification.

With this, we stop today's class. In today's class, we have seen various ways to control solar radiation ingress into buildings, with special emphasis on thermotropic and thermochromic materials as smart material applications. In our next class, we will continue the similar topic to learn about thermotropic materials. Until then, thank you.