Course Name: Building Materials as a Cornerstone to Sustainability

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Lecture 03

Facade systems - Smart Windows

Hello dear students. So we had commenced learning about smart materials in the building construction industry. We have seen generally first we saw the introduction of smart materials and then we had a glimpse about what are smart materials with some examples, with some applications, with what stimulus makes them react in what way and so on. Today we will see a system, facade system which integrates smart windows. The windows become smart by virtue of the materials that are used in them, which are smart materials. So today we will see about smart windows, what is happening in the world, and the world scenario.

In India, what is happening? and the waste management. So, we all know that the construction and building sector contributes humongously nearly one-third of global energy consumption and approximately 15% of carbon dioxide emissions. The significance of energy-efficient buildings is paramount in striving for carbon neutrality, with green-certified structures also yielding higher financial premiums. HVAC, as we call heating, ventilation, and air conditioning.

This constitutes the most substantial portion of building energy consumption, underscoring the need to minimize cooling and heating loads. Windows with inferior heat transfer properties as compared to walls contribute about 60% of heat loss in residential structures, particularly in glazed areas. Following the energy crisis in the 1970s, extensive research was conducted on energy efficient glass. While low emissivity, which is low e-glass, emerged as a mature technology. It suffered from poor adjustability and limited application scenarios.

In the 1980s, the concept of smart windows was introduced. And this concept was introduced by Swenson and Granquist. Smart windows represent an innovative approach to energy-efficient windows combining dimming materials with glass and other substrates to dynamically adjust solar radiation. These windows respond to various physical stimuli, allowing for changes in optical properties such as transmittance, reflectance, and absorption rate to regulate the indoor environment. As the prevalence of building curtain walls increases, the energy-saving potential of windows becomes more crucial.

Windows serving as transparent envelope components play a multifaceted role in thermal insulation, lighting, and ventilation. Optimizing window performance is imperative to enhance energy efficiency and ensure the quality of the indoor thermal environment, considering their significant impact on light and thermal comfort for occupants. Fast investigations into smart windows encompassed diverse technologies, including thermochromic, electrochromic, gasochromic, mechanochromic, photochromic, and humidity chromic windows. This evolution reflects a continuous pursuit of advanced window technologies that offer enhanced adaptability and efficiency for diverse environmental conditions. Now there are different types of smart windows.

Thermochromic. Thermochromic windows. So, these energy-efficient windows are a type of smart window that can regulate indoor solar irradiation by tinting the windows. That is, by dynamically and reversibly tuning the transmittance and the reflectance Or tuning the transmittance or reflectance of ultraviolet visible and near-infrared solar radiation. Then we have the electrochromic window.

The electrochromic window. Electrochromic windows are energy-efficient glazing solutions. They are relatively simple to build and operate. Chromogenic materials allow reversibly controlling the optical properties. which is refractive index and extinction coefficient of windows upon application of an electric potential.

So, when the power is off and the power is switched on, the way the materials align themselves changes. Then we have the gasochromic smart window. These windows produce a similar effect to electrochromic windows, but in order to colour the window, diluted hydrogen below the combustion limit of 3% is introduced into the cavity in an insulated glass unit. Exposure to oxygen returns the window to its original transparent state. maintain a particular state the gap is simply isolated from further changes in gas content.

Then we have the mechanochromic window. So what does it do? Mechanical strain driven by mechanical force Electricity, humidity, etc. reconfigures the surface topography or changes the interface structure, changing the optical transmittance by modulating the scattering or diffraction of light. The photochromic window film. This offers tints from anywhere between 15 to 25%.

As the film darkens by virtue of light falling on it, the higher amount of light and sun rejection it provides. This means you can block heat and light when you need it most while retaining as much natural light as possible. This type of film changes from clear to tinted when exposed to the sun's ultraviolet rays through a chemical process within the glass. And then there is the humidity chromic windows. Humidity chromic windows are activated by changes in ambient humidity resulting in the variation of optical properties.

Let us now look at the categories of smart windows. Intelligent glass is categorized into two main types based on its mode of operation. Passive control, which is self-regulating, and active control, which is adjustable to the user's specific needs. What are passive dynamical systems? Passive dynamic systems operate without the need for an electrical stimulus. They autonomously respond to natural stimuli like light, for example, photochromic glass, or heat, for example, thermochromic and thermotrophic glazing.

In contrast to active systems, they are simpler to install and more dependable as they do not rely on user-controlled requests. What are active dynamical systems? The active dynamic system, either directly controlled or linked to a building management system, responds to external and internal climatic conditions, enabling the adjustment of visible and infrared radiation penetration without screening systems. This reduces energy consumption for air conditioning and lighting by over 20%. Advanced systems integrate with photovoltaic systems, ensuring complete electrical self-sufficiency. They offer remote control via smartphones, independent adjustment of window panels through light zoning and the potential to function as imaging displays with touchscreen technology, which is an advanced tech window.

Let us look at passive dynamic systems with photochromic glass windows. Photochromic glass autonomously adjusts its transparency based on incidental light intensity. This capability is attributed to organic or inorganic compounds acting as optical sensitizers in the glass paste. These compounds like metal halides, chloride and silver bromide or plastics react to ultraviolet light or absorb solar energy leading to a reversible and intense coloration process when exposed to sunlight. The response time to environmental changes is typically a few minutes, with the transition from tinted to clear taking twice as long.

However, variations in response time may pose challenges during sudden brightness changes or cast shadows, resulting in uneven light distribution. After the colour transition, photochromic glasses become absorbent, potentially causing slab overheating and thermal shock rupture under intense solar radiation. Presently, these glasses find primary use in optical and automotive industries due to challenges such as high cost, technological complexity, lack of direct user control, difficulty in uniform distribution of photochromic substances in the slab, and gradual loss of reversibility over time. Despite these hurdles, technological advancements in recent years have mitigated some issues, enabling larger slab sizes and improving long-term stability. What are thermochromic glass windows? Thermochromic glazing, exemplified by technologies, autonomously adjusts its optical characteristics based on the external surface temperature undergoing a chemical reaction or phase transition between transparent and opaque states.

This transition occurs within a temperature range typically spanning 10 degrees Celsius for maximum transparency and 65 degrees Celsius for minimum transparency. Any temperature in between will lead to that specific transparency or opacity of the window. Thermochromic properties are exhibited in various organic and inorganic compounds, including metal oxide films like vanadium dioxide. which shifts from a semiconductor to a metallic state, resulting in highly sensitive reflective behavior in the infrared zone. The most promising technological solution for implementing thermochromic glazing involves incorporating thermochromic materials directly into a 1.

2 mm polyvinyl butyral plastic film, which is a PVB plastic film that was introduced in the market in the year 2010. As PVB is commonly used in laminated safety or acoustic glass production, this solution integrates seamlessly into manufacturing processes, providing a cost-effective, high-quality product. Paired with clear glass, the typical light transmission and solar heat gain ranges in transparent and opaque states are BLT as 60 to 13 percent or 55 to 5 percent and SHGC as 0.

37 to 0.17 or 0. 36 to 0.12 with switching times in the order of a few minutes. Despite the inability of user control, thermochromic glazing offers advantages such as operational durability exceeding 20 years and cost effectiveness compared to an active control dynamic system with a rate of returns less than 4 years. Let us now see the electrochromic glazing, which is exemplified by technologies. which utilizes specific materials to alter the transmission, reflection and absorption of solar radiation through an adjustable electrical stimulus. This change is induced by the addition or extraction of mobile ions from the electronic layer, altering the materials colour when an electric field is activated.

The core of an electrochromic device consists of an ion conductor sandwiched between two layers: an electrochromic film or electrode and an accumulation layer, which is the counter electrode. Light transmission varies from 60% in the transparent state to 1% when opaque and solar heat gain coefficient ranges between 0.46 and 0.06. The energy required for coloration switching is minimal.

and electrochromic materials possesses a bistable configuration requiring even less energy to maintain the tinted state. Although the device exhibits uniform properties over its surface, the darkening process is gradual, taking seconds to minutes depending on panel size and glass temperature. The gradual change of light transmission provides occupants with a natural adaptation to varying light levels without discomfort or distraction. Improvements in electrochromic glass technology may involve increasing the number of control states, enhancing switching speed, raising opacity for improved privacy and further reducing energy consumption. Let us look at the suspended particle devices SPD and PDLC.

So, suspended particle device technology utilized by companies knows these involve a double sheet of glass containing a layer of thin laminate with suspended particles. These particles align when an electric field is applied, allowing light transmission and rendering the glass clear. When the power is off, the particles randomly orient, blocking light and causing the glass to appear dark or opaque. Suspended particle device glass provides instantaneous control over light and heat with the ability to block up to 99.

4% of visible radiation when dark. It offers protection from harmful UV rays in both powered and unpowered states. Typical ranges for light transmission and solar heat gain in transparent and opaque states are are VLT of 65 to 0.5 percent and SHGC of 0.57 to 0.06 with switching times of a few seconds.

The device requires around 100 volts AC for operation and has power requirements of 5 watts per meter square for switching and 0.55 watts per meter square for maintaining constant transmission. Future developments may lead to reduced operating voltages and expanded color options. SPD glass finds applications in automotive, marine, and aviation sectors with slab sizes up to 1500 by 3000 millimeters.

Let us see the liquid crystal devices. LCDs such as those from certain companies involve a double sheet of glass with a polymer dispersed liquid crystal device, PDLC, comprising a polymer matrix film with dispersed liquid crystal spheres. In the absence of an electric field, the liquid crystals are disordered, causing the glass to appear white and translucent. When an electric field is applied, the crystals align, ensuring transparency. The degree of transparency can be controlled by the voltage applied. Liquid crystal glazing is mainly used for partitions requiring privacy and is non-bistable.

requiring a constantly applied electric field and consuming about 5 to 10 watts per meter square. PDLC devices are commonly used for interior or exterior partitions offering applications such as shop windows, meeting rooms, bathrooms, etc. Now from a particular research paper, we can see that in an office building that is built with a large external glass surface and lacks natural ventilation, which impacts the air quality and thermal comfort of employees in their workspaces and consequently their health, productivity, and adaptability get affected. Based on this, the selected case study is a proposed office building with approximately 85% single-glazed surface area. The figure here shows the building model created by the simulation program tools.

Accordingly, this building envelope becomes a thermal burden on the occupants, which leads to extensive use of mechanical technologies to achieve thermal comfort. The case study is located in the Cairo airport area and has a semi-square plan as shown in this figure. When it comes to monitoring its thermal performance, Previous simulations prove the effectiveness of retrofitting the existing glass with smart glass in enhancing the thermal performance of the building. Each type has different amounts. Output shows that electrochromic glazing achieves the best thermal performance as the operative temperature is reduced by about 3 to 7 degrees centigrade.

Outputs show that the electrochromic glazing achieves the best thermal performance as the operative temperature is reduced by about 3 to 7 degrees centigrade. Thermochromic glazing provides the lowest thermal performance as the operative temperature is reduced by about 2 to 5 degrees centigrade. According to simulation outputs, the order of these solutions is due to the better thermal performance of electrochromic glazing and double-glazed units with low E coating thermochromic glazing. Different types of smart glass retrofitting exhibit varying impacts, with electrochromic glazing standing out for achieving the most significant thermal improvement, reducing operative temperatures by approximately 3 to 7 degrees centigrade. In contrast, thermochromic glazing shows the lowest thermal performance with a reduction of about 2 to 5 degrees centigrade.

Energy analysis indicates that incorporating split air conditioning units alongside the proposed smart glass solutions leads to cooling energy consumption reductions ranging from 21 to 36.4 percent, depending on the smart glass solution type simulated. Thermochromic glazing demonstrates the most substantial energy savings at approximately 36.4 percent. Despite electrochromic glazing's superior thermal performance, it still achieves a noteworthy 21 percent reduction in energy consumption, recognizing its reliance on electricity.

From the analytical comparison of the outputs of simulating the building with the proposed smart solution and split air conditioning units, smart envelopes can reduce the energy consumption for cooling by about 21 to 36.4 percent depending on the solution type. From this figure 36, it summarizes the total fuel breakdown outputs for the case study in its base case comparison to each simulated smart solution when the air conditioning unit set point temperature is set at 20 or 23 degrees Celsius. Energy consumption is reduced by about 12.

5 percent to 14.5 percent when the set point temperature of the split unit is changed from 20 to 23 degrees centigrade. From all these studies, it can be concluded that smart windows, which are nothing but windows that use smart building materials along with some smart technologies, definitely help in sustainable architecture. So, we stop today's class with this and continue with another smart material in our next class. Thank you.