**Problem Overview**
We are undergraduate students in the Penn State College of Engineering who are currently researching high-performance glass windows. Last year in Pennsylvania, the commercial building sector produced 10.9 million metric tons of \( \text{CO}_2 \) from fossil fuels energy consumption (EIA, 2020). In addition, windows are responsible for 5-10% of a building’s energy use (IEA, 2020) since they let in solar energy from outside and lose heat through the glazing, requiring greater heating, ventilating, and cooling (HVAC) usage to offset these temperature gains and losses. Building owners can implement high-performance windows in buildings to increase HVAC efficiency and decrease \( \text{CO}_2 \) emissions.

**Engineering Design Process**
In order to address this problem we had to identify the stakeholders in our project and their respective needs. Our stakeholders include people who maintain buildings with windows in addition to people who install them. Landlords require low cost per unit and high efficiency while installers require windows that are easy to put in. Figure 1 shows a table of our stakeholders and their needs while Figure 2 shows these requirements compared subjectively using a Likert scale to find relative importance.

Knowing the importance of each stakeholder need allowed us to find existing concepts to develop further. Three of these concepts involve dynamic glass that tints to respond to changing daylight conditions. Electrochromic glass reacts to an applied electric charge, increasing its opacity. Thermochromic glass and photochromic glass are similar, however one responds to increased heat in the glass and the other responds to increased light exposure. The last concept is a low-emissivity coating that reflects infrared and ultraviolet light, decreasing radiated heat.

Using our requirement weights, we determined that thermochromic glass (Figure 3) best combines cost, ease of installation, and energy efficiency. It blocked the most radiated heat for its price point while being equally as easy to install as a regular window. Figure 4 shows the table used to compare these concepts.
Figure 4: Concepts compared using stakeholder needs and our weighting values from Figure 1

In addition, the small cost of a low-emissivity coating made it possible to integrate these two solutions into one concept to enter the prototyping stage.

Our prototype, as depicted in Figure 5, differs from conventional two-pane windows due to the addition of a low-e coating and a thermochromic layer between a glass laminate. In operation, heat tints the thermochromic layer which blocks the majority of radiated energy from the sun while passing visible light. The low-e coating increases efficiency by further reflecting heat out and retaining radiated heat inside the building. This prototype will require both lab and field testing to meet solar radiation protection as well as water and air tightness standards before production.

Figure 5: Expanded cross section of our prototype

Outcomes and Recommendations
This design has the potential to reduce heat loss and gain in buildings, increasing HVAC efficiency and decreasing CO\textsubscript{2} emissions on a large scale. With windows making up 5-10\% of a building’s energy use, implementation of our solution in both Pennsylvania and the rest of the world can considerably reduce global energy use and emissions. Building owners who install our windows can expect reductions in heating and cooling costs, offsetting the increased cost per unit of this solution compared to regular glass. In addition, reduced solar energy entering through windows will make the interior space more comfortable for occupants. The only barrier to large-scale implementation we can see is increased upfront cost. For this reason we chose to focus on the commercial sector. They have the luxury of greater capital compared to residential buildings to cover installation. In addition, a larger relative window area for commercial buildings will increase return on investment. With global emissions on the rise, people who choose to install high-performance thermochromic windows can save money over time and do their part to make our world a better and more sustainable place.

https://www.commercialwindows.org/thermochromic.php