An-Najah National University

Faculty of Engineering and Information Technology

Graduation Project 1

Presented in partial fulfillment of the requirements for

Bachelor degree in

(Telecommunications Engineering)

Smart Glass Window

Prepared by:

Amr Ishtyeh (1192656)
Rafah Nairat (11925994)
Yousef Shmlawi (11925103)

Supervised by:
Dr. Haneen Al-Autt

بِسْمِ اللهِ الرَّحْمنِ الرَّحِيم

قال تعالى: {وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ}

[التوبة: 105]

{يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ}

[المجادلة: 11]

{وَلَا تَحْسَبَنَّ الَّذِينَ قُتِلُوا فِي سَبِيلِ اللَّهِ أَمْوَاتًا بَلْ أَحْيَاءٌ عِنْدَ رَبِّهِمْ يُرْزَقُون

[آل عمران: 169]

صدق الله العظيم

Dedication

For our martyrs in our beloved Gaza…

For Our Palestine …

For Our University …

For Our Teachers …

For Our Family …

We Present This Report …

Acknowledgment

- First of all, we thank God for enabling us to complete our research.

-Our ability to accomplish this research is due to the good effort provided by our great university, An-Najah National University.

-We are very grateful to our parents who gave us everything in their lives. We also thank them for pushing us towards success.

-We would like to thank Dr. Haneen Al-Autt for her advice and continued support.

-To all our doctors at NNU. We would also like to thank our friends for their help.

Finally, thank you to everyone who contributes in any way to support us.

Table of contents

Contents

List of figures

List of tables

Abstract

The "Smart Glass Window" project addresses the pivotal issue of energy efficiency in homes by tackling the significant heat flow management. A primary source of heat gain and loss is solar radiation through windows. Conventional materials like window glazing are limited in their ability to adapt to changing environmental variables.

Our project combines a dynamic sensor system with an electrochromic window that can alter its light transmission properties in response to an applied voltage. This system collects ambient temperature and light data to make informed decisions for precise window adjustments, reducing solar heat gain and supporting the home's air conditioning system.

In simple terms, we've created a "smart window" that automatically adjusts its tint like transition lenses for eyeglasses. The goal is to minimize energy consumption for heating and cooling while maintaining comfortable indoor conditions. For example, on sunny days, the window darkens to reduce heat, lessening the workload on the air conditioning system. Conversely, on colder days, it allows more sunlight in to save on heating costs, improving energy efficiency. This project seamlessly integrates modern technology into everyday life by enhancing the windows of homes, hospitals, and offices.

Chapter one: Introduction

1.1 OVERVIEW

The "Smart Glass Window" project introduces an innovative window system that adapts its tint, much like transition lenses, to optimize energy efficiency and user comfort. This technology offers significant potential for various settings, including homes, hospitals, and offices. By dynamically adjusting to external conditions, the smart glass window minimizes energy wastage, conserving energy and enhancing the quality of indoor environments. This project marks a noteworthy advancement in the field of energy-efficient window solutions.

1.2 Statement of the problem

The "Smart Glass Window" project addresses a critical challenge in the realm of energy efficiency and user comfort, particularly in residential, commercial, and medical settings. The problem at hand revolves around the management of heat flow through windows, a major contributor to energy consumption in these environments.

Solar radiation passing through windows is a primary source of heat gain and loss within buildings. Traditional solutions, such as window glazing, offer limited adaptability to changing environmental variables, rendering them inefficient and less responsive to the dynamic needs of occupants.

The key problem is the inability of current window systems to effectively manage heat flow, leading to energy wastage and less than optimal indoor comfort. This issue becomes especially pronounced during periods of intense sunlight, where excessive heat gain forces air conditioning systems to work harder, resulting in higher energy costs.

In summary, the problem statement underscores the pressing need for innovative window systems like the "Smart Glass Window" to effectively regulate heat and light transmission, significantly enhancing energy efficiency and user comfort while mitigating energy waste and associated costs.

1.3 AIMS AND OBJECTIVES

1. Innovation: To innovate and introduce a revolutionary smart window system that transforms the way we manage energy efficiency and user comfort in different environments.

2. Environmental Impact: To contribute to a greener and more sustainable future by reducing energy consumption and waste in homes, offices, and healthcare facilities.

3. Technological Advancement: To advance and integrate cutting-edge technology into everyday life, enhancing the user experience.
4. Energy Efficiency: Develop a dynamic window system that efficiently manages heat flow,

significantly reducing energy consumption and environmental impact.

5. User Comfort: Optimize indoor conditions by dynamically adjusting lighting and temperature control to enhance the comfort and well-being of occupants.

6. Adaptability: Create a versatile and responsive window solution capable of adapting to changing environmental variables, such as sunlight and temperature.

7. Cost Reduction: Minimize energy costs associated with heating and cooling, ultimately providing economic benefits to homeowners, businesses, and healthcare facilities.

8. Versatility: Offer a versatile and applicable solution for a wide range of settings, including residential, commercial, and medical environments.

1.4 Scope of the work

1. Project Initiation: Define project objectives, goals, and success criteria. Assemble a skilled project team.

2. Research: Investigating existing smart glass technologies

3. Materials Selection: Identifying suitable smart glass materials considering properties, durability, cost, and sustainability.

4. Sensor Integration: Determining required sensors (light, temperature, occupancy) and integrating them into smart glass window.

5. Control System Design: Developing a control system that adjusts window transparency based on sensor data and user preferences.

6. Testing and Validation: Rigorously testing the smart glass system under various conditions, gathering data on energy usage, and reliability.

1.5 Importance of the work

In this section we show some of the key points to explain the importance of Smart Glass

1. Energy Efficiency and Sustainability: Reducing energy consumption through efficient control of natural lighting and heat gain. Lowering energy bills and contributing to environmental sustainability by reducing greenhouse gas emissions.

2. Improved Indoor Comfort and Well-being: Providing occupants with control over natural light and privacy. Enhancing visual comfort, increasing productivity, and creating a more pleasant indoor environment.

3. Flexibility in Building Design: Offering architects and designers the opportunity to create dynamic, adaptable spaces. Seamlessly integrating indoor and outdoor environments, especially valuable in commercial buildings.

4. Privacy and Security: Allowing instant switching from transparent to opaque for a high level of privacy. Enhancing security by preventing unwanted visual access to building interiors in various settings.

5. Reduction of Maintenance and Cleaning Costs: Eliminating the need for traditional window coverings like curtains and blinds. Reducing maintenance costs and efforts, with some smart glass technologies being self-cleaning.

Chapter Two: Theoretical Background and Previous Work

2.1 Literature Review

This chapter delves into the existing body of knowledge surrounding dynamic window technologies, focusing on electrochromic windows, heat flow management in buildings, and sensor technologies. The review provides a theoretical foundation for the Smart Glass Window project.

2.2 Problem Identification

This section identifies the critical issues related to energy inefficiency in buildings due to heat gain and loss, primarily caused by solar radiation through conventional windows. The need for a smart window solution is emphasized, setting the stage for the project's objectives and research.

2.3 Previous Work

Smart glass has great applications and is widely used in many industries.

1. Architecture Integration: Smart glass has been widely used in architecture to increase energy efficiency and occupant comfort. Buildings can dynamically adapt to sunlight entering the space, reducing unnecessary artificial lighting and HVAC systems.

2. Automotive Industry: Smart glass has found utility in automotive sunrooms and windows. It enhances the driving experience by dynamically adjusting the amount of light and heat entering the cabin, allowing for better control over interior comfort.

3. Application of electronic devices: Some electronic devices such as smart glasses and displays use smart glasses. This allows you to create interactive and editable pages.

4. Privacy solutions: Smart glass is used in places where privacy is important. For example, conference rooms or medical facilities can switch between explicit and implicit environments based on user preferences or environmental factors.

5. Sage Glass: Developed by Sage Electrochromic, Sage Glass is a pioneer in electrochromic smart glass technology. It has been widely used in commercial buildings to improve

daylighting, reduce glare and increase energy efficiency. Sageglass can be controlled manually or automatically depending on sensors and building management systems.

6. Mercedes-Benz Magic Sky Control: Mercedes-Benz has incorporated smart glass technology into its panoramic sunroof. The MAGIC SKY CONTROL feature allows drivers to adjust the exposure of sunroofs, creating an outdoor or shaded experience to reduce glare.

Chapter Three: Methodology

3.1 The used Technology

3.1.1 What Is Smart Glass?

Smart glass, also known as switchable glass, employs advanced technologies to regulate light and provide insulation. The light transmission properties of the glass can be manipulated by light, heat, or electricity. Typically, this involves a transition from translucent to transparent, selectively blocking specific wavelengths of light. This technology finds applications in homes, businesses, and institutions like hospitals, offering enhanced control over light, heat, and privacy. Smart glass contributes to cleaner environments and delivers superior and customizable control compared to manual solutions such as blinds, curtains, shades, and doors.

3.1.2 What are Smart Windows?

Smart Windows refer to windows that utilize specialized glazing materials to manage the amount of light passing through the glass panes. The glazing material, often termed "switchable," exhibits changes in optical behavior when an electrical voltage is applied. This dynamic characteristic allows Smart Windows to adapt their transparency based on external conditions, providing a sophisticated solution for controlling light levels.

3.1.3 Types of Smart Glass

Smart glass technologies can be classified into two main categories: passive and active. In passive technologies, the functional layer responds automatically to environmental changes, with options such as photochromic, which reacts to light, or thermochromic, which responds to heat. These are termed passive because they adjust without the need for an electrical charge, but users cannot manually control changes in tint or opacity.

Conversely, active smart glass technologies respond to electric current, facilitated by a conductive layer. This allows users to control or adjust the glass's functions. Electrified smart glass provides additional functionalities, including emitting light, serving as a display screen, enabling variable settings or patterns across a glass panel, or even harnessing solar power. Active technologies are further categorized into electrochromic, polymer-dispersed liquid crystal (PDLC), and suspended particle device (SPD).

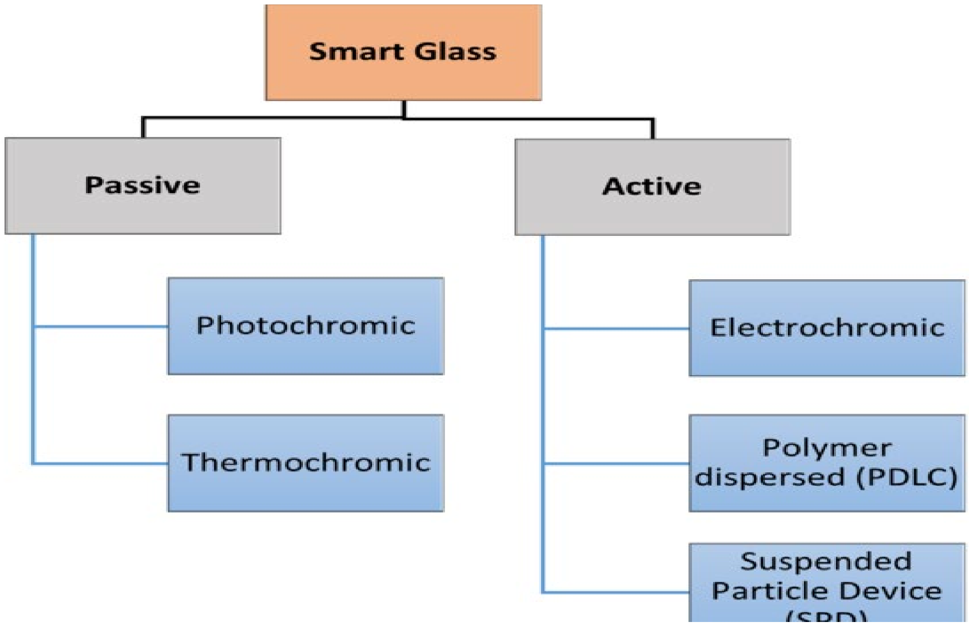

Figure 1-3: The smart glass category including both passive and active technologies.

Photochromic Glass: Photochromic smart glass, akin to the technology used in Transitions eyewear, incorporates a film with photo-sensitive molecules laminated to the inner or outer surface of the glass. These molecules remain invisible until exposed to UV rays, triggering a reaction that alters their structure and changes the transmittance of the glass from clear to darker. The degree of tint is contingent upon the amount of UV exposure, allowing the glass to adapt to varying light conditions. Once UV rays diminish, the glass returns to its transparent state.

Thermochromic Glass: Thermochromic smart glass commonly utilizes an interlayer of polyvinyl butyral (PVB) sandwiched between glass layers. When exposed to sunlight or radiant heat, the glass progressively darkens as the temperature increases. Different materials, such as ceramic coatings, are layered on the inner surface of the glass, effectively trapping heat within the thermochromic layer. This not only keeps the interior of a building or vehicle cool but also provides the added benefit of noise reduction.

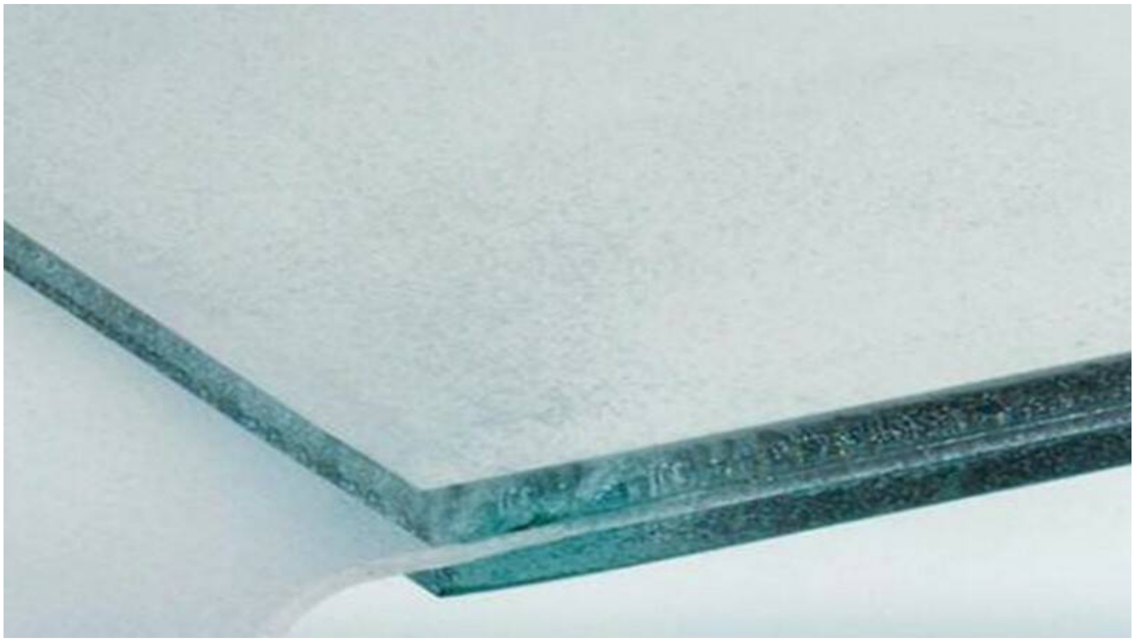

Figure 2-3: Thermochromic glass in production with a PVB layer sandwiched between two glass layers.

Electrochromic Glass: Electrochromic smart glass employs materials that undergo a change in color when an electrical current is applied. In this technology, an electrochromic layer is positioned between glass panels and conducting layers. The application of an electrical charge activates ions within an electrolyte layer, prompting the electrochromic layer to transition from a dark or opaque state to a transparent one. This dynamic process allows for controlled adjustments in the tint or transparency of the glass, offering a versatile solution for managing light and privacy in various environments.

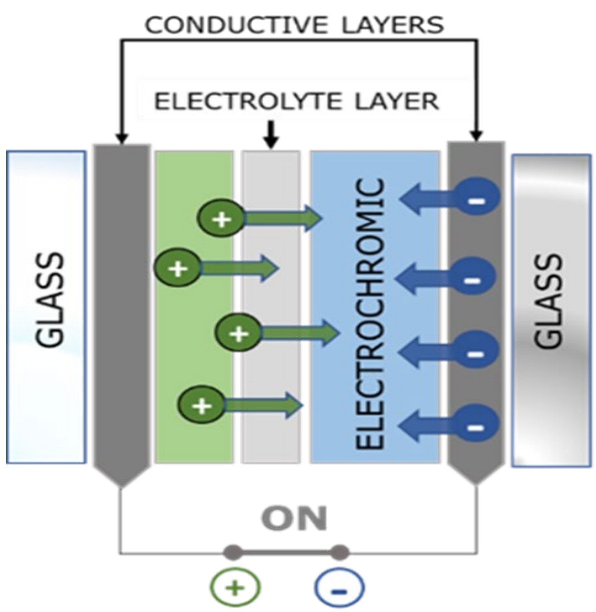

Figure 3-3: Schematic of electrochromic smart glass structure.

3.1.4 How Does Electrochromic Glass Work?

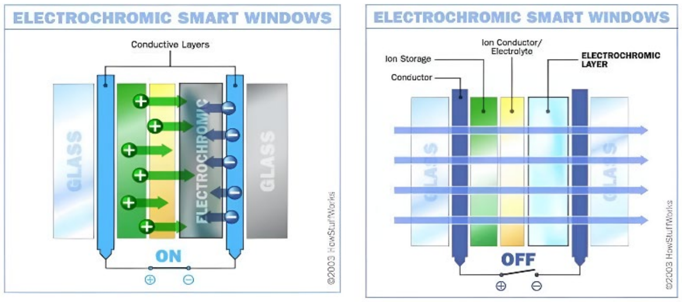

Figure 4-3: How does it work electrochromic glass.

Electrochromic glass operates on the fundamental principle of lithium-ion migration between two electrodes separated by a separator. In its clear state, lithium ions are situated in the innermost electrode. Upon applying a small voltage to the electrodes, these ions travel through the separator to the outermost electrode. In this position, they disperse incoming light, causing the glass to become opaque.

The lithium ions autonomously maintain this opaque state until the voltage is reversed. When the voltage is adjusted, the ions move back to their original position, allowing the glass to seamlessly transition back to its transparent state. This process enables dynamic control over the transparency of the glass, offering a versatile solution for on-demand adjustments to light and privacy.

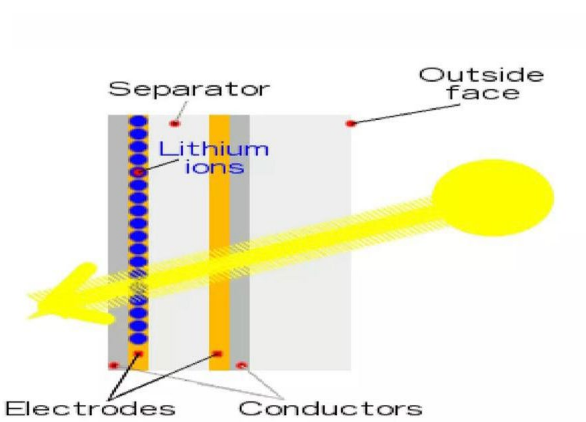

Figure 5-3: How an electrochromic window works.

The glass remains clear without the need for constant electric power; additional electrical input is only required to revert it to its original state. While the transition from clear to opaque used to be a gradual process, recent advancements have significantly reduced the switching time to a mere 2 seconds. Additionally, electrochromic glass is equipped with noise-blocking properties, enhancing its functionality beyond visual adaptability to contribute to a more comfortable and quieter environment.

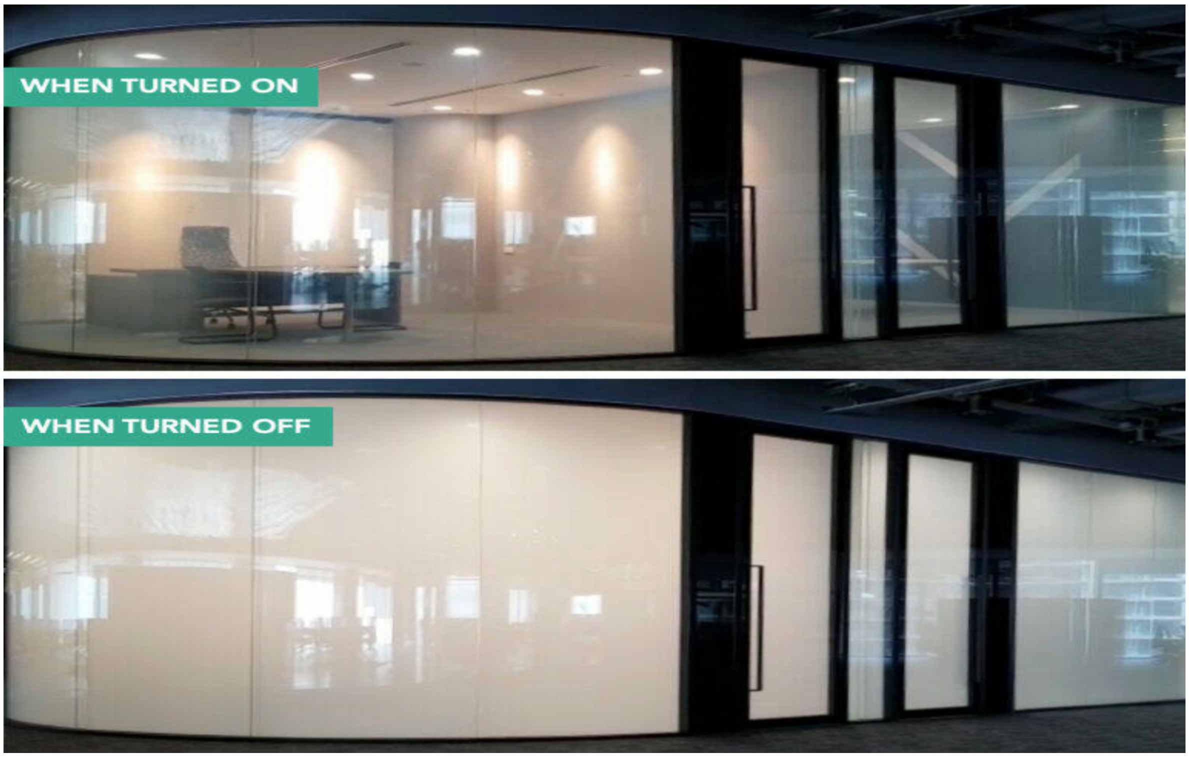

Figure 6-3: Electrochromic switchable partition in an office.

3.1.5 Suspended Particle Devices (SPD)

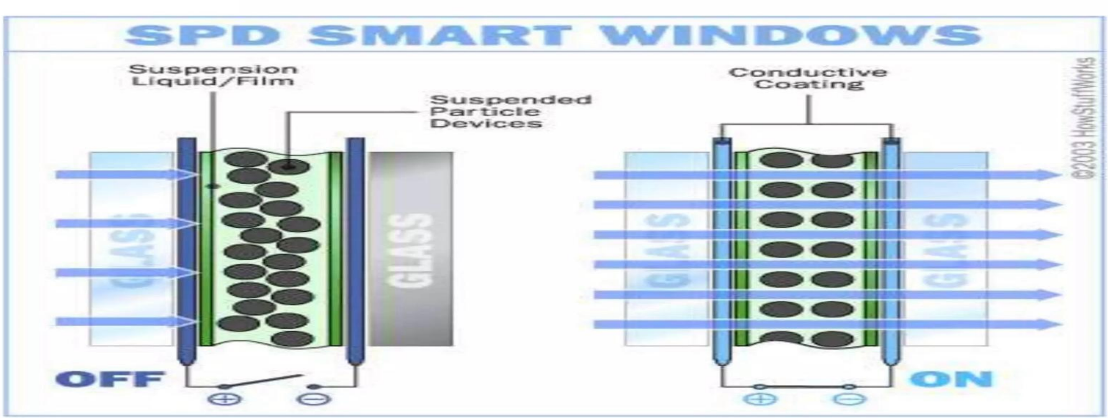

Figure 7-3: SPD-Enhanced Advanced Window Technology.

An SPD window comprises several layers, including two panels of glass or plastic.

These panels are coated with a conductive material. Between the two panes of glass, millions of black particles are suspended within a liquid film, allowing them to move freely. The control device, whether automatic or manual, manages the operation of the SPD Smart Glass.

In the case of suspended particle devices (SPD), a thin film laminate of rod-like particles suspended in a fluid is positioned between two layers of glass or plastic. When the power supply is activated, the rod-shaped suspended particles align, allowing light to pass through and rendering the SPD Smart Glass panel clear. Conversely, when the power supply is turned off, the rod-shaped suspended particles become randomly oriented, obstructing light and causing the glass panel to appear dark (opaque).

The SPD Smart Glass, when in its opaque state, can block up to 99.4% of light. Notably, SPD Smart Glass provides protection from damaging UV rays, whether in the clear or opaque state.

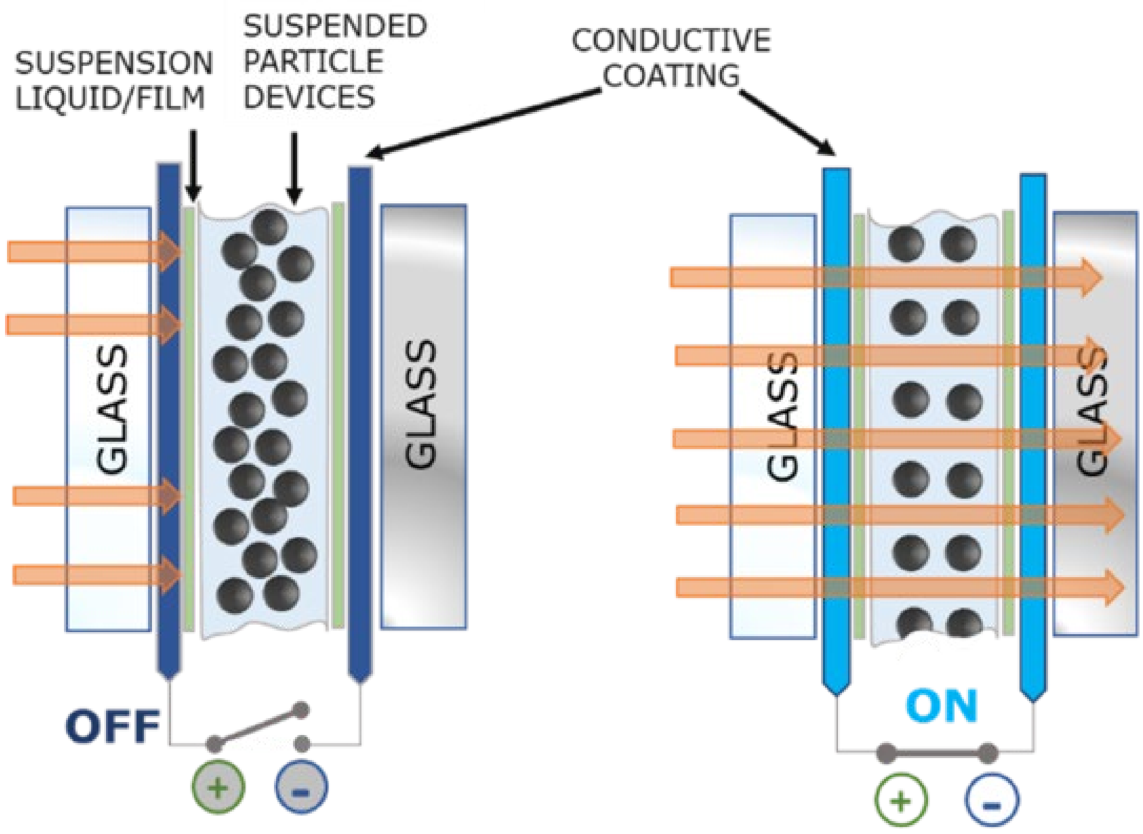

Figure 8-3: Schematic of suspended particle device (SPD) smart glass, in the off and on states.

3.1.6 Polymer Dispersed Liquid Crystal Devices (PDLC):

Polymer Dispersed Liquid Crystal (PDLC) involves micro droplets of liquid crystals encapsulated within a polymer matrix.

In PDLC devices, a liquid mixture comprising both polymer and liquid crystals is positioned between two layers of glass, which include a thin layer of transparent, conductive material. In the absence of applied voltage, the liquid crystal molecules maintain a randomized configuration, refracting incoming light and causing the material to appear opaque.

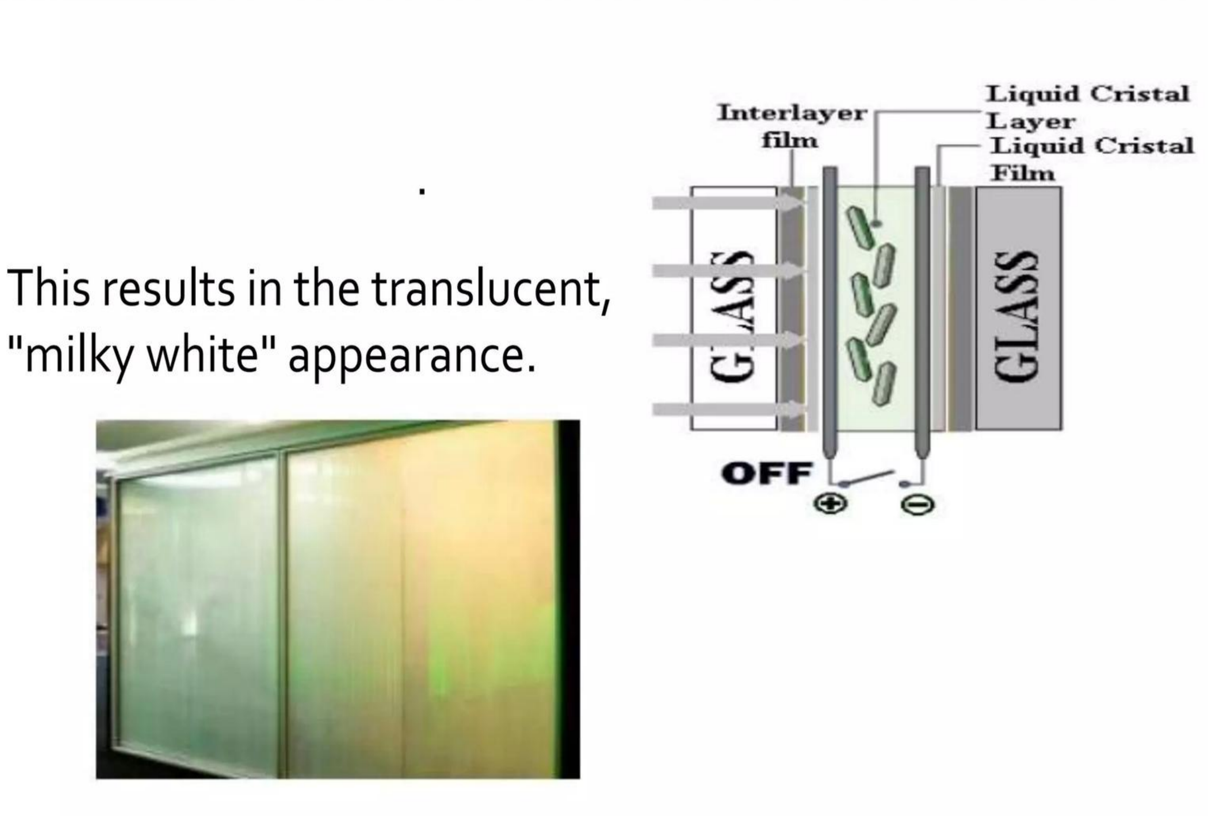

Figure 9-3: PDLC Technology Overview.

When a voltage is applied to the electrodes, an electric field forms between the two transparent electrodes on the glass. The electric field prompts the liquid crystal molecules to align along its direction, effectively allowing light to pass through the now transparent surface.

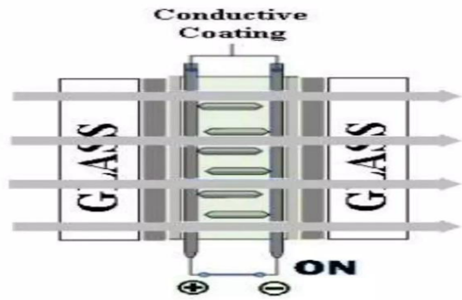

Figure 10-3: Voltage-Activated Transparency in PDLC.

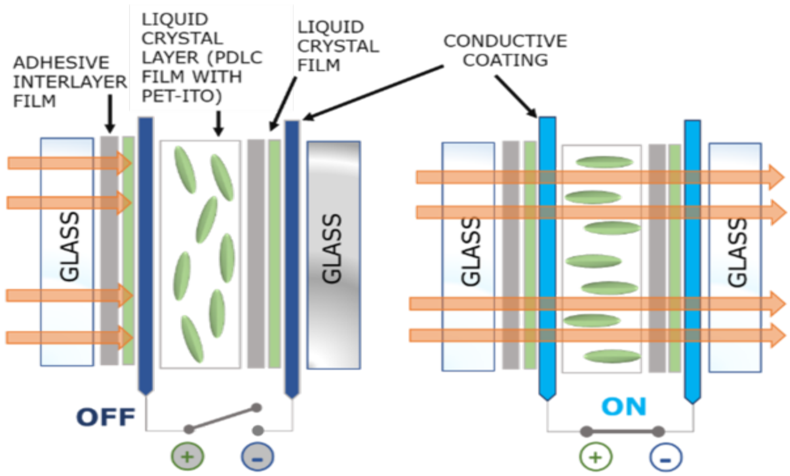

Figure 11-3: Schematic of Polymer Dispersed Liquid Crystal (PDLC) smart glass, in the off and on states.

The degree of transparency in PDLC can be controlled by adjusting the applied voltage. This technology provides a dynamic solution where transparency levels can be altered on demand, offering versatility in managing light and privacy in various architectural applications.

3.1.7 Comparison Between The Three Different Kinds Of Switchable Glass (EC,SPD,PDLC)

	EC	SPD	PDLC
When is transparent?	Switched OFF	Switched ON	
Continuous states between opaque and transparent?	Yes	Yes	No
Requires power to maintain the state?	No	Yes	Yes
Switching speed	Varies depending upon panel size; May take many minutes for large format panels	Several seconds regardless of panel size	Milliseconds regardless of panel size
Light transmission in dark/opaque	SHADING: YES PRIVACY: Typically, some view remains	SHADING: YES PRIVACY: YES	SHADING:
Energy used to operate	Very low	Very low	Very low

Table 1-3: Comparison between the three different kinds of switchable glass (EC, SPD, PDLC).

3.1.8 The Advantages of Smart Glass

1. Light Control: Smart glass provides precise control over the amount of light entering a space. This feature enables customization, allowing users to adjust transparency levels according to their preferences or environmental needs.

2. Energy Efficiency: By regulating the amount of sunlight entering a building, smart glass contributes to energy savings. This controlled approach to natural light reduces the need for artificial lighting, leading to decreased energy consumption and lower utility costs.

3. Ambient Temperature Control: Smart glass can help manage ambient temperature by selectively blocking or allowing sunlight. This feature contributes to improved thermal insulation, helping to maintain comfortable indoor temperatures and reduce reliance on heating or cooling systems.

4. UV Ray Protection: Smart glass is designed to protect occupants from harmful UV rays. By dynamically adjusting transparency, it can limit the penetration of ultraviolet radiation, safeguarding skin and preventing damage to interior furnishings.

5. Low Working Voltage: The technology behind smart glass typically operates at low working voltages, ensuring energy efficiency and safety in its use. This feature makes smart glass a viable and sustainable solution for various applications.

6. Long Life Span: Smart glass undergoes rigorous testing, often surpassing 100,000 cycles in its operational life. This longevity ensures durability and reliability, making smart glass a cost-effective and resilient choice for architectural and design purposes.

In summary, the benefits of smart glass extend beyond more visual adaptability. They encompass energy efficiency, temperature regulation, UV protection, and a prolonged operational lifespan, making smart glass a valuable and sustainable solution for modern spaces.

3.1.9 Applications of Smart Glass

1. Conference Rooms: Smart glass finds valuable application in conference rooms, offering an innovative solution for privacy and adaptability. It allows occupants to transform the transparency of glass partitions, balancing the need for openness during collaborative discussions and privacy during sensitive meetings.

2. Intensive-Care Areas: In healthcare settings, such as intensive-care areas, smart glass can be utilized to enhance patient care. It provides a means to control privacy levels, allowing healthcare professionals to create a more comfortable and adaptable environment for patients.

3. Commercial Buildings, Hotels, and Offices: Smart glass is widely employed in commercial spaces, hotels, and office buildings. It contributes to energy efficiency by controlling the amount of sunlight entering the interiors, reducing the reliance on artificial lighting and HVAC systems. Additionally, it enhances the overall aesthetics of these spaces, providing a modern and dynamic architectural element.

4. Residential Spaces: Smart glass is increasingly being integrated into residential spaces, offering homeowners the ability to control natural light, privacy, and views. It can be applied in windows, doors, or even as room dividers, providing a stylish and functional solution for modern living.

5. Retail Environments: In retail settings, smart glass can be employed for storefronts or display windows. Its ability to transition between transparent and opaque states adds a captivating element to the presentation of products, while also contributing to energy efficiency.

6. Hospitality Industry: Hotels and resorts often utilize smart glass in various areas, from room dividers to bathroom enclosures. This not only enhances the aesthetic appeal but also offers guests the convenience of adjusting privacy levels according to their preferences.

7. Educational Institutions: Smart glass can be applied in educational settings, such as classrooms or lecture halls. It provides flexibility in creating adaptable spaces, optimizing natural light, and enhancing the overall learning environment.

8. Transportation: In the transportation sector, smart glass is used in applications such as automotive sunroofs and windows. It allows passengers to control the level of sunlight entering the vehicle, improving comfort during travel.

Smart glass, with its adaptability and energy efficiency, finds versatile applications in modern architecture. It is transforming spaces in various industries, from offices and hospitals to homes. This technology, capable of converting different glass types into switchable glass, provides flexible solutions. Smart film applications also offer an easy upgrade for existing glass installations, enabling seamless control of privacy through various methods such as wall switches, remotes, smartphones, or voice commands. The dynamic nature of smart glass enhances both privacy and functionality in diverse settings.

Figure 12-3: Smart glass in hospital - versatile privacy solution.

3.2 Comparison between the Smart Glass and Traditional Window Tinting

Smart glass and traditional window tinting serve the common purpose of controlling light and heat entering a space, but they diverge significantly in terms of technology, control, and aesthetics.

3.2.1 Smart Glass

Smart glass, an emerging technology, revolutionizes window treatment with its advanced features.

Users can effortlessly control the intensity of window shading with a simple button press, providing unprecedented control and flexibility.

Integrated directly into window panes, smart glass eliminates the need for labor-intensive manual application of tinting film on individual windows.

The result is a clean, uniform appearance, free from common issues like bubbles or visual defects often associated with traditional film tinting.

While smart glass may entail a higher initial cost, it stands as a compelling alternative for those seeking cutting-edge sensing controls, superior energy efficiency, and a contemporary aesthetic.

3.2.2 Traditional Window Tinting:

Traditional window tinting, a longstanding practice, involves applying tinted film to windows to reduce glare and heat.

Control over tint level is fixed post-application, offering limited flexibility in managing the amount of light entering a space.

The manual application of tinting film on individual windows incurs additional labor costs, and it may lead to visual imperfections.

Although traditionally more cost-effective upfront, traditional window tinting may lack the advanced features and sleek appearance offered by smart glass.

Figure 13-3: Smart Glass vs Traditional Window Tinting.

In conclusion, smart glass emerges as a modern and sophisticated solution, surpassing traditional window tinting in terms of flexibility, integration, and aesthetics. While it may involve a higher initial investment, the benefits in terms of control, efficiency, and visual appeal position smart glass as a compelling choice for those seeking a forward-thinking window treatment option.

3.3Block Diagram

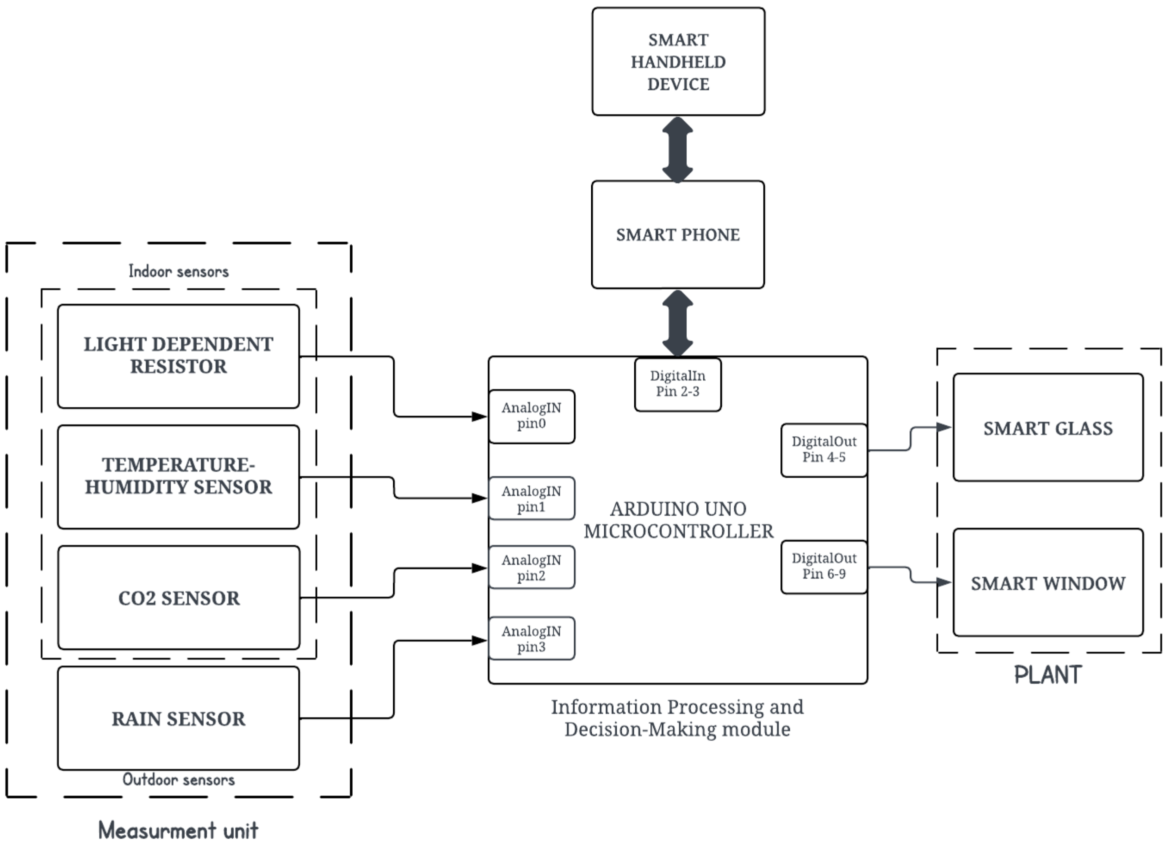

Figure 14-3: Smart Window Block Diagram.

3.3.1 Block Description

The block diagram illustrates a sophisticated system powered by an Arduino UNO microcontroller, integrating a diverse range of sensors and devices tailored for both indoor and outdoor applications. Indoor sensors, such as a Light Dependent Resistor (LDR), Temperature Humidity Sensor, and CO2 Sensor, play a pivotal role in environmental monitoring. Notably, Smart Glass and a Smart Window have been introduced as innovative elements, ensuring adaptability to changing environmental conditions. These smart components, controlled by the Arduino, enable seamless automation based on sensor inputs. The system extends its capabilities outdoors with a Rain Sensor detecting rainfall. An Information Processing and Decision-Making Module processes this data, dynamically influencing the state of the smart glass and smart window. Additionally, a handheld device allows convenient remote control, making this versatile system ideal for applications in smart home automation and environmental monitoring, offering enhanced control and efficiency.

3.4 Circuits

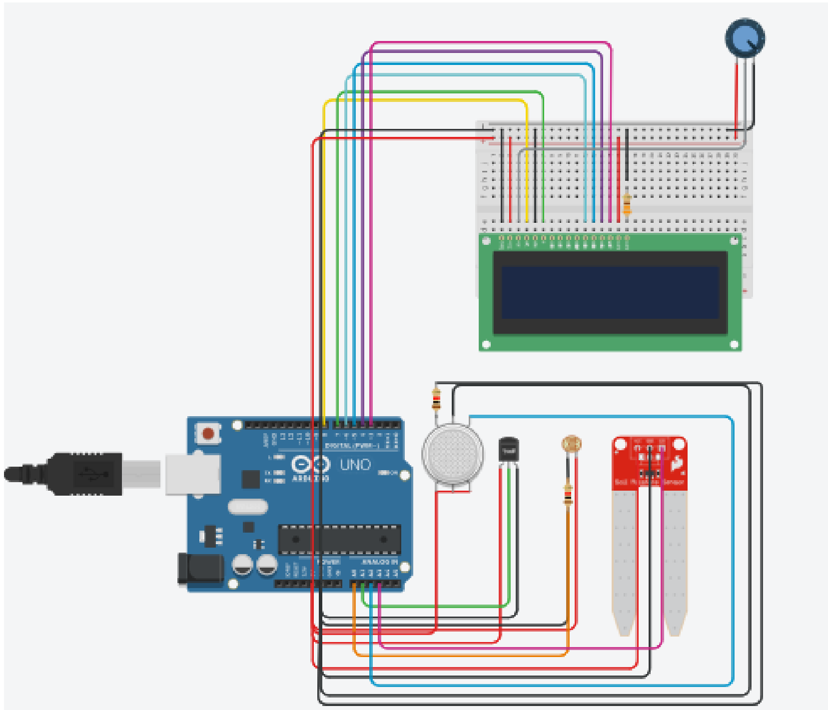

Figure 15-3: Smart Window Circuits

Our Smart Glass circuits include an Arduino Uno connected to four different sensors and an LCD display. The sensors are connected to the Arduino's analog input pins.

3.4.1 Circuit description

1. Photoresistor (Light Sensor): Connected to analog pin A0, it changes resistance based on the amount of light it detects.
2. Gas Sensor: Connected to analog pin A1, it detects the concentration of gas in the air.
3. Temperature Sensor: Connected to analog pin A2, it senses the temperature of the environment.
4. Rain sensor (note: soil moisture sensor is used instead of rain sensor due to the lack of rain sensors in Tinkercad): Connected to analog pin A3, This compact rainfall sensor module measures rainfall on a real-time basis.

The LCD is connected to digital pins on the Arduino for data communication.

3.4.2 Working Principle of sensors

- The Photoresistor decreases its resistance as light intensity increases, resulting in a higher voltage reading at pin A0.
- The gas sensor outputs a voltage that correlates to the concentration of a certain gas (likely to be calibrated for a specific gas like methane or carbon monoxide).
- The temperature sensor outputs a voltage that changes with temperature; the specific relationship depends on the type of sensor used.
- The rain sensor measures the presence and amount of rainfall, and outputs a corresponding voltage. The sensing pad with series of exposed copper traces, together acts as a variable

resistor (just like a potentiometer) whose resistance varies according to the amount of water on its surface.

The Arduino reads the voltage across these sensors via its analog-to-digital converter (ADC) and converts it to a digital value between 0 and 1023 due to the fact that Arduino cannot process analog signals. The LCD then displays these readings after converting them into digital form.

Results: When the circuit is powered on and the Arduino runs the appropriate code, each sensor's reading is displayed on the LCD. The display likely updates at regular intervals, showing real-time sensor data. The layout on the LCD is arranged to show the readings in an organized manner, with labels for each sensor's data for easy reading.

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(8, 7, 6, 5, 4, 3);// Initialize the library with the numbers of the interface pins
void setup() {
  lcd.begin(16, 2);   // Set up the LCD's number of columns and rows:
  // Set up the analog pins
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  pinMode(A2, INPUT);
  pinMode(A3, INPUT);
}
void loop() {
  // Read the sensor's values
  int photoresistorValue = analogRead(A0);
  int gasSensorValue = analogRead(A1);
  int temperatureSensorValue = analogRead(A2);
  int soilMoistureValue = analogRead(A3);

  lcd.clear();   // Clear the LCD

  lcd.setCursor(0, 0);   // Setting the cursor to the beginning of the first line
```

```
  lcd.print("L:");  // Printing the photoresistor value to the LCD
  lcd.print(photoresistorValue);

  lcd.setCursor(0, 1); // Setting the cursor to the beginning of the second line
  lcd.print("G:");  // Printing the gas sensor value to the LCD
  lcd.print(gasSensorValue);

  lcd.setCursor(8, 0); // Set the cursor to column 9 of the first line
  lcd.print("T:"); //Print the Temperature sensor value to the LCD
  lcd.print(temperatureSensorValue);

  lcd.setCursor(8, 1);   // Setting the cursor to column 9 of the second line
  lcd.print("S:");   // Printing the soil moisture value to the LCD
  lcd.print(soilMoistureValue);
  delay(1000);   // Waiting a bit time before refreshing the display
}
```

3.5 Flow Chart and Project Description

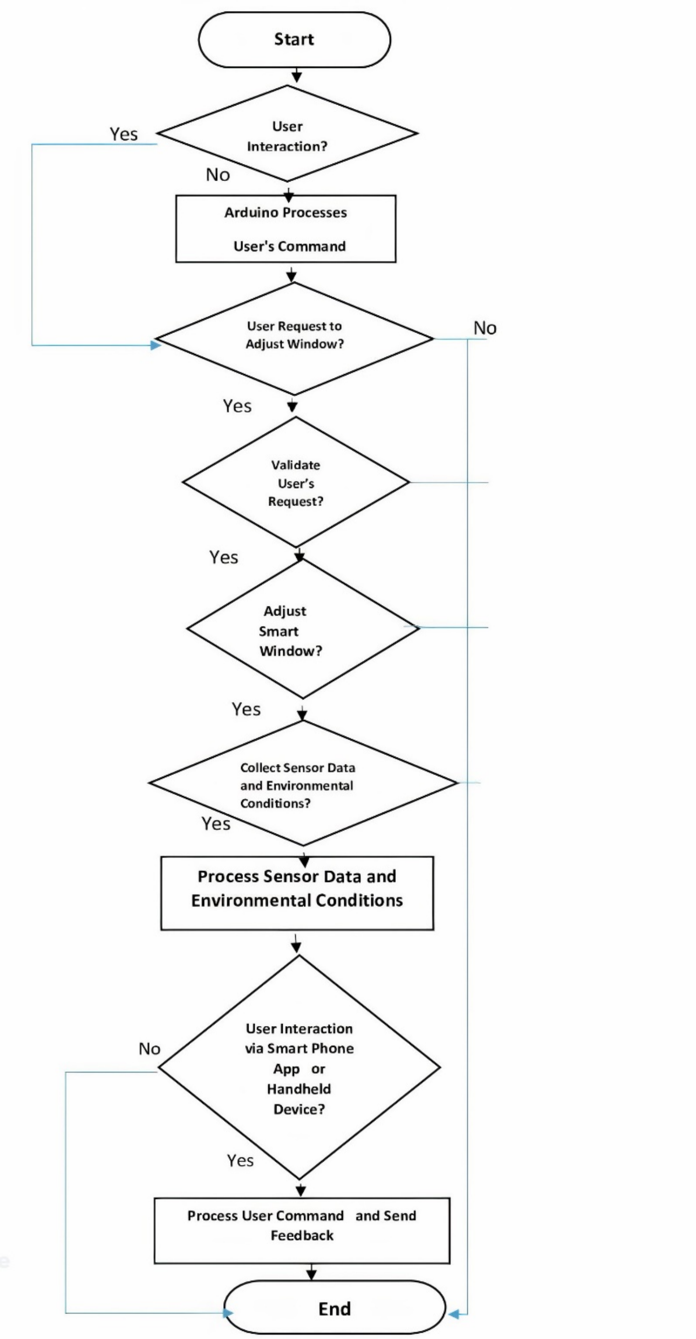

Figure 16-3: Project Flow Chart.

In this innovative project, a smart window system utilizing smart glass technology has been developed to enhance user experience and environmental adaptability. The system is designed to interact with users through a smartphone application or handheld device, providing seamless control over the window's state. Initiated by user interaction, the Arduino UNO central control unit processes the user's command, validating and adjusting the window based on sensor data and environmental conditions. Key components include temperature and humidity sensors, carbon dioxide (CO2) sensors, and rain sensors. These sensors collect precise data to enable the system to autonomously adapt the window's state. The integration of user interaction and environmental sensing ensures a smart and efficient window control experience, allowing users to manage lighting and temperature comfortably and securely. The project aims to achieve a sophisticated level of window intelligence, combining user-friendly interaction with sensor-driven environmental responsiveness. This integration facilitates a smart and adaptable window system, contributing to user comfort and safety.

3.6 Project Components

3.6.1 Arduino UNO Microcontroller

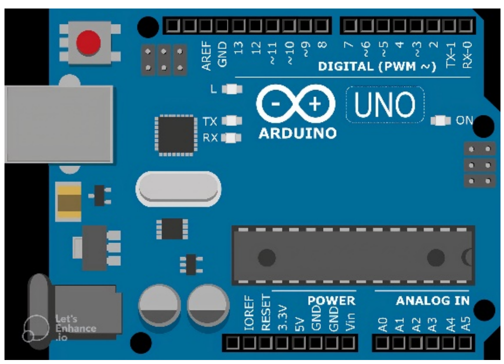

Figure 17-3: Arduino UNO Microcontroller.

- Description: The Arduino UNO acts as the central processing unit, managing communication and coordination between all connected devices. It interprets data from sensors and executes commands to control various components within the smart system.

- Key Information: The Arduino UNO has multiple digital and analog pins for connecting to sensors and devices, enabling both input and output operations. It serves as the brain of the smart system.

3.6.2 Handheld Device

- Description: This component, represented as a handheld device, serves as a remote control or mobile application. Users can interact with the smart system wirelessly, providing a convenient interface for monitoring and controlling connected devices.

- Key Information: The handheld device enhances user accessibility, offering a means to adjust settings or check the system status from a distance.

Figure 18-3: Handheld Device.

3.6.3 Mobile App (Smartphone)

- Description: A dedicated mobile application transforms your smartphone into a control interface for the smart system. It enables users to interact with the Arduino UNO, providing a user-friendly means to monitor and adjust connected devices and sensors remotely.

Figure 19-3: Mobile App (Smartphone).

3.6.4 Light Dependent Resistor (LDR)

- Description: Measures ambient light levels indoors.
- Key Information: Analog sensor providing data on the brightness of the environment.

Figure 20-3: Light Dependent Resistor (LDR).

3.6.5 Temperature-Humidity Sensor

- Description: Monitors indoor temperature and humidity conditions.
- Key Information: Provides valuable data for climate control and comfort monitoring.

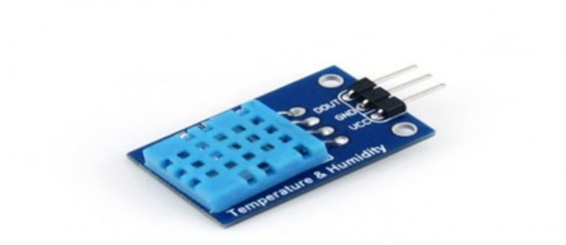

Figure 21-3: Temperature Humidity Sensor.

3.6.6 CO2 Sensor

- Description: Detects carbon dioxide levels in the indoor environment.
- Key Information: Essential for assessing air quality and ventilation requirements.

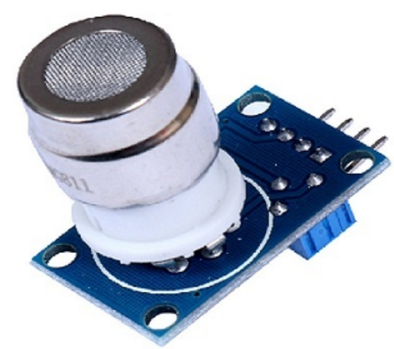

Figure 22-3: CO2 Sensor.

3.6.7 Rain Sensor

- Description: Identifies the presence of rain indoors.
- Key Information: Useful for automated responses, such as closing windows or adjusting the environment.

Figure 23-3: Rain sensor.

3.6.8 Smart Glass

- Description: Innovative glass technology adapting transparency based on environmental cues.
- Key Information: Enhances energy efficiency and user comfort by dynamically adjusting transparency.

Figure 24-3: Smart Glass.

3.6.9 Smart Window

- Description: Window technology responding intelligently to environmental changes and user preferences.
- Key Information: Provides optimal indoor conditions by dynamically adjusting transparency and ventilation.

Figure 25-3: Smart Window.

3.6.10 Breadboard

- Description: Solderless device for prototyping electronic circuits, facilitating easy experimentation.
- Key Information: Enables quick and flexible assembly of electronic components for testing and development.

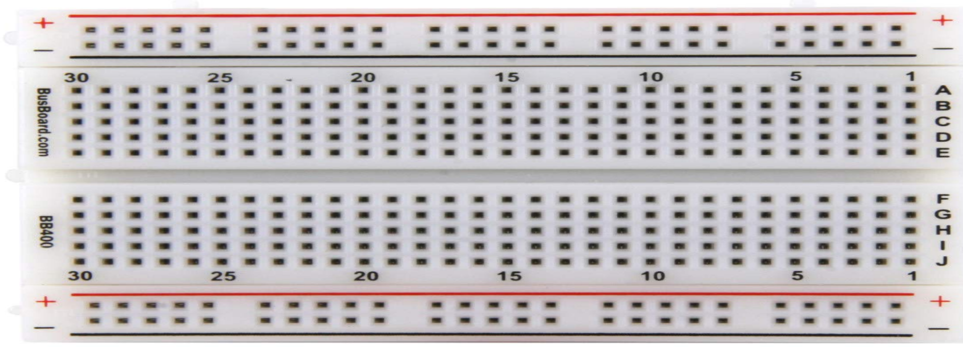

Figure 26-3: Breadboard.

3.6.11 Power Supply

- Description: Device providing electrical energy to the system for proper functionality.
- Key Information: Ensures a stable and reliable power source to drive the electronic components of the system.

Figure 27-3: Power Supply.

3.7 Design Specification, Standards & Constrains

Introduction:
The standard Arduino Uno stands out as a microcontroller board based on the ATmega328P chip. Renowned for its user-friendly design and versatility, it has become a go-to choose for both beginners entering the realms of electronics and coding. Affordable and well-supported, this board offers a solid foundation with an array of features suitable for a wide range of projects.
Key Features and Capabilities:
With a microcontroller at its core, the Arduino Uno boasts 14 digital I/O pins, including 6 PWM outputs, and 6 analog input pins. Operating at a clock speed of 16 MHz, it supports various functionalities such as actuator control for LEDs and motors, sensor readings from temperature and light sensors, and seamless communication through UART and I2C. Its USB connection serves a dual purpose, facilitating both programming and power supply.
Power and Flexibility:
The Arduino Uno's power options include USB connectivity or an external supply within the 7-12V range. While not the most robust Arduino board available, it provides ample capability for most beginner projects. Its design simplicity and ease of use make it an ideal starting point for those new to the world of microcontrollers.
Considerations and Enhancements:
It's important to note that the Arduino Uno lacks built-in Wi-Fi or Bluetooth connectivity. If wireless capabilities are desired, additional modules must be integrated. The board's popularity has led to various versions, with the R3 being the most prevalent, offering standardized compatibility across a multitude of shields and libraries.

Conclusion:
In conclusion, the Arduino Uno, with its accessible design, affordability, and compatibility, serves as an excellent introductory microcontroller board. Its standardized nature fosters a supportive community and a vast ecosystem of add-on boards, expanding its capabilities and making it an attractive choice for both beginners and experienced hobbyists alike.

Properties	**the information**
Board Name	Arduino UNO R3
SKU	A000066
Microcontroller	ATmega328P
USB Connector	USB-B
Built-in LED Pin	13
Digital I/O Pins	14
Analog Input Pins	6

Properties	**the information**
PWM Pins	6
Communication	
UART	Yes
I2C	Yes
SPI	Yes
Power	
I/O Voltage	5V
Input Voltage (Nominal)	7-12V
DC Current per I/O Pin	20 mA
Power Supply Connector	Barrel Plug
Clock Speed	
Main Processor	ATmega328P 16 MHz
USB-Serial Processor	ATmega16U2 16 MHz
Memory	
ATmega328P	2KB SRAM, 32KB FLASH, 1KB EEPROM
Dimensions	
Weight	25 g
Width	53.4 mm
Length	68.6 mm

Table 2-3: Arduino Uno standard.

Chapter Four: Smart Glass Landscape and Comparative Analysis

4.1 Smart Glass Manufacturers

In the realm of smart glass industry, six standout manufacturers lead the way with cutting-edge technologies and solutions.

Manufacturer	Description
Gauzy	Offers smart glass solutions for large-scale commercial projects, automotive, and aerospace industries.
Gentex	Known for innovations in smart glass technology.
Halio	Provides smart glass solutions and has an exclusive agreement with Marvin Windows for residential applications.
Raven Window	Focuses on developing smart glass technology for various applications.
SageGlass	A manufacturer specializing in dynamic glass solutions for energy efficiency and comfort.
View	Known for its smart glass technology used in commercial buildings.

Table 1-4: Manufacturers of Smart Glass.

4.2 Market segmentation

the global market for smart glass and windows is segmented by technology, application, and region. This includes diverse applications in architectural, automotive, aircraft, and consumer electronics sectors across North America, Europe, Asia Pacific, Latin America, Middle East, and Africa.

4.2.1 By Technology The market includes both active technologies (like Electrochromic, PDLC, SPD) and passive technologies.

Technology Type	Examples
Active	Electrochromic, PDLC, SPD
Passive	Tinted, isolated

Table 2-4: technology types of smart glass.

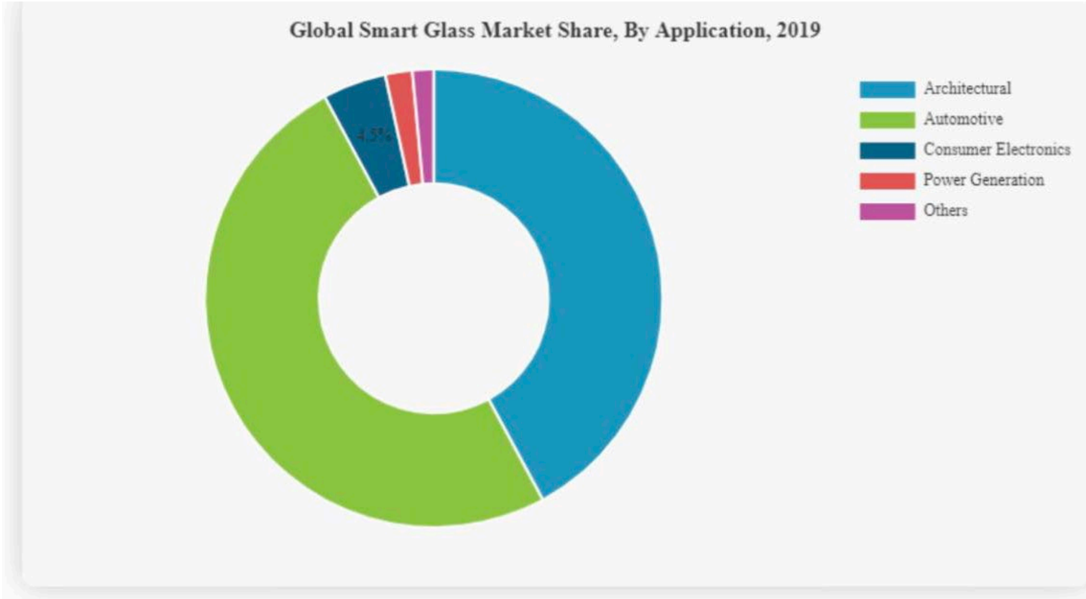

Figure 1-4: Smart Glass Market Segmentation by Application, 2019.

The distribution of smart glass applications. The largest market share is held by architectural applications, followed by automotive, consumer electronics, power generation, and other sectors, signifying the diverse utility of smart glass across industries.

4.2.2 By Application Applications span architectural, automotive, aircraft, consumer electronics, and other sectors.

Application	Description
Architectural	Buildings, offices etc.
Automotive	Vehicle windows
Aircraft	Airplane windows
Consumer Electronics	Smart devices and displays

Table 3-4: Application of Smart Glass.

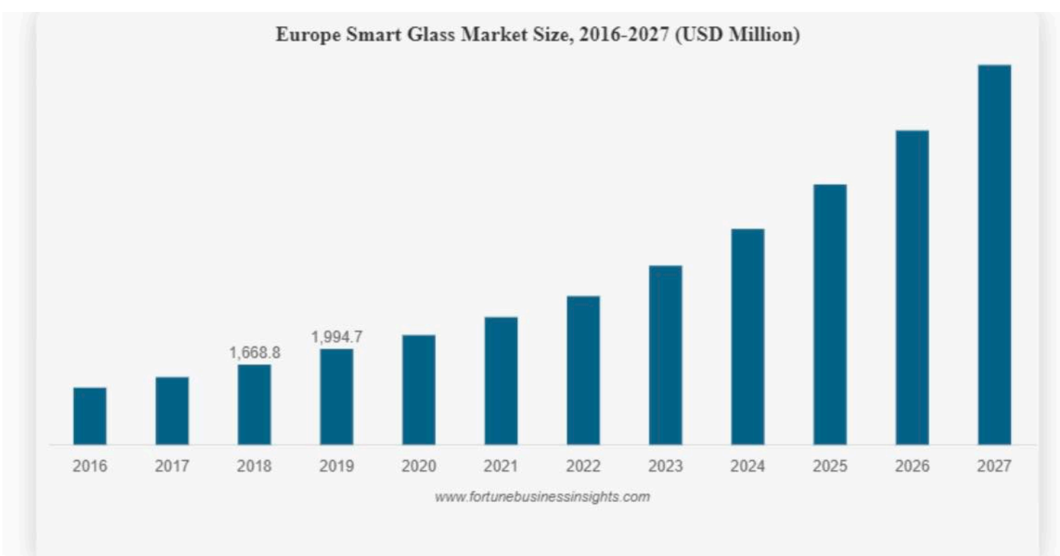

Figure 2-4: Growth Trajectory of the European Smart Glass Market.

4.2.3 By Region North America and Europe are mature markets, while Asia Pacific shows the fastest growth. Opportunities are also identified in the Middle East, Africa, and Latin America.

Region	**Market status**
Europe	Mature Market
North America	Mature Market
Asia Pacific	Fastest growing region
Middle east & Africa	Expected to create significant opportunities
Latin America	Emerging market with growth potential

Table 4-4: By Region market segmentation

4.3 Cost Comparison with Traditional Windows

Smart glass and windows are more expensive than traditional glass and windows, which impacts market expansion. However, the benefits they offer, such as energy efficiency, may justify the higher costs in certain applications.

Aspect	**Smart Glass**	**Traditional Windows**
Cost	Higher initial cost	Lower initial cost
Energy Efficiency	Higher (controls light and heat transmission)	Lower
Technology	Advanced (Electrochromic, PDLC, SPD, etc.)	Basic
Applications	Architectural, Automotive, Aircraft, Consumer Electronics	Residential and Commercial buildings
Market Growth	Expected to grow significantly in the next decade	Stable, with moderate growth
Innovation	High (ongoing advancements in materials and technology)	Low to moderate (limited to design and materials)

Table 5-4: comparison between Smart Glass and ordinary window

4.4 Future of Smart Glass (SWOT Analysis)

1. **Strengths** The innovation in smart glass and window materials and manufacturing technologies are creating new market opportunities.

2. **Weaknesses** High costs of smart glass products compared to traditional glass and windows are a significant hindrance to market growth.

3. **Opportunities** There are substantial growth prospects in regions like Asia Pacific, Middle East, Africa, and Latin America.

4. **Threats** Market threats were not directly outlined in the report but could include technological competition and evolving consumer preferences.

Chapter Five: Results and Analysis

This chapter will include the results and discussion of our project.

5.1 Current Achievements

Our project has reached several noteworthy achievements, particularly in the realm of enhancing the capabilities of smart windows. With the successful integration of an Arduino-based control system and a diverse array of sensors, our smart glass and window components now exhibit dynamic adaptability to environmental conditions. This has significantly improved user comfort and energy efficiency.

5.2 Economical Feasibility

Assessing the economic feasibility of our project, initial costs associated with smart glass technology may be relatively higher than traditional window solutions. However, the long-term benefits derived from the system's energy efficiency and its ability to seamlessly adapt to changing conditions position it as a cost-effective solution over time. The reduction in energy consumption aligns with sustainability goals, making it a viable and economically feasible option for various applications.

Chapter Six: Conclusions and Recommendation

In conclusion, our project has demonstrated considerable success in creating an intelligent and responsive system for smart windows. The integration of advanced technologies, coupled with the adaptability and efficiency improvements, opens doors to diverse applications. As we wrap up this project, it is recommended to explore avenues for further enhancements and potential integrations, ensuring a continuous evolution of smart window technology. Additionally, recommendations for real-world implementations and areas for future research could be explored to maximize the impact of our innovative solution.

References

1. Paper by *Jonathan Zong and Gabriel Valderrama*
2. "Two New Uses for Research Frontiers' SPD-SmartGlass Technology Produced by Gauzy Lt. Unveiled at the IAA Munich Auto Show This Week. Research Frontiers, September 8, 2021.
3. arduino.cc/hardware/uno-rev3/#tech-specs
4. Smart Glass Market Size, Share…Forecast, 2020-2027, Fortune Business Insights, September 2020.
5. Boris Lamontagne, Pedro Barrios, Christophe Py and Suwas Nikumb (2009). "The next generation of switchable glass: the Micro-Blinds".GLASS PERFORMANCE DAYS 2009.
6. UN-TEC Swiss United Technologies Inc. Daniel Shavit, "Translucent conductive Interlayer with SMD Surface Mounted Electronic Devices – LED embedded films"