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An Automated Extension and Retraction of a High-Grade Polycarbonate Plastic Modular Roof with Transition Lens Technology

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ABSTRACT: This paper is about the design concept of the automation of a smart roofing system. The designed was based on experimentation by simulation of the circuit, program coding, and actual function through application platforms like Fritzing and Tinker CAD. The materials selected are in actual used in the circuitry which are available in the market for its cheap price and is best used for experimentation to attain the basic concept of the main function of the automated roof system. The roof system was powered by 220 volts and once power on, the automation starts through the sensing of the environmental input of temperature and rain. The roof starts to extend from a 28oC or higher temperature or as rain falls on the sensor of the roof. It will retract as soon as the temperature is less than 28oC and no rain fall on the rain sensor. The roof panels were tinted with chromatic layers that will protect the area from too much light and give shade to the area. The tint automatically gives off shade as the temperature increases. The actual design of the smart roofing was done in CAD with the actual dimension and placement of the roof panels, roof frames, DC motors, sensors, and circuit box. The program codes were based on the circuit design and followed the process we designed for the function of the system. The actual price of the materials was included based on the online pricing in the Philippine market. The price was based on the small-scale design but is also ready for a bigger scale if given with financial funding. With this, adjustment for a better selection of materials is recommended and the price will increase as well. The program codes maybe adjusted based on the re-design of the customer of the roof system. This design was developed to simplify and help chores at home especially nowadays of fast transition of weather condition.

KEYWORDS: Automated Extension of Polycarbonate Modular Roof, Retraction of High-Grade Polycarbonate Plastic Modular Roof, and Transition Lens Technology

INTRODUCTION

In the Philippine setting, home roofing designs commonly use traditional materials like tarpaulins and wide linen materials for roofing purposes to cover wide open spaces to minimize hot temperature and exposure to excessive light and rain (Zhang, et al. 2024). Some use fixed and framed tinted fiberglass materials, while others in the marketplace sell manually retracted, extending, and small roofing systems of galvanized aluminum material (Matimbwa, 2025). Automation in the field of roofing systems has few applications and manual operation are most applied. This paper presents a design concept of an automated roofing system integrated with strong, lightweight, and UV-resistant material in modular segments with lens technology for eye comfort and surface protection during hot and wet seasons (World Health Organization2025). The system will be using a microcontroller to command the sliding mechanism and linear actuators responding to a real-time environmental input implementation and readiness (Mallillin, et al. 2020). Additionally, the system design is loaded with an AC power source (Sobhita, et al. 2025, pp. 1-9). Once the system is powered, sensors will respond to environment temperatures continuously to trigger the motors connected to the roof panels that will either extend or retract the roof panels integration knowledge (Mallillin, et al. 2020). The smart roof system may be applied for various residential and commercial uses within any community of Caloocan City whether for a large or small spaces which our team will customize the design but for now, we designed an automated roof system for a concept only (Hoendarto, et al. 2025, pp. 25-39).

Objectives

The general objective of this project is to create a design concept of an automated extension and retraction of a roof system. The specific objectives are:

1. To select a roof panel that is durable and transparent that can be applied with UV layer.
2. To select sensors that will detect temperature and water.
3. To select a material that will act as an actuator for the sliding function of the roof panels.
4. To design the roof frames with dimension, measurement of the roof panels, and the actual placement of the materials selected.
5. To design a circuit and simulate to create the actual extension and retraction of the roof panels.
6. To code a program that will be integrated to the circuit for an automatic function of the system.
7. To create a financial report of the costs of the materials.

In this process, the researchers will create a design concept of the automated roofing system as a partial design for prototyping purposes in the future.

METHODOLOGY

The researchers selected a design concept to preliminarily develop an automatic operation for the smart roofing system in Figure 1, where the modular roofs extend when heat or rain is sensed and retract when the environmental inputs return to normal. When the heat or rain sensor is triggered, the ESP32 microcontroller will direct the linear actuators to position the modular roofs from the panel storage to the railings of the frame (Bakkali, 2025). Plastic sliding supports and rollers will help extend the roof panels through a metal frame. The transition lens will automatically adjust its transparency to sunlight. The same sliding mechanism will be used to retract the roof panels when the water has dried up or the temperature reduces. The source of electricity that supports the system is a solar panel, but with a backup of 220V electricity. The system may also adapt the use of smartphones to mainly control its movement, aside from powering on and off (Ginny, Kumar, & Naik, 2021, pp. 1377-1454).

Conceptual Design

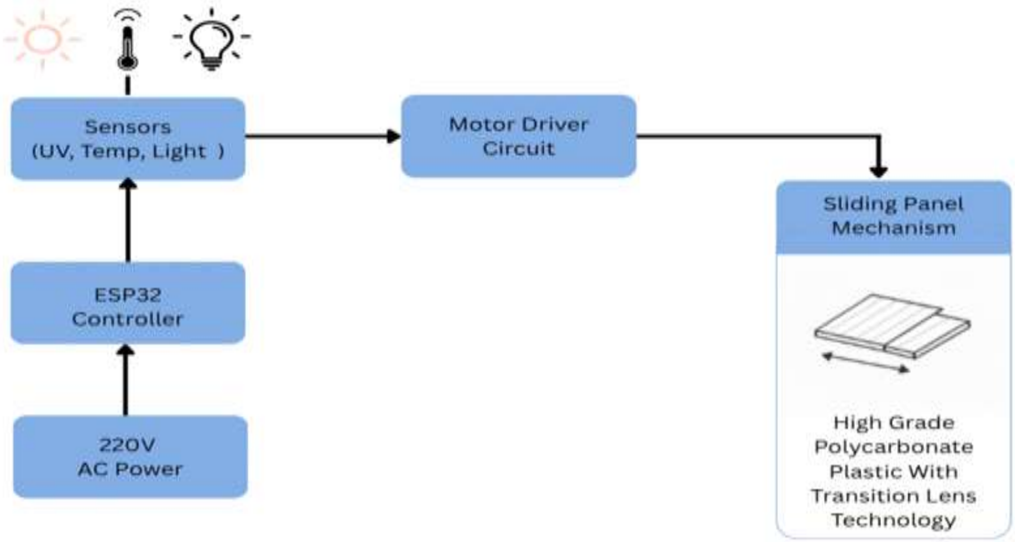


Figure 1. Conceptual Diagram

The conceptual diagram is the process flow of the smart roof system. It is powered by a 220-volt source, stepped down to a regulated voltage supply via USB port to support the ESP32 microcontroller, which supports the DC motors and sensors of the system. Once the sensors detect either the temperature or rain, the microcontroller will send a command to the DC motors to pull the roof panels and cover the roof frame and retract when the weather is normal.

A. Material Selection Analysis

This section presents the selected materials to test and use in the system to conclude correct functionality.

1. Roof panels

For the roof panels, the researchers have chosen a solid polycarbonate plastic with a thickness of 8 mm and a length of 2 feet by 4 feet per panel (61 x 122 x 0.8 cm), as it is suitable to withstand heavy rain, hail, and strong winds. The weight of polycarbonate is about 7.13 kg per panel. Due to changing temperatures, polycarbonate is exposed to discoloration and warping. To prevent it, the roof panel is being coated with a UV-protective layer. In the project, researchers will use 3 panels to illustrate the design (Ürge-Vorsatz, et al. 2025).

2. Roof frame

The stand is made of an aluminum metal tube with a wall thickness of 3 mm and an outer diameter of 75 mm. Two posts are made of aluminum metal tube and have a height of 6 feet, and the other two posts of 4.972 feet, creating a 5-degree inclination of the panels. The main frame will use an H-profile (connector) made from aluminum with a size of 8 mm. The H-profile will join the two sheets of panel side by side. The U-profile (end cap) is made from aluminum with a size of 8 mm. The U-profile will be used to protect the sheet edges (Pozzi, & Paris, 2025, pp. 97-107).

3. DC motor

The DC motor is a hobby gearmotor with a 48:1 gearbox. It is a dual shaft gearmotor with 140 rpm at 4.5 DC volts. The no-load current is 190 mA and a maximum current of 250 mA, and a torque of 800 gf-cm. It has a 5.5-inch-long wire with male pins. The weight is 1.02 ounces, and the body dimensions are 2.5" x 0.74" x 0.88" (Lyshuk, et al. 2026, pp. 48-55).

4. Sensors

The sensors to use are temperature and rain sensors. This will use the environmental temperature to command the system. The DHT22 humidity and temperature sensor has an input power supply of 3.5 to 5.5 volts. The operating current is 0.3mA, the temperature range is -40°C to 80ºC, the humidity range is 0% to 100%, the resolution for both temperature and humidity is 16-bit, and the accuracy is ±0.5°C and ±1%. The rain sensor to use is the YL-83 raindrop sensor board with a circuit module. This rain detector operates from drops of water and not by threshold signals. The circuit module has a supply voltage of 12 VDC + 10% with a supply current of less than 150 mA and a maximum current of 260 mA. The sensor plate heating power reaches from 0.5 to 2.3 W and has a sensing area of 7.2 cm^2. The operating temperature ranges from -15 to +55°C. The circuit module has analog and digital output pins and a pin for the ground and is 3.2 cm x 1.4 cm in physical size (Talotta, et al. 2025, pp. 223-227).

5. ESP32 Dev Kit Microcontroller

Microcontrollers are the most significant components for reading sensors and controlling devices. This will serve as the brain of the whole system. The ESP32 Dev Kit has a 32-bit, single-core LX6 microprocessor with a 260 MHz clock frequency, 520 KB SRAM, 448 KB ROM, and 16 KB RTC SRAM. It supports 802.11 WIFI connectivity UP TO 150 Mbps speed. It supports both classic Bluetooth v4.2 and BLE specifications. It has 34 programmable input-output pins—18 channels of SAR ADC, 2 channels of DAC, and 16 channels of LED PWM, serial connectivity, and Ethernet MAC for LAN communication (Cameron, 2023, pp. pp. 1-54).

6. L298N Motor Driver

The motor driver is used to avoid overvoltage or overheating of the microcontroller. It is also a module that serves as the driver for the DC motor. It should be connected between the microcontroller and the DC motor. The main component of the module includes the L298N motor drive IC, 78M05 voltage regulator, the 5-volt enable jumper, and the heat sink (Sudhakar, et al. 2025, pp. 1-5).

7. Power supply

The system design will use a 220-volt AC source and will be stepped down to 6–7 volts via the USB DC Adapter of the microcontroller.

B. Circuit Diagram

The illustration below shows a compact circuit design for environmental input response where the ESP32 microcontroller is the brain of the whole circuit. We have chosen ESP32 as our microcontroller because it has low power consumption, capable of reading sensors, control motors, and other features which can be added in this design in the future The circuit has the following sections:

Section A is composed of the YL-83 rain sensor and control module. The rain sensor board is connected to the positive and negative polarities of the control module. The control module has four (4) pins namely AO (Analog output), DO (Digital output), GND (ground), and VCC which is the voltage supply for the module. The analog output AO is connected to the GPIO36 is a pin that is safe to use for analog sensors like rain sensor. This pin also serves as the SVP or sensor voltage positive that is capable of an internal capacitive touch. For the software-controlled power or Vcc, we use the GPIO32 to turn on and off the module through code. In this, we can save energy when the sensor is off. The GND of the control module of the rain sensor should be connected of course to the same label of the microcontroller to avoid short circuit. And the DO or digital output of the control module is connected to the GPIO13 of the microcontroller. It is used to activate or power the rain sensor (Wati, et al. 2025).

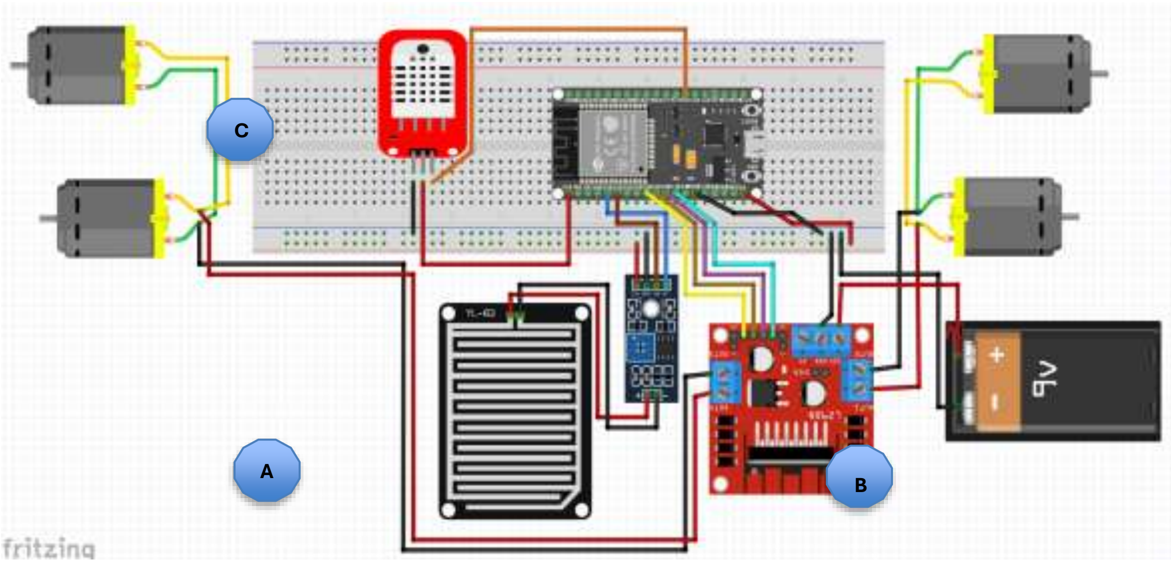


Figure 2. Smart Roof Breadboard Circuit Design

Section B is composed of the L298N motor driver, the 9 volts battery, and the four (4) DC motors. The L298N motor driver controls the speed and the direction of the DC motors. The speed of the DC motors can be set on the source code. In our design, we only use a speed of 150 which means $\frac{150}{250} \approx 0.59$ or 59% power of the motor. The speed ranges from 0 to 255 meaning, the speed 59% is moderate. We use L298N motor driver because it has a dual H-bridge which can control two independent DC motors just as we wanted in our design. The left side two DC motors is specified as motor A from the L298N motor driver to GPIOs 4, 16 and 17 of the ESP32 microcontroller. While the right side two DC Motor as Motor B and is connected to GPIO's 5,18, and 19. These pins are useful to support the transmission and reception of speed and change of direction. The four (4) DC motors will be connected to the roof panels that will either extend or retract depending on the environment input on the sensors. Each time the sensor receives the environmental signal, the microcontroller will command the motors to run in the same direction.

Section C is composed of the DHT22 or the humidity and temperature sensor. It is a digital sensor which can measure both temperature and humidity. It is connected to a 10k ohms resistor to ensure proper voltage level of 3.3 volts and avoid communication errors of data signals. The DHT22 has four (4) pins reading it from left to right: Vcc, Data, NC (No connection), and GND (ground) respectively. The Vcc supplies the 3.3 volts from the microcontroller to the sensor, pin 2 is the data connection, which sends digital data of temperature and humidity to the microcontroller, and the GND completes the continuity of voltage for the sensor (Mahmud, et al. 2026).

The whole circuit is powered via DC power adapter through the USB port of the ESP32 microcontroller by 12 volts.

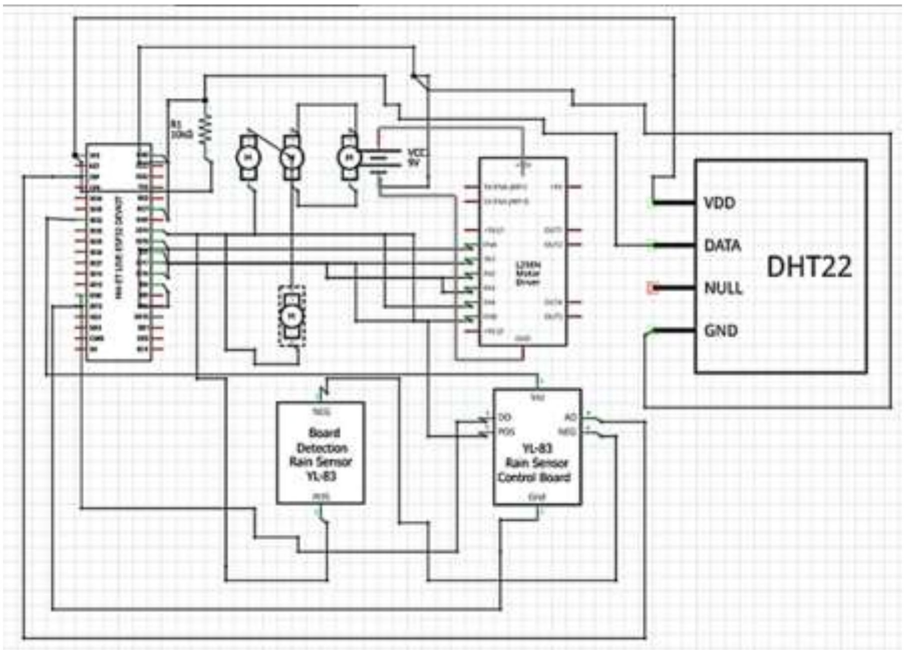


Figure 3. Smart Roof Schematic Circuit Design

Figure 3 illustrates the electrical circuit design of the automated roofing system based on the breadboard circuit design. We used Fritzing software to simulate the electrical circuit design.

C. Coding

The coding is the programming source code using Arduino IDE, which will provide the algorithm of commands to the microcontroller. As soon as the codes are burned into the microcontroller, the loop of commands will stand as a continuous function of the roofing system (Nannim, et al. 2025, pp. 1-24).

```
#include <DHT.h>

// ------------------ SENSOR PINS (UNCHANGED FROM FIRST CODE) --------------
#define DHTPIN 4
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);

#define RAIN_SENSOR_PIN 34   // YL-83 Analog Output

// ------------------ MOTOR DRIVER PINS (UNCHANGED FROM FIRST CODE) ----
#define IN1 14
#define IN2 27
#define IN3 26
#define IN4 25
```

```
// ------------------ SYSTEM THRESHOLDS ------------------
const float HOT_TEMP = 28.0;     // Deploy cover at 28°C or above
const float COOL_TEMP = 27.0;    // Retract below 27°C
const int RAIN_THRESHOLD = 700;  // Lower value = rain detected

bool roofExtended = false;       // Track roof state

// ------------------ SETUP ------------------
void setup() {
  Serial.begin(115200);
  dht.begin();

  pinMode(RAIN_SENSOR_PIN, INPUT);

  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);
  pinMode(IN3, OUTPUT);
  pinMode(IN4, OUTPUT);

  stopMotors();

  Serial.println("Smart Roof System ACTIVE");
  delay(1500);

// ------------------ MAIN LOOP ------------------
void loop() {
  float temp = dht.readTemperature();
  float hum = dht.readHumidity();
  int rainValue = analogRead(RAIN_SENSOR_PIN);
  bool isRaining = (rainValue < RAIN_THRESHOLD);

  Serial.println("---------------------------------------------------------------");
  Serial.print("Temperature: "); Serial.print(temp); Serial.println(" °C");
  Serial.print("Humidity: "); Serial.print(hum); Serial.println(" %");
  Serial.print("Rain Sensor: "); Serial.println(rainValue);

  // PRIORITY 1 → RAIN
  if (isRaining) {
    Serial.println("Rain detected → Deploying cover!");
    extendRoof();
  }
  // PRIORITY 2 → TEMP
  else {
    if (temp >= HOT_TEMP) {
      Serial.println("High temperature → Deploying cover.");
      extendRoof();
    }
    else if (temp < COOL_TEMP) {
      Serial.println("Cool temperature → Retracting cover.");
      retractRoof();
    }
    else {
      Serial.println("Moderate conditions → Hold position.");
    }
    }
  delay(5000);
   }
// ------------------ ROOF MOVEMENT FUNCTIONS ------------------
void extendRoof() {
```

```
 if (!roofExtended) {
  Serial.println("Extending cover...");
  moveMotors(true);   // forward
  roofExtended = true;
  Serial.println("Cover extended.");
 } else {
  Serial.println("Cover already extended.");
 }
 }
void retractRoof() {
 if (roofExtended) {
  Serial.println("Retracting cover...");
  moveMotors(false);  // reverse
  roofExtended = false;
  Serial.println("Cover retracted.");
 } else {
  Serial.println("Cover already retracted.");
 }
 }

// ------------------ MOTOR CONTROL (IN1–IN4 ONLY) ------------------
void moveMotors(bool forward) {
 if (forward) {
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);
  digitalWrite(IN3, HIGH);
  digitalWrite(IN4, LOW);
 } else {
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, HIGH);
  digitalWrite(IN3, LOW);
  digitalWrite(IN4, HIGH);
 }
 // Let motors run for 7 seconds (your extend/retract time)
 delay(7000);

 stopMotors();
}

void stopMotors() {
 digitalWrite(IN1, LOW);
 digitalWrite(IN2, LOW);
 digitalWrite(IN3, LOW);
 digitalWrite(IN4, LOW);
}
```

D. Flowchart of the System Function

The flowchart below tells the system process from the start button to the continuous cycle of receiving signals from the environmental inputs, such as temperature and rain, that will trigger the DC motors to extend or retract the roof panels.

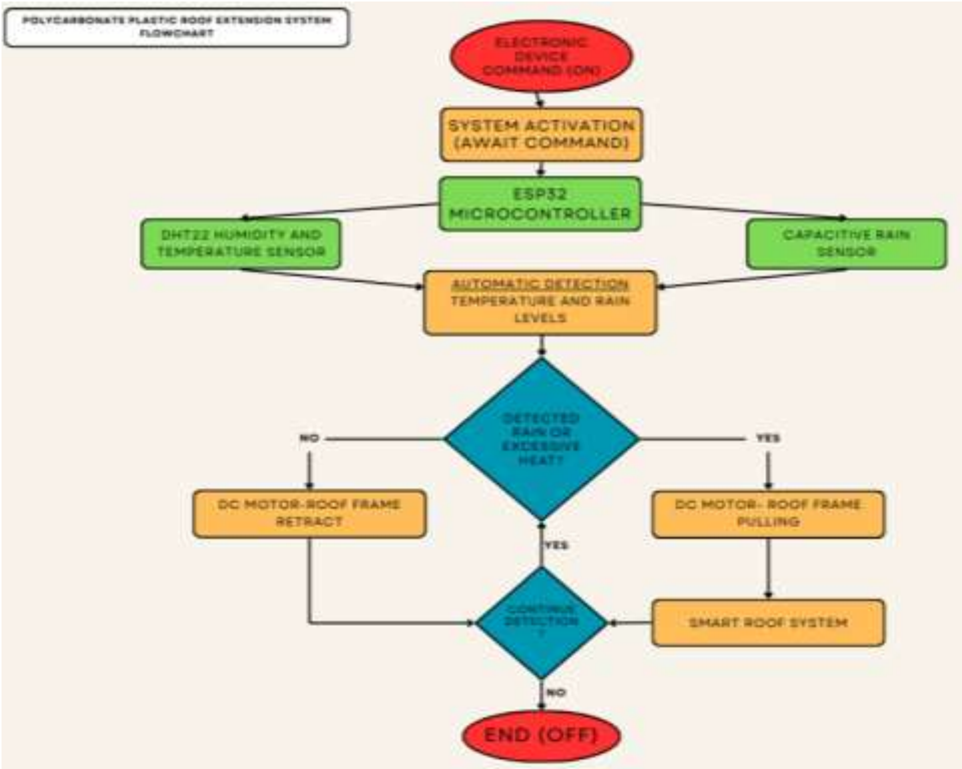


Figure 4. Smart Roof System Function

In Figure 4, the smart roof system is initialized by turning it on using an electronic device (portable or computer) or a button from the microcontroller. During activation, it will wait for the commands from the ESP32 Microcontroller, followed by its connected sensors: the Capacitive Rain Sensor and the DHT22 Temperature and Humidity Sensor. Analyzing data gathered by weather conditions based on the variable given, such as excessive heat or rain. A threshold temperature greater than 35 degrees Celsius will automatically trigger the humidity sensor to pull the roof panel via the DC motors. A stop in the system will only happen when the owner has chosen to keep the roof panels pulled down, there is a power shortage, or there is a system failure (Cha, et al. 2025).

E. 3D Design of Smart Roof System

Below is the perspective design of the Smart Roof System using CAD. The parts of the illustration include the roof frame with a sliding mechanism, roof posts, and the location of sensors and DC motors. All measurements are labeled and in actual values.

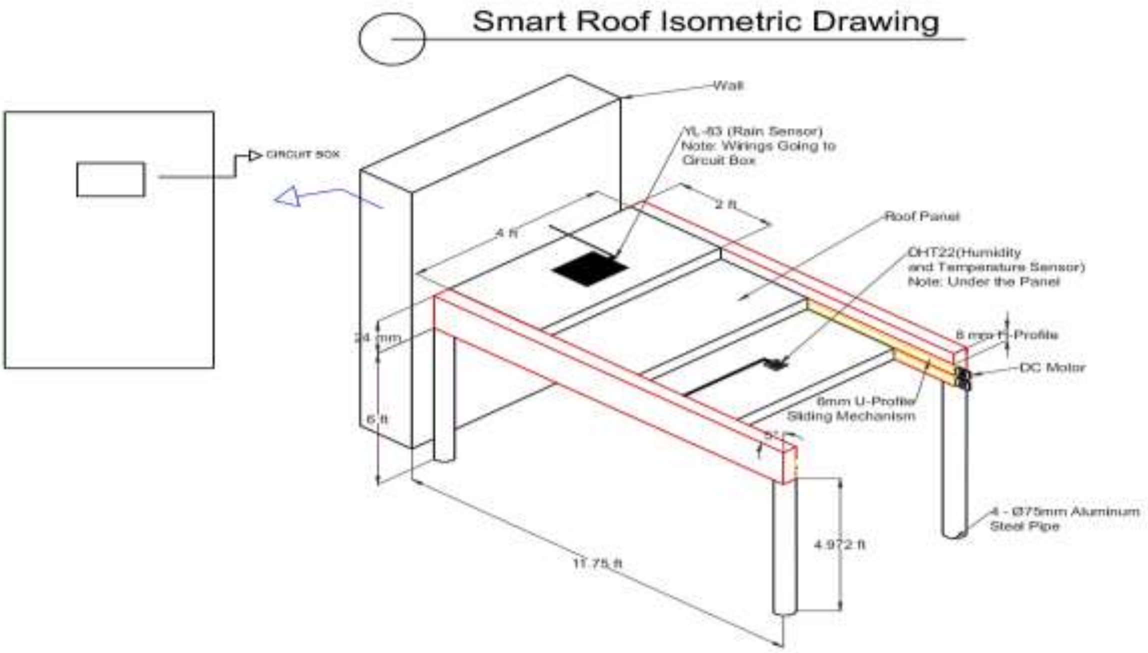


Figure 5. Smart Roof System Isometric

Figure 5 illustrates the actual installation of stainless-steel posts, a roof frame with sliding mechanisms, roof panels, DC motors, and sensors. The sensors and DC motors are placed in the designated location from the roof frames. The circuit box is placed inside the house where the wiring passes through the wall and stainless-steel posts and is then connected to the DC motors and sensors.

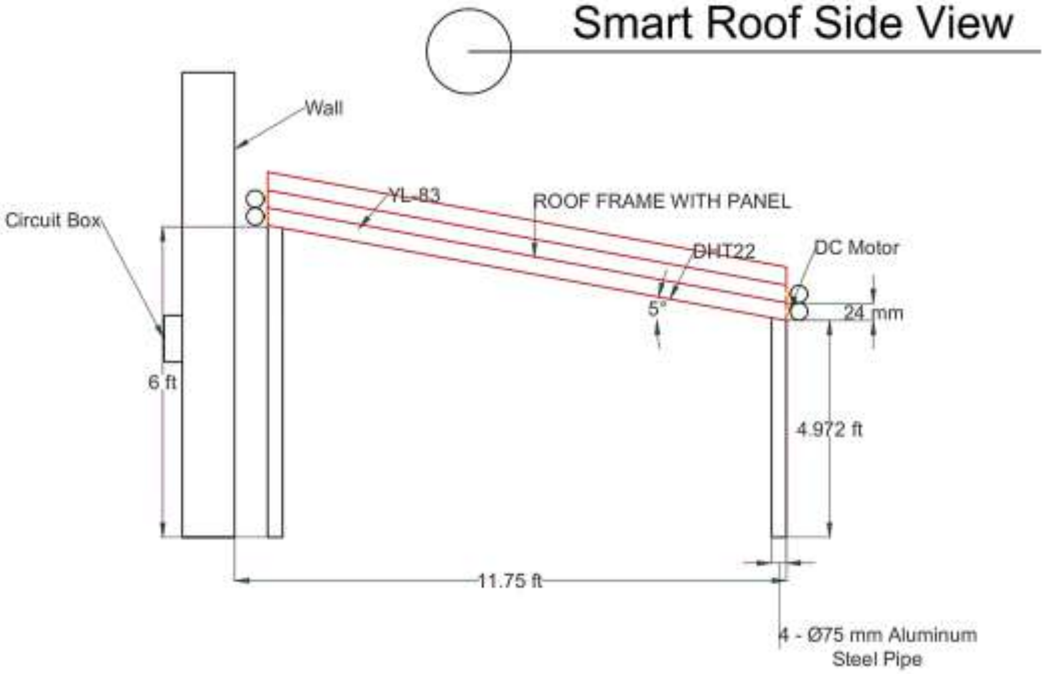


Figure 5.1 Roof Panel Side View

Figure 5.1 illustrates the right-side view of the smart roof system, showing the inclined roof frame with panels, stainless steel posts, DC motor, sensors, and the circuit box. The roof frame is positioned at a 5° angle, supported by a Ø75 mm aluminum-steel post measuring 4.972 ft in height and spaced 11.75 ft from the wall. The DHT22 sensor and YL-83 rain sensor are installed on the roof frame at their designated positions.

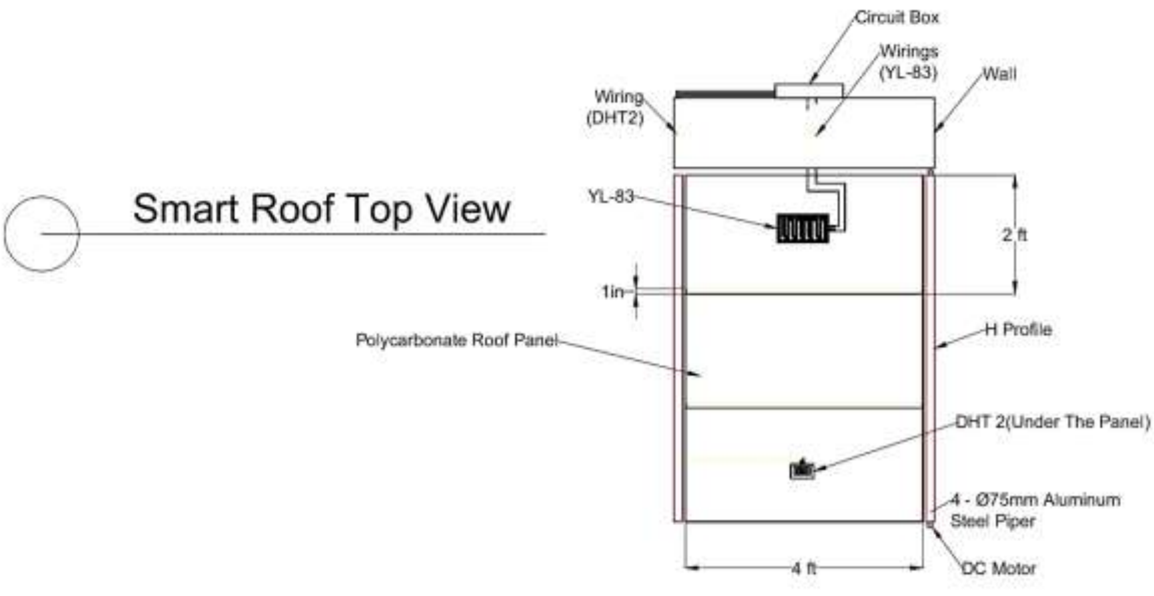


Figure 5.2 Roof Panel Top View

Figure 5.2 illustrates the top view of the smart roof system when fully extended, showing the arrangement of the roof panels, sensors, wiring, and supporting structures. The roof is composed of polycarbonate panels joined by H-profiles and supported by Ø75 mm aluminum-steel pipes. The YL-83 rain sensor is positioned on top of the roof panel, while the DHT22 temperature sensor is placed underneath the panel for accurate ambient readings. The circuit box is mounted on the wall, where the wirings from both sensors pass through and are connected to the control system and DC motor.

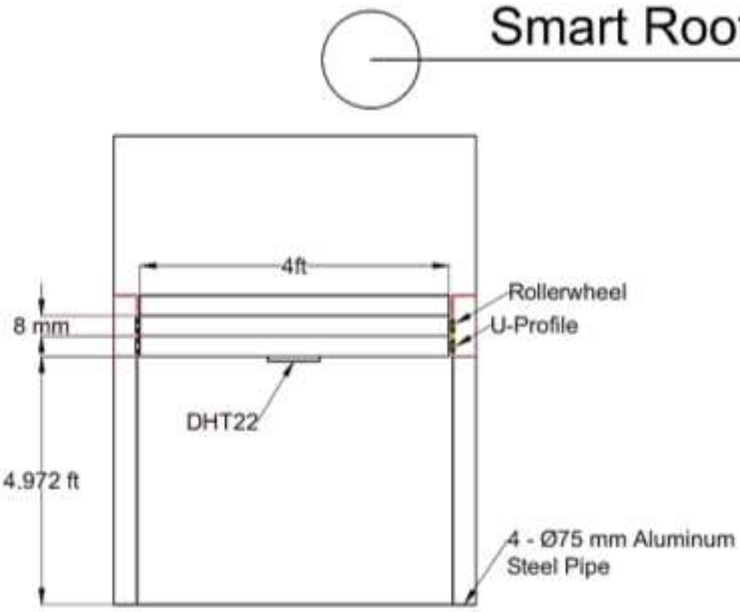
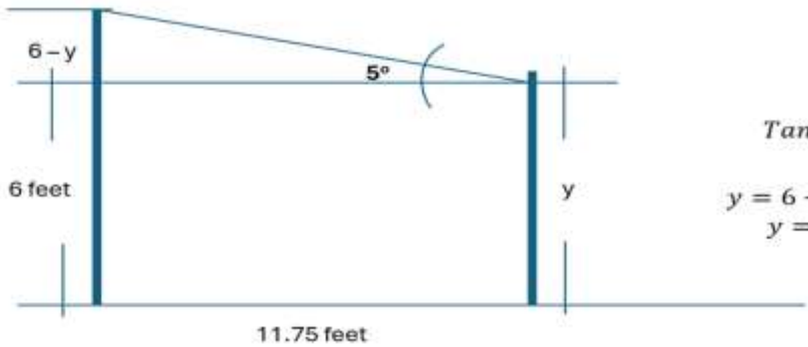


Figure 5.3 Roof Panel Front View

Figure 5.3 illustrates the front view of the smart roof system, showing the arrangement of the three (3) roof panels mounted on the roof frame. The panels are supported by Ø75 mm aluminum-steel pipes and are connected using U-profiles and roller wheels to allow smooth movement during operation. The DHT22 temperature and humidity sensor is positioned beneath the roof panel to accurately detect environmental conditions.

Computation of the Lower Pole:

Figure 6 show the upper pole designed with a height of 6 feet, and the inclination of the roof panel is 5 degrees. The computation above shows the height of the lower pole (y) if the inclination of the roof panels is 5 degrees. The sum of the length of the 3 roof panels, with lengths of 4 feet each, and one panel is overlapped to the other by 1 inch, is 9 feet and 33 inches, or 11.75 feet.



$$Tan\ 5^o = \frac{6-y}{11.75}$$

$$y = 6 - 11.75\ Tan\ 5^o$$
$$y = 4.972\ feet$$

Figure 6. Stainless steel post computed height

F. Materials Budget Proposal

The budget proposal is an estimation based on the online market price in the Philippines. There are two sections for the materials, one for the roof system and the other for the main circuit.

Table 1. Materials for the Roof System

Item	Estimated Cost (Php)
60 cm x 120 cm x 0.3 cm Solid Polycarbonate Panels with UV protection (3 pieces)	Php 448 x 3 = 1,344
H-Profile	Php 467
U-Profile	Php 449
Roof Panel Wiring	Php 140
Aluminum Metal Tube	Php 223
Total	**Php 2,623**

The total cost for the list of materials in Table 1 is 2,623. The list will produce the physical design of the roof system. Only the main materials are listed in the table for costing. The screws for the frames and posts as well as soldering, roof panel wirings on each side to the DC motor along the sliding mechanism, the number of pieces for each item and the lubricants are not included in the costing of materials. The labor cost for soldering the frames for a day is Php 520 per day, based on the daily labor cost for contractual workers.

Table 1. Materials for the Roof System

Item	Estimated Cost (Php)
ESP32 Dev Kit	Php. 179
DC Motor Gear motor (4 pcs)	Php. 956
DHT22 Humidity and Temperature Sensor	Php. 200
Capacitive Rain Sensor	Php. 992
L298N Motor Gear	Php. 249
Wires (Male – Male), (Male – Female)	Php. 28, Php. 10
Total	**Php. 2,614.00**

The total cost of materials in Table 2 is Php 2,614.00. The list of materials will form the main circuit to control the roof panels from environmental inputs. A total of Php 5,237 is the cost of the smart roof system. If the installation fee is added, an additional labor cost ranging from Php 500 to Php 1000 per day will be included based on the Philippine daily labor cost for contractual workers. Screws, bolts, lubricants, and strings were not added the total price.

RESULTS AND DISCUSSION

The automated extension and retraction of a high-grade polycarbonate plastic modular roof with transition lens technology is conceptually designed with an actual circuit design, coding; and the simulation of the circuit was done using Tinker CAD and Fritzing software applications. The materials selected for the circuit board are based on the actual design requirements, ensuring durability, compatibility, and alignment in the Philippine weather. The roof panels, frames, and posts were physically measured and designed in CAD software, ensuring precise alignment and mechanical integration with the electrical system.

The smart roof system can be activated through an electronic device or via a manual button connected to the microcontroller. Once it is activated, the ESP32 microcontroller begins to turn on the Capacitive Rain Sensor and the DHT22 Temperature and Humidity Sensor. These sensors collect real-time environmental data, which the system analyzes so that when the temperature exceeds 30°C, the DHT22 sensor triggers the system to extend or pull the roof panels, and the capacitive rain sensor sends a signal to the ESP32 to retract or extend the panels.

RECOMMENDATION

The system is for a preliminary design concept of the smart roof system. In this design, a heavy-duty DC motor should replace the introductory motors to pull a solid, high-grade polycarbonate plastic modular roof that will weigh 7 kg per panel. An alternative power supply should be provided in case of a power outage and the addition of a heavy-duty DC motor. Since the system will just use 3 roof panels, a larger scale for the roof panels and the roof frame can be added. An integration of WIFI or GSM technology controlled via an Android phone will add beauty to advance the technology of the system.

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