Energy Harvesting Roof:

Rain or Shine, Day or Night, Let There Be Light!

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Summary: Integration of piezoelectric, photovoltaic, and thermoelectric technologies for self-sustainable green energy harvesting roof. This reduces energy waste promoting affordable and accessible renewable energy solutions. By utilizing diverse energy sources, this roof enables cost-effective systems that adapt to various environmental conditions, paving the way for eco-friendly and affordable energy alternatives.

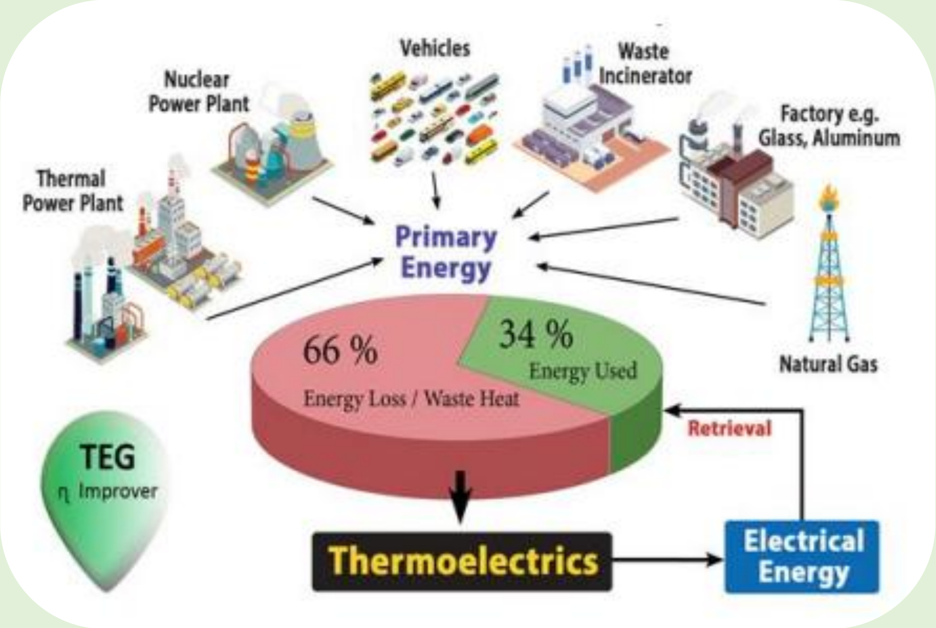
Energy Efficient Roof :

Made of Piezoelectric & Photovoltaic Thermoelectric Generator (PZT-PV-TEG)

Introduction

Problem Statement:

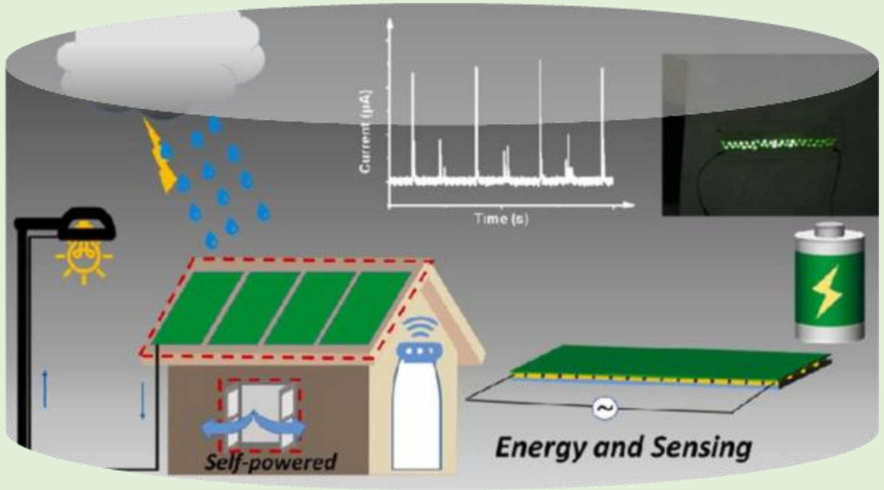
- 66% of energy in industrial environments is lost as waste heat [1]
- 70% of produced energy in automobiles is wasted in the form of heat
- Solar energy striking the earth is 10,000 times more than the energy used by the world
- Solar energy cannot generate power at night or during stormy, rainy weather and their efficiency falls



Energy loss by waste heat [1]

Objectives:

- This project is to engineer models to test continuous renewable sources of energy that could be used on a roof to make homes more energy efficient and sustainable.
- The goal for the piezoelectric model is to successfully generate electricity from the impact of rain.
- The goal for the Hybrid solar and Thermoelectric model is to successfully generate energy day and night, even during cloudy weather when the solar does not perform at its optimum.

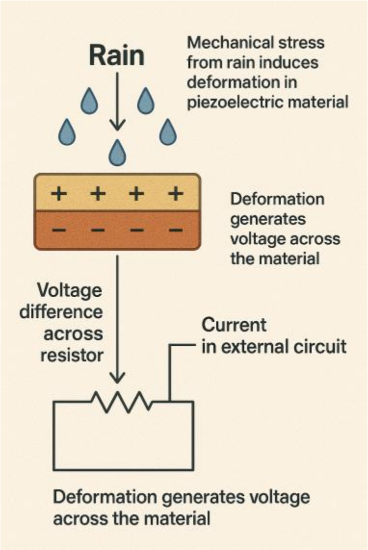


Engineering Goals:

- Harvest energy from rain using Piezoelectric discs
- Harvest solar energy on the roof with semiconductor monocrystalline Silicon
- Recycle wasted thermal energy into electrical energy by Seebeck effect
- Use clean energy harvesting methods and reduce greenhouse gas emissions

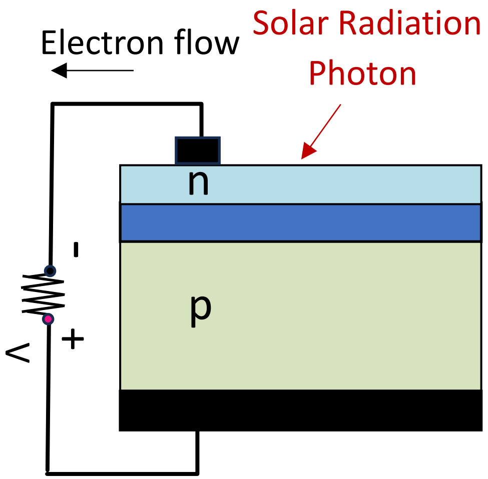
Literature Review

Piezoelectric Transducer



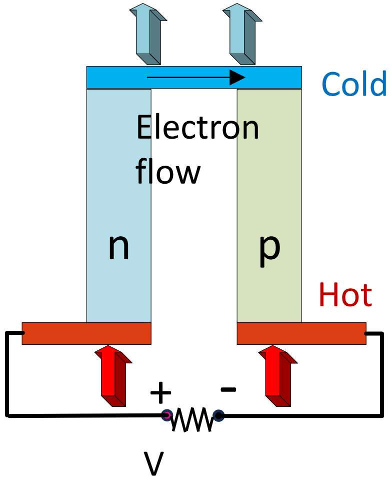
- Rain impacts the surface, applying mechanical stress to the piezoelectric material.
- Mechanical stress induces deformation in the piezoelectric layer.
- This deformation generates a voltage across the material (positive and negative charge separation).The voltage creates a potential difference across a resistor.
- This causes current to flow through an external circuit, enabling energy harvesting.
- Rain energy is converted into electrical energy using the piezoelectric effect [11]

Photovoltaic Solar Cell



- Incident photons absorb in p-n junction of semiconductor to generate electron-hole pairs [2]
- Electron flows out of n-region, passes through external circuit, recombines with holes
- Electron flow generates current in the opposite direction
- Voltage difference across resistor

Thermoelectric Generator (TEG)



- p- & n- type semiconductor materials connected at hot & cold ends [3]
- Electron flows out of n-region
- Electron flow generates current in the opposite direction
- Voltage difference across resistor

Seebeck Effect:

$$\nabla T \longrightarrow V$$

Methods

<table>
<tr><th>Technology</th><th>CONSTRUCTION</th><th>MEASUREMENT</th><th>RESULT & ANALYSIS</th></tr>
<tr>
<td>Piezoelectric Transducer
(For one side of the model roof)</td>
<td>Roof structure- I designed to mimic a house, made of wood.
Testing surface- made with 4 PZT discs, 41 mm diameter, 0.3 mm thickness embedded on a foam sheet. I used a standard bridge rectifier
The roof structure and testing surface are connected using spacers, spring and foam pad, creating the piezoelectric roof.
I used series connection, so the voltage adds up.</td>
<td>I used an oscilloscope to record and note the voltages and power produced when force from water (from hose) was applied in low, medium and high setting. I was able to light up a LED.</td>
<td>
<table>
<tr><th>Water Force</th><th>Peak Voltage (V)</th><th>RMS Voltage (V)</th><th>Power Output (mW)</th></tr>
<tr><td>Low</td><td>~2.4</td><td>~1</td><td>~0.11</td></tr>
<tr><td>Medium</td><td>~4.7</td><td>~2</td><td>~0.43</td></tr>
<tr><td>High</td><td>~6.5</td><td>~2.8</td><td>~0.83</td></tr>
</table>
Piezoelectric
Initially I had used smaller PZT disc size. By increasing the disc diameter to 41mm, I was able to improve the prototype and got larger output.
Larger area (41 mm diameter): More waterdrops per second hit the transducer.
Thinner disc (0.3 mm thickness): Higher strain sensitivity so better energy conversion per impact.
</td>
</tr>
<tr>
<td>Photo-Voltaic
Thermoelectric
(Generator for the other side of the model roof)</td>
<td>I built a model with a hybrid material after a lot of research. I put Sunpower Maxeon C60 (Top), TEG (Middle) and Heatsink (Bottom).
With this I constructed a hybrid set up of Thin film Photovoltaics and Thermoelectric generator that can complement each other day and night.</td>
<td>I used an oscilloscope to record and note the voltages and power produced under the sun using photo-voltaic cell. I was able to light up a LED.
For TEG I measured voltage using multimeter and converted to power using supplier’s datasheet.</td>
<td>
Photo-Voltaic
<table>
<tr><th>No.</th><th>Power [W]</th></tr>
<tr><td>1</td><td>3.4</td></tr>
<tr><td>2</td><td>3.12</td></tr>
<tr><td>3</td><td>3.26</td></tr>
<tr><td>4</td><td>3.35</td></tr>
<tr><td>5</td><td>3.16</td></tr>
<tr><td>6</td><td>3.21</td></tr>
<tr><td>Mean</td><td>3.25</td></tr>
</table>
Thermoelectric Generator
TEGs generates 62.97 mV (0.23 mW) in clear sky
The relative output power from solar is very high when compared to TEG which is low
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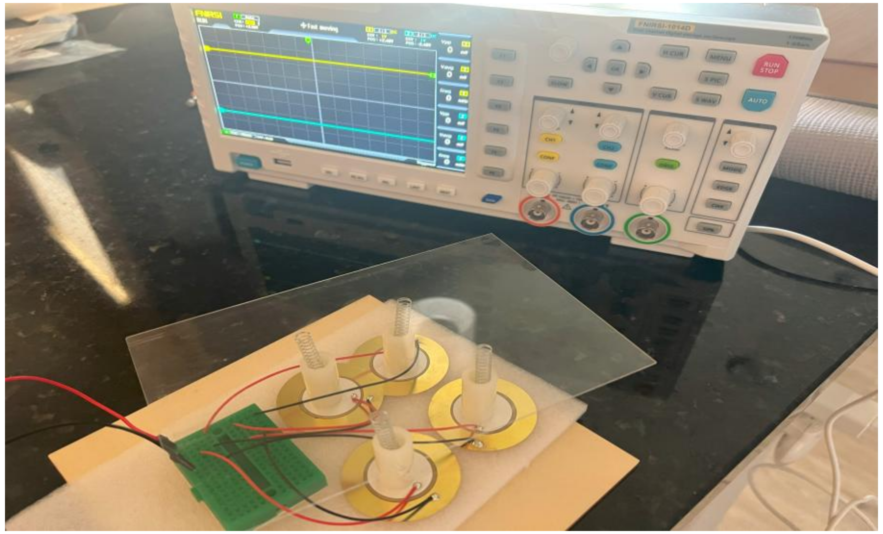
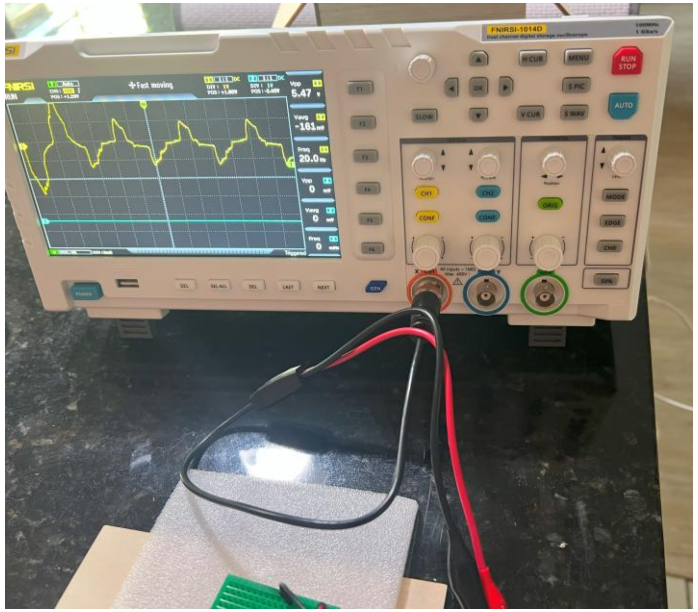
Energy Engineering and Design





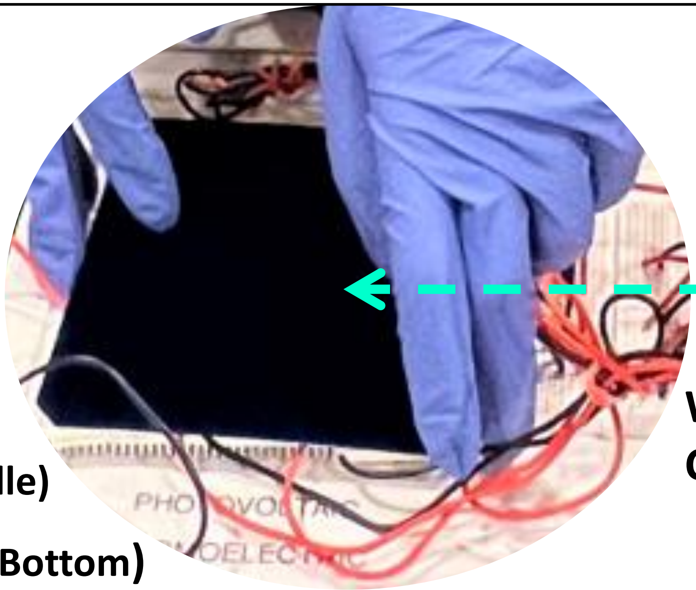
Prototype 1: (Piezoelectric Transducer)

Pros: Can generate power during stormy and rainy weather

Cons: Power generated is lower than Solar

HC06 BT

PV-TEG

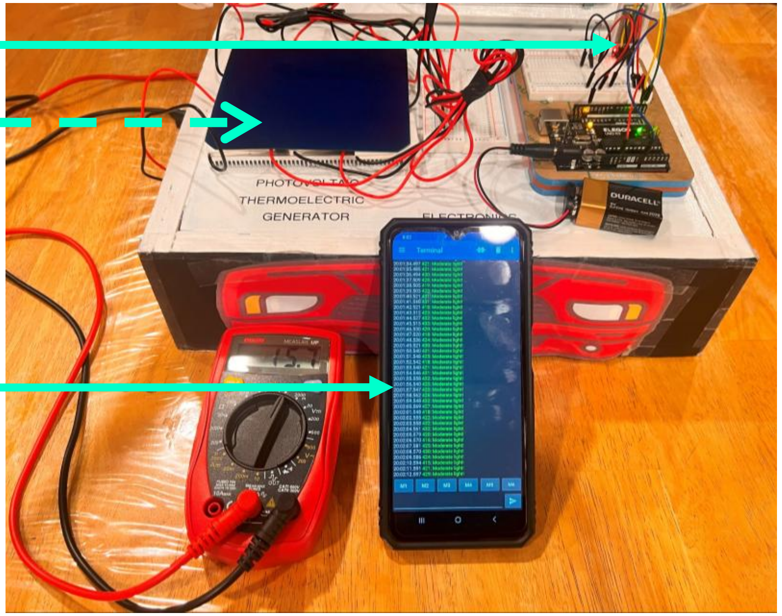


PV(Top)

TEG (Middle)

Heatsink (Bottom)

Wireless Connection (BT)



Prototype 2: (PV-TEG)

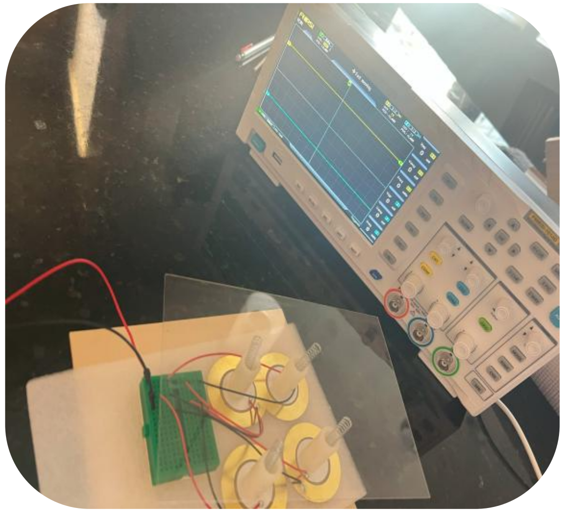
Pros: Increased power efficiency of solar with TEG
day and night

Cons: Cannot generate power during stormy and rainy weather

Energy Engineering Device: Construction Steps

1

2



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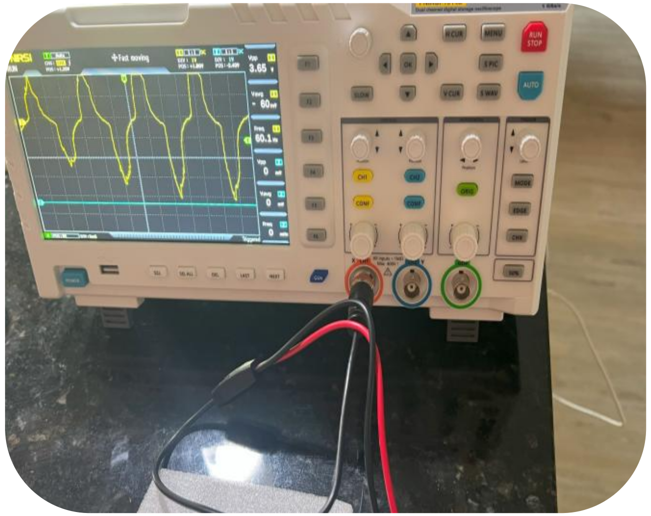

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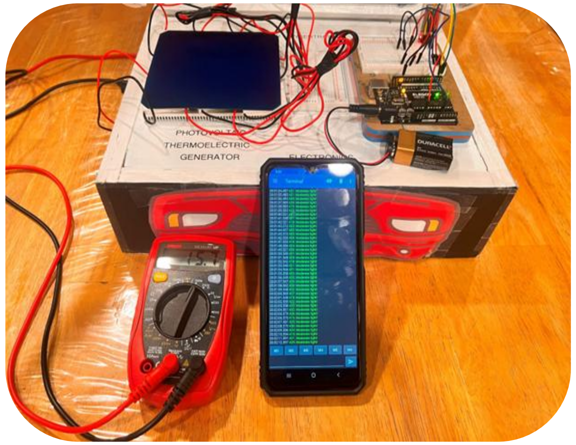

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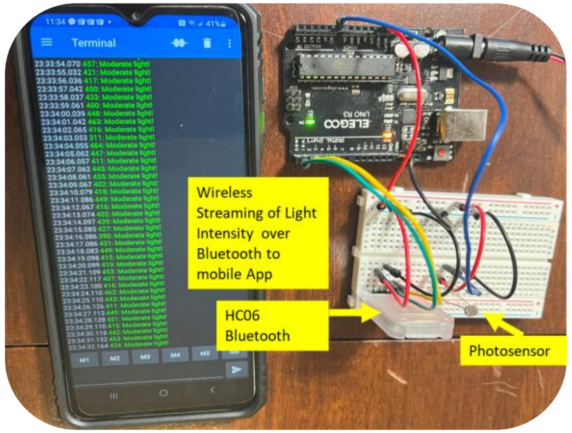

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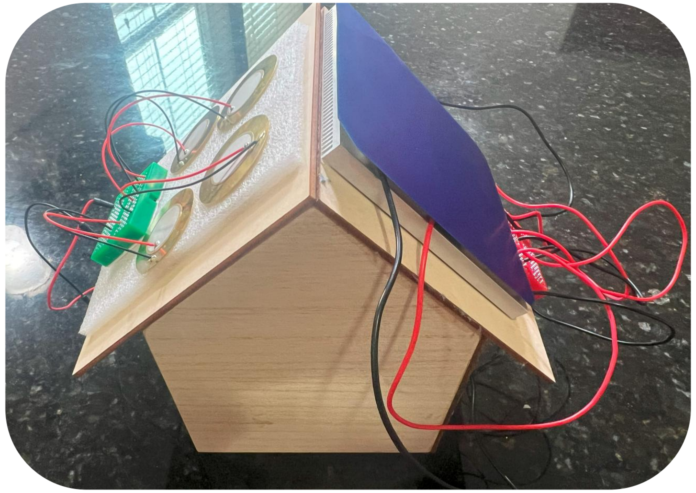

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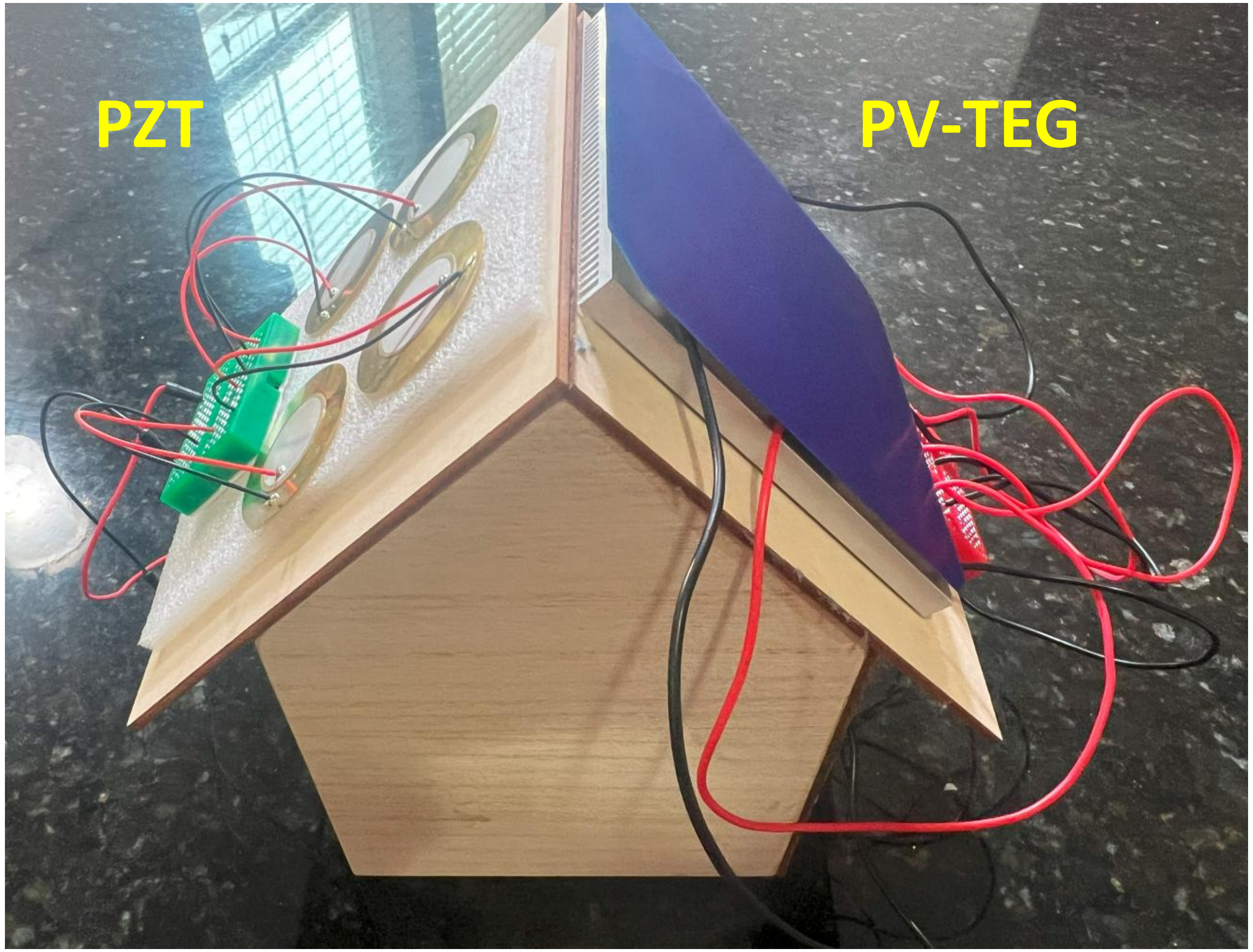
Energy Engineering & Design: Final Prototype (PZT-PV-TEG)

Benefits:

- Can be housed on one single roof (PZT+ Hybrid PVTEG)
- Can generate power day and night, Rain or Shine
- Converts Waste to Watts in a sustainable manner
- Wireless connectivity allows for light intensity to be directly tracked



One Side of the roof:
PZT: Piezoelectric Transducer embedded on a foam sheet

One Side of the roof:

Hybrid PV-TEG:
1. Sunpower Maxeon C60 (Top)
2. TEG (Middle)
3. Heatsink (Bottom)

Final Prototype : PZT-PV-TEG

Piezoelectric Transducer: Electronics

```
//Energy Harvesting Roof-Piezoelectric:Ayan Bera
const int piezoPin = A0;      // Analog input from piezo after rectifier
const int ledPin = 8;         // Digital output to LED
const int threshold = 150;    // Adjust based on testing

void setup() {
  pinMode(ledPin, OUTPUT);
  Serial.begin(9600);
}

void loop() {
  int sensorValue = analogRead(piezoPin);  // Read the rectified signal
  Serial.println(sensorValue);             // Monitor values for calibration

  if (sensorValue > threshold) {
    digitalWrite(ledPin, HIGH);  // Turn LED on if knock/vibration detected
    delay(200);                  // Keep LED on briefly
  } else {
    digitalWrite(ledPin, LOW);   // Turn LED off
  }
}
```

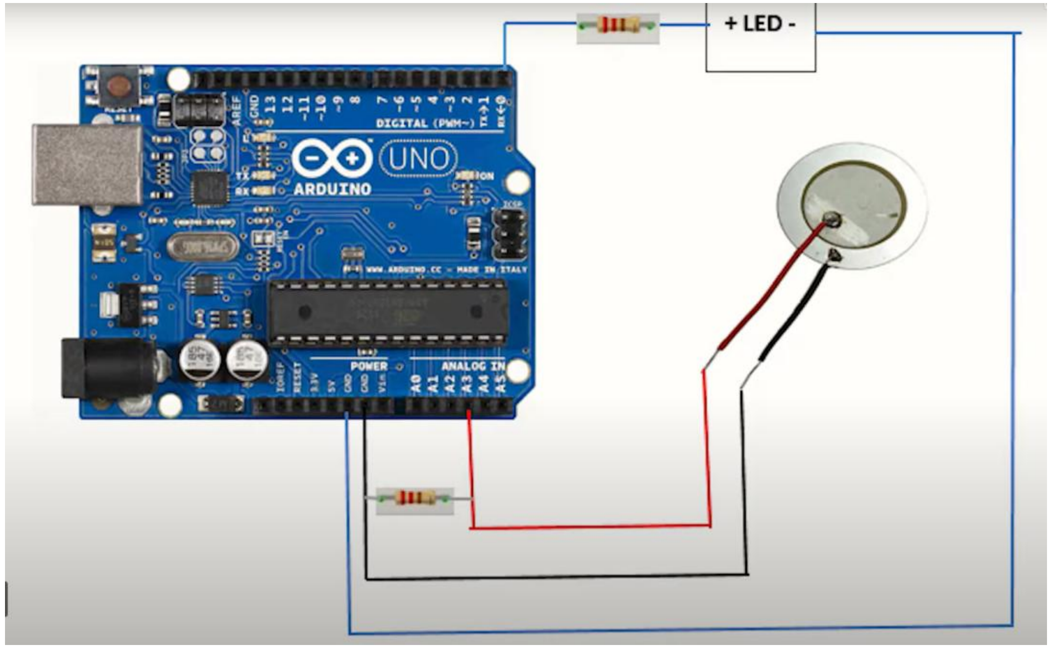
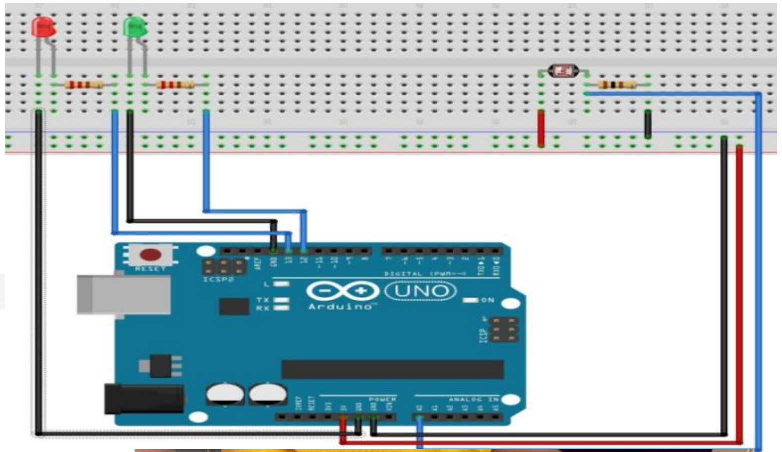
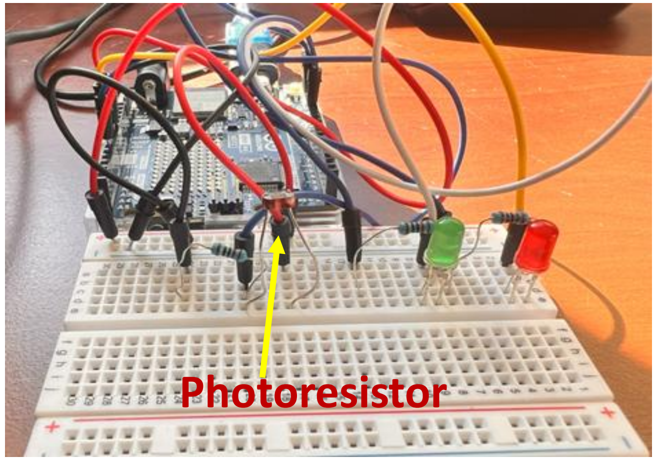


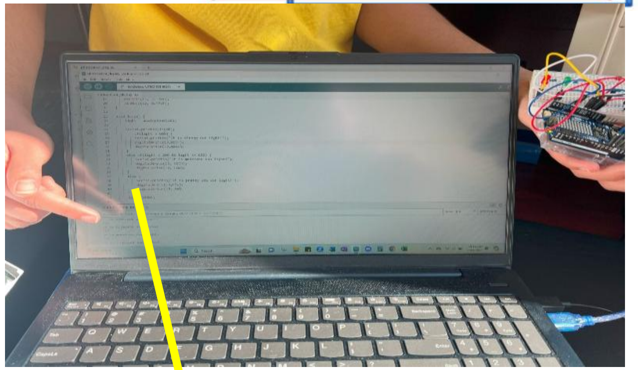
Photo-Voltaic Thermoelectric Generator: Electronics

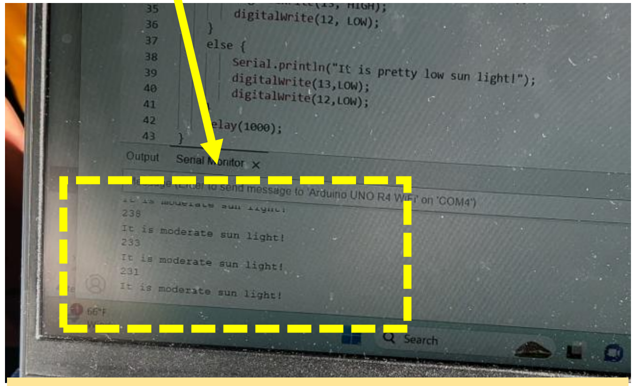
```
void  loop() {
    // put your main code here, to run repeatedly:
    light = analogRead(A0);  // read and save value from PR

    Serial.println(light); // print current  light value

    if(light > 450) { // If it is bright...
        Serial.println("It  is quite light!");
        digitalWrite(13,LOW); //turn left LED off
        digitalWrite(12,LOW);  // turn right LED off
    }
    else if(light > 229 && light < 451) { // If  it is average light...
        Serial.println("It is average light!");
        digitalWrite(13, HIGH); // turn left LED on
        digitalWrite(12,LOW);  // turn right LED off
    }
    else { // If it's dark...
        Serial.println("It  is pretty dark!");
        digitalWrite(13,HIGH); // Turn left LED on
        digitalWrite(12,HIGH);  // Turn right LED on
    }
    delay(1000); // don't spam the computer!
}
```

```
int light = 0; // store the current light value

void setup() {
    // put your setup code here, to run once:
    Serial.begin(9600); //configure  serial to talk to computer
    pinMode(13, OUTPUT); // configure digital pin  13 as an output
    pinMode(12, OUTPUT); // configure digital pin 12 as an output
}
```

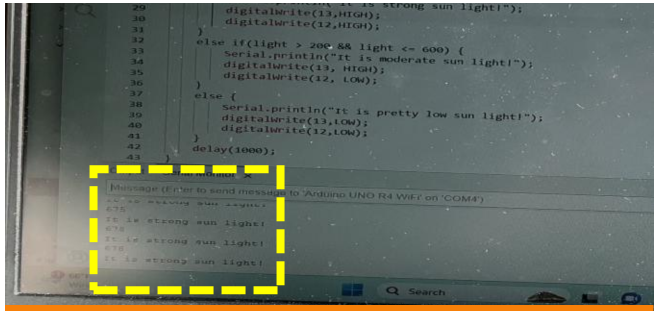








Moderate Light recorded on Arduino serial monitor.

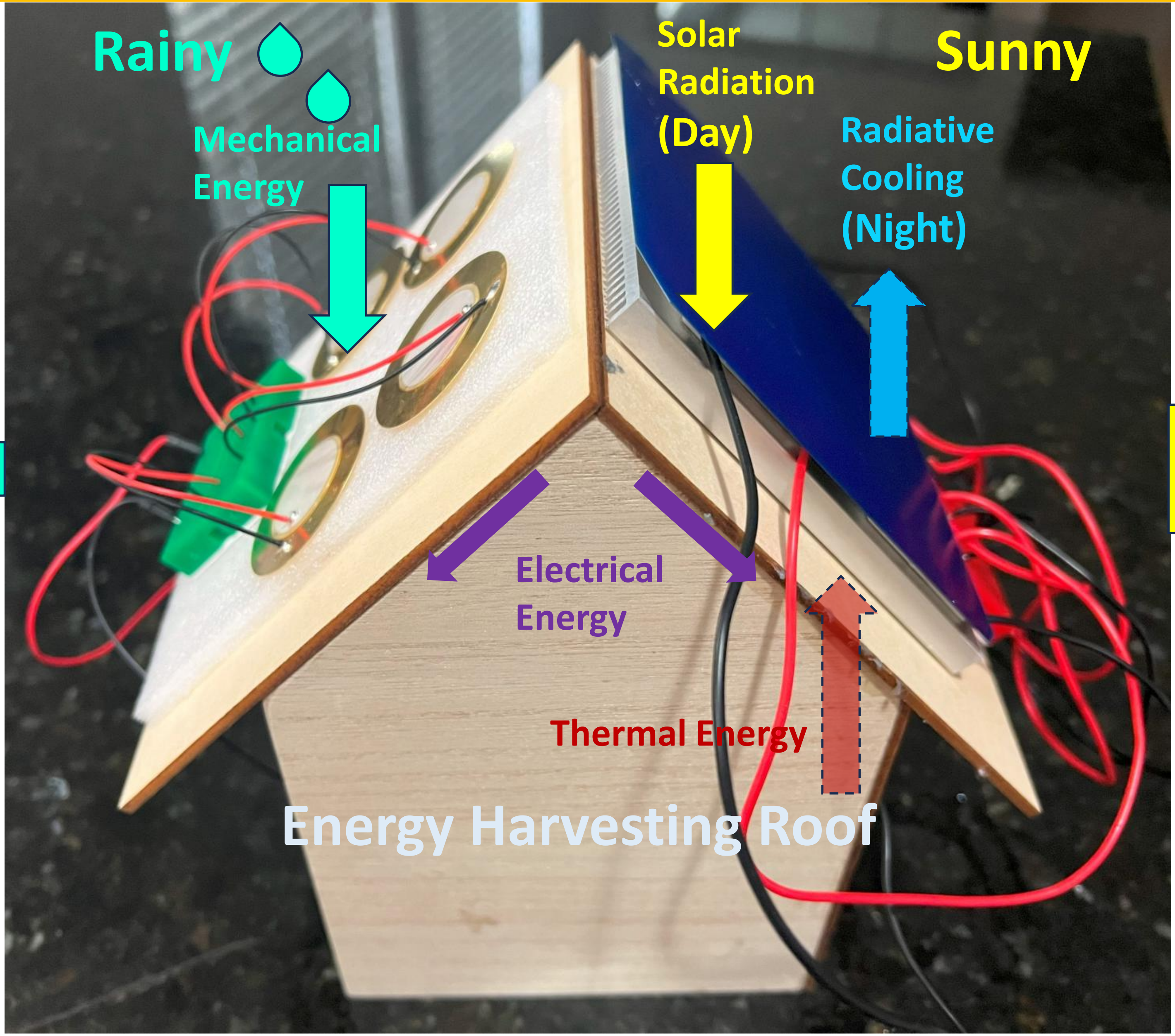


Strong Light shown on Arduino serial monitor

- Arduino Uno R4
- LDR (light dependent resistor) photoresistor
- Breadboard
- Jumper wires
- IDE on laptop

Energy Flow: Final Prototype

A. Piezoelectric Transducer



B. Photo-voltaic Thermoelectric Generator Hybrid (PV-TEG)

Constraints

Piezoelectric Energy Generator

- **Low Power Output** – Energy generated per raindrop is small, limiting power scalability.
- **Intermittent Input** – Rainfall is unpredictable and non-continuous.

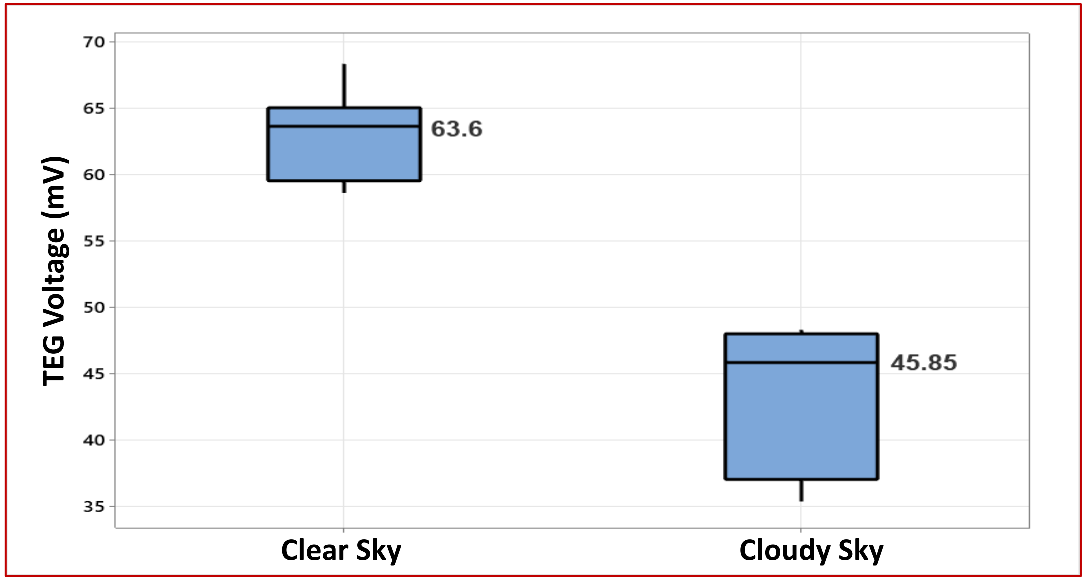
Photovoltaic Energy Generator

- Cannot generate power during stormy and rainy weather

Thermoelectric Energy Generator

- TEG generates low output voltage and power
- Materials with low Seebeck coefficient gives low energy output
- Environmental Factors: Cloudy sky vs clear sky impact power generation.

Box plot: TEG Voltage



Statistics

Variable	Mean	StDev	Minimum	Median	Maximum
Clear Sky	62.97	3.44	58.60	63.60	68.30
Cloudy Sky	43.48	5.55	35.40	45.85	48.30

- TEGs generates **62.97 mV (0.23 mW)** in clear sky, and **43.48 mV (0.11 mW)** in cloudy sky

Conclusions

Summary

1. My Energy Engineering and Design are both unique as they have the potential for clean energy harvesting sustainably day or night, Rain or Shine. No energy efficient roofs like these exists yet.

2. The relative output power from solar is very high when compared to TEG which is low, however the output of PZT is promising and will be useful in areas of rainfall

3. Raindrops, the gift of nature is difficult to be utilized for conventional hydroelectric power due to the relatively low kinetic energy. Converting the kinetic energy of raindrops into electricity before they touch the ground is a very versatile idea

4. The data showed that the impact of simulated rain generated significant electricity & this test can be further used to test impact of wind. This model demonstrates it is possible to make energy from the simplest, most common resources, like sun, rain, waste heat , ambient air and wind.

5. I was able to provide thermal & solar data by Wi-Fi/Bluetooth continuously to a mobile device.

6. Piezoelectric, Photovoltaic & Thermoelectric generators complementarily generate power day or night, rain or shine allowing creativity & flexibility in renewable energy harvesting

Social Value

My Project supports the following **United Nation Sustainable Development Goals**

1. **Affordable Clean Energy-** Piezoelectric**,** Photovoltaics & Thermoelectrics are clean, robust, flexible energy sources that can function in remote areas
2. **Sustainable Consumption and Production Patterns**- Reducing & reusing energy waste
3. **Transport and Deploy**- Light, portable, easy to transport/deploy in comparison to other renewable energy solutions
4. **Sustainability**- Self-sustainable energy source
5. **Climate Action** -Reducing carbon emissions
6. **Protecting** humans, wildlife, and ecosystems

SUSTAINABLE DEVELOPMENT GOALS

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Acknowledgement:

Special thanks to my Engineering teacher at High School. Community Outreach through local library (Santa Clara County) and High School Newsletter