Thermoelectric Heating System for Dew Prevention on Solar Panels in Northern Vietnam

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I. Abstract

This report presents a simulation-based investigation of a thermoelectric heating system designed to prevent dew formation on solar panels in Northern Vietnam. The system utilizes a Thermoelectric Cooler (TEC) operating in reverse as a Peltier heater to raise the surface temperature of tempered glass above the local dew point. Power consumption ranged from 0.176 W at 35°C to 0.515 W at 55°C. The study demonstrates that thermoelectric heating is a viable, solid-state solution for dew prevention in humid subtropical climates.

II. Introduction

In Northern Vietnam, the dew point, which represents the temperature at which air becomes saturated and condensation forms, averages approximately 23.5°C across the year [7].

Dew formation on solar panel surfaces is a significant challenge in humid climates. When water condenses on the surface of a Concentrated Photovoltaic (CPV) panel or a Photovoltaic (PV) panel, it scatters incoming sunlight, reducing the amount of light reaching the photovoltaic cells. This scattering effect can lead to substantial efficiency losses, particularly during early morning hours when dew formation is most prevalent [2]. Additionally, repeated dew cycles can accelerate surface degradation and promote the growth of algae or moss, further reducing panel performance and lifespan [2].

To prevent dew formation, a small and controlled temperature increase of approximately 3-5°C above the dew point is required. A Thermoelectric Cooler (TEC), operating in reverse as a Peltier heater, is an ideal solution for this application. When a DC current passes through alternating P-type and N-type semiconductor legs, the Peltier effect creates a heat flux: one side of the TEC absorbs heat while the opposite side rejects heat [3]. By directing this rejected heat toward the CPV panel's surface, the temperature can be raised above the dew point. This localized heating prevents condensation without the need for moving parts, coolants, or complex control systems. Unlike resistive heaters, a TEC provides thermal management that can be easily modulated with current input, making it highly suitable for the varying seasonal conditions of Northern Vietnam.

The primary objectives of this study were to quantify the electrical power requirements for the custom TEC device.

III. Methodology and Theory

The operation of the TEC is governed by three fundamental thermoelectric effects:

The Peltier Effect is when a DC current passes through a junction of two dissimilar conductors (P-type and N-type semiconductors), and heat is absorbed or released at the junction. This effect is reversible, reversing the current direction reverses the direction of heat flow [3].

The Seebeck Effect is a temperature difference between two junctions of dissimilar conductors that generates a voltage proportional to the temperature difference. This is the operating principle of thermoelectric power generation [3].

Joule heating is the process by which electrical energy is converted into thermal energy when an electric current flows through a conductor. In thermoelectric systems, Joule heating is a parasitic effect that contributes to inefficiency by generating unwanted heat within the P-type and N-type semiconductor legs and the copper interconnects, counteracting the desired Peltier cooling or heating effect [3].

The TEC operates on the Peltier effect: when a DC current *I* passes through a series of alternating P-type and N-type semiconductor legs, heat is absorbed at one junction and rejected at the opposite junction [3]. The heat rejection rate Q_h at the hot side is given by [3][6]:

$$Q_h \approx SIT_h + \frac{1}{2}I^2R - K\Delta T \,, \tag{1}$$

where the first term is heat pumped by the Peltier effect, the second term is the Joule heating, and the third term is the heat conducted to the cold side [6].

$$K = \frac{nkA}{L} \,, \tag{2}$$

where n is the number of thermoelectric pairs, k is the thermal conductivity value, A is the cross sectional area of one semiconductor leg, and L is the length of one semiconductor leg.

The performance of a thermoelectric material is quantified by its figure of merit, defined as [5]:

$$zT = \frac{S^2}{\rho\kappa}T \,, \tag{3}$$

where S is the Seebeck coefficient, ρ is the electrical resistivity, κ is the thermal conductivity, and T is the absolute temperature. A higher zT value indicates better thermoelectric efficiency, as it represents a material's ability to convert thermal energy into electrical energy (or vice versa) with minimal losses [5]. For the P-type and N-type semiconductors used in this study, the Seebeck coefficients were ±0.000187 V/K, with a resistivity of $1.64 \cdot 10^{-5}$ Ω·m and a thermal conductivity of 1.46 $\frac{W}{m \cdot K}$. The zT values at 5 different temperatures were noted in Table 1.

Table 1: zT Values

Temperature (°C)	**zT Value**
35	0.450
40	0.457
45	0.465
50	0.472
55	0.479

Sample calculation of zT value at 35 °C (4):

$$zT = \frac{S^2}{\rho\kappa}T = \frac{(0.000187)^2}{(1.65 \cdot 10^{-5})(1.46)}(308.15) = 0.450 \qquad (4)$$

The frame of the TEC is made of alumina, a thermally conductive, electrically insulating (TCEI) material, to prevent electrical shorting, as each copper plate operates at a different voltage.

IV. Simulation Setup:

A thermal-electric analysis was conducted to determine the electrical power required to achieve the center temperatures that were desired. The current was adjusted until the desired center temperature was reached. The resulting voltage and current were recorded, and power was calculated as:

$$P = V \times I \qquad (5)$$

The following materials were defined or found in the Ansys Library in ANSYS Engineering Data (Table 2):

Table 2: Material Properties

Material	**Density** ($\frac{kg}{m^3}$)	**Specific Heat Constant Pressure** ($\frac{J}{kg \cdot C}$)	**Seebeck Coefficient** ($\frac{V}{K}$)	**Isotropic Thermal Conductivity** ($\frac{W}{m \cdot C}$)	**Isotropic Resistivity** ($\Omega \cdot m$)
P-type Semiconductor	7850	434	0.000187	1.46	$1.64 \cdot 10^{-5}$
N-type Semiconductor	7850	434	-0.000187	1.46	$1.64 \cdot 10^{-5}$
Copper Alloy (found in General Materials)	8300	385	-	401	Not Constant
Alumina 96% (found in Thermal Materials)	3800	880	-	25	-

The TEC Module and Frame were imported into Ansys. They had a radius of 0.018 m and a thickness of 0.002 m. The meshing was done with an element size of 0.0015 m. The end step time was set as 120 seconds.

Table 3 shows the boundary conditions used.

Table 3: Boundary Conditions: Thermal-Electric Analysis

Boundary Condition	**Location**	**Value**
Voltage (Ground)	Terminal 1	0 V
Current	Terminal 2	0.8 - 1.6 A (varied)
Convection	All Exposed Surfaces	10 W/m^2·°C, 23.5°C ambient

Convection values are set for surfaces that will be touching other materials instead of air for simplicity. The heat loss in practice will be lower than in simulation.

V. Results

Electrical Power Requirements

At a current of about 0.85 A and a voltage of 0.207 V (Fig. 2), the center temperature was 35 °C (Fig. 1). The cold side was 30.852 °C.

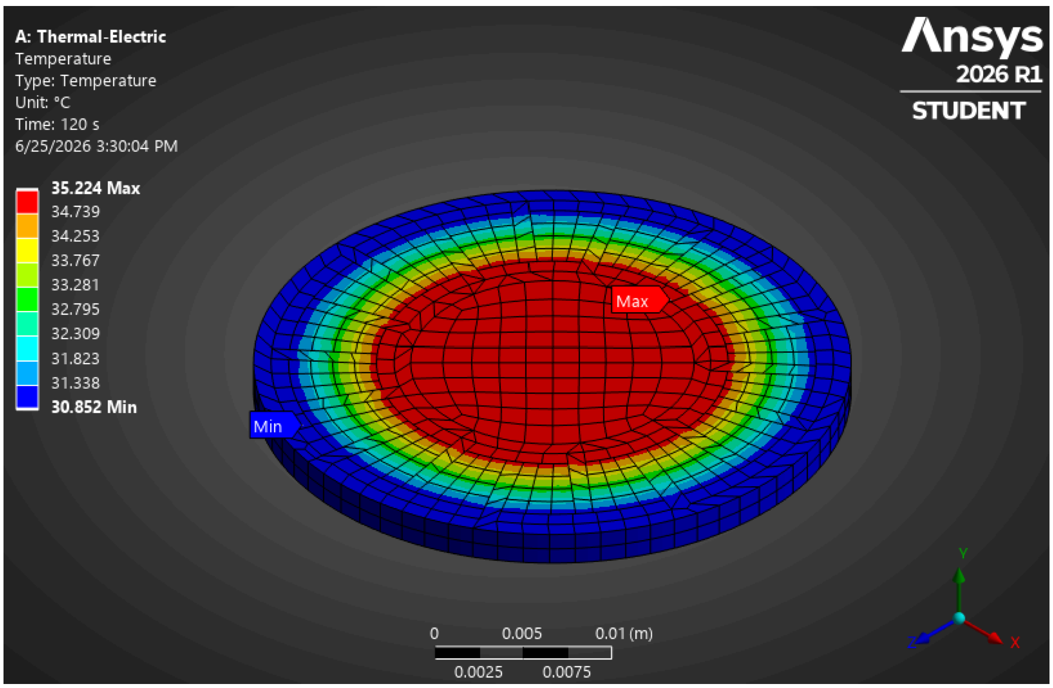

Fig 1: Temperature Analysis at 0.85 A

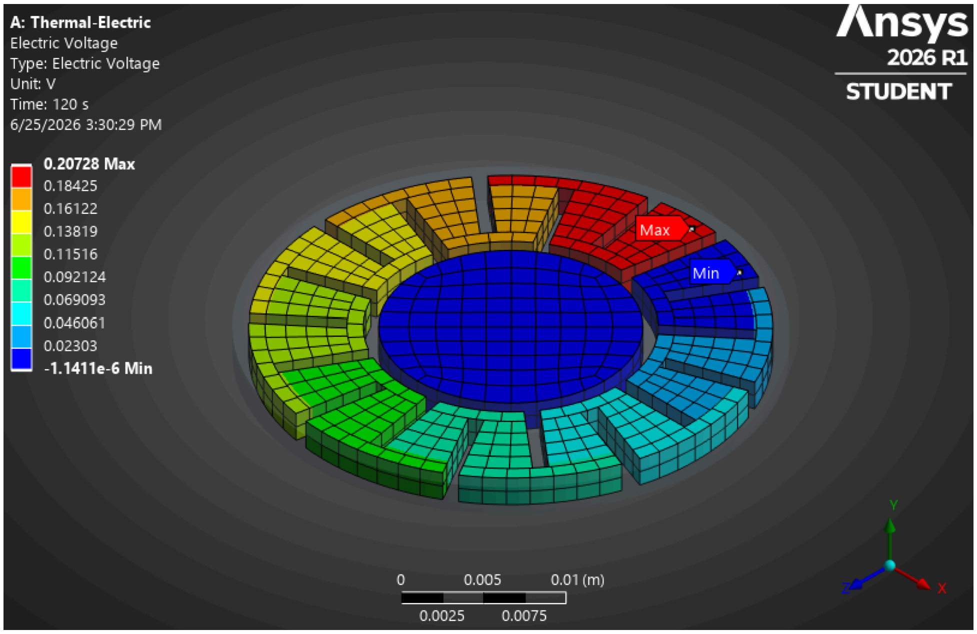

Fig 2: Voltage Analysis at 0.85 A

Fig. 3 shows the current density vector distribution at the interfaces between the semiconductor legs and the copper connectors. The vectors indicate that current density is significantly higher at the edges and corners of the contact regions, with a noticeable concentration at the points where the current enters and exits the semiconductor legs. This phenomenon, known as current crowding [3], occurs due to the abrupt change in electrical conductivity between the copper and the semiconductor materials. The non-uniform current distribution leads to localized Joule heating at these interface regions [3], which can create hot spots and reduce the overall efficiency of the thermoelectric device.

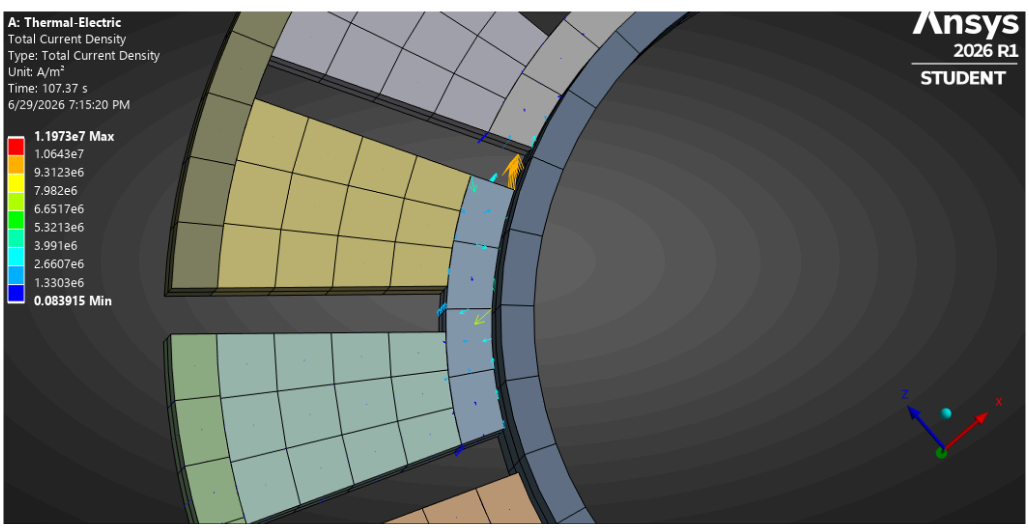

Fig 3: Current Vector Display

At a current of about 1.02 A and a voltage of 0.249 V (Fig. 5), the center temperature was 40 °C (Fig. 4). The cold side was 34.496 °C.

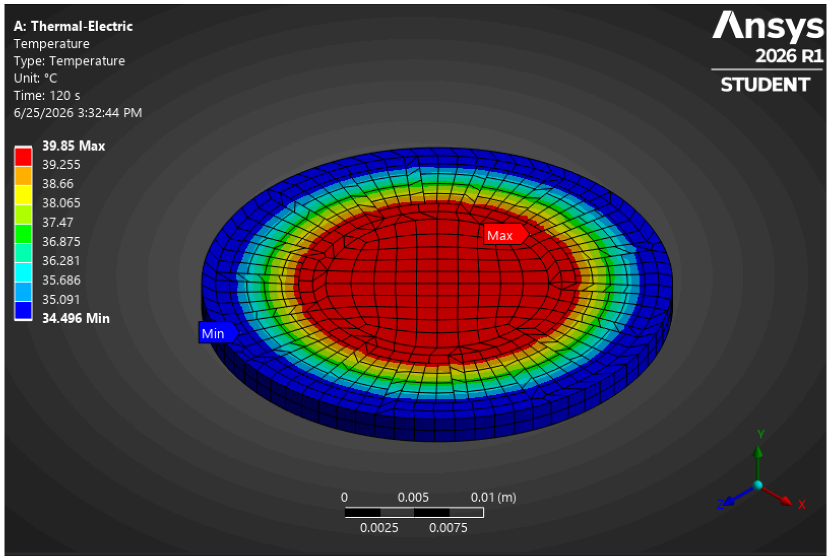

Fig 4: Temperature Analysis at 1.02 A

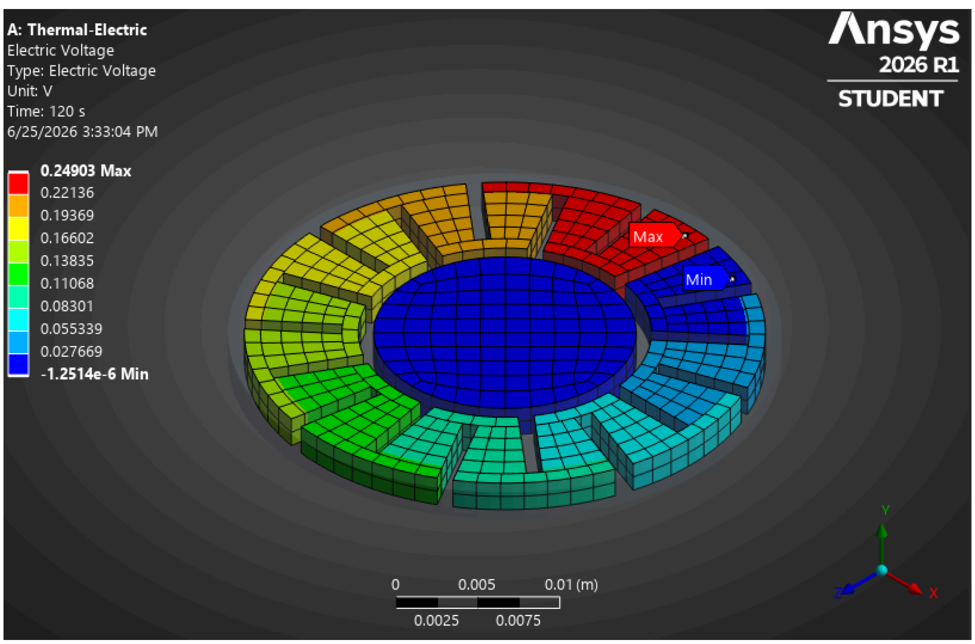

Fig 5: Voltage Analysis at 1.02 A

At a current of about 1.19 A and a voltage of 0.291 V (Fig. 7), the center temperature was 45 °C (Fig 6). The cold side was 38.868 C.

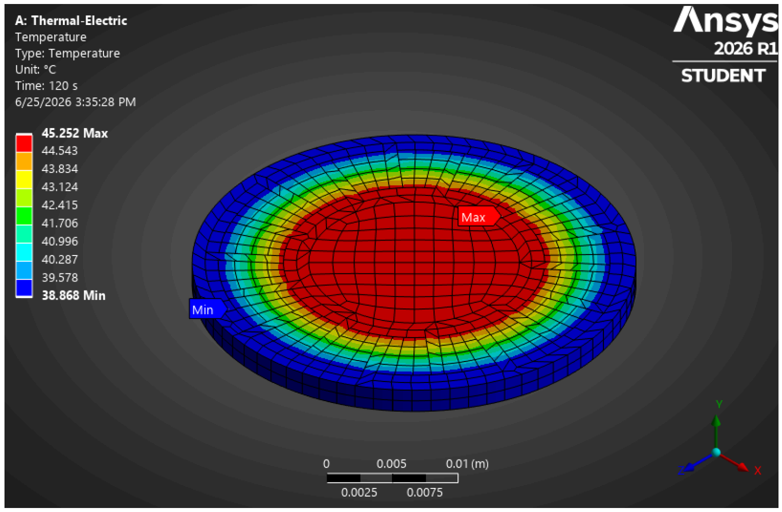

Fig 6: Temperature Analysis at 1.19 A

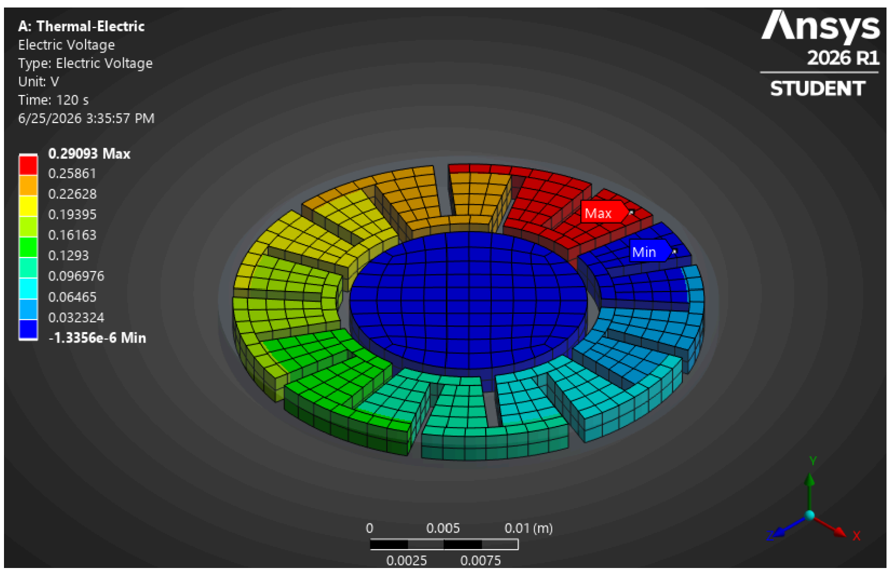

Fig 7: Voltage Analysis at 1.19 A

At a current of about 1.32 A and a voltage of 0.323 V (Fig. 9), the center temperature was 50 °C (Fig. 8). The cold side was 42.704 °C.

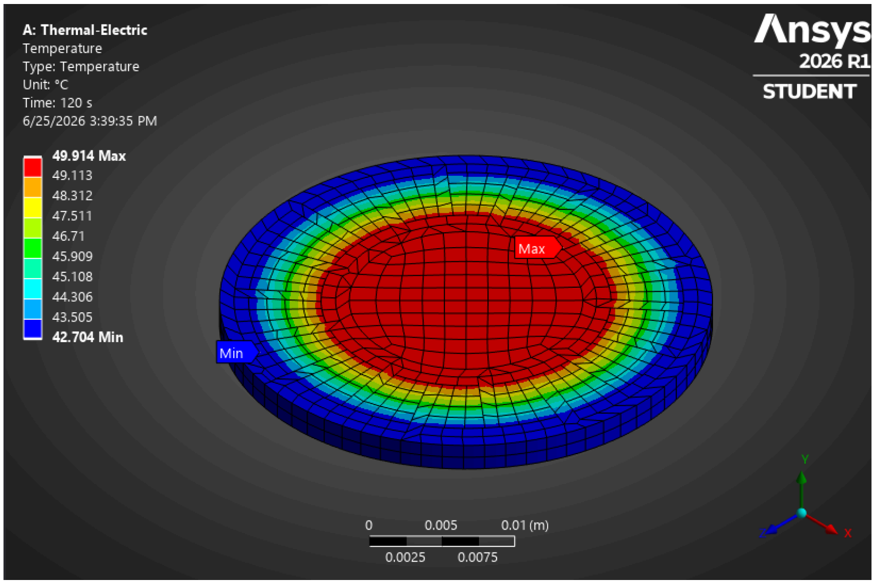

Fig 8: Temperature Analysis at 1.32 A

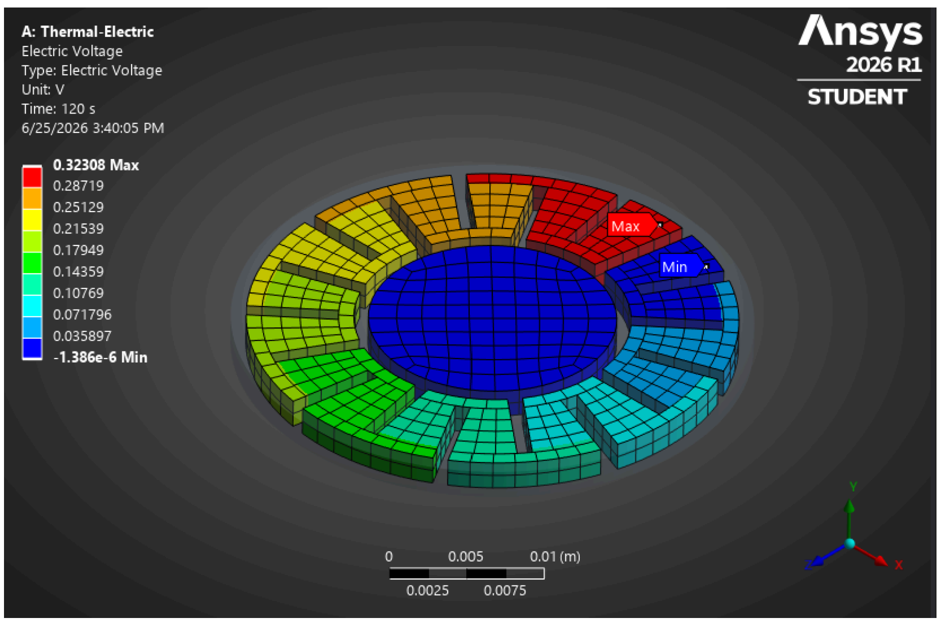

Fig 9: Voltage Analysis at 1.32 A

At a current of 1.45 A and a voltage of 0.355 V (Fig. 11), the center temperature was 55 °C (Fig. 10). The cold side was 46.969 °C.

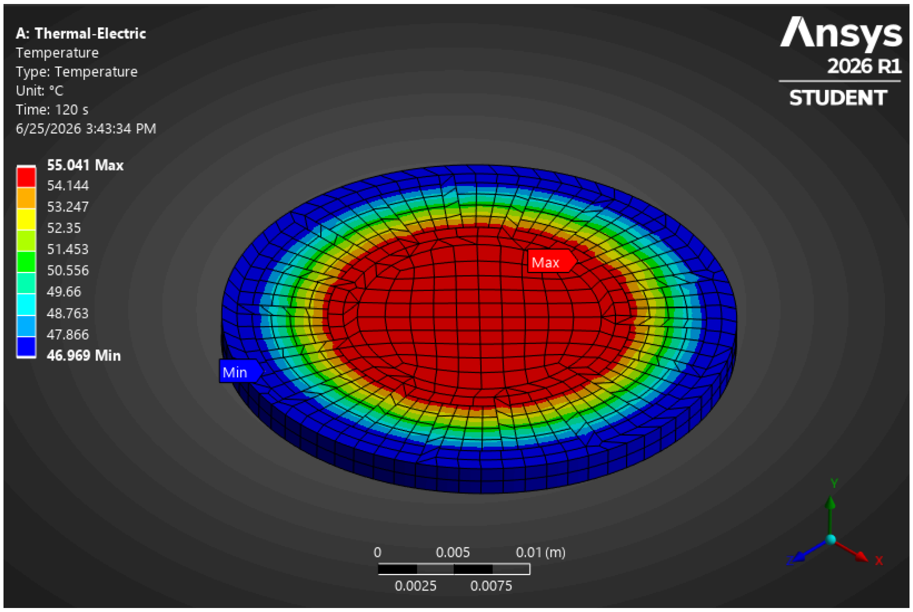

Fig 10: Temperature Analysis at 1.45 A

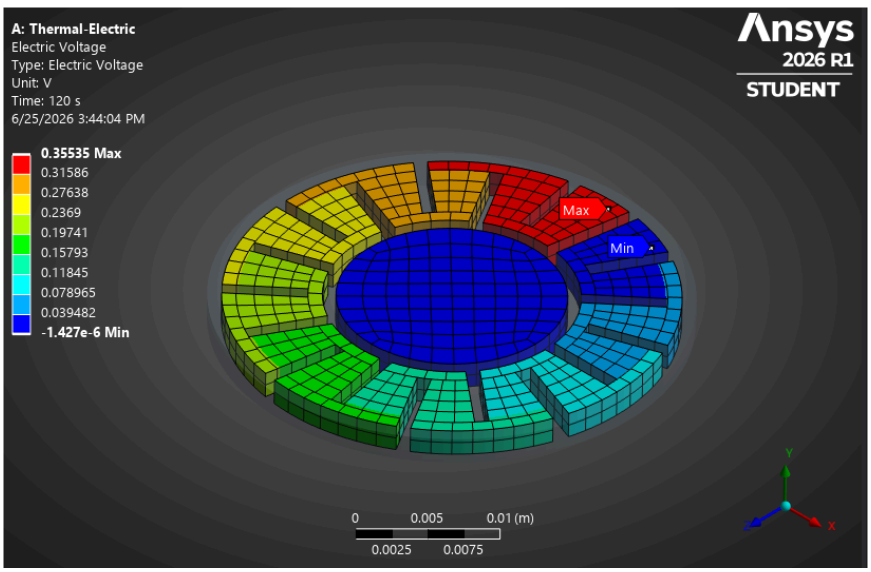

Fig 11: Voltage Analysis at 1.45 A

The electrical power required to maintain each center temperature was calculated and noted in Table 4.

Table 4: Electrical Power Requirements

Center Temperature (°C)	Current (A)	Voltage (V)	Power (W)
35	0.85	0.207	0.176
40	1.02	0.249	0.254
45	1.19	0.291	0.346
50	1.32	0.323	0.426
55	1.45	0.355	0.515

The relationships between voltage, temperature, current, and power were noted in Table 5.

Table 5: Relationships between Voltage, Temperature, Current, and Power

Parameter	Relationship	Equation
Temperature vs. Current	Linear	T ≈ 25I + 13.75
Voltage vs. Current	Linear	$V \approx 0.25I - 0.005$
Power vs. Current	Quadratic	$P \approx 0.25I^2$
Current vs. Temperature	Linear	$I = \frac{T-13.75}{25}$

The coefficient of performance values for each temperature was calculated with eq. (1) and eq. (2), and stored in Table 6.

Table 6: Complete COP Results Across All Temperatures:

Hot Side Temp (°C)	Current (A)	Voltage (V)	Total Qh (W)	Power Input (W)	COP Heating
35	0.85	0.207	0.0641	0.176	0.364
40	1.02	0.249	0.090	0.254	0.354
45	1.19	0.291	0.136	0.346	0.392
50	1.32	0.323	0.166	0.426	0.390
55	1.45	0.355	0.209	0.515	0.406

A sample calculation of the coefficient of performance at 35°C can be seen in eq. (5). The cross-sectional area of the semiconductor leg varies. So, the average of the biggest cross-sectional area ($8.440\cdot 10^{-6}\, m^2$), and the smallest cross-sectional area ($4.947\cdot 10^{-6}\, m^2$), was $6.6935\cdot 10^{-6}\, m^2$.

The length of the semiconductor leg was 0.005 m, the number of thermoelectric pairs was 9, and the thermal conductivity value was 1.46 $\frac{W}{m\cdot K}$. The temperature differential in Kelvin was 4.148 K.

$$K = \frac{nkA}{L} = \frac{(9)(1.45)(6.6935e-6)}{0.005} = 0.01759\, \frac{W}{K}$$

$$SIT_h = (0.000187)(0.85)(308.15) = 0.0490\, W$$

$$\frac{1}{2}I^2R = \frac{1}{2}(0.85)^2(\frac{.207}{0.85}) = 0.088\, W,$$

so,

$$Q_h \approx SIT_h + \frac{1}{2}I^2R - K\Delta T = 0.0490 + 0.088 - 0.01759(4.148) = 0.0641\, W$$

$$COP = \frac{Q_h}{P} = \frac{0.0641}{0.176} = 0.364 \tag{6}$$

VI. Discussion

Relationship Between Temperature and Power

The power required to maintain higher center temperatures increased from 0.176 W at 35°C to 0.515 W at 55°C, a 2.9 times increase in power consumption.As the TEC operates at higher temperatures, the Peltier effect becomes less efficient, and more power is dissipated as Joule heating, contributing to the diminishing returns observed.

Comparison to Commercial TEC Specifications

To contextualize the performance of the custom TEC design used in this study, its simulated performance was compared to a commercially available thermoelectric cooler [4] with the specifications shown in Table 5.

Table 5: Pundit TEC1-12706 3 2025 12 Performance Specifications [4]

Parameter	**25°C**	**50°C**
Qmax (W)	50	57
ΔTmax (°C)	66	75
Imax (A)	6.4	6.4
Vmax (V)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30

Table 6: Simulated Custom TEC Performance

Parameter	**35°C**	**40°C**	**45°C**	**50°C**	**55°C**
Current (A)	0.85	1.02	1.19	1.32	1.45
Voltage (V)	0.207	0.249	0.291	0.323	0.355
Hot Side Temperature (°C)	35	40	45	50	55
Cold Side Temperature (°C)	30.852	34.496	38.868	42.704	46.969
Temperature Difference (ΔT)	4.148	5.505	6.132	7.296	8.031
Power (W)	0.176	0.254	0.346	0.426	0.515

The custom TEC design operates at significantly lower current and voltage levels (Table 6) than the commercial module. While the commercial module requires 6.4 A to achieve its rated performance, the custom design achieves its target hot side temperatures (35–55°C) with currents ranging from only 0.85 A to 1.45 A. This represents a current reduction of approximately 77–87% compared to the commercial module. Similarly, the custom design operates at voltages between 0.207 V and 0.355 V, compared to 14.4 V for the commercial module, a voltage reduction of over 97%.

The commercial module consumes 92.16 W at 25°C (14.4 V × 6.4 A) and 104.96 W at 50°C (16.4 V × 6.4 A). In contrast, the custom TEC design consumes between 0.176 W and 0.515 W, depending on the operating temperature. This represents a power reduction of over 99% compared to the commercial module.

The custom TEC design operates with a relatively small temperature difference between its hot and cold sides, ranging from 4.148°C at 35°C hot side temperature to 8.031°C at 55°C hot side temperature. This small ΔT is a direct result of the application-specific design: since the TEC is used in heating mode rather than cooling mode, there is no need to pump heat against a large temperature gradient. The cold side remains close to the hot side temperature, only 4–8°C cooler. In contrast, the commercial module is designed to maintain a large ΔT of up to 75°C, which requires significantly more electrical power to achieve.

The COP (0.35–0.41) and ZT (around 0.45) values are consistent with thermoelectrics. While the efficiency is moderate, the absolute power consumption is low (0.176–0.515 W), making the system viable for dew prevention where only a small temperature rise is required.

VII. Conclusion

This study investigated a thermoelectric heating system for dew prevention on solar panels in Northern Vietnam. The following conclusions were drawn:

- Power consumption increases from 0.176 W at 35°C to 0.515 W at 55°C, a 2.9 times increase.
- Thermoelectric heating is a viable, solid-state solution for dew prevention on solar panels in humid subtropical climates. The system operates without moving parts, responds instantly to current adjustments, and can be optimized for varying seasonal conditions.

Limitation

The simulation results assume steady-state conditions with constant convection. In practice, heat extracted from the hot side to warm the panel surface requires additional power to compensate. Real-world operation may require higher power input.

Recommendations for Future Work

Future work should incorporate seasonal variations in ambient temperature and convection coefficients for more accurate power predictions. (One limitation of this study is that the convection film coefficient was kept constant at 10 $W/m^2 \cdot °C$ across all simulations.) Physical experiments should be conducted to validate the simulation results. Investigation of non-shading heat spreading materials applied onto solar panel surfaces should be conducted. Direct simulation and experimental validation of the TEC heating system on actual PV and CPV panels should be conducted. A simulation considering the additional power needed for keeping the center heat constant should be done.

VIII. References

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