Thermoelectric Heating System for Dew Prevention on Solar Panels using Transparent Graphene Film to Spread Heat

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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 using Ansys. 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. A thin layer of graphene with high thermal conductivity is used to spread the heat. This layer is non-shading, allowing all parts of the solar panel to continue getting solar energy.

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 [8].

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 [3]. Additionally, repeated dew cycles can accelerate surface degradation and promote the growth of algae or moss, further reducing panel performance and lifespan [3].

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 [4]. 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.

Graphene is a single atomic plane of sp^2-bound carbon that has thermal conductivity of 3000-5000 W m^{-1} K^{-1} at room temperatures [2][5].

The primary objectives of this study were to find relationships between the area of glass raised 5 °C above the dew point and power consumption.

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 [4].

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 [4].

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 [4].

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 [4]. The heat rejection rate Q_h at the hot side is given by [4][7]:

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

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 [7].

$$K = \frac{nkA}{L} \, , \quad (2)$$

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 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.

Graphene is a single layer of carbon atoms arranged in a hexagonal lattice. It is one of the most promising materials for thermal conductivity since its isolation in 2004. Theoretical thermal conductivity values reach up to 5300 W m^{-1} K^{-1} [2][5][6].

IV. Simulation Setup:

A thermal-electric analysis was conducted to determine the area of the glass heated 5 °C above the dew point at different current levels. The resulting voltage, area, current, and temperature were recorded, and power was calculated as:

$$P = V \times I \quad (3)$$

The following materials were defined or found in the Ansys Library in ANSYS Engineering Data (Table 1):

Table 1: Material Properties

Material	**Seebeck Coefficient** $(\frac{V}{K})$	**Isotropic Thermal Conductivity** $(\frac{W}{m \cdot C})$	**Isotropic Resistivity** $(\Omega \cdot m)$
P-type Semiconductor	0.000187	1.46	$1.64 \cdot 10^{-5}$
N-type Semiconductor	-0.000187	1.46	$1.64 \cdot 10^{-5}$
Copper Alloy (found in General Materials)	-	401	Not Constant
Alumina 96% (found in Thermal Materials)	-	25	-
Graphene	-	3000	-
PCB laminate, Epoxy/Glass fiber (found in Granta Design typical Materials)	-	0.4899	$1 \cdot 10^{13}$
Glass (found in Thermal Materials)	-	1.4	-
Aluminium Alloy (found in General Materials)	-	Not Constant	Not Constant

A 4 mm thick, 1 x 1 m plane of glass was created in AutoCAD, with the TEC placed in the center of it. A thermally conductive transparent graphene layer that was 1 x 1 m and 0.00003 m (30 micrometers) thick, was created. Having a very thin layer of graphene ensured that it would be transparent. A hole was cut out in the graphene to allow the aluminium center TEC piece to connect to the conductive graphene layer, and maximize the heated area of the glass.

A fiberglass cap that surrounded all parts of the TEC by 2 mm was created for thermal insulation (Fig. 1).

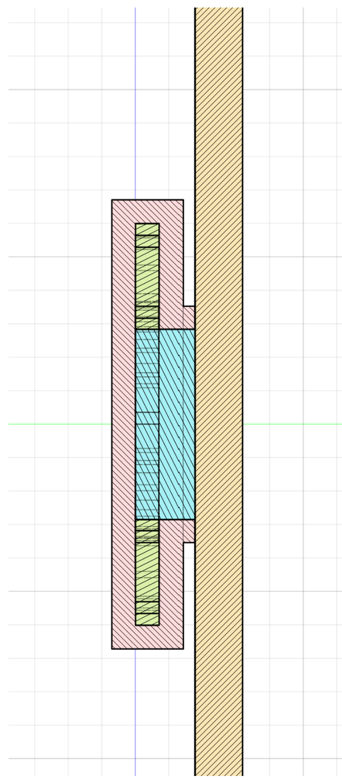

Fig 1: Cross-sectional View of Parts

The TEC Module and Frame were imported into Ansys [1]. The meshing was done with an element size of 0.0015 m with hard behavior for the more detailed TEC parts. This allowed all the meaningful semiconductor junctions to be connected precisely. The meshing was done with an element size of 0.018 with soft behavior for the glass and graphene layers. The environment temperature was set to 23.5 °C, the dew point. The end step time was set as 5000 seconds, because at 5000 seconds the heated area stops expanding significantly.

Convection values were assigned to all the faces that touched air (Table 2). One terminal of the TEC was grounded, and the other was set as the current source (Table 2).

Table 2: Boundary Conditions: Thermal-Electric Analysis

Boundary Condition	**Location**	**Value**
Voltage (Ground)	Terminal 1	0 V
Current	Terminal 2	5 - 7 A (varied)
Convection	The exposed Graphene surface, the exposed fiberglass cap	2 W/m²·°C, 23.5°C ambient

V. Results

The area heated 5 °C above the dew point was measured by setting the geometry of the temperature solution as capped Isosurfaces, and making the bottom boundary 28.5 °C. Since the shape of this area was a circle, the area was calculated based on the radius heated.

At 4 A, the TEC had a maximum voltage of 0.9485 V (Fig. 3). A radius of 0.13 m was heated 5 °C above the dew point, with a total area of 0.05309 m^2 (Fig. 4). The center temperature reached a maximum of 48.214 °C (Fig. 2).

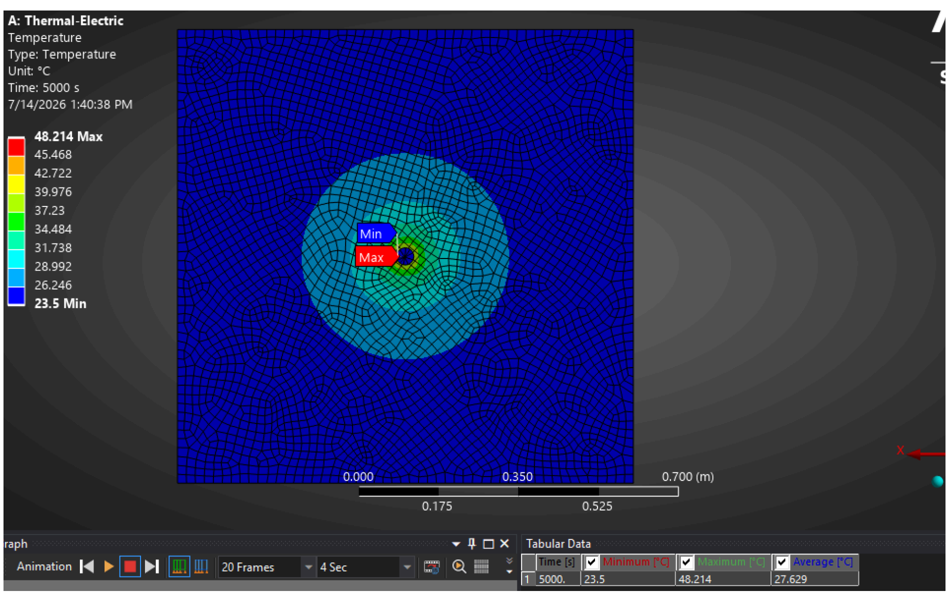

Fig 2: Temperature Results of TEC at 4 A

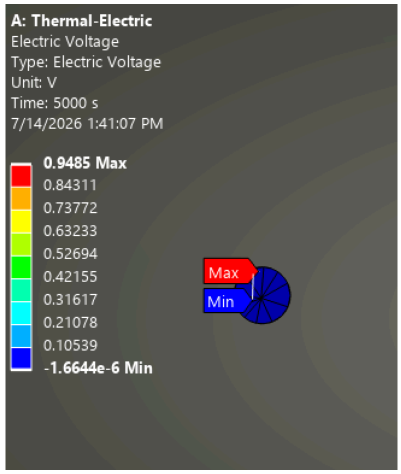

Fig 3: Voltage Results of TEC at 4 A

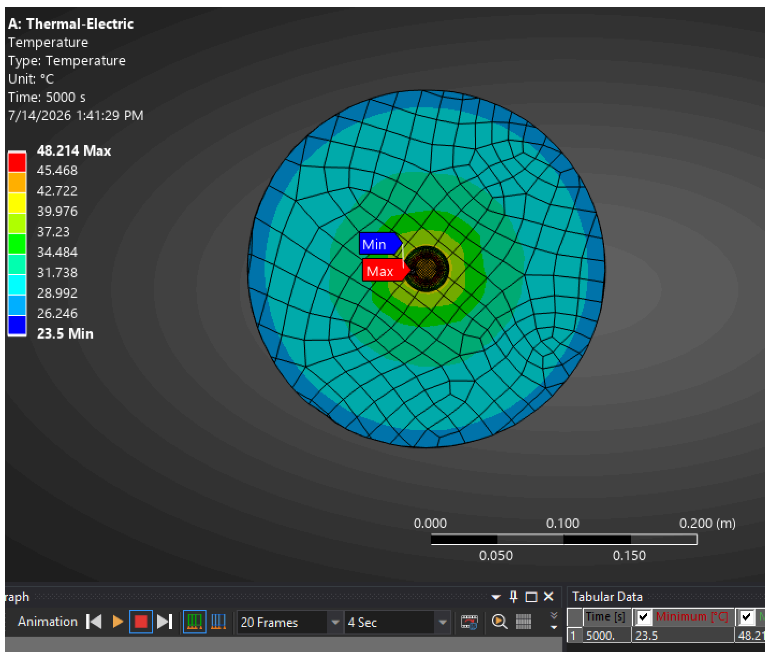

Fig 4: Heated Area at 4 A

At 5 A, the TEC had a maximum voltage of 1.1805 V (Fig. 6). A radius of 0.2 m was heated 5 °C above the dew point, with a total area of 0.12566 m^2 (Fig. 7). The center temperature reached a maximum of 63.321 °C (Fig. 5).

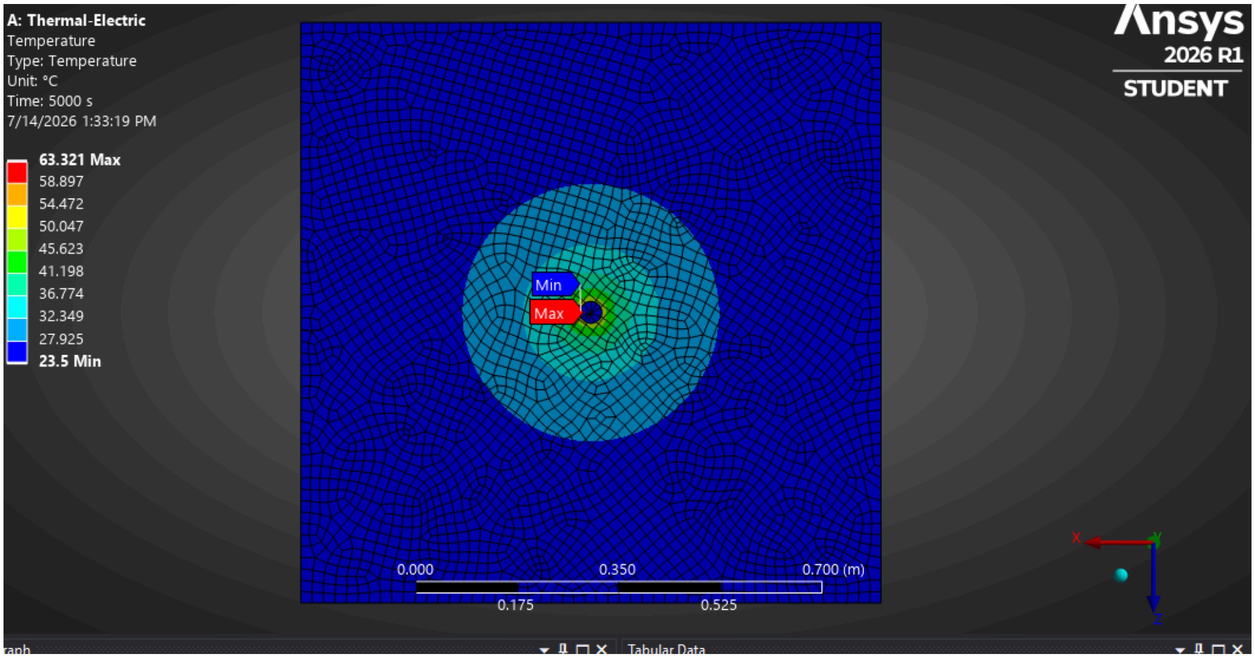

Fig 5: Temperature Results of TEC at 5 A

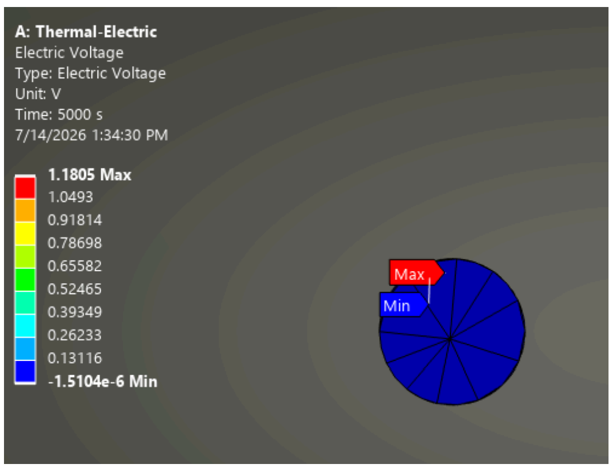

Fig 6: Voltage Results of TEC at 5 A

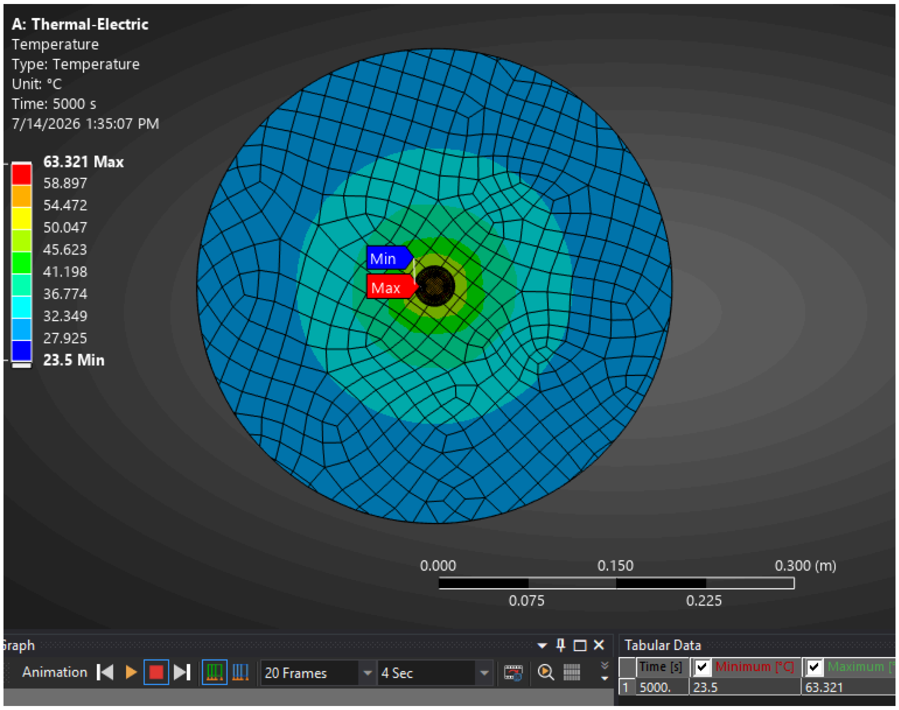

Fig 7: Heated Area at 5 A

At 6 A, the TEC had a maximum voltage of 1.4114 V (Fig. 9). A radius of 0.27 m was heated 5 °C above the dew point, with a total area of 0.22902 m^2 (Fig. 10). The center temperature reached a maximum of 82.168 °C (Fig. 8).

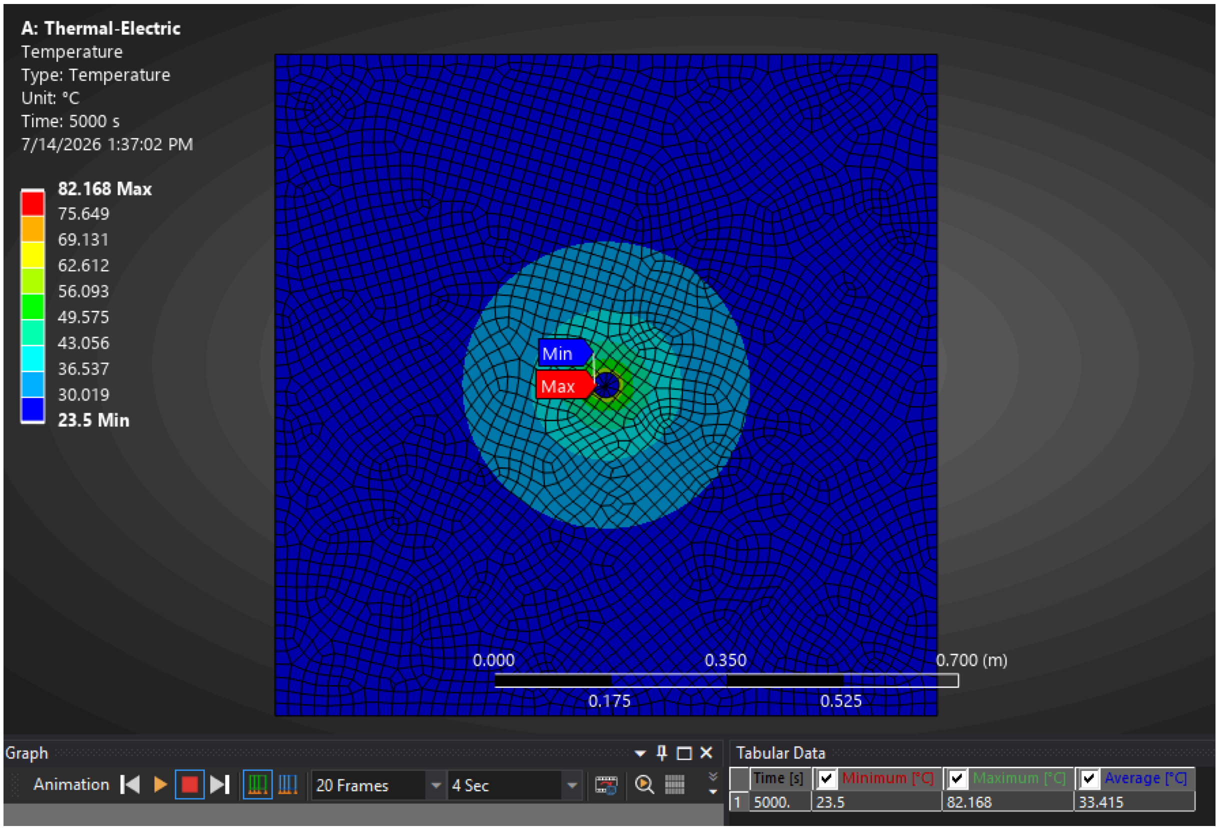

Fig 8: Temperature Results of TEC at 6 A

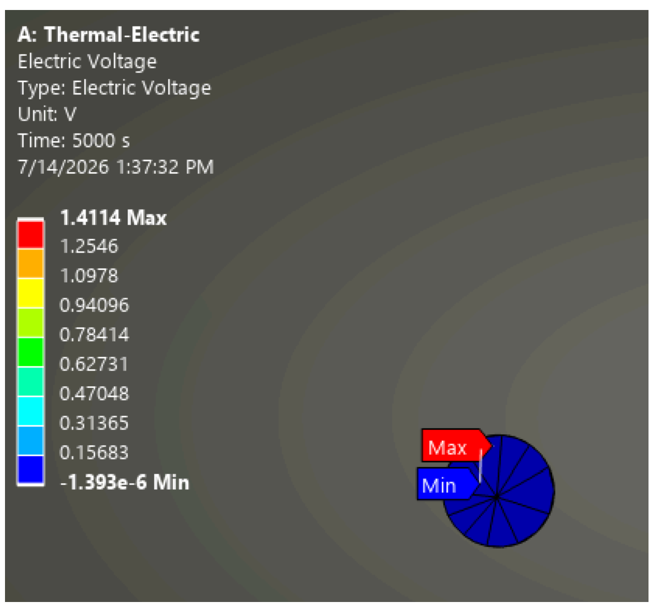

Fig 9: Voltage Results of TEC at 6 A

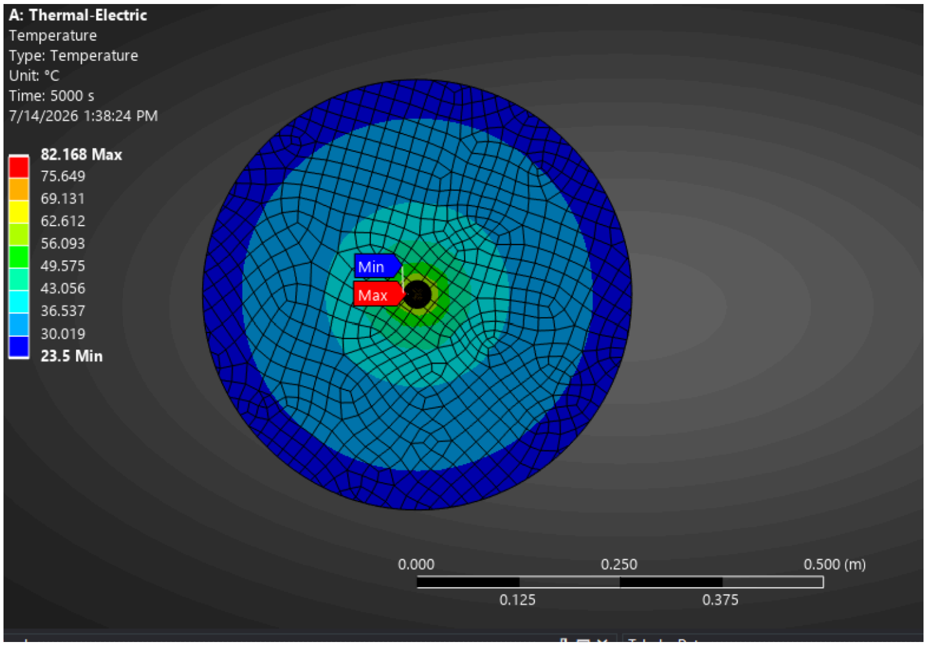

Fig 10: Heated Area at 6 A

At 7 A, the TEC had a maximum voltage of 1.6418 V (Fig. 12). A radius of 0.34 m was heated 5 °C above the dew point, with a total area of 0.36317 m^2 (Fig. 13). The center temperature reached a maximum of 104.52 °C (Fig. 11).

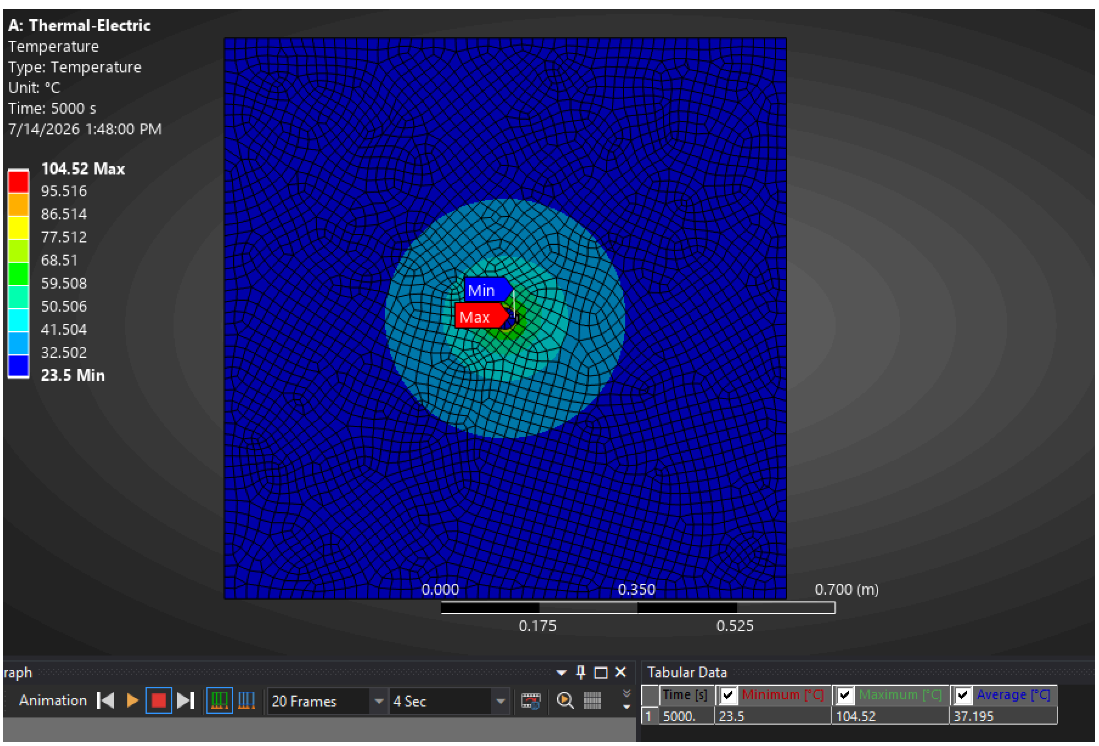

Fig 11: Temperature Results of TEC at 7 A

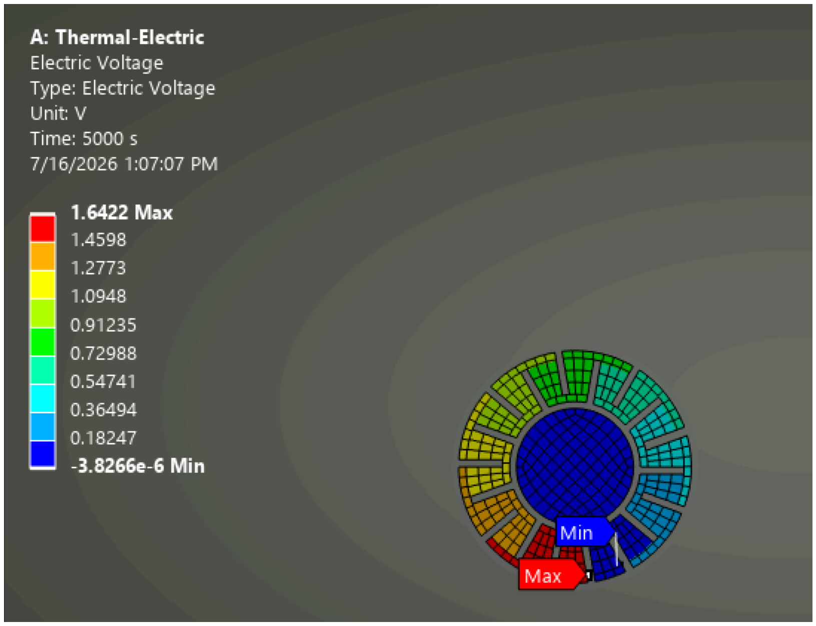

Fig 12: Voltage Results of TEC at 7 A

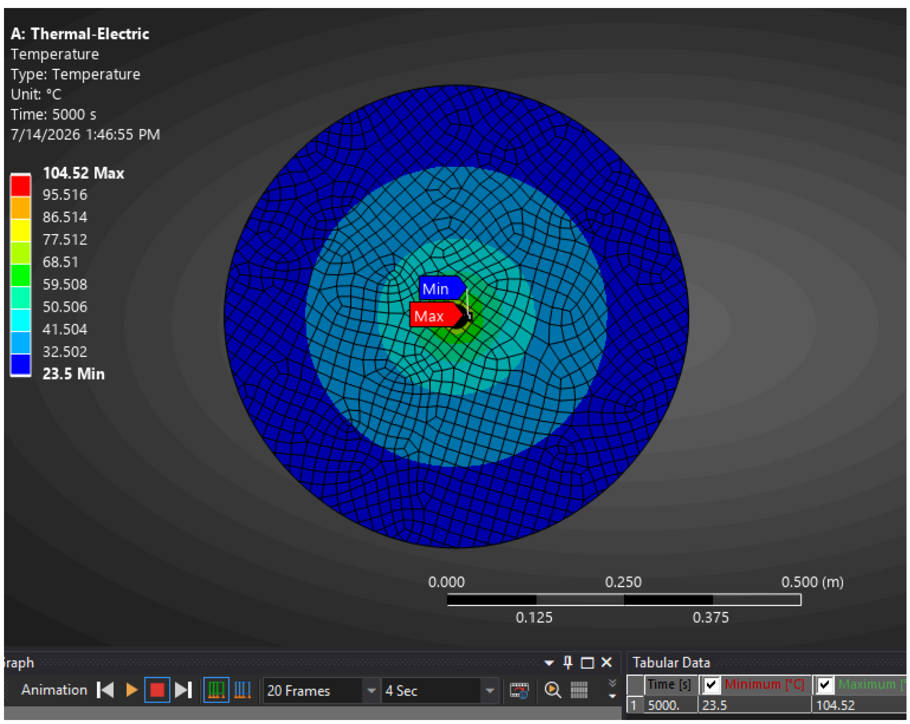

Fig 13: Heated Area at 7 A

VI. Discussion

As the current increased by 1 amp, the heated radius increased by 0.07 m, and the heated area increased exponentially (Table 3). As the current increased, the power increased exponentially (Table 3).

Table 3: Electrical Power Requirements

Maximum Temperature (°C)	**Current (A)**	**Maximum Voltage (V)**	**Power (W)**	**Area Heated Above Dew Point (m^2)**
48.214	4	0.9485	3.794	0.05309
63.321	5	1.1805	5.9025	0.12566
82.168	6	1.4114	8.4684	0.22902
104.52	7	1.6418	11.4926	0.36317

At higher temperatures, the heated area per watt is maximized. The 11.4926 W system is the most efficient out of the four trials tested, covering 0.03160 m^2 per Watt (Table 4).

Table 4: Efficiency of Different Power Levels

Temperature (°C)	**Power (W)**	**Star Area (m^2)**	**Area per Watt (m^2/W)**
48.214	3.794	0.05309	0.01399
63.321	5.9025	0.12566	0.02129
82.168	8.4684	0.22902	0.02704
104.52	11.4926	0.36317	0.03160

The simulated glass panel (1 m × 1 m) represents approximately half of a commercial solar panel. The heated area achieved at 11.4926 W represents approximately 18% of the panel surface. For a full 2 × 1 m panel (2.0 m^2), 5 to 6 TEC units would be required to achieve full coverage (57.463 W - 68.9556 W).

It should be noted that at high temperatures such as 104.52 °C, the TEC parts are at risk of getting damaged. Even though all parts have a melting point above 200 °C, caution should be taken when testing high temperatures in physical experiments.

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 3.794 W heating an area of 0.05309 m^2**,** to 11.4926 W heating an area of 0.36317 m^2**.**
- The heated area per Watt value becomes significantly higher at higher current levels. In order to keep power consumption at a minimum, higher current levels should be considered.
- 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 conditions with constant convection. In practice, film coefficient values of air vary as seasons change. The simulation also assumed conditions with a single ambient temperature value, 23.5 °C. In practice, this value would constantly fluctuate between 18 °C to 30 °C [8].

Recommendations for Future Work

Future work should incorporate seasonal variations in ambient temperature and convection coefficients for more accurate power predictions. 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.

VIII. References

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