TECHNICAL CASE STUDY
Thermoelectric Control · Transient CFD

Transient TEC-Based Lid Thermal Control with CFD Validation

At a Glance

Advanced Thermal Solutions, Inc. (ATS) designed and validated a compact thermoelectric cooling assembly for the lid of a bioscience fluidics station. The system controlled a sample cartridge interface across a 22°C to 75°C range at 25°C ambient, including operation at 2,300 m altitude.

CUSTOMER OVERVIEW

The customer was developing a bioscience fluidics station requiring tightly controlled sample cartridge temperatures inside a compact lid assembly. The design needed fast bidirectional thermal control with accurate sensing and stable performance across lab conditions and altitude (Figure 1).

- Compact lid-integrated thermal control architecture
- Bidirectional thermal control using a TEC assembly
- Performance maintained at altitude and across typical lab humidity conditions

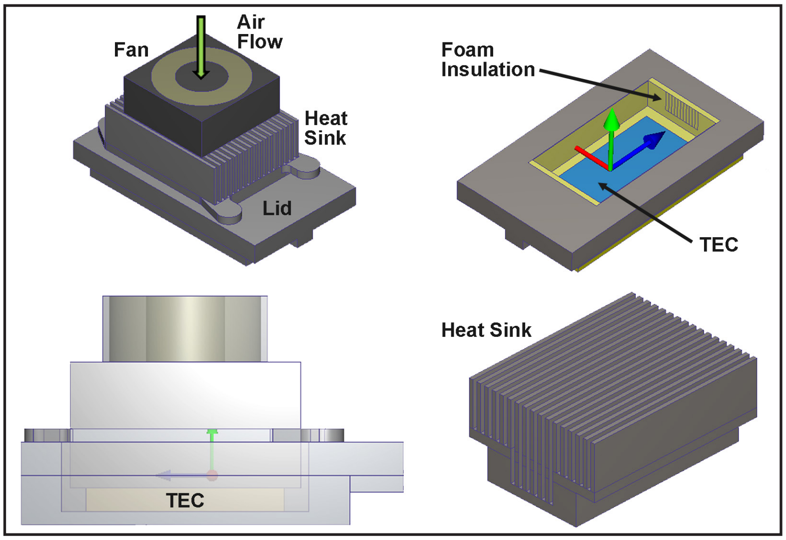

Figure 1. CFD Model Generated for Developing Cooling Method

CHALLENGE

The system needed to control the sample cartridge interface from 22°C to 75°C at 25°C ambient, while also performing reliably at 2,300 m altitude. The core challenge was creating a compact design that could transition quickly between heating and cooling, support precise thermistor feedback, and use different airflow strategies for each mode.

System architecture and components:

- TEC: ATS-TEC15-15-246 (15 × 30 mm)
- Heat sink: Aluminum 6061
- Fan: 12/24V PWM axial (Sunon MF25101V1-1000U-G99)
- TIM: Parker Chomerics T670 thermal grease
- Thermistors: NTC 10K@25°C on hot and cold sides
- Ambient: 25°C
- Relative humidity: 20–80%
- Altitude: 2,300 m

The design had to reach the required temperature extremes with acceptable ramp rates and a practical switching strategy between cooling and heating modes.

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METHODOLOGY

ATS used transient CFD modeling to evaluate the lid assembly in cooling and heating modes (Figures 2 & 3). Separate scenarios captured the behavior of the TEC, heat sink, thermistors, insulation, and airflow under forced-convection and buoyancy-driven conditions.

Model Integrity and CFD Setup

- Cooling scenario:
  235,232 nodes and 863,984 elements
- Heating scenario:
  26,768 nodes and 91,983 elements
- Maximum aspect ratio remained below 100 for numerical stability
- Altitude-adjusted air properties were incorporated into the boundary conditions

Scenario Definitions

- **Scenario 1** – Cooling: 75°C down to 22°C, fan on, transient 180 sec, input current 2.0 A
- **Scenario 2** – Heating: 22°C up to 75°C, fan off, transient 180 sec, input current 2.1 A
- Cooling used the manufacturer fan curve
- Heating relied on buoyancy-driven flow with fan disabled

This approach validated ramp-rate behavior, thermistor placement, and mode-specific airflow effects across the operating range.

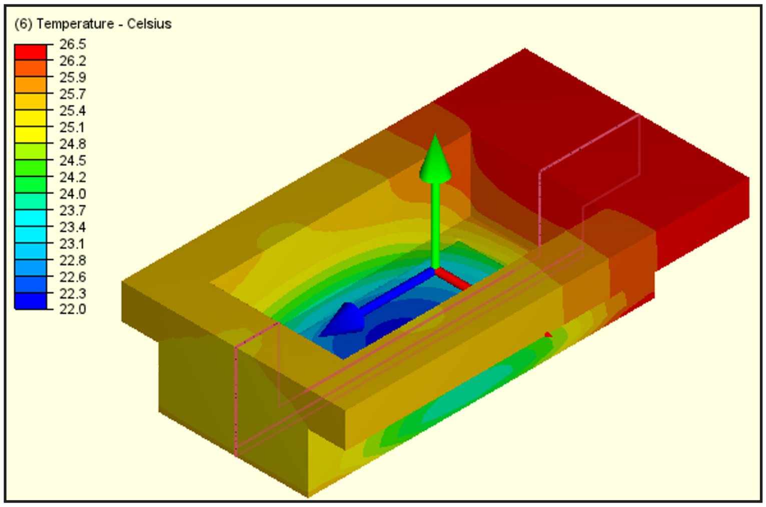

Figure 2. Temperature Contour Study Inside System Lid

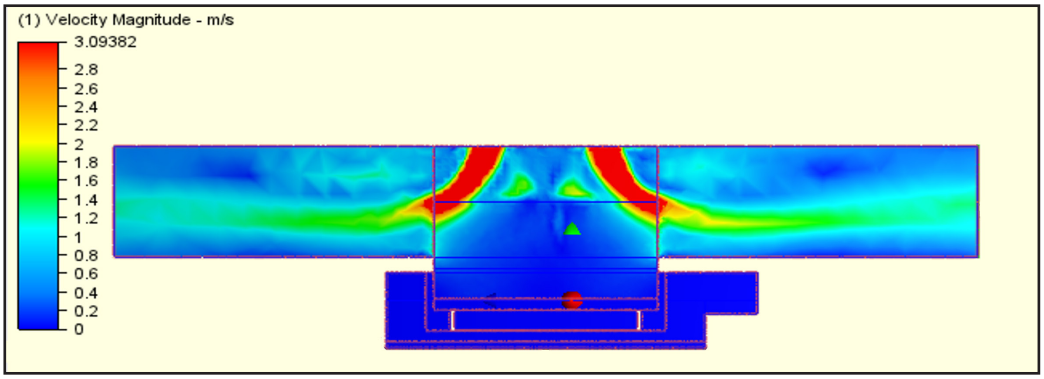

Figure 3. Cooling Transient Velocity Contour

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SOLUTION

ATS developed an integrated TEC-based lid architecture (Figure 4) combining a compact thermoelectric module, aluminum heat sink, optional PWM axial fan, foam insulation, thermistor feedback, and high-performance thermal grease. The control strategy used fan-assisted forced convection for cooling and fan-off natural convection for heating to maximize ramp performance in each direction.

- Integrated a compact TEC assembly into the lid structure
- Used aluminum heat sinking and high-performance TIM for efficient coupling
- Placed hot-side and cold-side thermistors for closed-loop control support
- Applied foam insulation to reduce parasitic thermal losses
- Used the fan to improve cooling ramp performance
- Disabled forced airflow during heating to improve warm-up rate
- Required polarity reversal to switch between heating and cooling modes

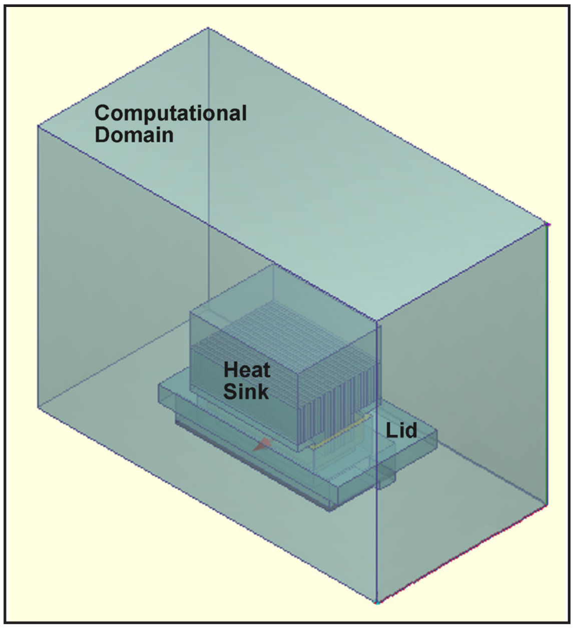

Figure 4. CFD Model Used for Heating the System Lid from 22°C to 75°C with the Fan Turned Off

This created a practical thermal control solution capable of fast transitions, accurate sensing, and operation across the target range and environmental conditions.

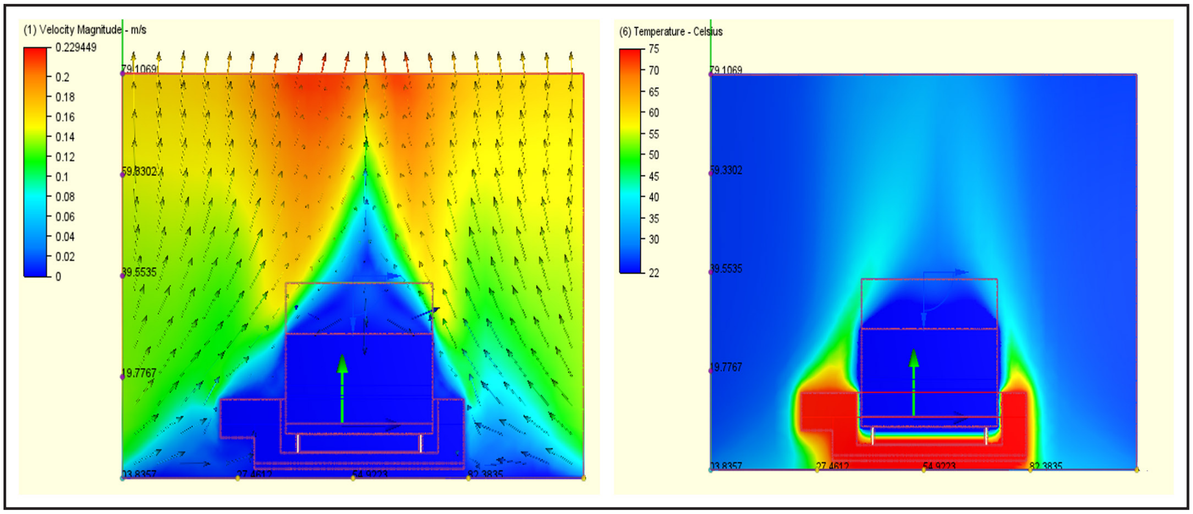

Figure 5. Velocity and Temperature Contours Showing Heating Performance After 100 Seconds

RESULTS & DATA

The transient CFD study confirmed that the lid system could achieve the required thermal range and ramp performance in both directions (Figure 5).

Cooling results:

- Cooling transient duration evaluated over 180 seconds
- At 120 seconds: lid maximum 26.5°C and minimum 22°C
- Cooling ramp rate: approximately 0.44 °C/sec at the thermistor location
- Velocity contours confirmed forced convection through the fin field

Heating Results:

- Heating transient duration evaluated over 180 seconds
- At 85 seconds: lid maximum 76°C and minimum 67°C
- Heating ramp rate: approximately 0.55 to 0.66 °C/sec
- Faster heating was achieved with the fan turned off

Overall, the study showed that the system achieved the full 22°C to 75°C control range, with cooling ramp performance of about 0.44 °C/sec and heating ramp performance of about 0.66 °C/sec.

Thermal engineering outcomes:

- Transient CFD validated thermistor placement accuracy
- Altitude-adjusted air properties were successfully incorporated
- Foam insulation reduced parasitic losses
- Fan use improved cooling but degraded heating ramp
- TEC current-based control enabled rapid thermal transitions

ANALYSIS & CONCLUSION

This study shows that TEC-based thermal control systems must be designed as integrated assemblies rather than isolated component selections. In this project, performance depended on the interaction of TEC sizing, heat sinking, insulation, airflow strategy, thermistor placement, and transient control behavior.

- Transient CFD was essential to validate real ramp-rate performance
- Heating and cooling required different airflow strategies for best results
- Thermistor placement and closed-loop readiness were validated through simulation
- The final architecture supported accurate, rapid bidirectional thermal control across the full target range

ATS delivered a practical, validated TEC-based architecture for fast, accurate bidirectional thermal control across the required operating range.

Take control of your thermal performance with expert analysis and design services, contact ATS to speak with our engineers and start optimizing your system today.