FEASIBILITY OF GEOTHERMAL ENERGY FOR BRIDGE DEICING AND DECK COOLING IN MONTANA

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INTRODUCTION

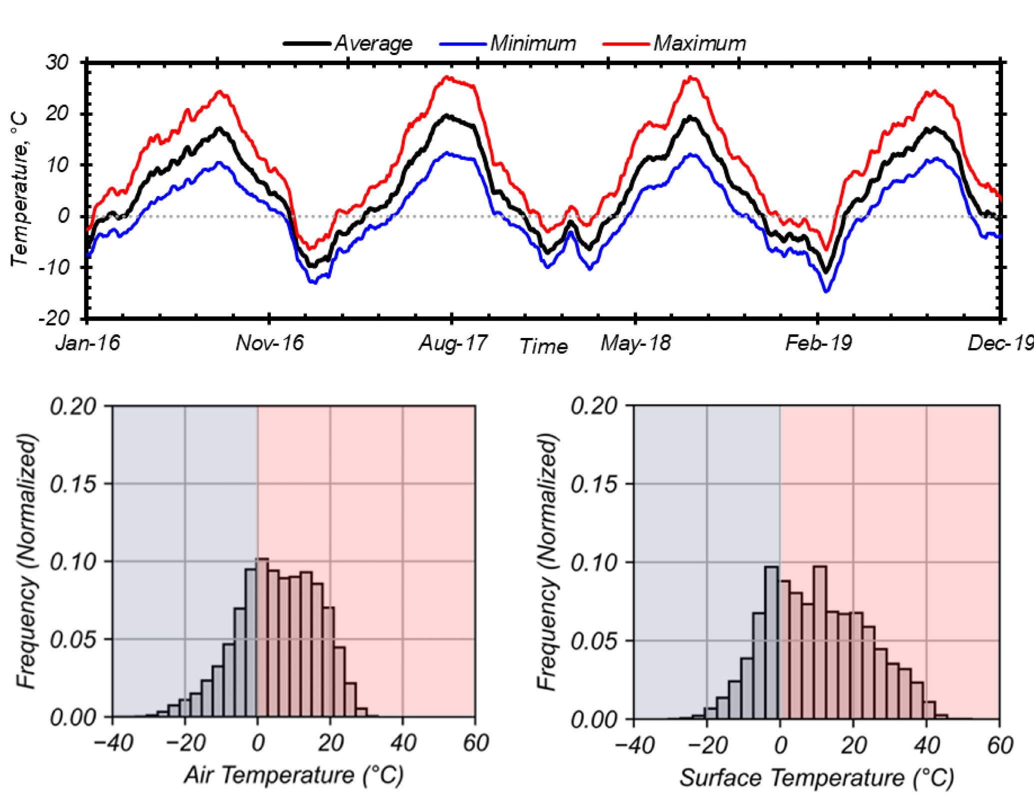
Snow and ice accumulation on bridge decks compromises roadway safety, causes traffic delays, and accelerates structural deterioration. Traditional deicing methods, primarily based on salts and chemicals, are ineffective in extreme cold (below -9.4°C) and contribute to corrosion and cracking in reinforced concrete. The availability of stable ground temperatures enables the use of ground-source heat pumps (GSHPs) as a sustainable and energy-efficient solution in cold climates. This thermal stability makes GSHPs a viable alternative for bridge deck deicing and snow removal, reducing reliance on conventional chemical-based methods. This study investigates the feasibility of such systems through surveys, laboratory testing, numerical modeling, and machine learning, highlighting their potential to improve safety, extend bridge service life, and reduce long-term maintenance costs.

OBJECTIVES

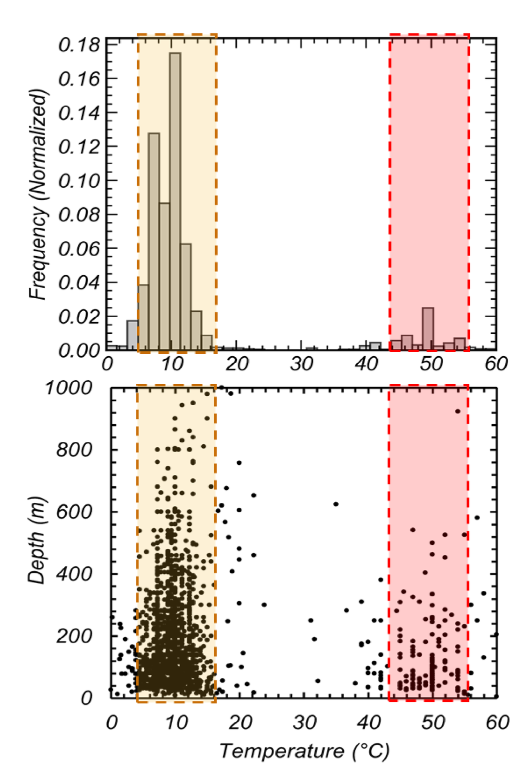
- Investigate the application of shallow geothermal systems for snow and ice mitigation in bridge decks under cold-region conditions.
- Assess the effects of geothermal heating on thermal behavior, including surface temperature regulation, frost depth, thermal gradients, and early-age cracking in concrete.
- Develop and validate a machine learning–based approach to predict bridge surface temperatures under various weather and design conditions.

RESEARCH METHODS

DATA COLLECTION - MONTANA



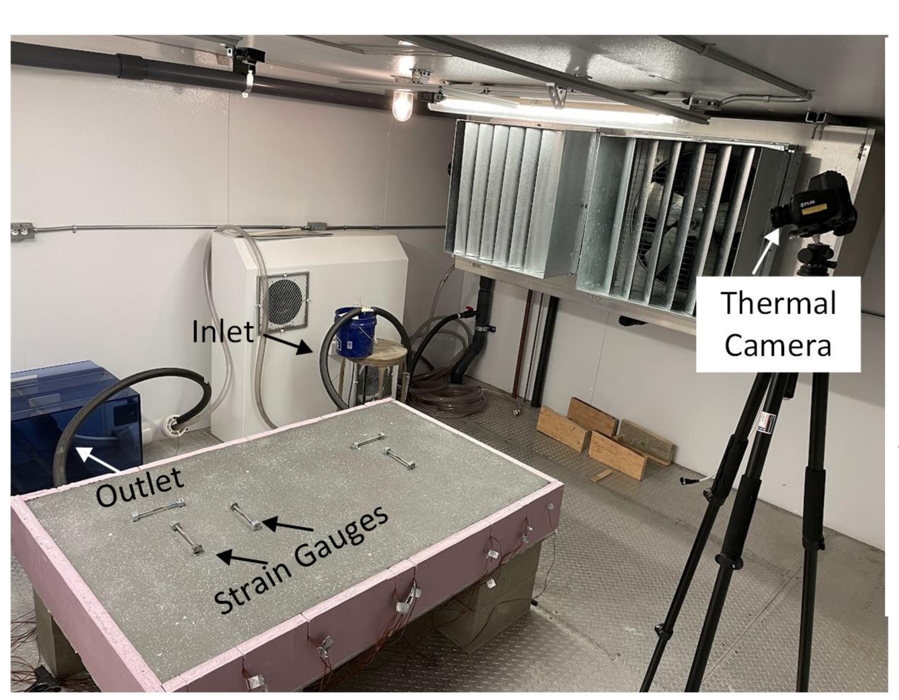
Ambient Data.

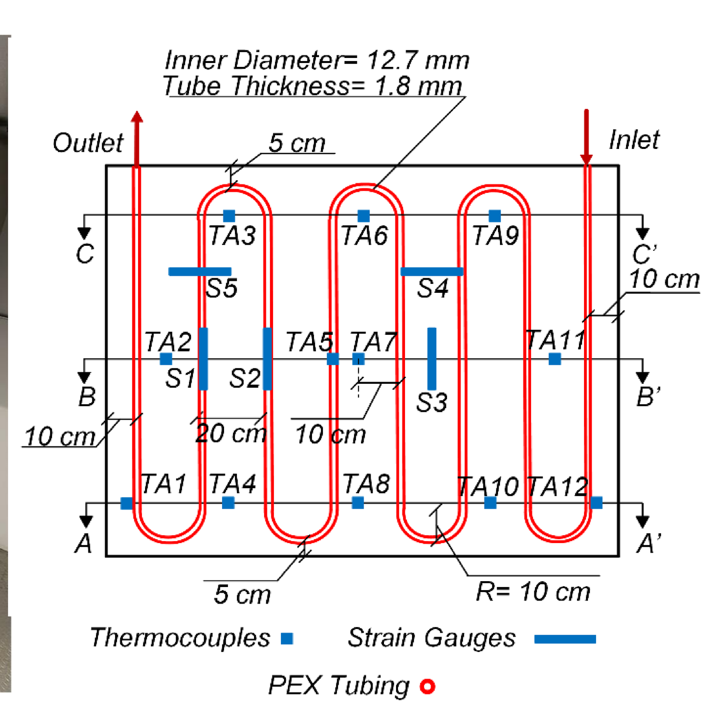


Ground Temperature Data

MODEL SCALE EXPERIMENTS

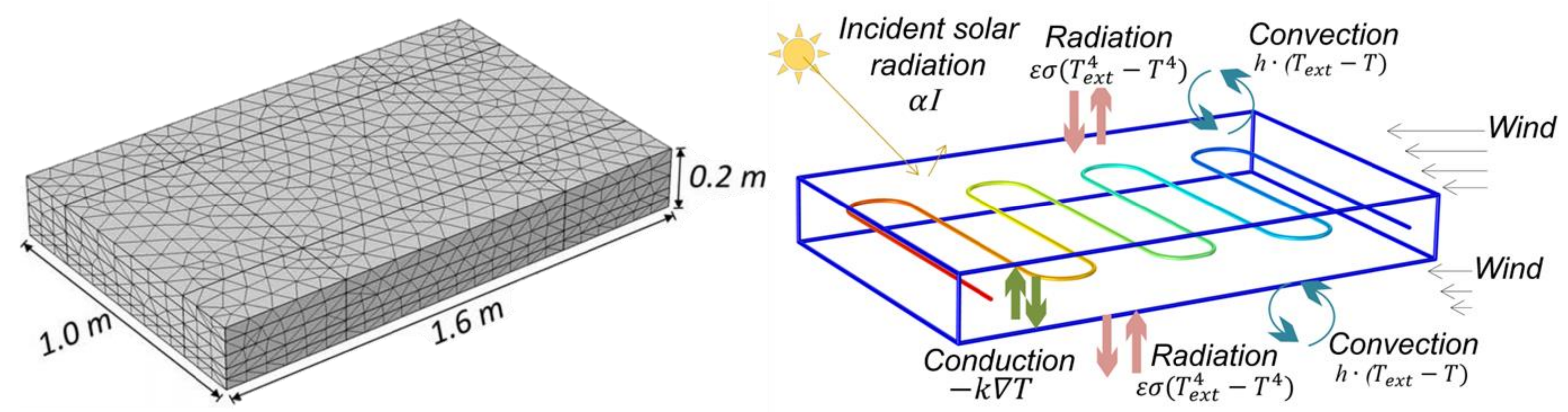
- Model-scale bridge deck experiments were conducted under controlled cold-weather scenarios to evaluate the thermal performance of geothermal heating systems.
- Effects of solar radiation and geothermal heating on surface temperature, frost depth, and thermal gradients were studied using synthetic and realistic weather profiles.





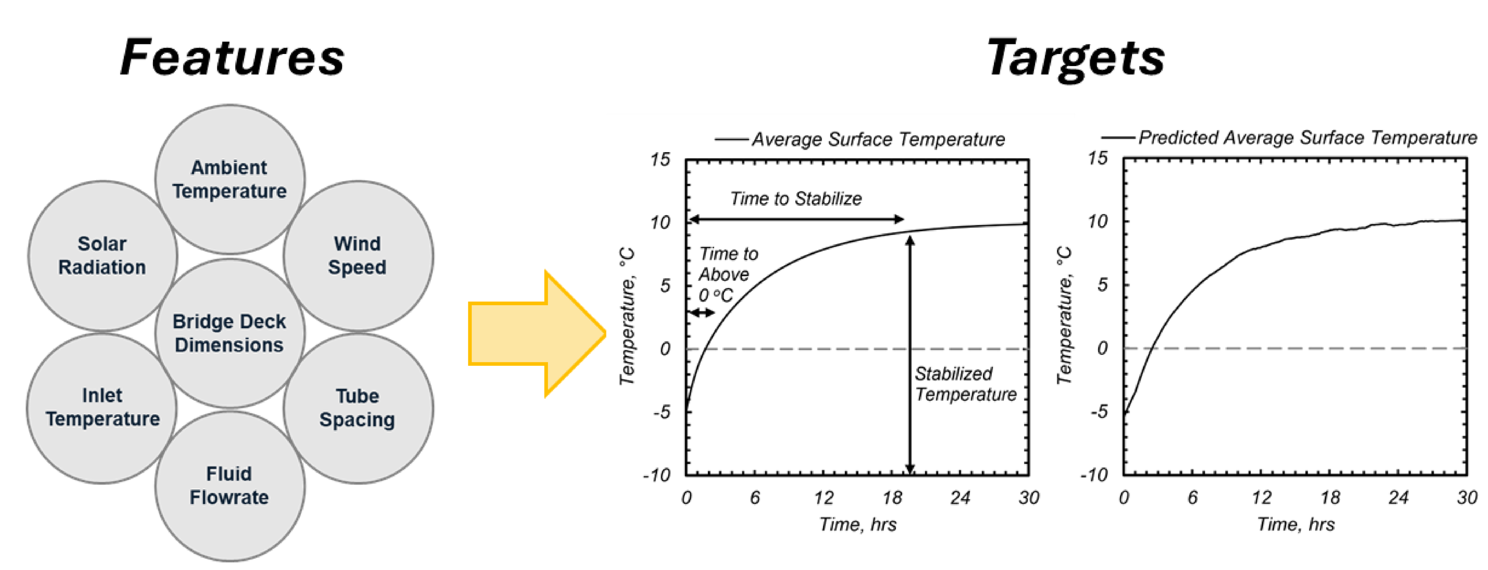
NUMERICAL MODEL

- 3D finite element models were developed in COMSOL and validated against laboratory data to simulate heat transfer in bridge decks with and without geothermal heating.
- Parametric studies assessed the influence of inlet temperature, tubing layout, wind, and solar radiation on surface temperature performance under various weather scenarios.



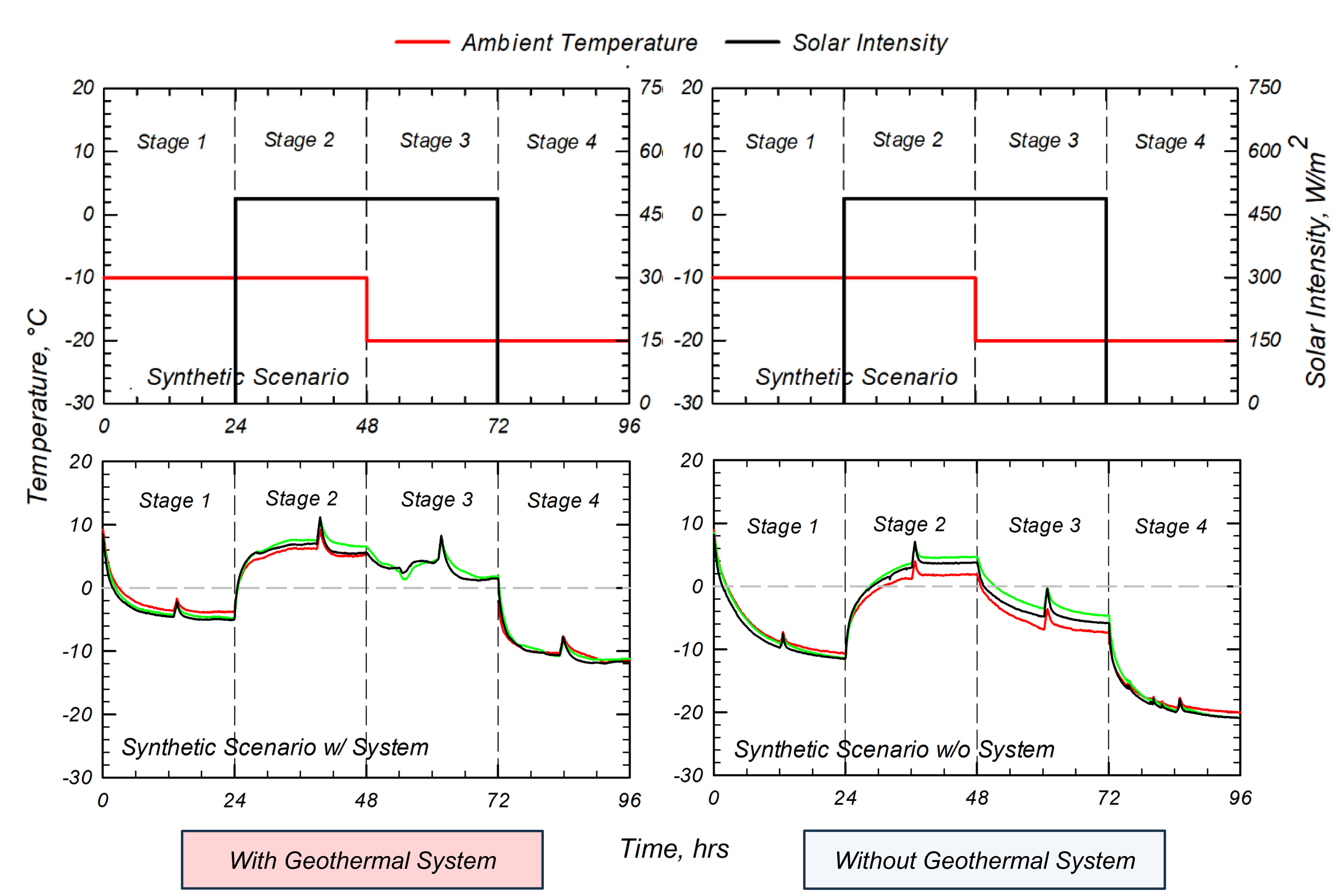
FEASIBILITY ANALYSIS

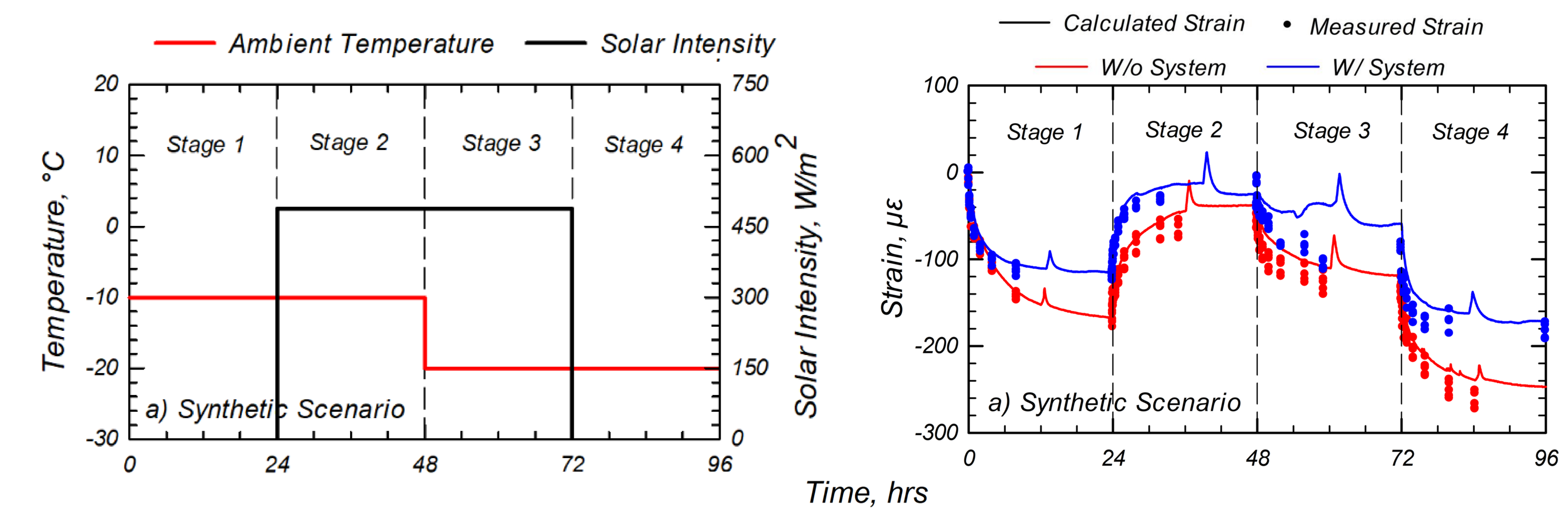
- A machine learning model was developed using simulation and climate data to predict bridge surface temperatures. Datasets from COMSOL split into training/testing sets; optimization of models using k-fold cross-validation.
- Feature importance analysis identified key parameters influencing surface heating performance, including weather and design factors.
- An interactive tool was created to support site-specific screening and design of geothermal deicing systems across Montana.



RESULTS AND DISCUSSIONS

EXPERIMENTAL RESULTS

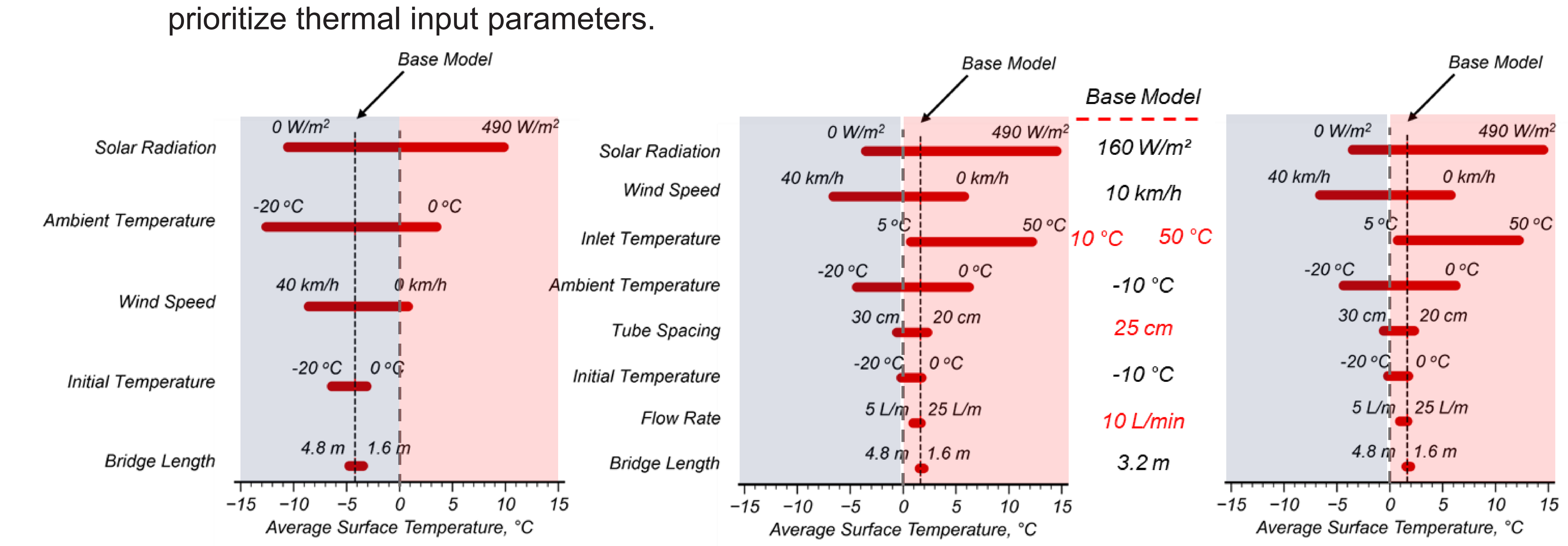




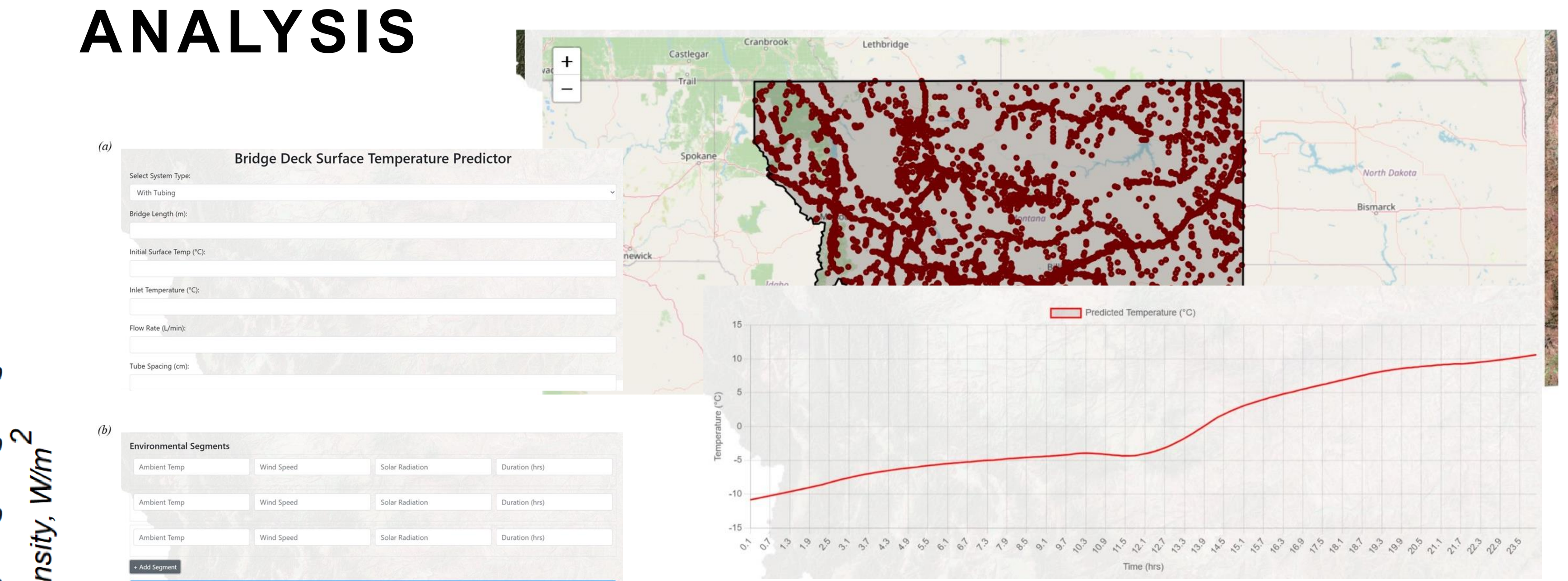
- Geothermal heating raised surface temperatures above freezing during stages with solar radiation (Stages 2 and 3), reducing ice formation risk.
- Geothermal heating reduced thermal strain in the bridge deck during solar gain periods, lowering the magnitude of contraction compared to the unheated condition.

SENSITIVITY ANALYSIS

- Surface temperature is most sensitive to solar radiation, ambient temperature, and inlet fluid temperature, with higher values in these parameters significantly improving deicing performance.
- Wind speed, bridge length, and flow rate also influence surface temperature, but their impact is smaller compared to solar and inlet temperature effects, indicating optimization efforts should prioritize thermal input parameters.



SURFACE PREDICTION AND FEASIBILITY ANALYSIS



- Developed an interactive web-based portal that allows users to estimate bridge surface temperatures under various design and climate conditions

CONCLUSIONS AND RECOMMENDATIONS

- Geothermal systems can elevate bridge deck temperatures above freezing, especially when combined with solar radiation during cold periods.
- Model-scale experiments confirmed reduced frost depth, lower thermal gradients, and mitigation of early-age cracking with geothermal heating.
- Numerical simulations showed that inlet temperature and tubing layout significantly influence surface temperature performance.
- Validated COMSOL models closely matched lab results across synthetic and realistic weather scenarios.
- Geothermal heating is most effective when designed to complement solar gain and optimized for local weather and subsurface conditions.