Solar-driven Ground Cooling System for Foundations in Marginal Permafrost for Alaska

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Principal Investigator	**:**	Zhaohui (Joey) Yang, Ph.D. School of Engineering University of Alaska Anchorage 3211 Providence Drive Anchorage, AK 99508 Tel.: (907) 786-6431
Project Partners	**:**	Simon A. Evans, MS, PE Applied Research and Engineering, Inc. P.O. Box 1303 Girdwood, AK 99587 Tel.: (907) 230-0310 Benjamin A. Still, MS School of Engineering University of Alaska Anchorage 3211 Providence Drive Anchorage, AK 99508 Tel.: (907) 230-9897

Total Project Cost	**:**	$369,500
Grant Funds Requested	**:**	$295,300
Matching Funds	**:**	$ 74,200
Previous Project Titles	**:**	None

1. Project Summary

a. Project Description

In an effort to reduce construction, material, and maintenance costs for energy infrastructure foundations such as wind turbine tower foundation in permafrost sites, we propose to design and test a solar-driven, hydronic active cooling system that will maintain long-term stability for foundations in warm permafrost. The system will be powered by a photovoltaic power plant, will be self-sustainable, and will require a minimal amount of maintenance for its long-term operation. Its successful implementation will improve the reliability of wind energy harvesting throughout Alaska, particularly in those areas where warm permafrost poses a threat to the short- and long-term stability of energy infrastructure foundations.

Currently, passive cooling systems such as thermosyphons or thermopiles are primarily used in maintaining the integrity and stability of foundations in warm permafrost. The limitations of a passive system include a maximum ground cooling capacity of only 3-5°C, and high construction costs. With the occurrence of more extreme weather events, such systems may not be able to provide sufficient capacity for some ground cooling applications. This solar-driven, active ground cooling technology is intended to either complement an existing foundation cooling system if additional cooling capacity is needed, or serve as a design alternative for new construction. The active cooling system will operate on the same basic cooling principles as a commercially available system like that used for an Ice Hockey Rink, except for at a much lower power demand since the design limits phase change (i.e. water to ice).

The feasibility of the project is inherent in its design since this active cooling system takes advantage of two existing technologies: an electric refrigeration system, and electric power generation by photovoltaic technology. Both technologies are mature and commercially available. A preliminary calculation has been carried out based on monthly average daily solar radiation values for the intended operation environment, and it shows that there is ample solar energy available to power such a system. We have already conducted a ground freezing test in the Geotechnical and Frozen Ground Research Laboratory at UAA. Our preliminary analysis shows promising results. This project has an Anticipated Technology Readiness Level of 4.

The system consists of a combination of readily available, and easy to transport components including existing cooling and solar power generation technologies. Figure A provides a schematic of the solar-driven ground cooling system, and a profile view of a typical field application. The hydronic cooling loop will be installed near the ground surface, allowing easy access, reduced installation costs, and design flexibility to add cooling capacity if needed.

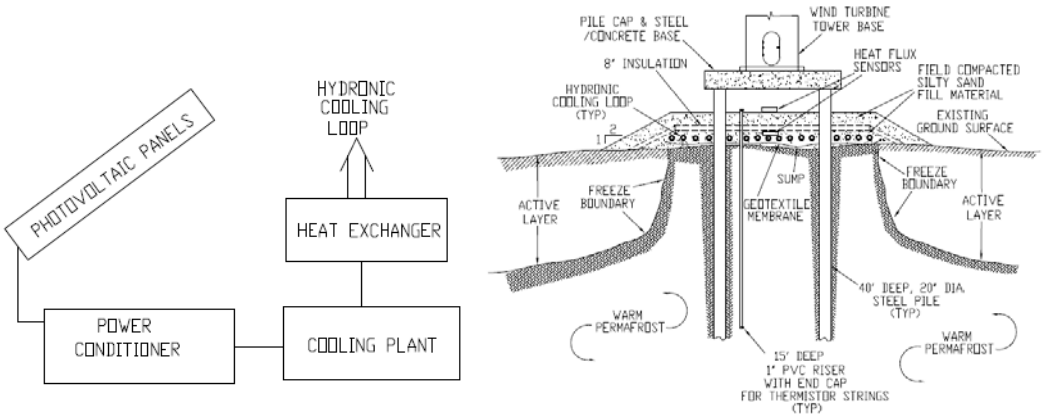


Figure A: Solar-driven cooling system schematic (left) and profile view of installation (right).

Potential benefits: This system will be applicable for energy infrastructure built on warm permafrost sites including but not limited to wind turbine foundations, bulk fuel storage facilities, and energy transmission systems. This system will be most cost-effective for rural communities throughout Alaska. The benefits of this system will be immediately realized in ***reduced capital costs, improved reliability and extended lifespan for energy infrastructure in permafrost sites***.

b. Project Innovation

The major difference between the active ground cooling system proposed here and a traditional passive cooling system lies in that the active system operates during period of high solar radiation, while a passive system only works during winter months when the air temperature is lower than the ground temperature. The fundamental concept of this system is that it provides cooling to the subsurface permafrost during times of significant solar radiation when foundation degradation would normally occur. The system prevents permafrost degradation in the vicinity of the foundation of interest in a proactive manner. The energy requirements of the system are kept to a minimum by preventing the phase change of the moisture within the soil.

This ground cooling system will be an improvement over existing passive cooling technologies in two aspects: 1) its higher cooling capacity and 2) its low installation cost and flexibility of system configuration. The system can be expanded and updated as necessary in most cases with the use of locally available equipment. The system itself is modular and is relatively easy to transport to remote locations. It is applicable for new foundation construction and existing foundation rehabilitation. For example, in cases where existing foundations are subject to failure due to permafrost degradation, this system can be used to extend its useful lifespan due to the adaptability of the installation process, and its application at or near the ground surface. Operating costs will be minimal and will generally consist of routine maintenance.

In summary, this system will provide both short- and long-term integrity and stability for foundations in warm permafrost sites, and will allow for operational flexibility to compensate for environmental variability due to climate change or other detrimental forces as needed.

c. Project Site and Demonstration Environment

Warm permafrost exists throughout Alaska including the Bethel area and many foundation problems originated from marginal permafrost. A test location will be selected based on this criterion. For this project, we propose to design and construct a prototype cooling system in Western Alaska in collaboration with the science and engineering education coordinator at Bethel Regional High School (BRHS). BRHS Principal Janelle Vanasse is very supportive of this effort and she has agreed to help secure a test site at BRHS. The prototype will be installed in a soil column instrumented with thermistor arrays and heat flux sensors to allow our team to continuously monitor the soil thermal regime and validate the feasibility and functionality of this foundation cooling/preservation system.

d. Priority

This project will be led by Prof. Zhaohui (Joey) Yang at the Civil Engineering Department of University of Alaska Anchorage (UAA). Mr. Benjamin Still, a Ph.D. student from UAF/UAA Joint Ph.D. program, Mr. Simon A. Evans, MS, P.E., President of Applied Research and Engineering, Inc., an Alaska native graduate student, and two summer interns from Bethel Regional High School will form the research team. All members of the research team are Alaskan residents. We will have 25% matching funds from UAA's Alaska Native Science and Engineering Program (ANSEP) and School of Engineering. This project will be applicable for foundations constructed in permafrost sites throughout Alaska.

2. Technology Validation and Data Collection

a. Objectives

The objective will be to minimize or eliminate the active layer during the summer months and cool the surrounding warm permafrost at a reasonable cost. A thermal regime below 32°F of the typical active layer maintained throughout summer, and a decrease in the permafrost temperature will be considered as a success.

b. Data Collection

This project will include a geotechnical exploration, and analyses of the collected soil samples at UAA Geotechnical Laboratory. We plan to collect ground thermal data on the surface and at depth with thermistor strings. We will also collect preliminary temperature data prior to site preparation. Solar energy harvesting, energy consumption, and flow rates in the refrigeration system will be monitored for system optimization. Weather data will be collected from local weather stations for system performance evaluation. A cost analysis will be made with the data collected during this project.

3. Project Schedule and Project Budget

The team anticipates this project will be completed in one and a half years, with the project starting in January 2014. The technologies required for this system are mature and we do not anticipate go/no-go milestones in this schedule. The following is a tentative project schedule:

- Jan. 1 – Feb. 28 — Design of prototype solar-driven ground cooling system
- March 1 to April 30 — Assembly and laboratory testing of prototype solar-driven ground cooling system
- May 1 – May 31 — Site preparation and field installation of the solar-driven foundation cooling system
- June 1 – Sept. 15 — Monitoring and analysis of soil thermal regime variation and solar energy harvesting; analysis of cooling system performance
- Oct. 1 – Dec. 31 — Interim report and presentation to project advisory board
- Jan. 1 – May 31 — Continued monitoring of thermal regime variation and solar energy harvest
- June 1 – June 30 — Final reporting

A total of $369,500 is proposed for the entire project. Of the total budget, $295,300 is requested from Alaska Energy Authority's EETF fund and $74,200 will be provided as matching funds (25% matching of requested EETF fund). The funds requested from Alaska Energy Authority's EETF fund breaks down as follows: $78,050 for salaries and benefits of UAA personnel, $17,250 for travels to the project site, $17,500 in subcontract to Salzbrun Services and Drilling for borehole drilling/casing, $95,000 in subcontract to Applied Research & Engineering, Inc. for design, system assembly and field implementation, $19,000 for procuring solar power generation system and temperature monitoring system, $18,000 for field supplies and miscellaneous costs, $10,550 for Ph.D. student tuition, and $39,950 for UAA facilities & administration costs.

With regard to the matching funds, UAA's ANSEP program has committed a fellowship worth of $56,700 to support a full time graduate student for one and a half years including tuition and stipend. UAA's Innovate Fund has committed $10,000 to support this project. UAA's School of Engineering will provide a CR-3000 datalogger and necessary accessories worth of $5,000 as in-kind support. Bethel Regional High School will provide internet access and other in-kind support worth of $2,500 for this project.

4. Project Team Qualifications

Dr. Joey Yang will serve as the PI to lead the overall execution of this project. Dr. Yang is the PI of a project currently funded by Alaska Energy Authority's Capital Project focusing on wind turbine foundation vibration monitoring and load assessment. His expertise is in geotechnical and frozen ground engineering and he has served as PI or Co-PI on more than a dozen federal and state funded projects. He is the inventor of a new deicing technology based on carbon fiber materials.

Mr. Simon A. Evans, M.S., P.E., is registered in the State of Alaska and has accumulated more than fifteen years of field experience as a Design & Field Construction Engineer. Mr. Evans will be in charge of the design and field implementation of this project.

Mr. Benjamin Still earned a Master of Science in Arctic Engineering from UAA and has accumulated expertise in thermal modeling as related to frozen ground engineering problems, data analysis, finite element modeling. He is currently a Ph.D. student in the UAF/UAA Joint Ph.D. program. He will be responsible for thermal modeling, sizing of the ground refrigeration system and will lead the data analysis.

Besides the core members mentioned above, Mr. Corbin Rowe, Prototype Machinist at UAA's Mechanical Engineering Workshop, will contribute in the assembly of the prototype ground cooling system. An Alaska native graduate student and two Bethel Regional High School summer interns will help with data analysis and field implementation.

5. Discussion of Commercialization of Funded Technology

This technology will increase the cost effectiveness of wind energy harvesting infrastructure in areas with degrading permafrost throughout Alaska. Large wind turbine farms will be more feasible due to a substantial reduction in the cost of foundations and increased lifespan of the foundations. This technology can be used throughout Alaska to ensure structural integrity and short- or long-term stability of all foundations for energy-related infrastructure such as bulk fuel storage and energy transmission facilities in marginal permafrost. After testing, this technology will be commercialized and be made available for application as a proactive measure to prevent future problems, or as an emergency stabilization measure for foundations which are at or near failure.

6. Signed Applicant Certificate

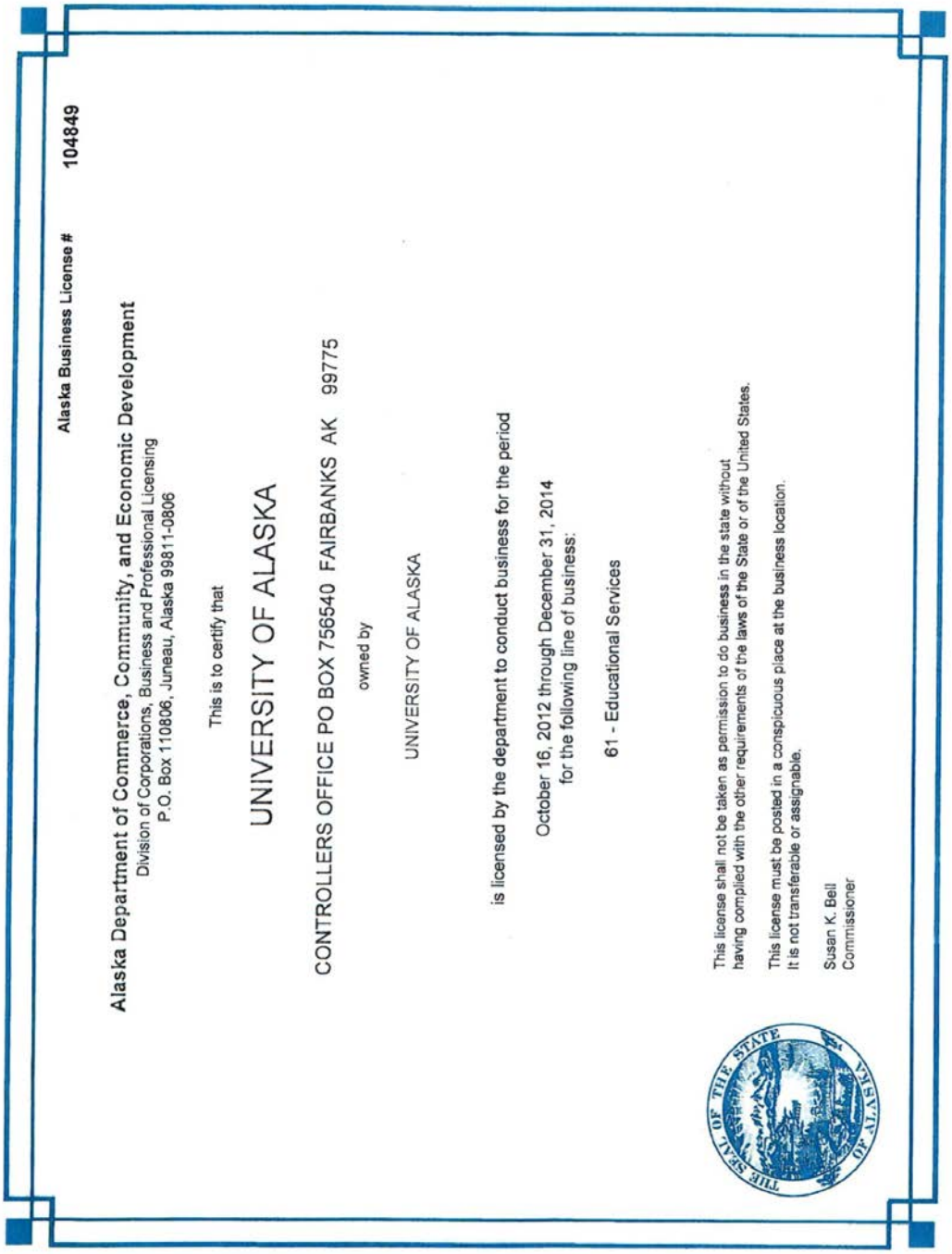
By signature of this application, I certify that we are complying and will comply with the amount of matching funds being offered.

Tien-Chien Jen, Ph.D.

Dean, School of Engineering
University of Alaska Anchorage

Proof of Eligibility

Alaska Business Licenses for the University of Alaska, of which the University of Alaska Anchorage is a part, and the partner Applied Research and Engineering, Inc., are attached with this proposal.



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