Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-010

Proposal Title: Enhanced Thermo-Active Foundations for Space Heating in Minnesota

Project Manager Information

Name: Aggrey Mwesigye

Organization: U of MN - Duluth

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Project Basic Information

Project Summary: This project primarily involves the design and optimization of cost-competitive, thermally enhanced and compact heat exchanger systems for deep thermo-active building foundations for Minnesota's space heating and cooling industry

Funds Requested: $367,000

Proposed Project Completion: 2024-06-30

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Globally, buildings contribute about 40% of the total carbon dioxide emissions and use about 36% of the total energy supplied. In Minnesota, about 78% of the total energy bill goes to providing space heating and domestic hot water supply owing to the state's cold climate.

To reduce energy consumption in buildings, ground source heat pumps (GSHPs) are increasingly being considered given their ability to provide energy efficiently compared to conventional systems. They give about 25-45% energy savings compared to air source heat pumps and about 75% energy savings compared to electric resistance heating. Despite these benefits, several challenges have hindered widespread utilization of these systems. These include higher upfront costs, lack of drilling space in densely populated areas and performance degradation in cases where building heating and cooling loads vary significantly leading to ground thermal imbalance.

The use of thermo-active building foundations, where heat exchangers are embedded in the foundation structure has emerged as an excellent means to reduce drilling costs and space requirements for GSHPs. However, compared to conventional systems, limited studies have reported the performance of thermo-active foundations in the US climates. Moreover, these systems are shallower than conventional ones, thus requiring compact and optimized heat exchangers.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

This study involves the design and optimization of thermally enhanced heat exchanger systems for thermo-active foundations for Minnesota's cold climate. When incorporated in building foundation structures, capital costs of GSHPs will significantly reduce, leading to increased uptake of the technology. Specific emphasis will be on pile and caisson foundations which present considerable lengths for energy transfer to and from the ground and are not space intensive.

Moreover, we will consider the influence of different heat exchanger configurations and several backfill materials on long-term system performance. Furthermore, we will engineer optimal configurations for the incorporation of phase change material for energy storage to alleviate thermal imbalance, while optimizing the cost of these systems. Using latent thermal energy storage minimizes ground thermal imbalance and improves the long-term performance of the system.

Detailed determination of building energy loads for proper sizing of heat exchangers will be undertaken. This requires the use of site specific climatic data to cater for temperature variation throughout the different seasons. Moreover, ground temperature variation affects heat transfer and long-term performance. As such, for the developed systems, the long-term coefficients of performance will be established by coupling building energy modeling and finite element analysis using TRNSYS and COMSOL.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

Successful completion of the project will provide designs of optimal configurations of enhanced heat exchangers for deep thermo-active foundations, demonstrate the influence of building energy loads on long-term system performance in Minnesota's cold climate and establish the energy saving potential and the resulting emission reductions from these systems. Moreover, a detailed economic analysis will be undertaken to establish the cost competitiveness of the developed solutions. Adoption of these systems for space heating and cooling will lead to reduced use of natural gas and biomass for space heating resulting in the conservation and preservation of Minnesota's natural resources.

Activities and Milestones

Activity 1: Determination of building energy loads and ground temperature profiles for different locations in different regions of Minnesota

Activity Budget: $105,506

Activity Description:
The performance of a ground source heat pump system is influenced by the deep ground temperatures as well as the nature of the building energy loads. The building energy loads and the ground temperature are dependent on the local climatic conditions of the system's location. In this task, we will select representative sites to be used in the evaluation of system performance. For the selected sites, climatic data will be collected from different sources including the Minnesota State Climatology Office, the National Weather Services, the U.S. Climate data and others. This data will be organized and analyzed for use in the energy modelling studies. Then, models for determining the building heating and cooling loads for each site will be developed in the transient system simulation (TRNSYS) software.

Activity Milestones:

Description	Completion Date
Selection of different locations within the state for use in building energy modelling and transient system analysis studies	2021-09-30
Development of soil thermal property and ground temperature variation models for the selected sites	2021-11-30
Development of building models in TRNBuild for use in the determination of building loads	2021-12-31
Determination of building energy loads for the selected sites using TRNSYS	2022-06-30

Activity 2: Development, evaluation and optimization of thermally enhanced heat exchanger configurations for thermo-active building foundations in cold climates

Activity Budget: $157,412

Activity Description:
To properly design and size heat exchanger for thermo-active building foundations, a survey of the different deep foundations used in Minnesota will be undertaken. We will particularly look for the available diameters and depths of the pile and drilled caisson foundations. Furthermore, a survey of available heat exchanger designs for ground source heat pump systems will be done to be used for benchmarking performance of the developed concepts. With this information, different designs of heat exchangers for thermo-active foundations for cold climates will be developed, evaluated and the best configurations optimized for further study. First law and second laws of thermodynamics with entropy generation minimization will be used to determine optimal configurations. Furthermore, optimal ways for incorporation of latent thermal energy storage (LTES) will be engineered and evaluated. It should be noted that this study does not intend to design building foundation, but heat exchanger systems that can be incorporated in already existing designs of foundation structures.

Activity Milestones:

Description	Completion Date
Survey of building foundations in Minnesota	2023-04-30
Development, evaluation and selection of thermally enhanced heat exchanger concepts for thermo-active foundations.	2023-06-30
Development of numerical models of different concepts and evaluation of the potential enhancements with LTES	2023-08-31

Development of a field scale system model to investigate long-term system performance with/without LTES	2023-12-31

Activity 3: Evaluation of long-term system performance and techno-economic assessment of the developed heat exchanger systems

Activity Budget: $104,082

Activity Description:
Knowledge of the long-term performance of the system is essential in ensuring reliability and determining whether the system will continue to perform as expected. Here, the performance of the developed heat exchanger systems in a thermo-active foundation will be evaluated over 4 year, 10 year and 25 year periods. The coefficient of performance of the system over time will be evaluated to establish: (i) any performance enhancements or degradation, (iii) the energy usage and resulting carbon dioxide emission reductions, and (iii) the overall value of the technology by looking at benefits (savings) and costs - the Net Present Value (NPV) of such an investment will be determined. Moreover, the influence of latent energy storage on ground thermal imbalance will be investigated and any improvements in performance quantified and compared with a system having no latent thermal energy storage.

Activity Milestones:

Description	Completion Date
Determination of energy savings and emission reduction potential of the developed systems	2024-04-30
Numerical simulation and determination of the long-term performance of the developed enhanced thermo-active foundations.	2024-04-30
Development of a techno-economic assessment model to evaluate feasibility and profitability of different configurations	2024-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Robert D. Palumbo	University of Minnesota Duluth	Prof. Palumbo has extensive experience in heat transfer and thermodynamics, he will be assisting with the assessment and evaluation of different heat exchanger configurations. He will also co-mentor the postdoctoral fellow and the masters students working on the project.	No

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

Results from the study will be shared with stakeholders in industry and professionals in the Heating, Ventilation, Air Conditioning and refrigeration (HVAC&R) discipline. With the results obtained from this study, we anticipate partnering with industry to write a grant proposal to be submitted to the U.S. Department of Energy for field scale experimentation and demonstration of performance of the optimized heat exchanger configurations for thermo-active foundations. Such experiments will enable us to validate the long-term performance of the system which is essential in assuring potential clients of the performance and reliability of the technology.

Project Manager and Organization Qualifications

Project Manager Name: Aggrey Mwesigye

Job Title: Assistant Professor

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Mwesigye is an assistant professor in the department of Mechanical and Industrial Engineering at the University of Minnesota, Duluth starting in the spring of 2019. He obtained a Ph.D. in Mechanical Engineering with specialization in Thermofluids from the University of Pretoria, South Africa in 2015, a Master of Science in Mechanical Engineering specializing in Sustainable Energy Engineering from the Royal Institute of Technology, Sweden, in 2009 and a Bachelor of Science in Mechanical Engineering, Summa Cummu Laude from Makerere University, Uganda in 2005. Throughout his postgraduate education, Dr. Mwesigye has applied fundamentals of heat transfer, thermodynamics and fluid mechanics to the design, modeling and optimization of renewable thermal energy systems. He has extensively researched concentrated solar thermal systems for electricity generation, solar assisted heating and cooling systems and ground source heat pump systems. He was a postdoctoral research fellow at Ryerson University in Canada from January 2018 - December 2019 where he continued to develop expertise in the modeling, analysis and optimization of sustainable energy systems including the ejector refrigeration technology, radiant floor heating systems and ground source heat pump systems for space heating and cooling. He has extensive expertise in the application of computational tools to the study of the performance of energy systems, including the determination of long term performance ground source heat pump systems incorporating building loads. He has developed numerical models in ANSYS Fluent, COMSOL Multiphysics and Engineering Equation Solver to study several energy systems. Dr. Mwesigye will lead the proposed work and he will be responsible for the overall project management.

Organization: U of MN - Duluth

Organization Description:

The University of Minnesota Duluth campus grew from its early roots as the Duluth Normal School, to become a University of Minnesota campus in 1947. Today, UMD is a medium-sized regional university that offers students a supportive atmosphere and access to the resources of the larger University of Minnesota system. UMD students can choose from more than 93 undergraduate and post-baccalaureate degrees, and from graduate programs in more than 20 different fields. The College of Science and Engineering at the University of Minnesota Duluth is the largest college at the University and the third largest in the University of Minnesota System. It currently has an enrollment of over 3,200 undergraduate and 200 graduate. This research fits in with one of the grand challenges of the college i.e. developing an international reputation in the nascent areas of materials science, water, sustainable energy and mining innovation.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Principal investigator, Mwesigye		Project administration, student advising and development of numerical models in COMSOL. $14,145/yr (63.5% salary, 36.5% fringe). 50% paid effort during summer months x 3 yrs.			26%	0.39		$59,677
Postdoctoral Fellow		Assisting the PI with project administration and performing numerical modelling studies in both TRNSYS and COMSOL. Includes two periods of summer appointment. ($50000 base salary for 100 FTE and 25.4% fringe benefits)			20.2%	1.75		$161,584
1 MSc Research Assistant		1 U of M MSc student working of determination of energy loads using Transient System Simulation (TRNSYS) software and numerical modeling using COMSOL. Full time for two years and two summer periods (2.5 FTE, 19.9% fringe benefits: 50% of time per year and 25% for the summer months)			48.6%	0.88		$85,570
2 Undergraduate research assistants		Two U of M undergraduate research assistants (5 hrs/week, 12.5% FTE each year for 2 years i.e. 25% for two students). . Conducting numerical studies and assisting with the survey of building foundations and review of heat exchangers for GSHPs			0%	0.69		$18,984
							Sub Total	**$325,815**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	1 COMSOL Multiphysics Floating Network Licence. Initial licence cost and subscription for two years	COMSOL Multiphysics will be used for most of the numerical simulations. It will be use for both steady state and transient simulations studies to determine ground temperature					$21,185

			variation and the coefficient of performance over a period of 10 years					
	Tools and Supplies	TRNSYS software	TRNSYS is a transient thermal system simulation software, it will be used for the determination of building loads, which is essential for the prediction of the performance of a ground source heat pump					$11,000
							Sub Total	**$32,185**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	During the course or the project, we will establish connections with industry. Visits are anticipated as the project progresses	Meeting potential industry partners in the state and collaborating travel to sites where installation of geothermal heat pump systems might be taking place. Also presentation of findings to potential industrial partners					$3,000
	Conference Registration Miles/ Meals/ Lodging	Minnesota Geothermal Heat Pump Association Conference for two people every year. Conference registration, meals and transport at a cost of 1000 per person per year	I am in the process of registering as a member of the Minnesota Geothermal Heat Pump Association, the largest geothermal assembly of installers, designers and educators in Minnesota, as a group we plan to be attending the annual conference and present our findings and learning from the contractors					$6,000
							Sub Total	**$9,000**
Travel Outside Minnesota								

							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$367,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	University of Minnesota Unrecovered indirect costs at 55% Modified total direct costs	This is the unrecovered indirect cost amount contributed to the running of the project by the University of Minnesota	Secured	$184,331
			Non State Sub Total	**$184,331**
			Funds Total	**$184,331**

Attachments

Required Attachments

Visual Component

File: c1b76fa9-b3d.pdf

Alternate Text for Visual Component

The attached visual shows how the ground source heat pump system maintains thermal comfort in winter and summer by exchanging heat with the ground. The second visual shows a helical steel type pile thermo-active foundation and the incorporated u-loop heat exchanger. Different enhanced heat exchanger configurations will be developed, optimized and compared with this conventional type.

Optional Attachments

Support Letter or Other

Title	File
Institutional Support Letter	c1fc82ca-b32.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

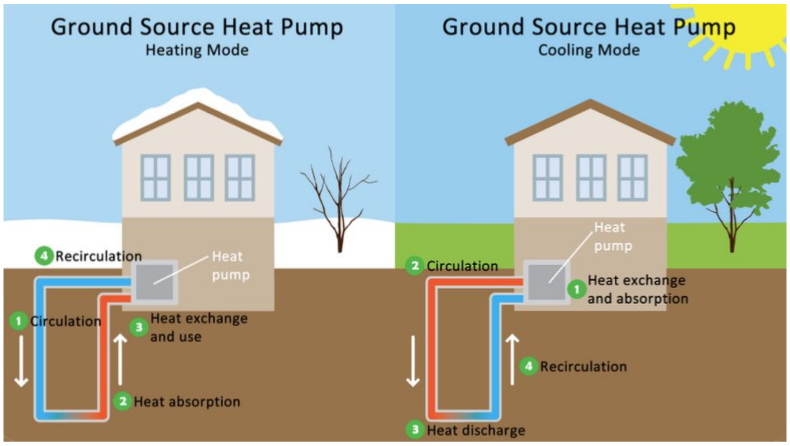
- Patent, Copyright, or Royalty Potential

Does your project include research?

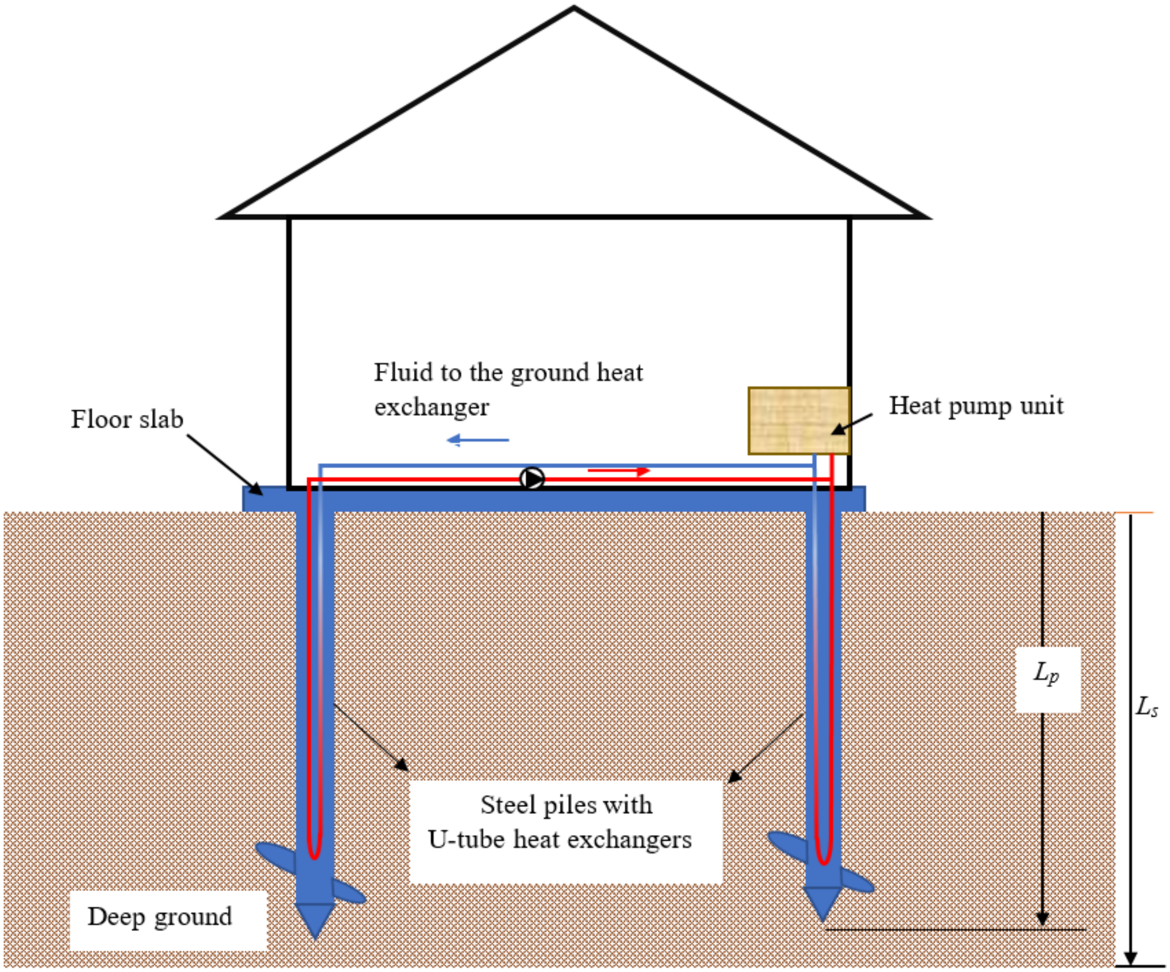
Yes

Does the organization have a fiscal agent for this project?

No



A geothermal system uses the relatively stable deep ground temperature to provide cooling in summer and heating in winter with high coefficients of performance[1].



A heat pump coupled to a thermo-active helical steel pile type building foundation using u-shaped heat exchanger. This is the conventional heat exchanger system, enhanced heat exchanger systems will be developed and optimized and their performance compared with the standard u-loop heat exchangers.

[1] https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html