Use of Geothermal Energy in Snow Melting and Deicing of Transportation Infrastructures

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Transportation Research Board
July 21, 2016

Webinar Outline

- Background and concept
- Geothermal heat-exchange systems
- Applications related to transportation infrastructure
- Examples from recent research on bridge deck deicing
- Summary and conclusions

Learning Objectives

- Identify near-surface geothermal energy and heat exchange systems
- Understand different applications of geothermal energy in transportation systems
- Identify different case histories and research projects
- Understand the basic design principles of geothermal heat exchange systems

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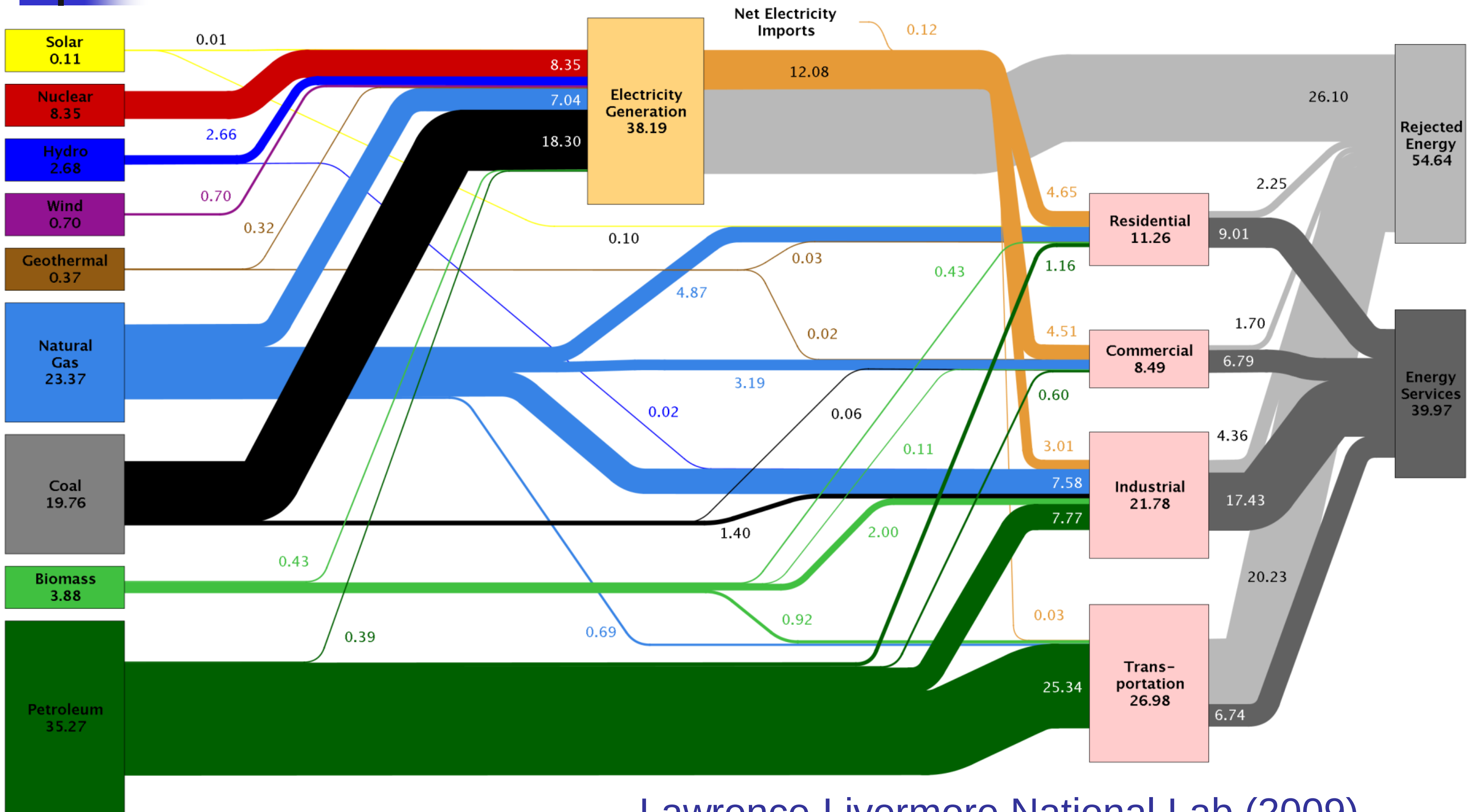
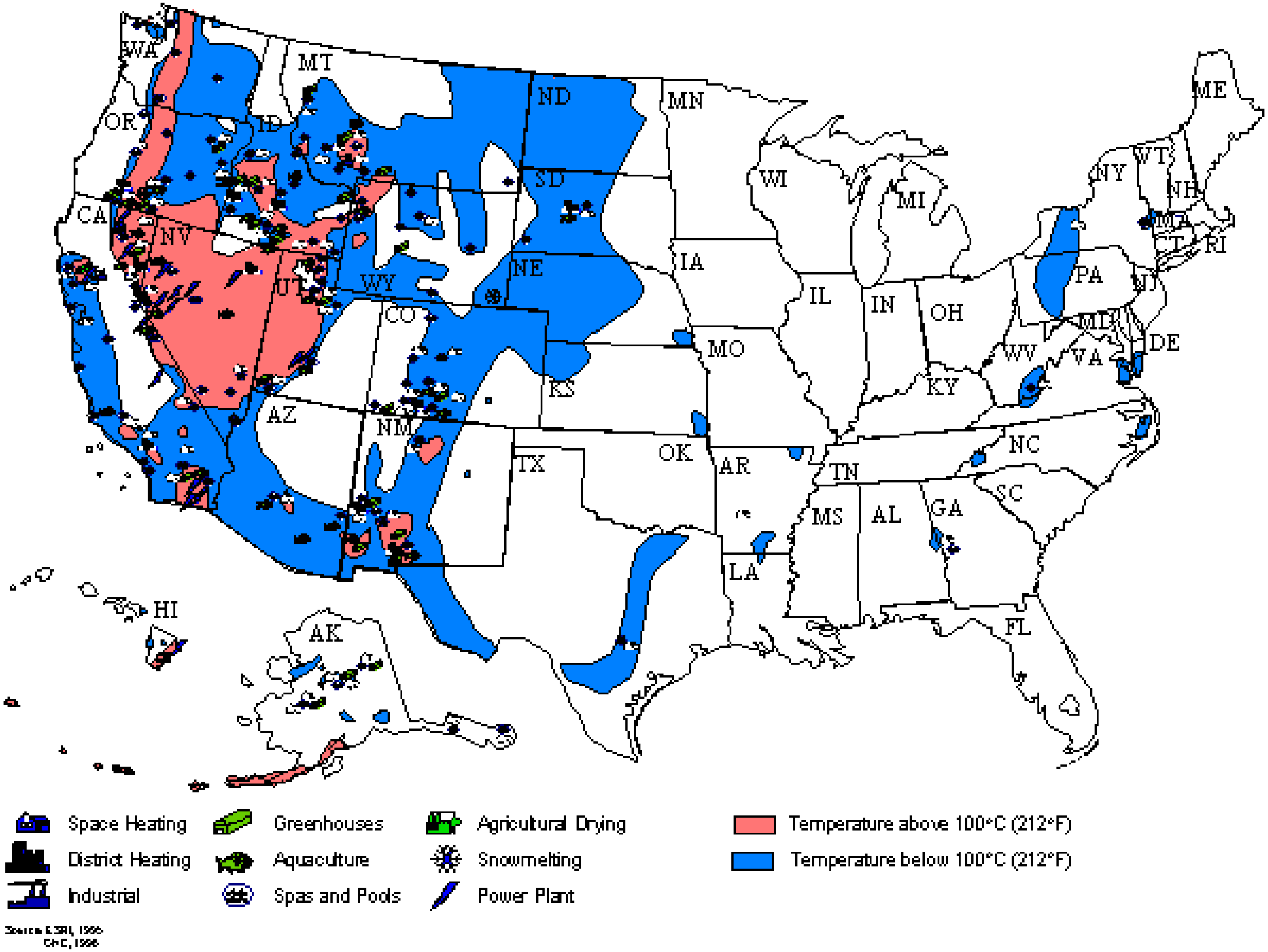
U.S. Energy Flow Chart



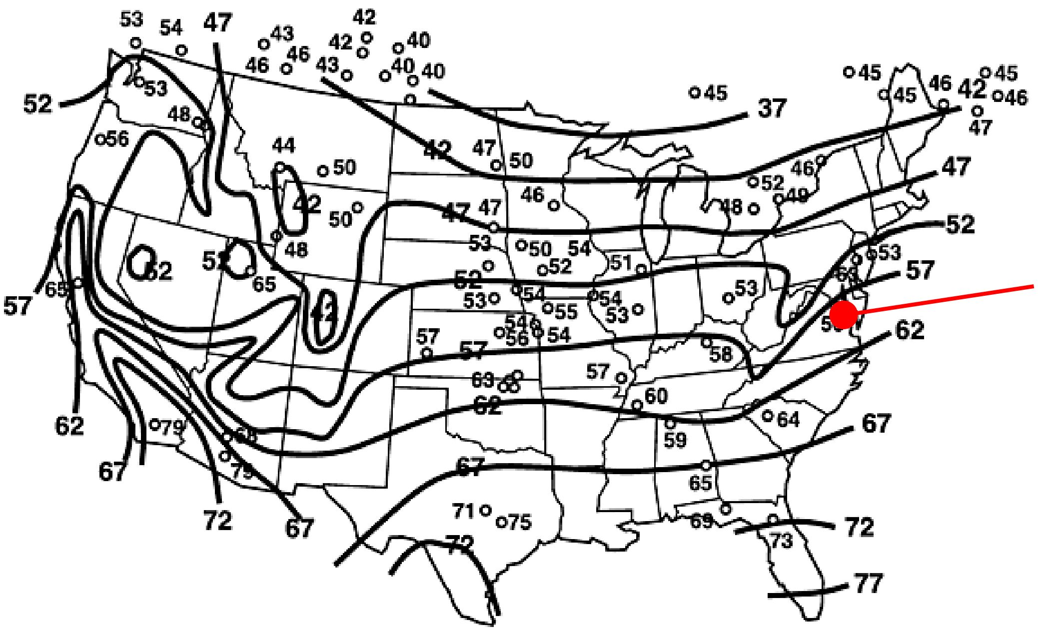
Lawrence Livermore National Lab (2009)

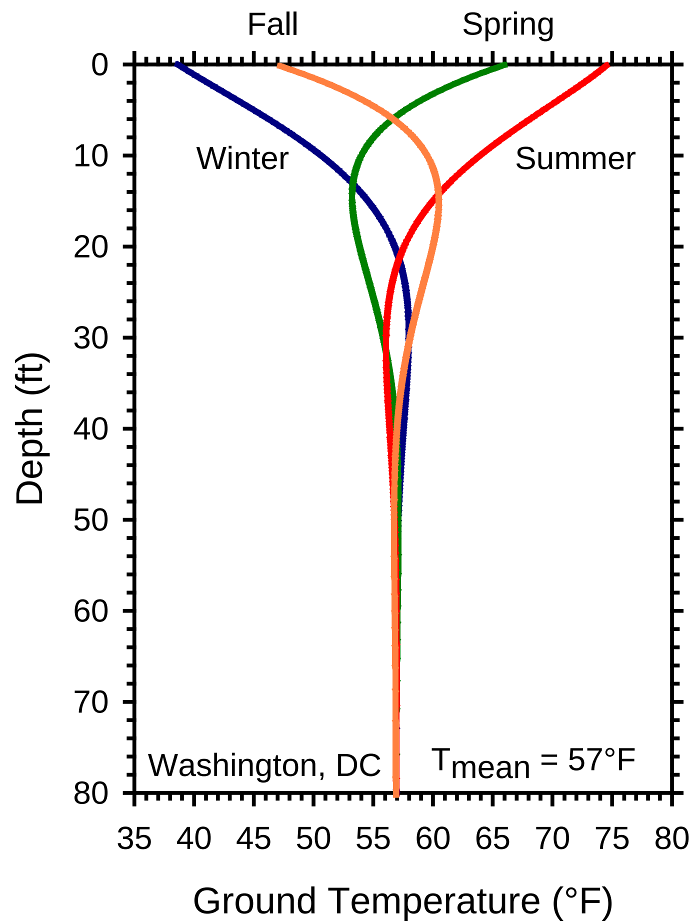
Significant energy consumption in buildings mainly for heating and cooling

U.S. Geothermal Resources & Projects



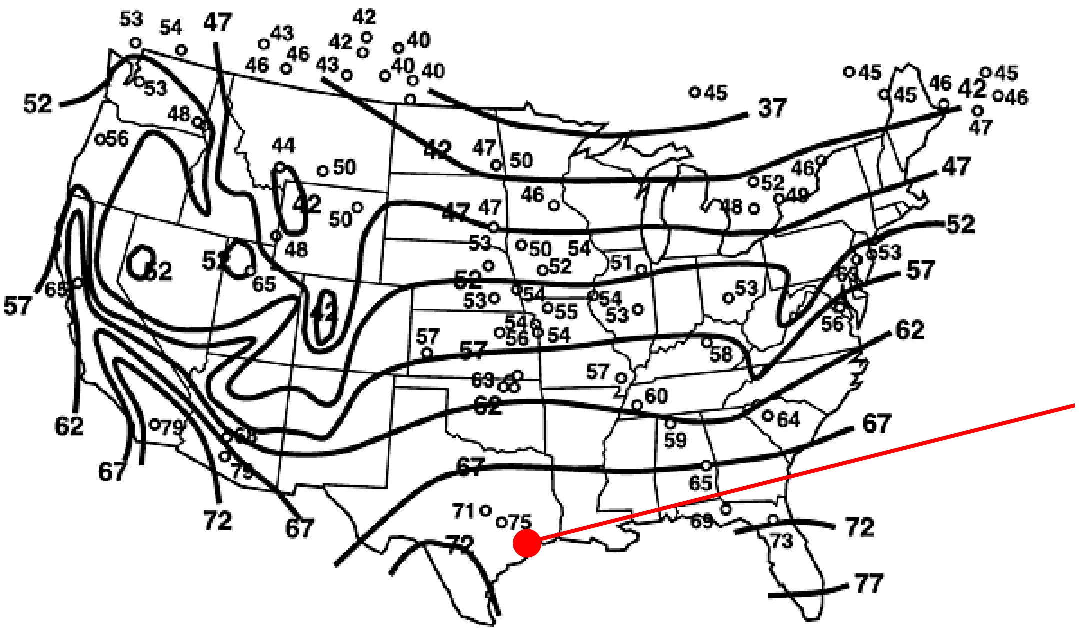
Ground Temperatures & Heat Exchange

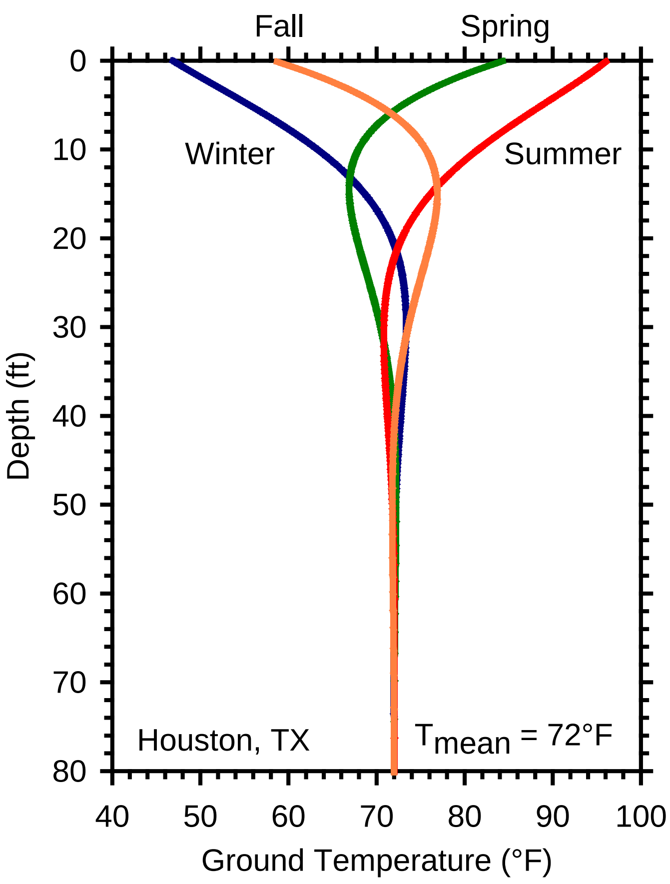




Seasonally constant temperature and the thermal storage capacity of the ground can be leveraged for geothermal heat exchange

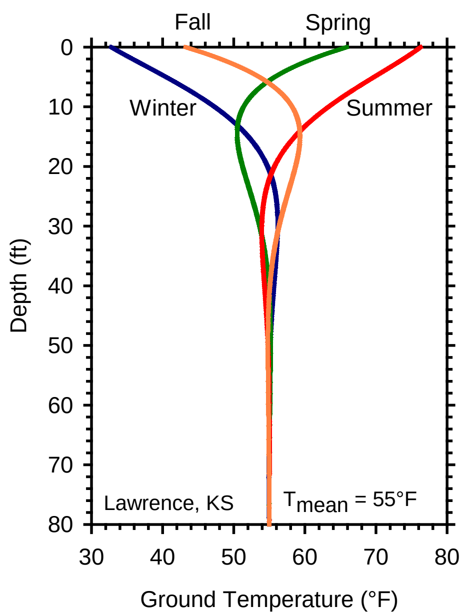
Ground Temperature Profile

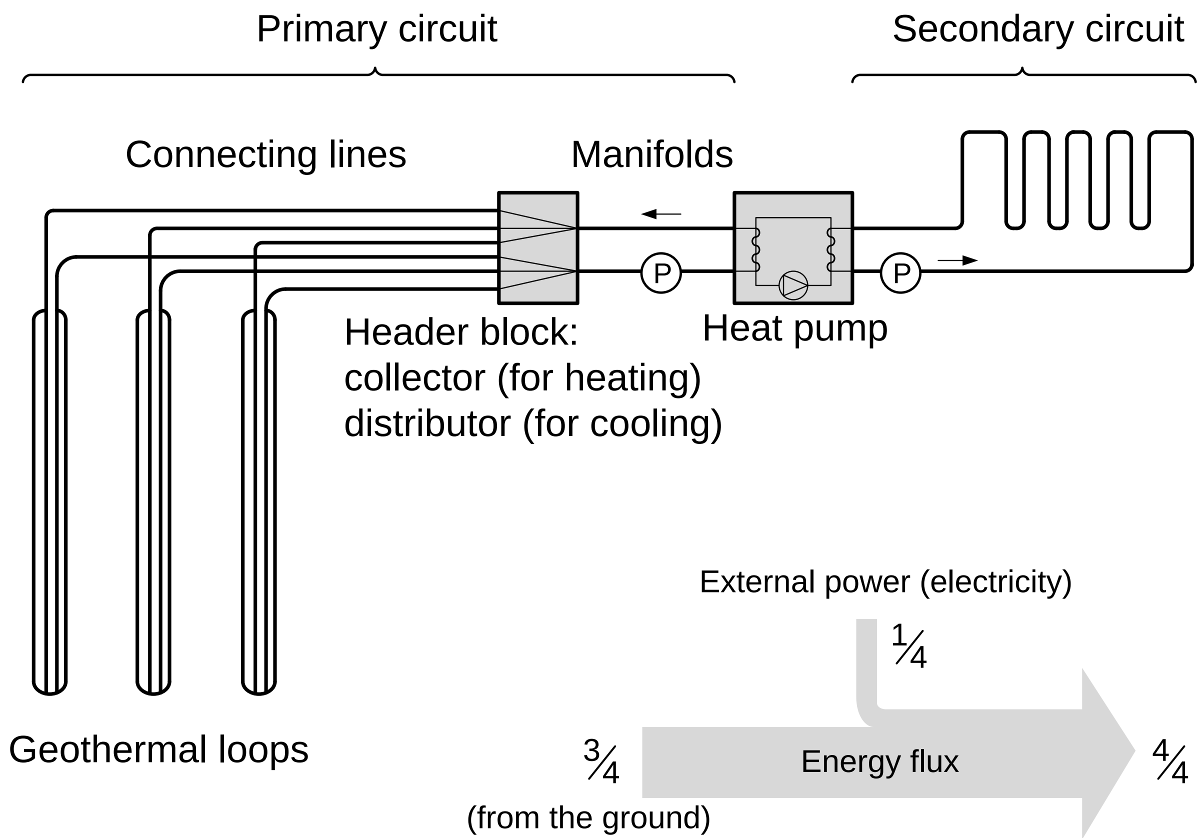




Mean ground temperature

Geothermal Heat-Exchange Systems



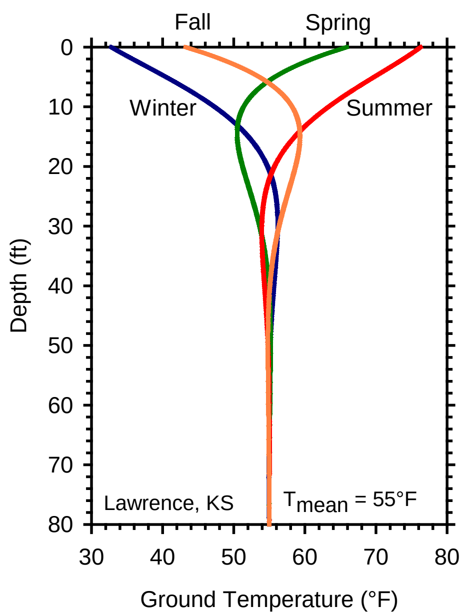


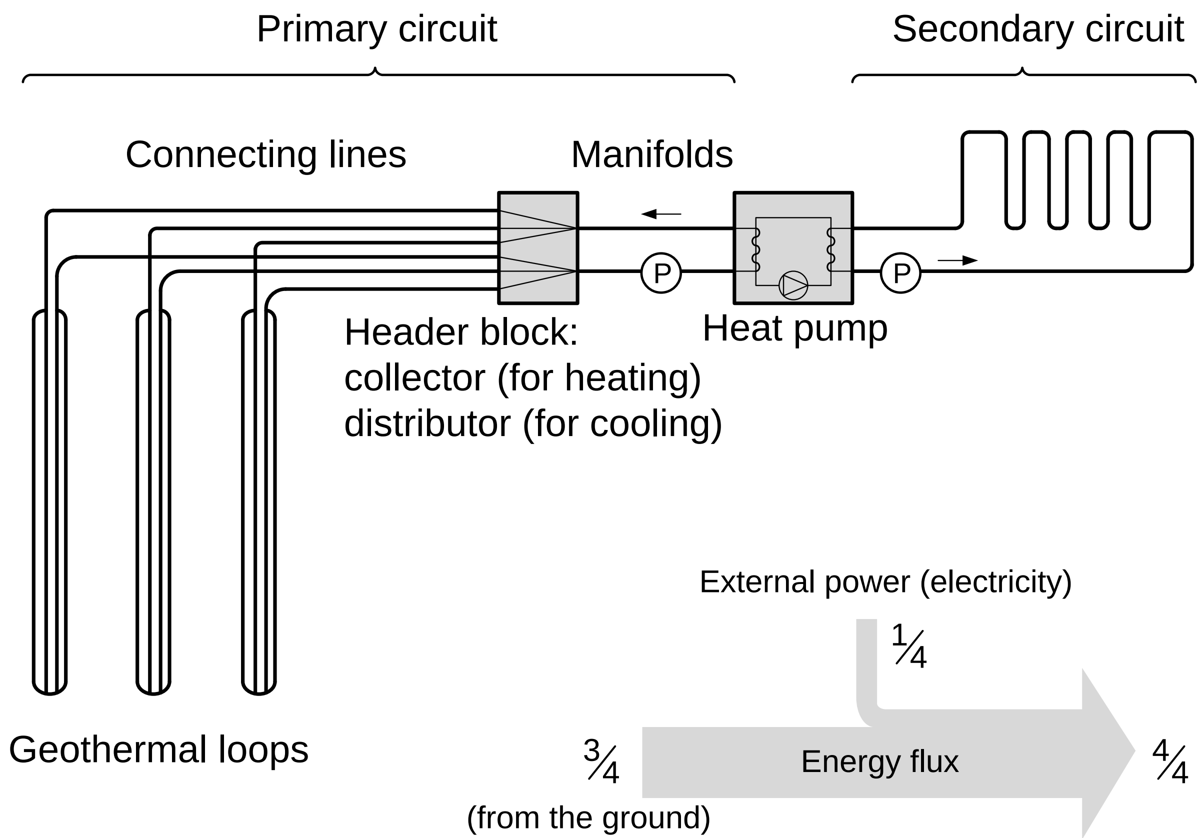
Utilize the relatively constant temperature of the ground and use it for heating in the winter and cooling in the summer

Ground Source Heating/Cooling

- Geothermal heat exchange systems provide ground-source energy for heating and cooling
- The use of ground-source systems for heating and cooling has increased exponentially especially in Europe
- Basic idea been around for long time – make use of the heat energy stored in the ground; access this energy using heat exchangers buried in the ground (fluid-filled HDPE loops)
- In ideal conditions these systems can provide majority of required heating/cooling energy and significantly reduce costs and carbon footprint

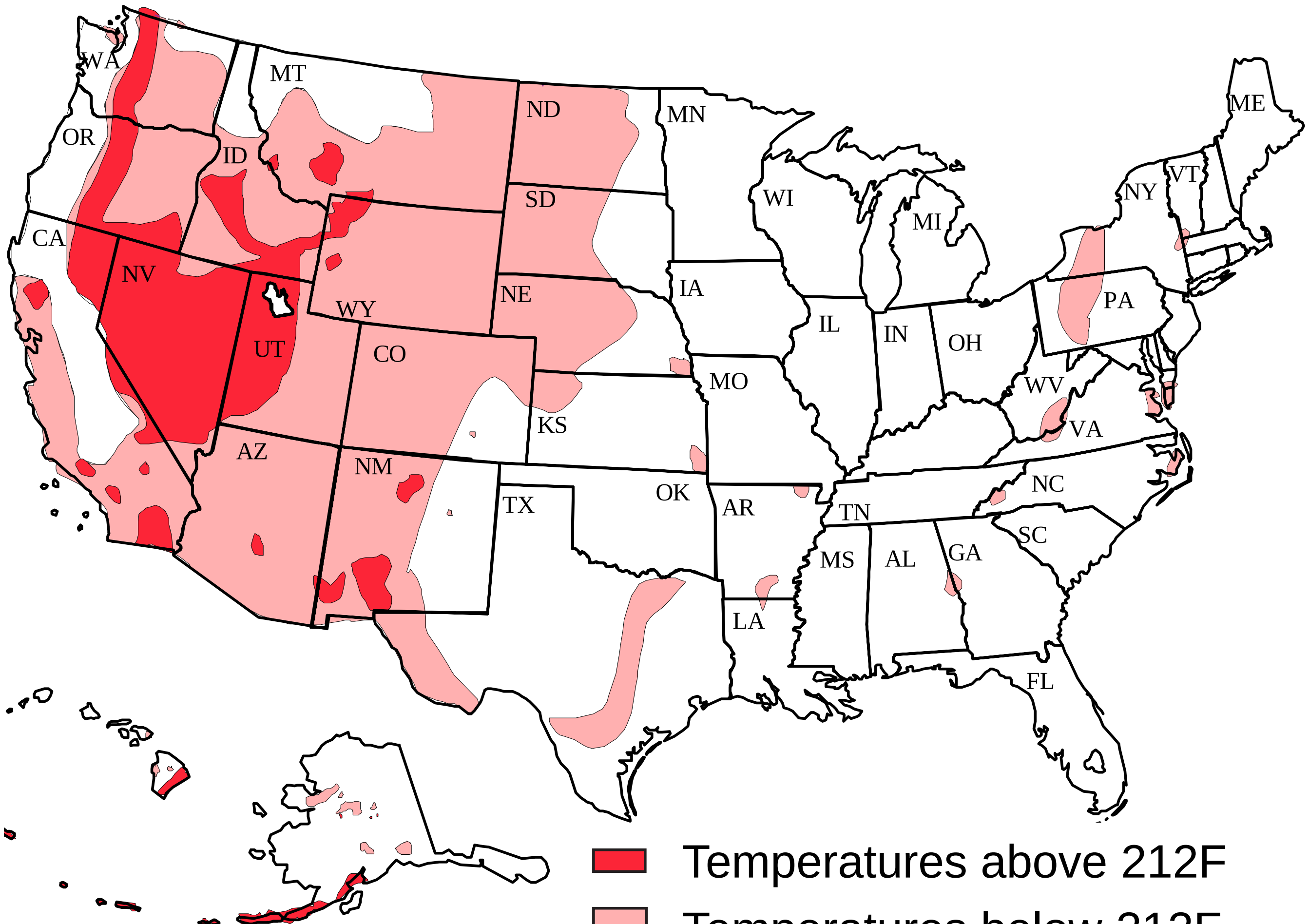
Geothermal Heat-Exchange Systems





Utilize the relatively constant temperature of the ground and use it for heating in the winter and cooling in the summer

Geothermal Resources



Temperatures above 212F

Temperatures below 212F

Suitable for geothermal heat exchange (entire U.S.)

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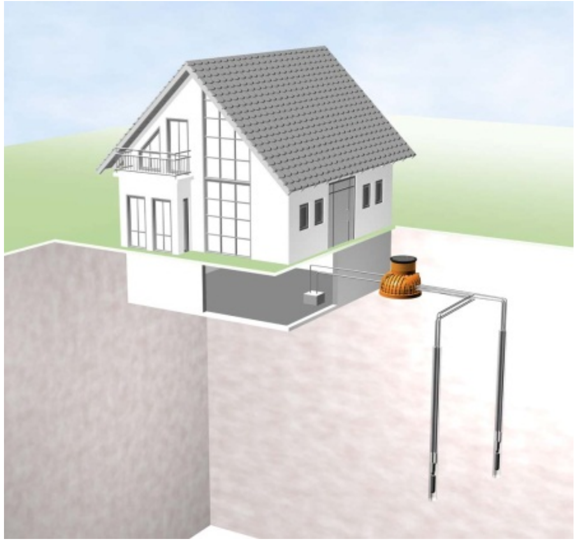
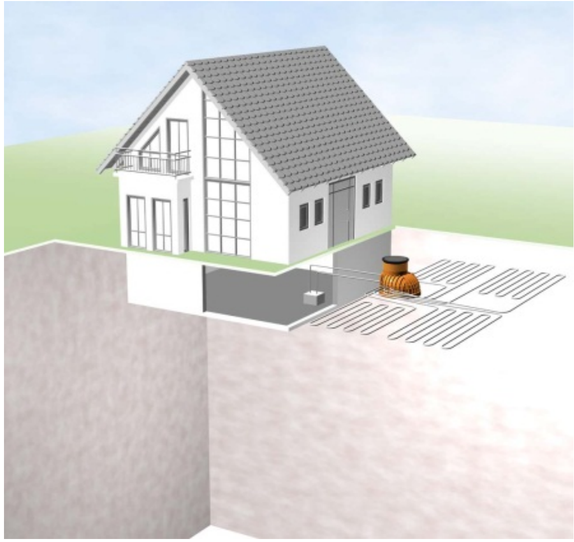
Geothermal Heat Exchange Systems



Geothermal Boreholes

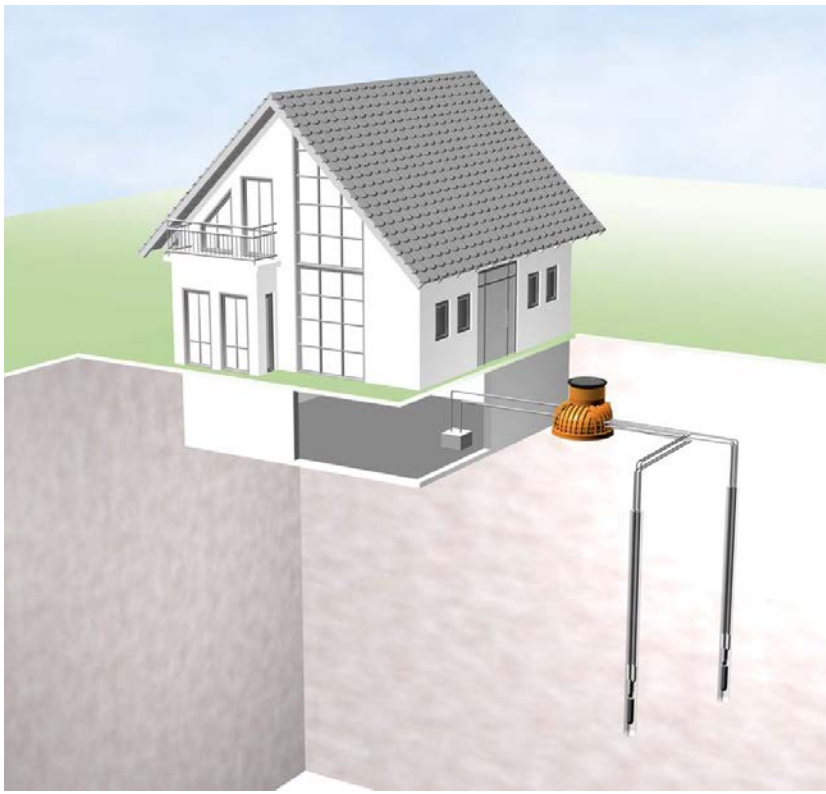


Horizontal Loops

Energy Piles

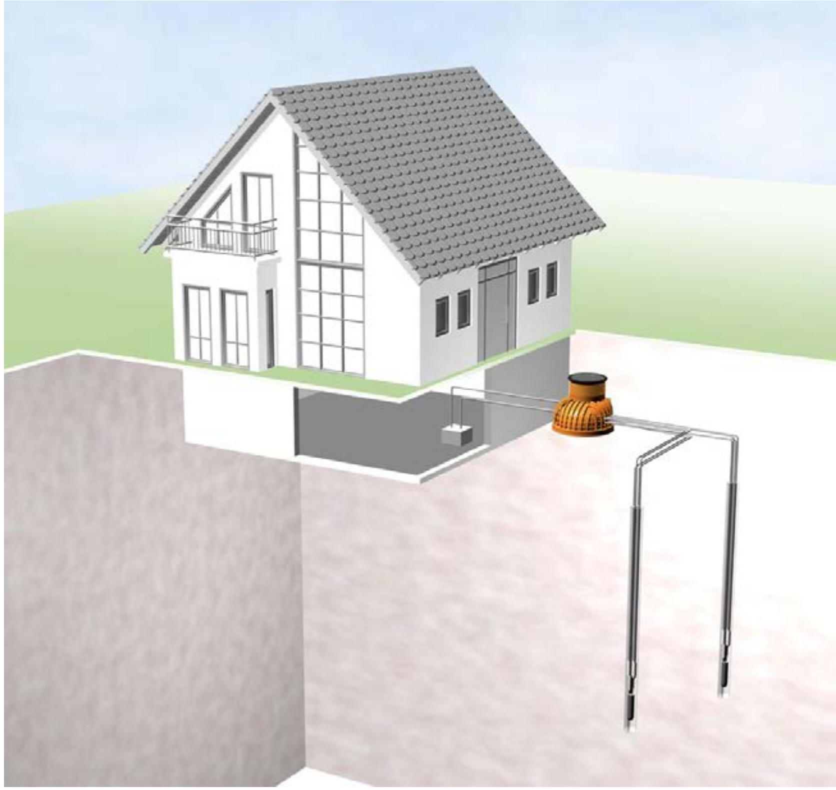
Geothermal Borehole Wells

- 4-6 inch diameter borehole
- 200 ft - 500 ft deep
- Small residential to large commercial

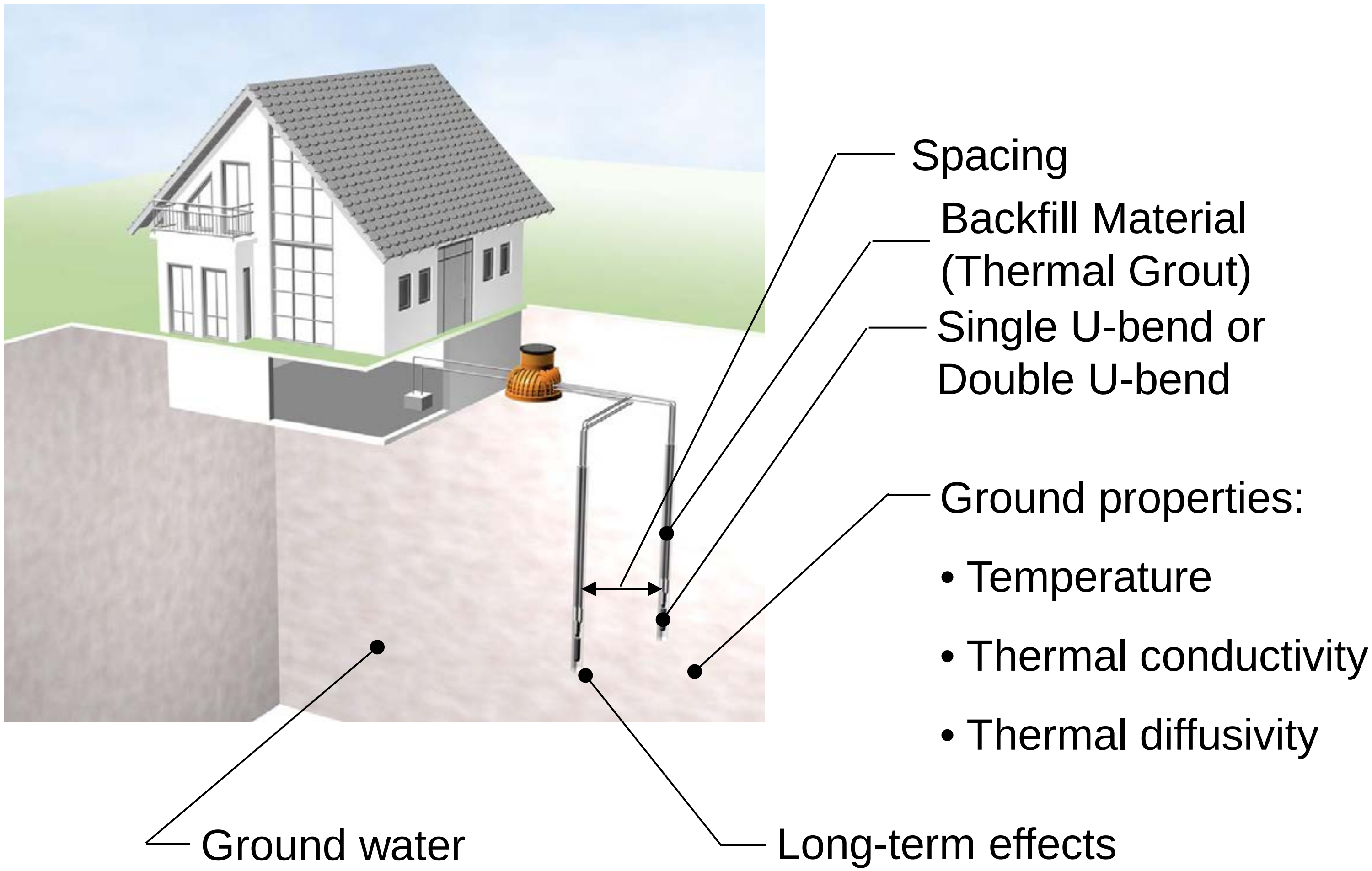


Major cost is drilling and materials

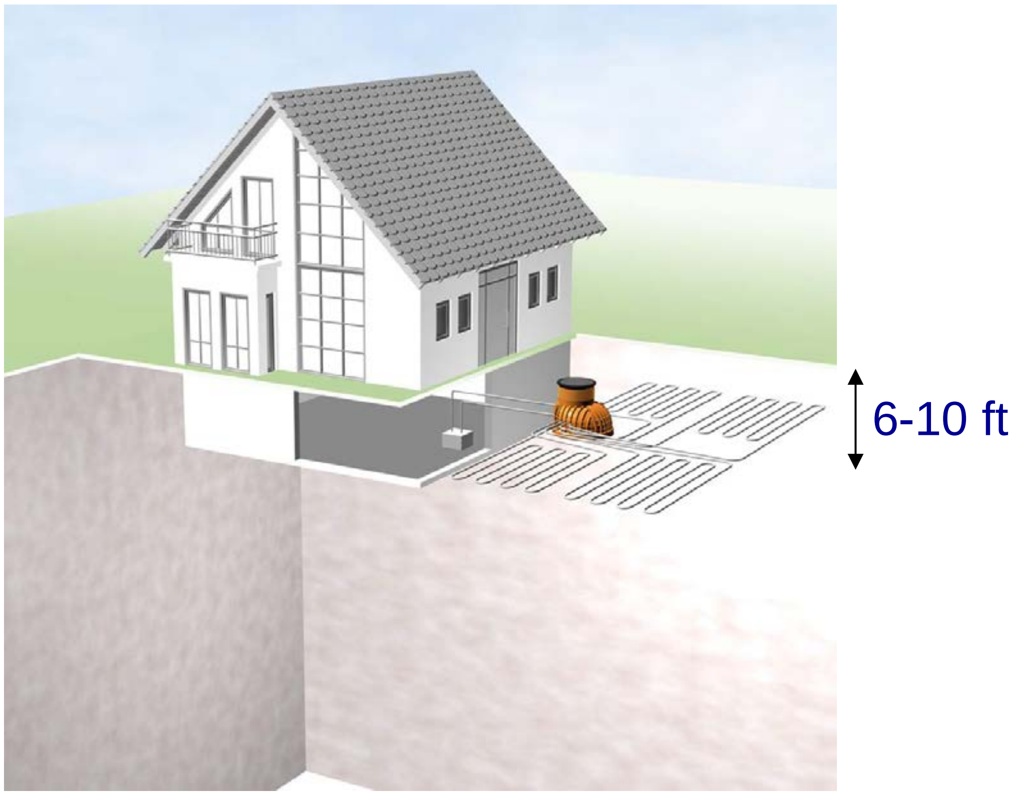
Geothermal Borehole Wells



Geothermal Borehole Wells – Design Considerations



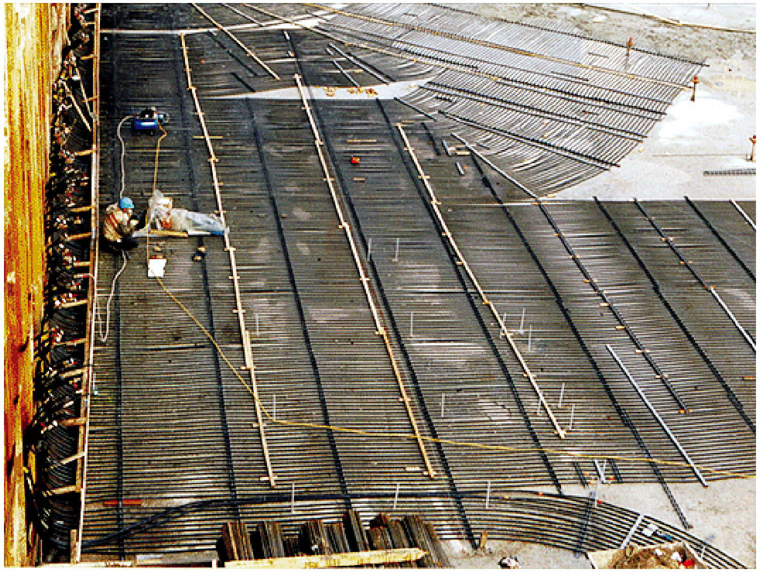
Horizontal Loops



Horizontal Loops

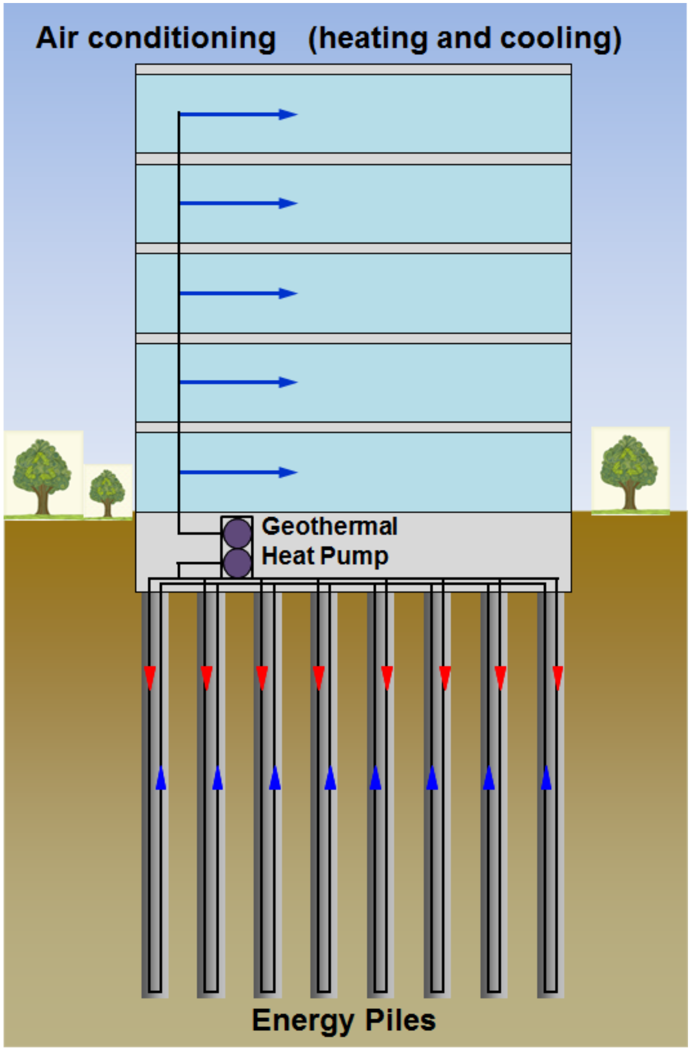
Recently built house in Blacksburg, VA with a trench loop system

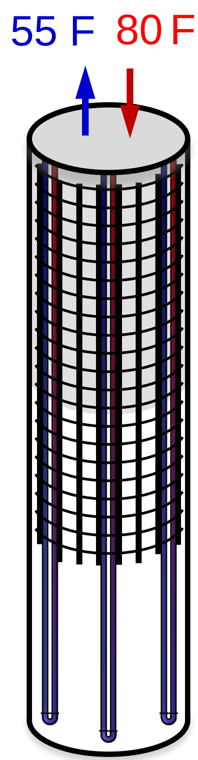
Horizontal Loops



Horizontal loop systems within/beneath slabs

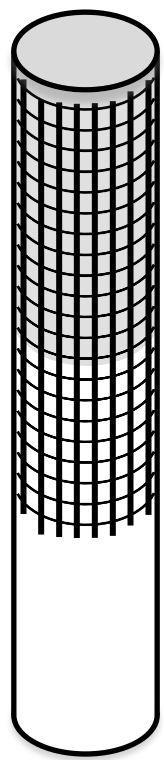
Geothermal Energy Piles





Geothermal Energy Piles – Dual Purpose Elements

Deep Foundation



Foundation support
(micropile, drilled shaft, CFA)

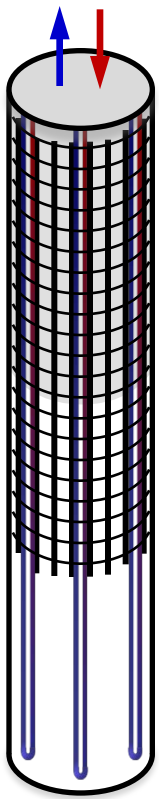
+

Geothermal Loops

Heating/cooling
(PEX, HDPE)

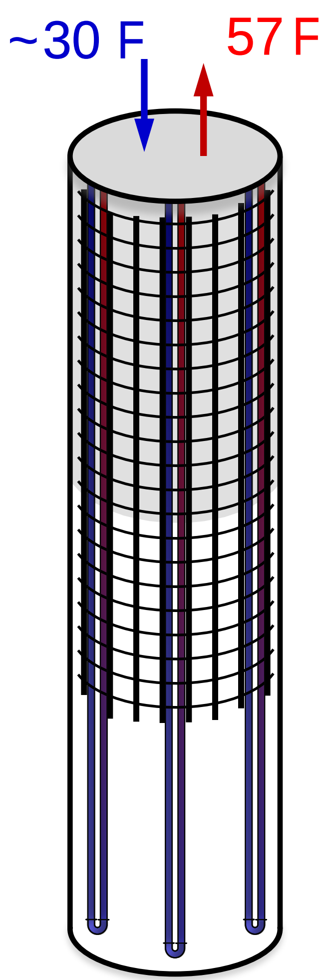
=

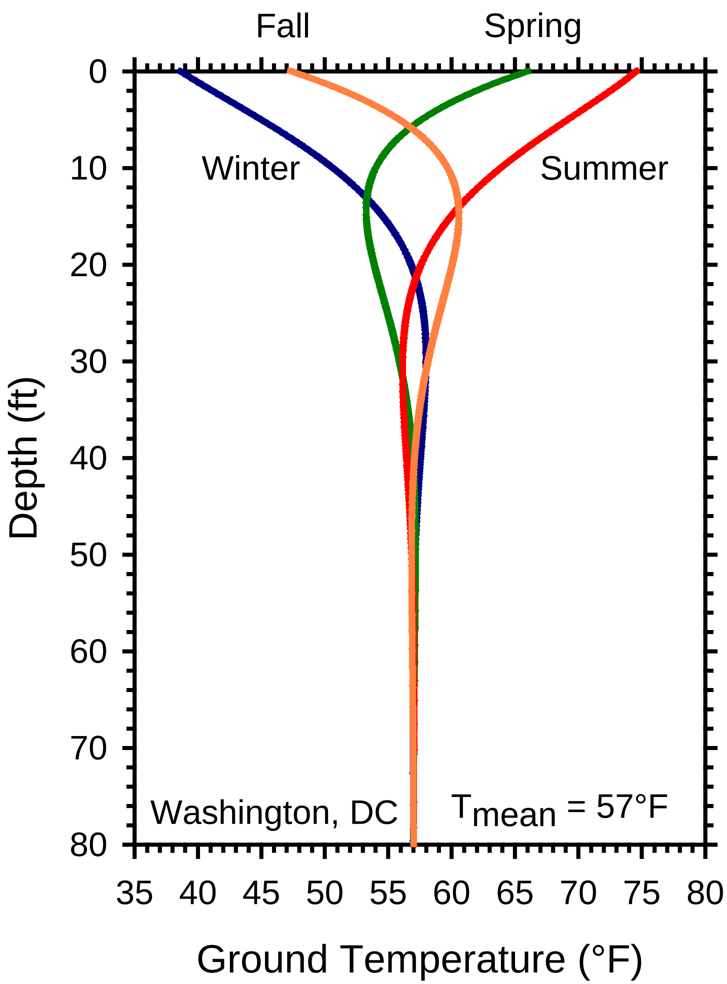
Energy Pile



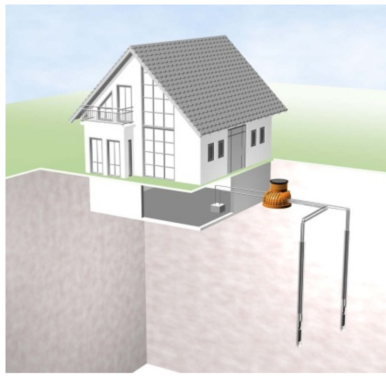
Foundation support &
heating/cooling

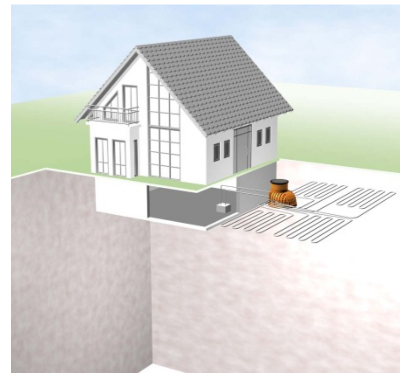
Geothermal Energy Piles – Dual Purpose Elements





Performance of Heat Exchange Systems

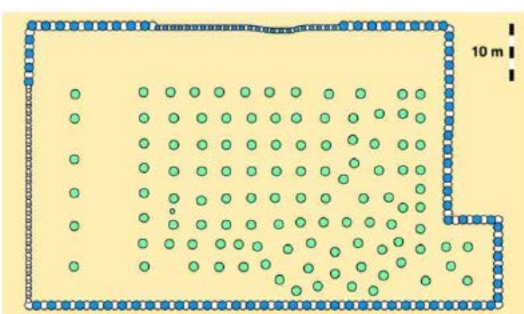


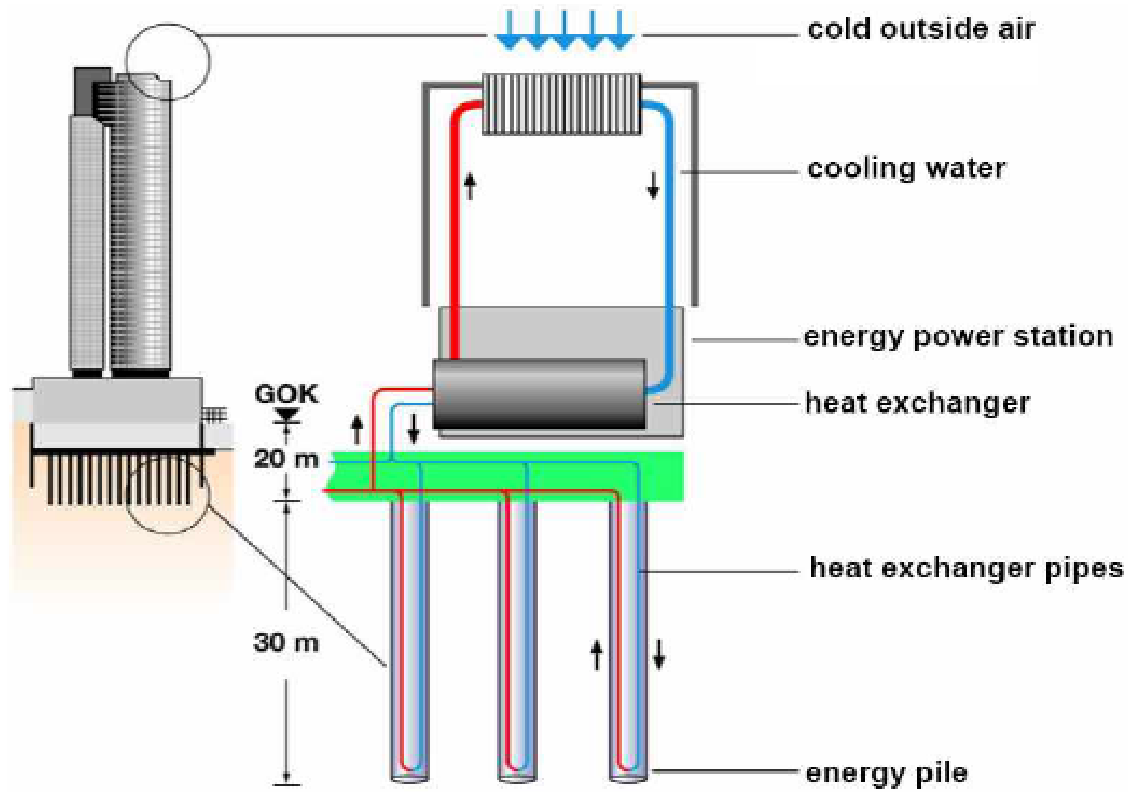


	Vertical	Horizontal	Energy Pile
Poor ground quality	8 W/ft	1 W/ft^2	8 W/ft
Average ground quality	15 W/ft	2.5 W/ft^2	15 W/ft
Excellent ground quality	25 W/ft	4 W/ft^2	25 W/ft

1W ~ 3.4Btu/hr

Frankfurt Main Tower



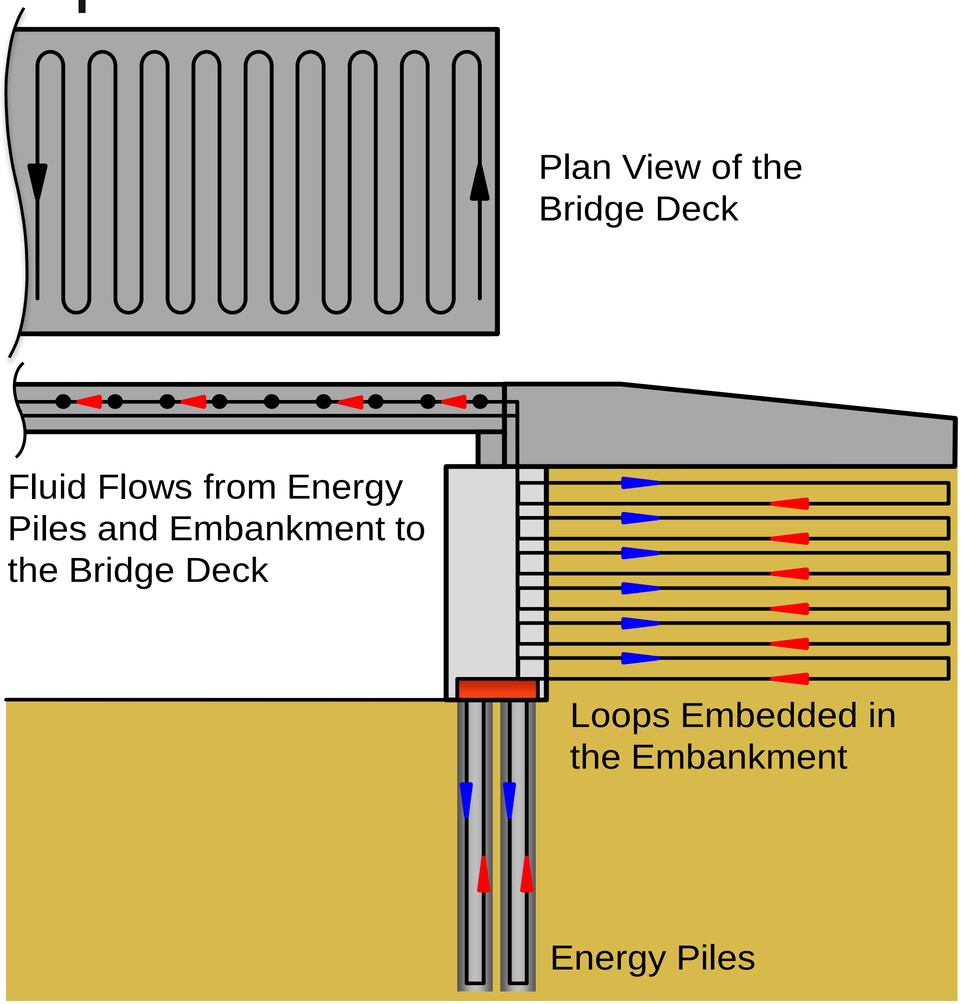


223 Energy piles were installed
Power : 500kW
Courtesy : R. Katzenbach, Technical University of Darmstadt

Keble College, Oxford UK

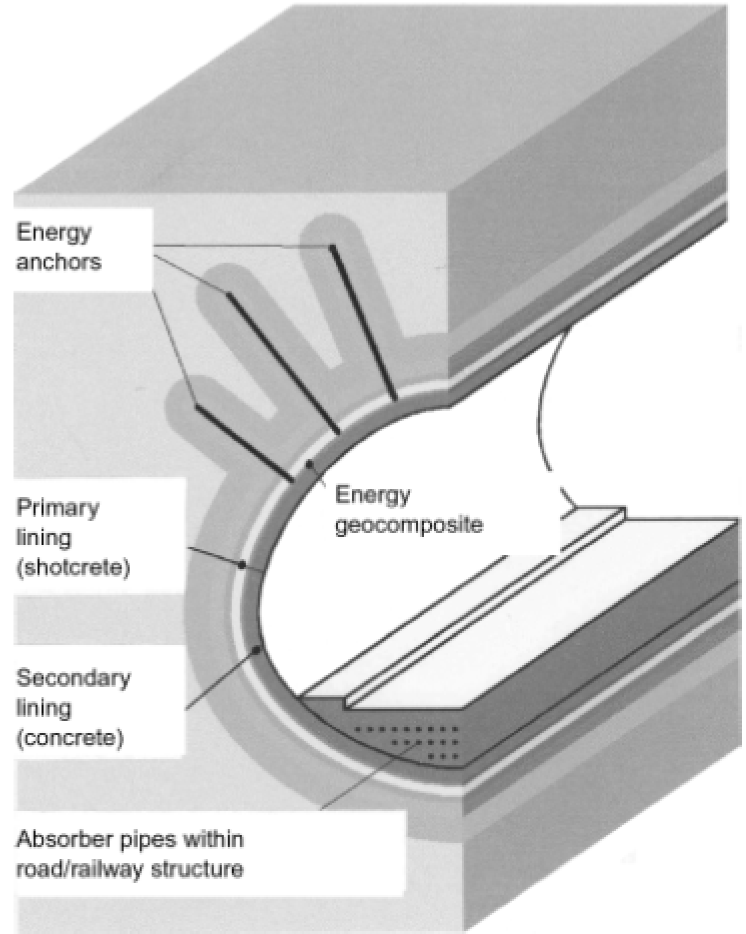
First Energy Wall Project in the UK
Completion: 2002
Type of Absorber: Pile wall, 61 drilled shafts
Heating Capacity: 45 kW
Cooling Capacity: 45 kW
Courtesy : Tony Amis, Geothermal International

Geothermal Bridge Deck Deicing



- Heat exchanger foundation elements can be used to deice bridge decks in the winter.
- Can reduce bridge deck deterioration and aging.
- Bridge deck and the tubing system can be used for heat collection in the summer.
- Can also utilize the approach embankment as a thermal mass for heat storage and extraction.

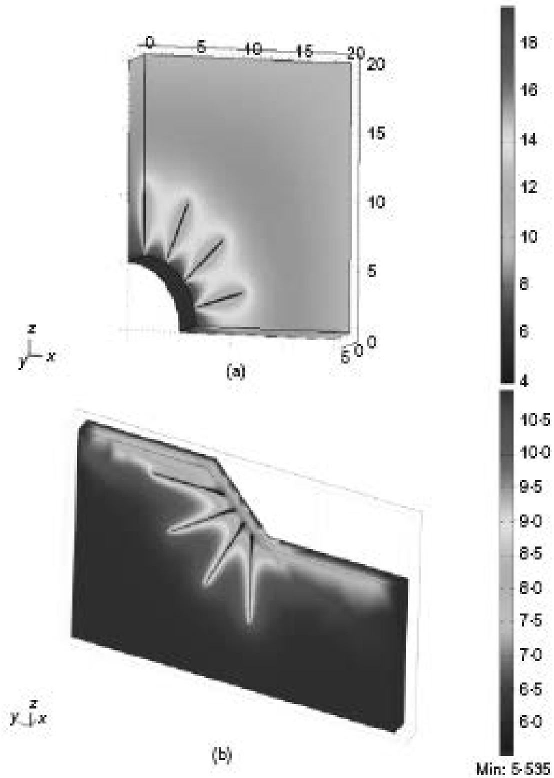
Energy Tunnels



Energy tunnel/anchor systems (Brandl 2006)

Heat can be harvested from tunnels with the use of heat exchanger systems

Energy Tunnels



Energy tunnel/anchor systems (Brandl 2006)

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Geothermal Applications for Transportation

- Airports
  - Runway deicing
  - Terminal heating/cooling
- Road deicing and summer cooling
- Roadside facility heating/cooling
- Bridge deck deicing and stress control

Airport Applications

- Terminal heating/cooling
  - Terminals can account for 75% of an airport’s energy requirements
  - Of that, 25-80% is required for HVAC
  - Significant savings could be realized by utilizing geothermal energy
  - Nashville International Airport currently implementing this and expected to save more than $430,000/yr

Airport Applications

- Terminal heating/cooling – Zurich Airport Terminal E
  - 310 of the 440 piles are energy piles, 30 m (100 ft) each
  - Supplies 85,200 m^2
  - Heating seasonal performance factor of 3.9
  - Cooling seasonal performance factor of 2.7

Airport Applications

- Runway and Apron Deicing
  - Usually airports employ a combination of mechanical and chemical methods: plows, salts, sand, etc.
  - Each time a plow has to clear the runway, operations are slowed
  - Chemicals can be damaging to the environment and runway concrete
  - A lot of ground volume beneath runways that could be utilized for geothermal energy
  - Note: Geothermally heated hot water could potentially be used to deice the planes
  - Example: Apron deicing at Greater Binghamton Airport, NY

Airport Applications

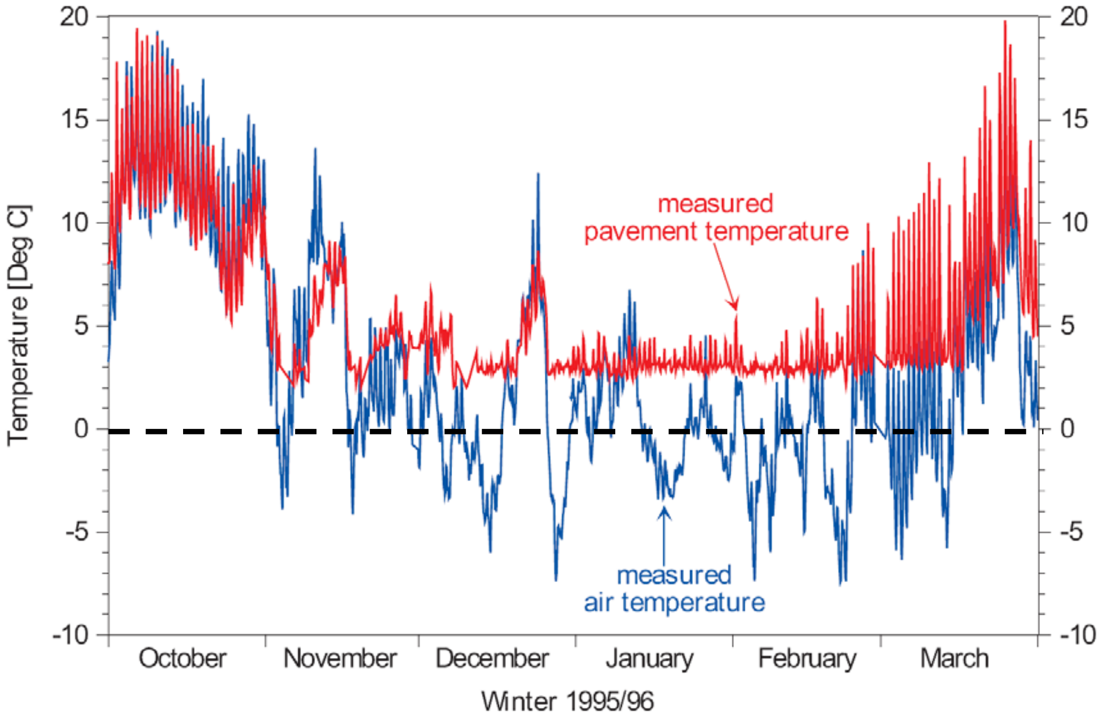
- Apron Deicing at Greater Binghampton Airport
  - $1,300,000 in construction costs
  - 4,000ft^2 of apron and walkway heated area
  - Twenty 500ft vertical and two 140ft horizontal geothermal wells
  - Operating costs - $15,000/yr or $0.16/passenger
  - Utilized for terminal cooling in the summer

Road Deicing and Summer Cooling

- During winter storm events, roads can often be covered with snow/ice.
  - Dangerous for motorists
  - Expensive to remove (plowing)
  - Can be damaging to environment (from deicing chemicals)
- During the summer, the cyclic heating and cooling can degrade the pavement
- Geothermal energy can heat the roads in the winter and cool them during the summer
- Example: SERSO road in Switzerland

Road Deicing

- SERSO Pilot Plant in Switzerland (EGEC 2007)
  - Collects heat during summer and stores in ground for winter
  - 91 borehole heat exchangers to a depth of 70 m



Roadside Facility Heating/Cooling

- Tollbooths and toll plazas
  - Vehicles approach toll plazas at a high rate of speed and decelerate quickly
  - This can be dangerous during winter weather for both motorists and tollbooth operators
  - Can geothermally heat the pavements of the toll plaza to prevent snow and ice formation/accumulation
  - Can also heat the tollbooths and cool them in the summer

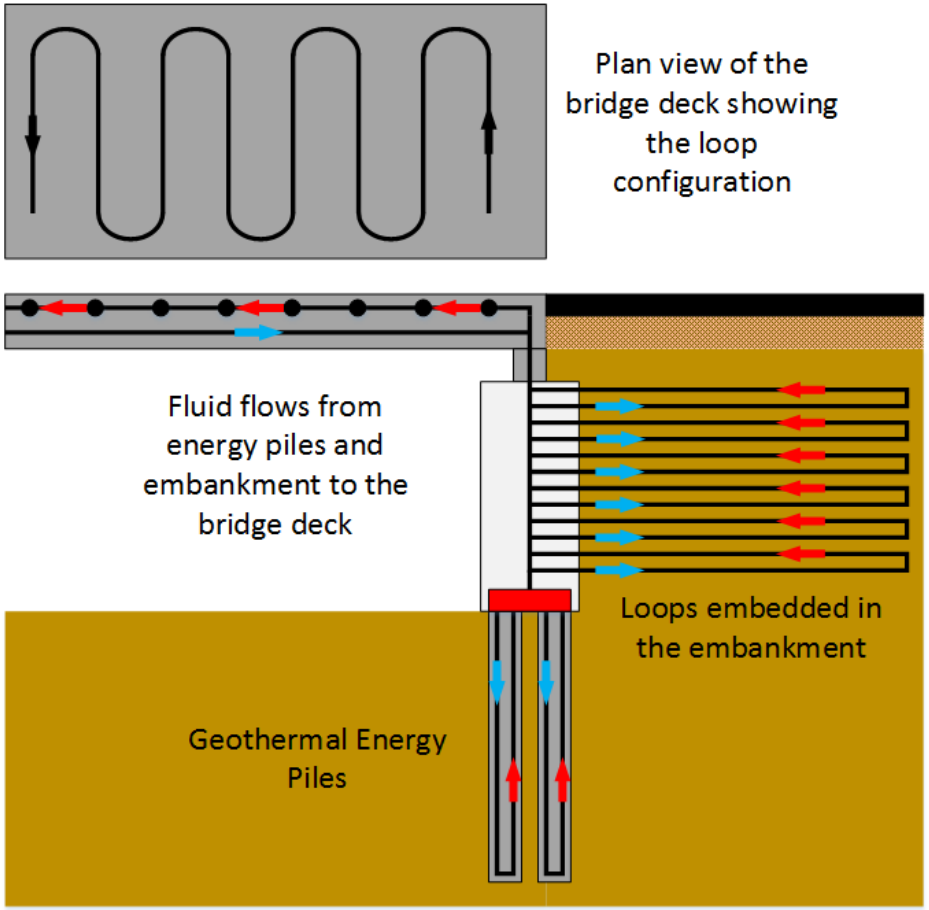
Bridge Deck Deicing and Stress Control

- Winter weather-related problems with bridge decks:
  - Preferential icing
  - Accelerated corrosion (from chemicals)
  - Environmental contamination (from chemicals)
- Cyclic stressing and straining of bridges in the summer can also be problematic and lead to accelerated deterioration

Ground-Source Bridge Deck Deicing

Ground-source deicing: Fluid is warmed as it circulates through the energy piles and approach embankment and then circulated in the deck, heating the deck

- Can be operated in reverse during the summer
- Not meant to replace mechanical removal



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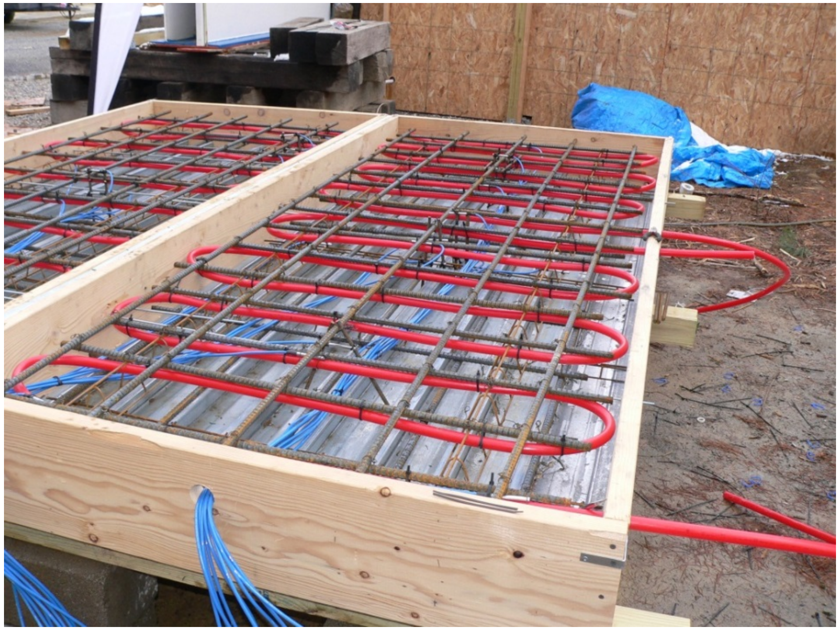
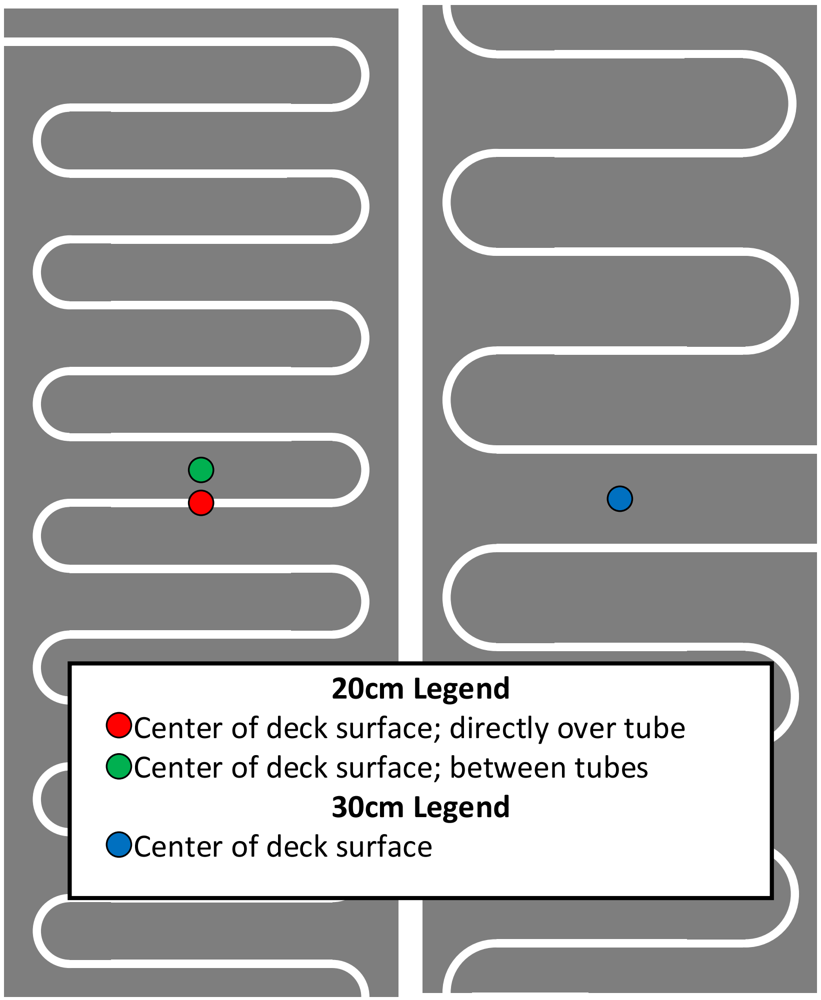
Experimental Investigation



The Setup:

- Two 1.3m x 3.3m x 25cm doubly reinforced concrete slabs
  - PEX circulation tubes
  - Loops spaced 20 and 30cm
  - Total of 36 thermistors
- Four 33m Energy Piles
  - Spaced 2.6m apart
  - Only 1 used for the experimental results
- Three observation boreholes to monitor temperature

Model-Scale Experiments



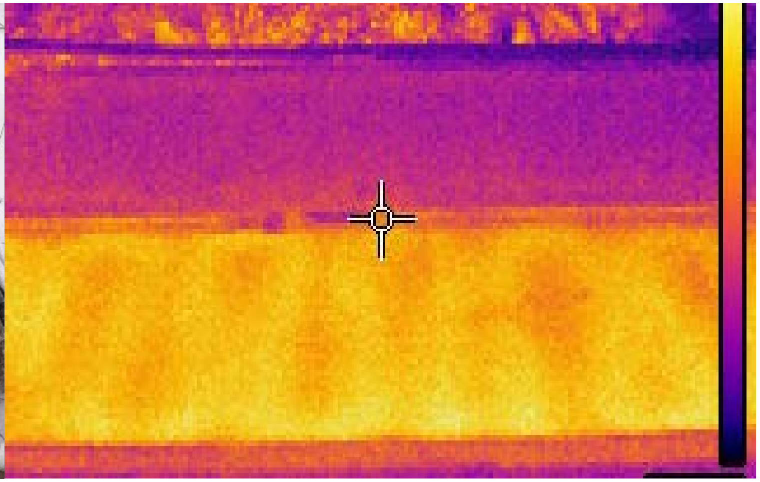
The Setup:

- One side was heated (20cm), other side was left as a control (30cm)
- Temperature was measured in all 36 thermistors, but only showing the results from 3 near the deck surface

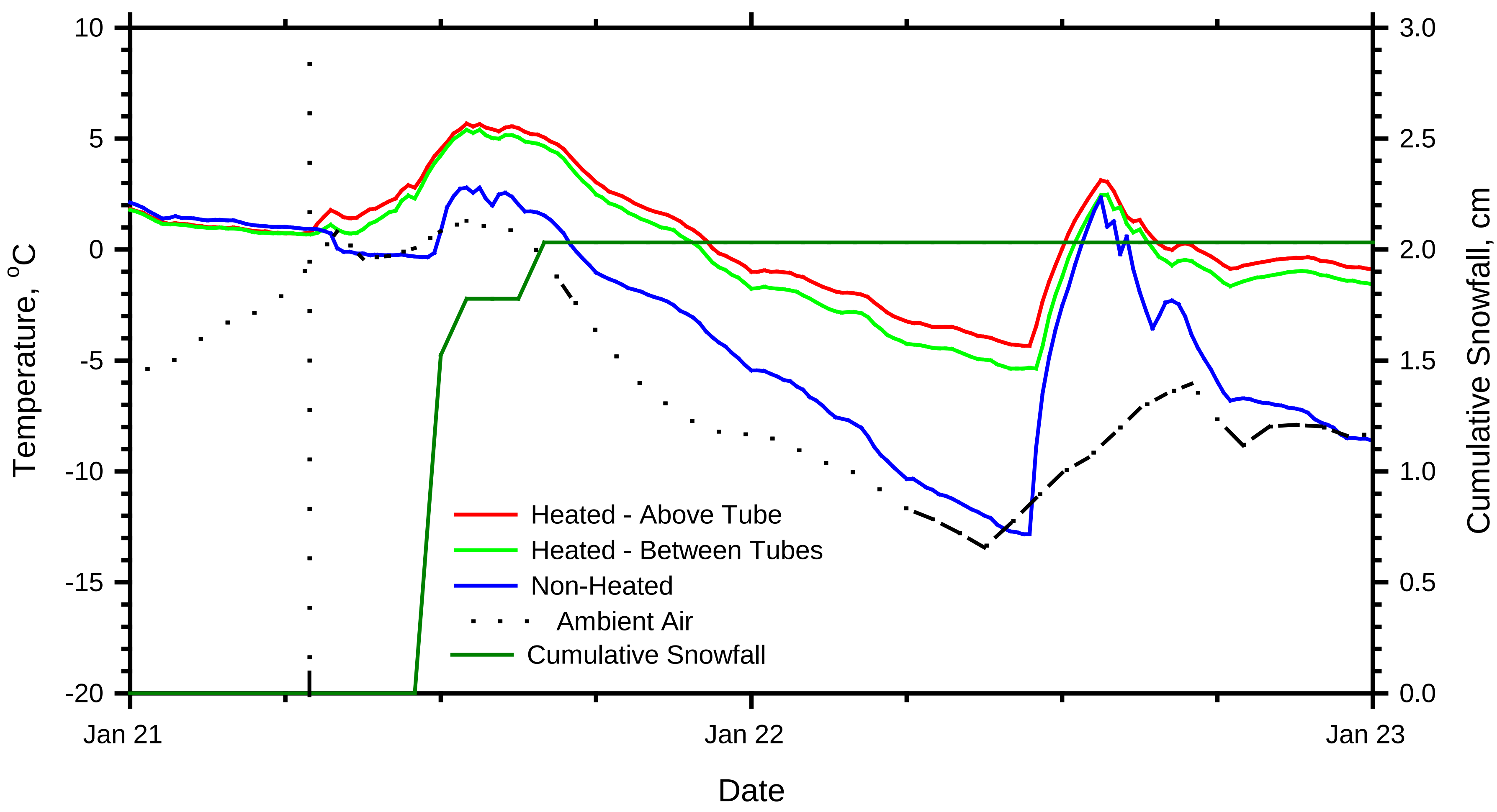
Experimental Results

Mild Winter Storm: January 21, 2014

- 2.1cm of snow fell while ambient temperature was -0.5^{o}C
- Turned on system before the start of snowfall and left running during snowfall
- The side that was operated remained snow free the entire time



Mild Winter Storm

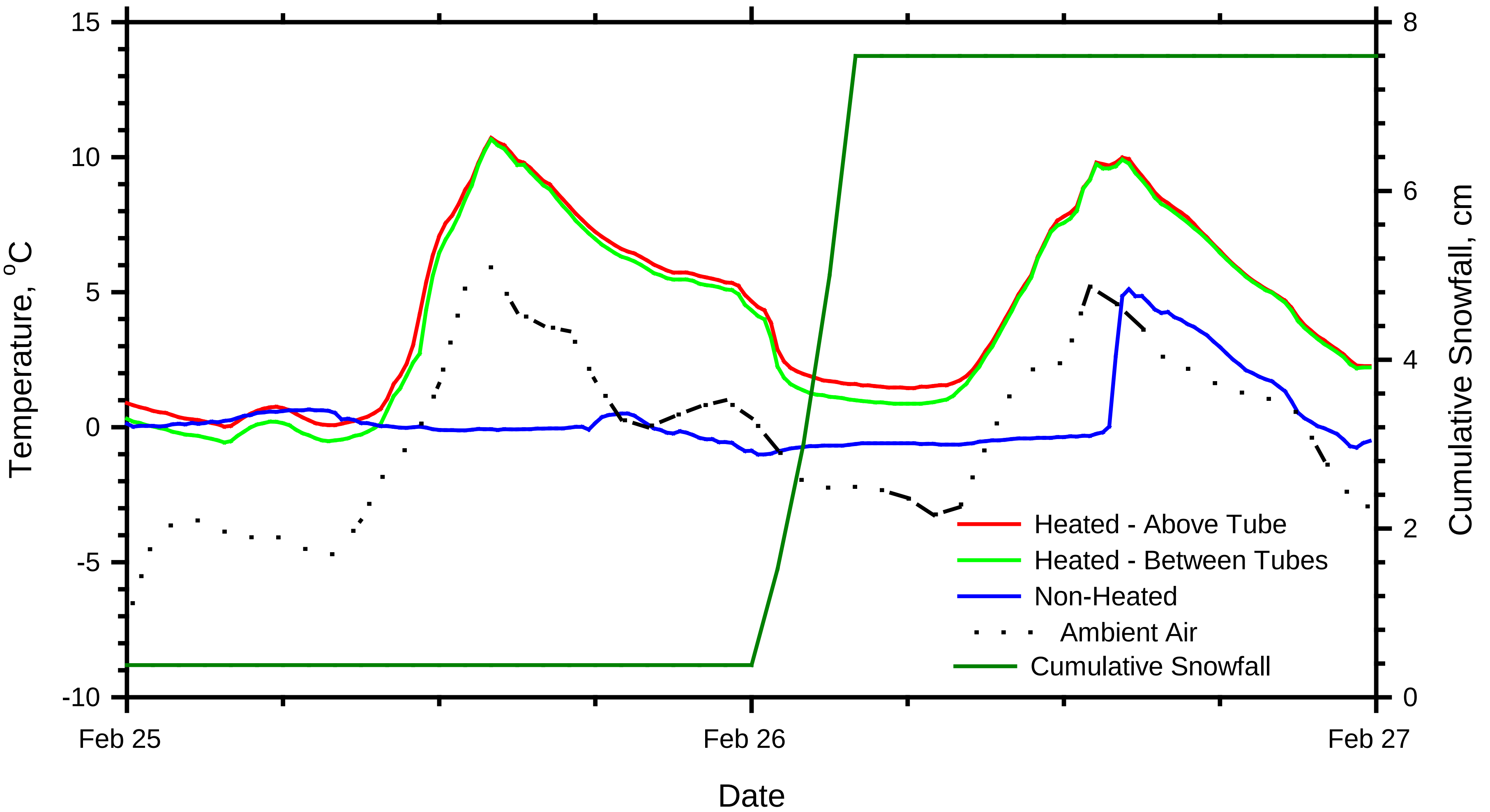


Moderate Winter Storm

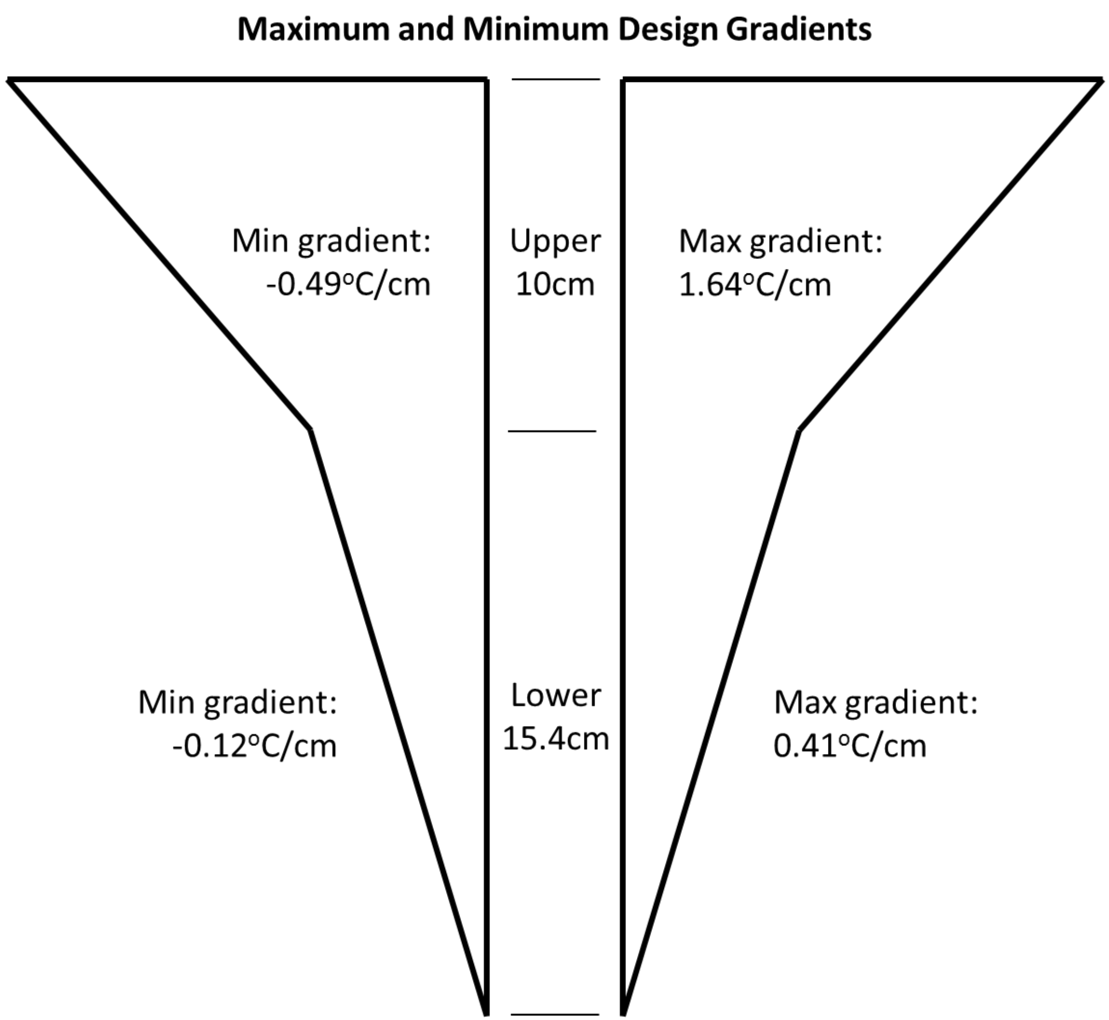
Moderate Winter Storm: February 25-26, 2015

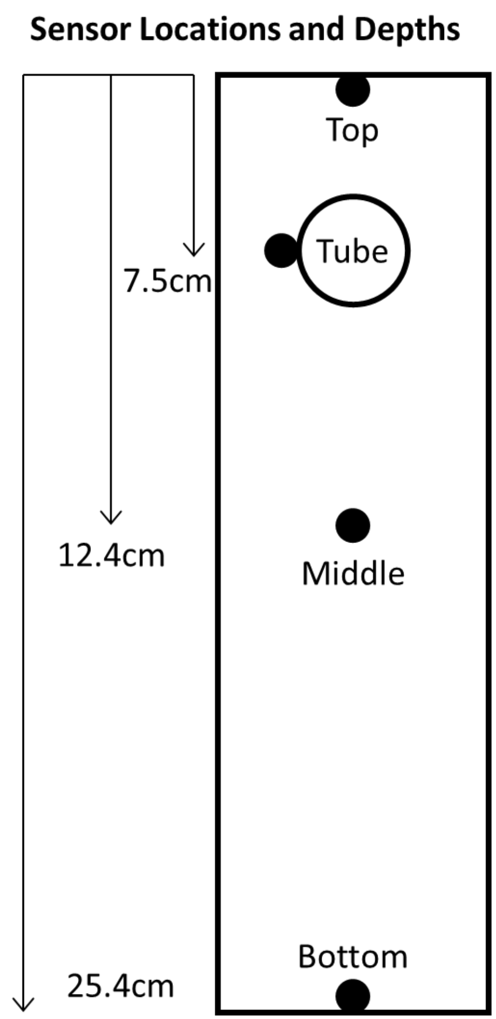
- 7.6 cm (3 in) of snow fell while the ambient air temperature was -2 to -3^{o}C
- Turned on system before the start of snowfall and left running during snowfall
- The side that was operated had a surface temperature >0^{o}C the entire time and remained snow-free

Moderate Winter Storm

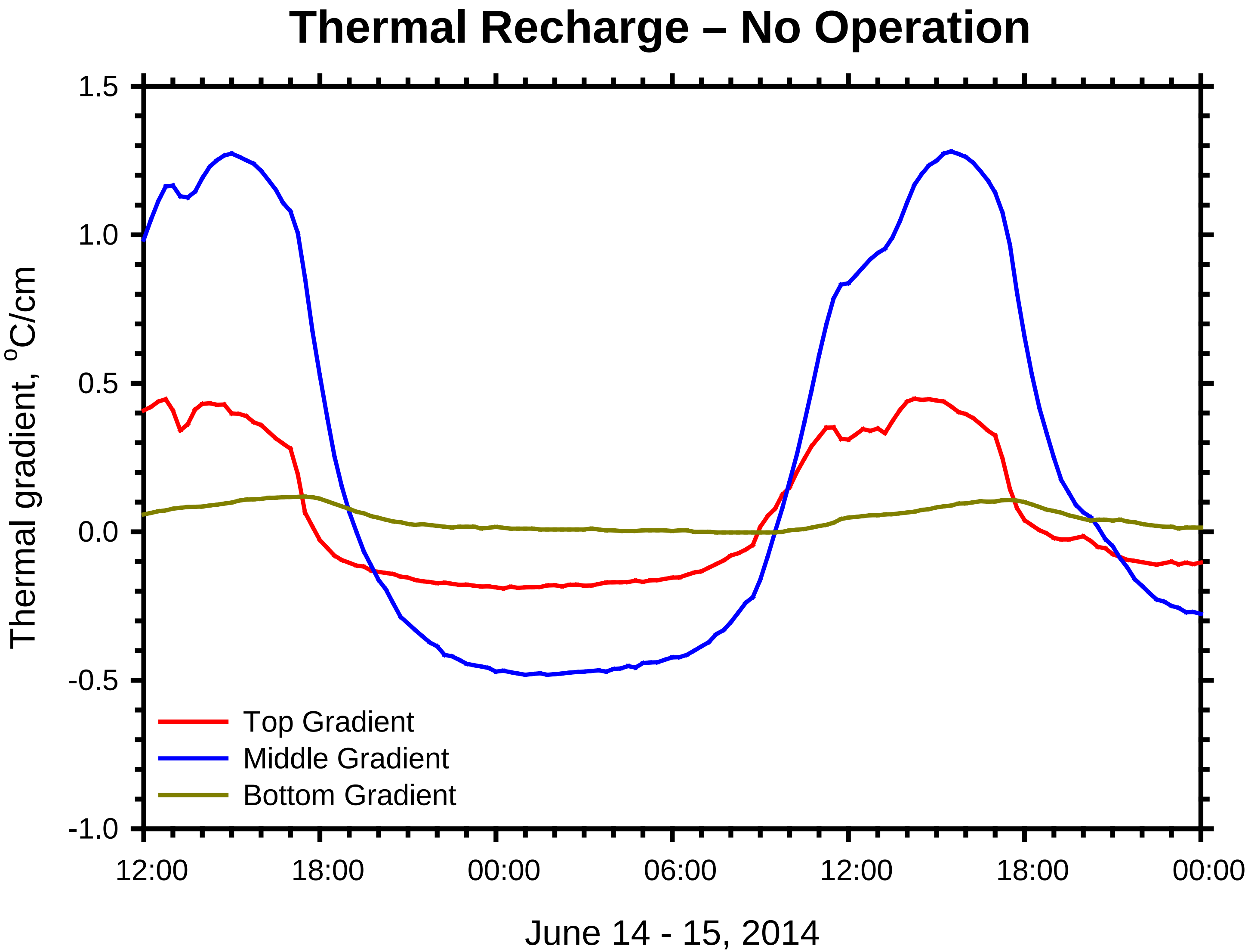


Bridge Deck Temperature Gradients

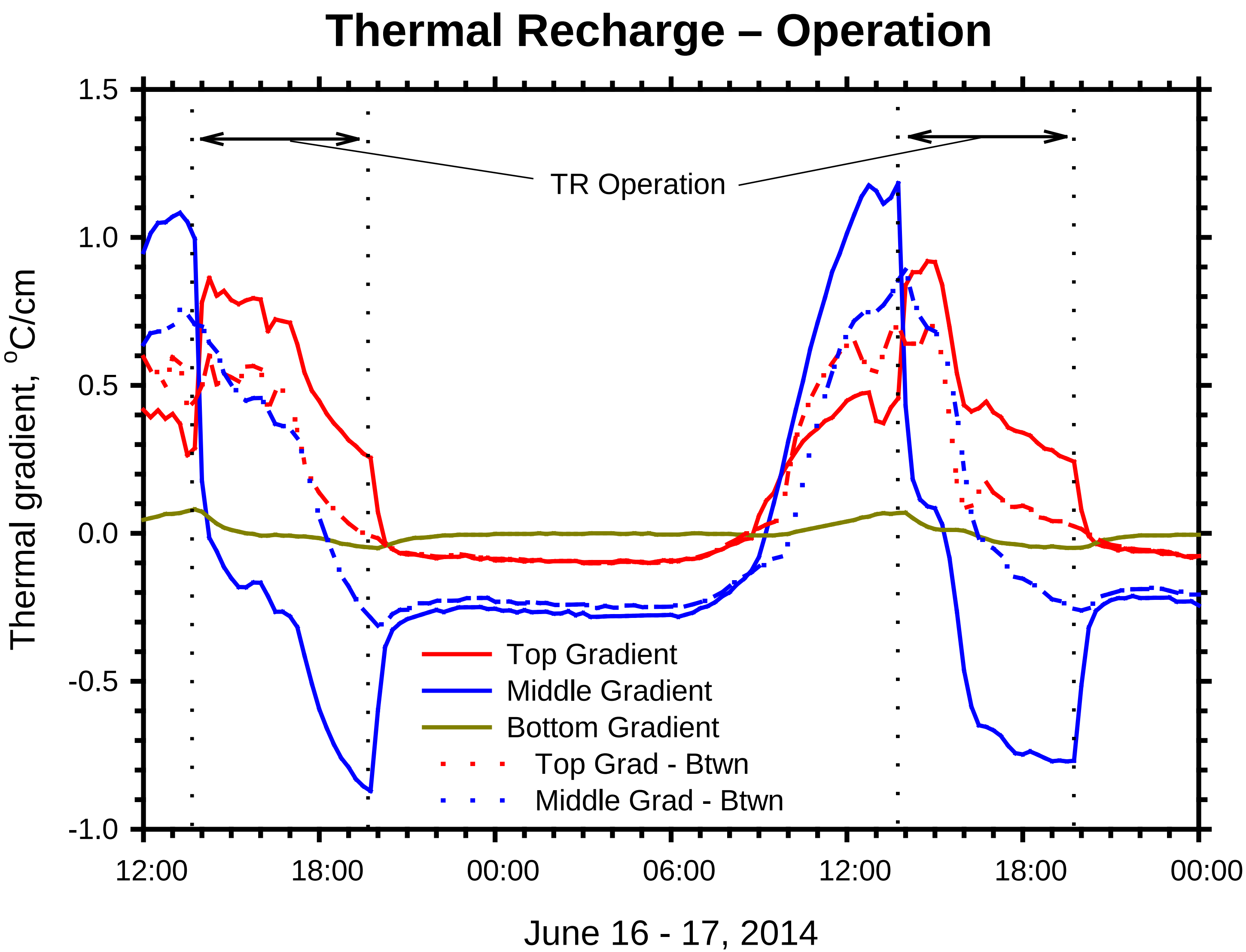




Bridge Deck Temperature Gradients



Bridge Deck Temperature Gradients

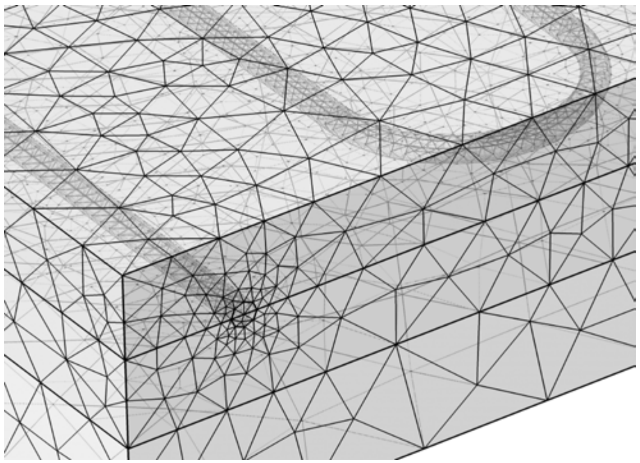


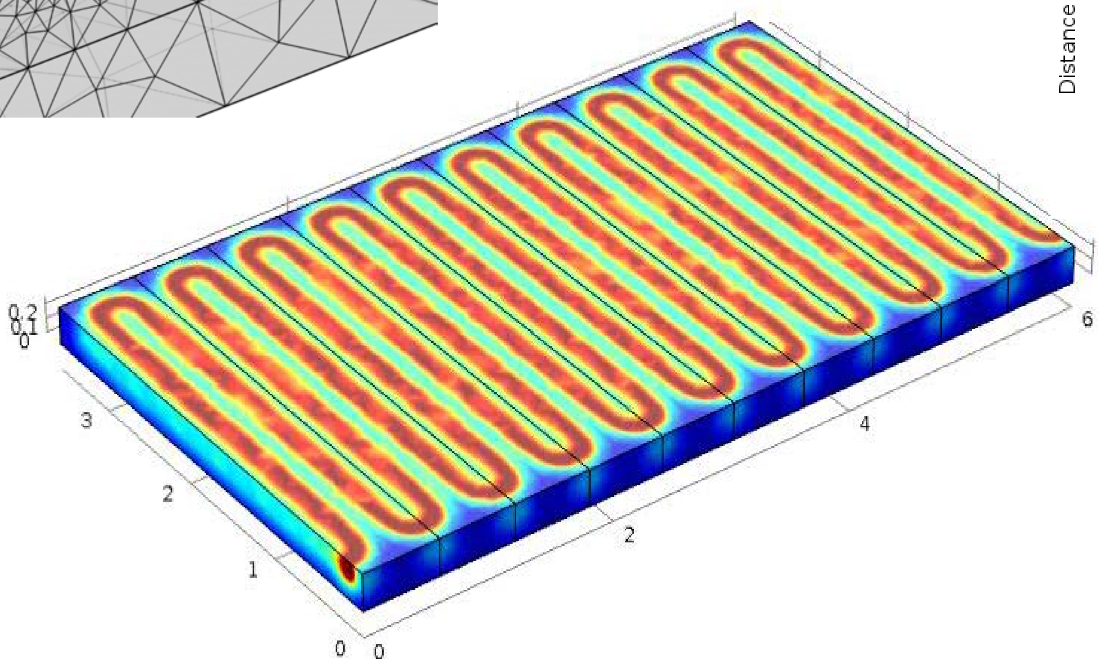
Summary of Experimental Tests

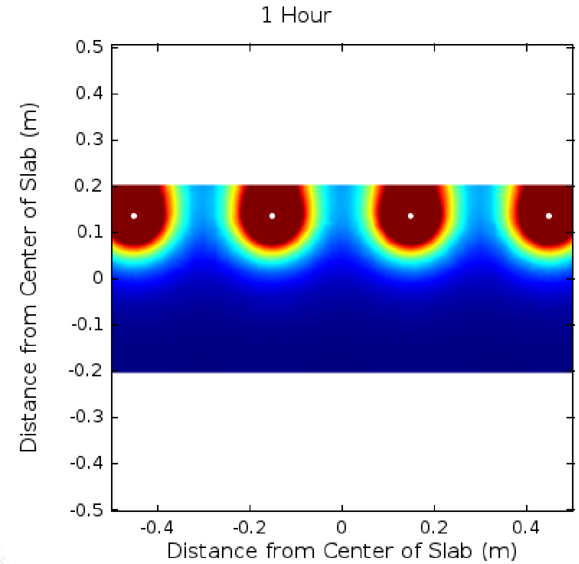
- Tests in mild, moderate, and severe winter storms demonstrated:
  - The system was capable of handling moderate amounts of snow in moderate weather conditions without the need of external energy (heat pump)
  - Whenever the system was not capable of handling the snow by itself, it was able to maintain a surface temperature above 0^{o}C → when combined with mechanical removal a snow-free surface will exist
  - The system is self-adjusting → when more energy is needed it is able to generate it (through gradients)
  - Operation of system in summer reduces the extreme temperature gradients experienced by the bridge deck

Numerical Modeling of Bridge Heating

- Modeled the experimental bridge deck slab for validation.





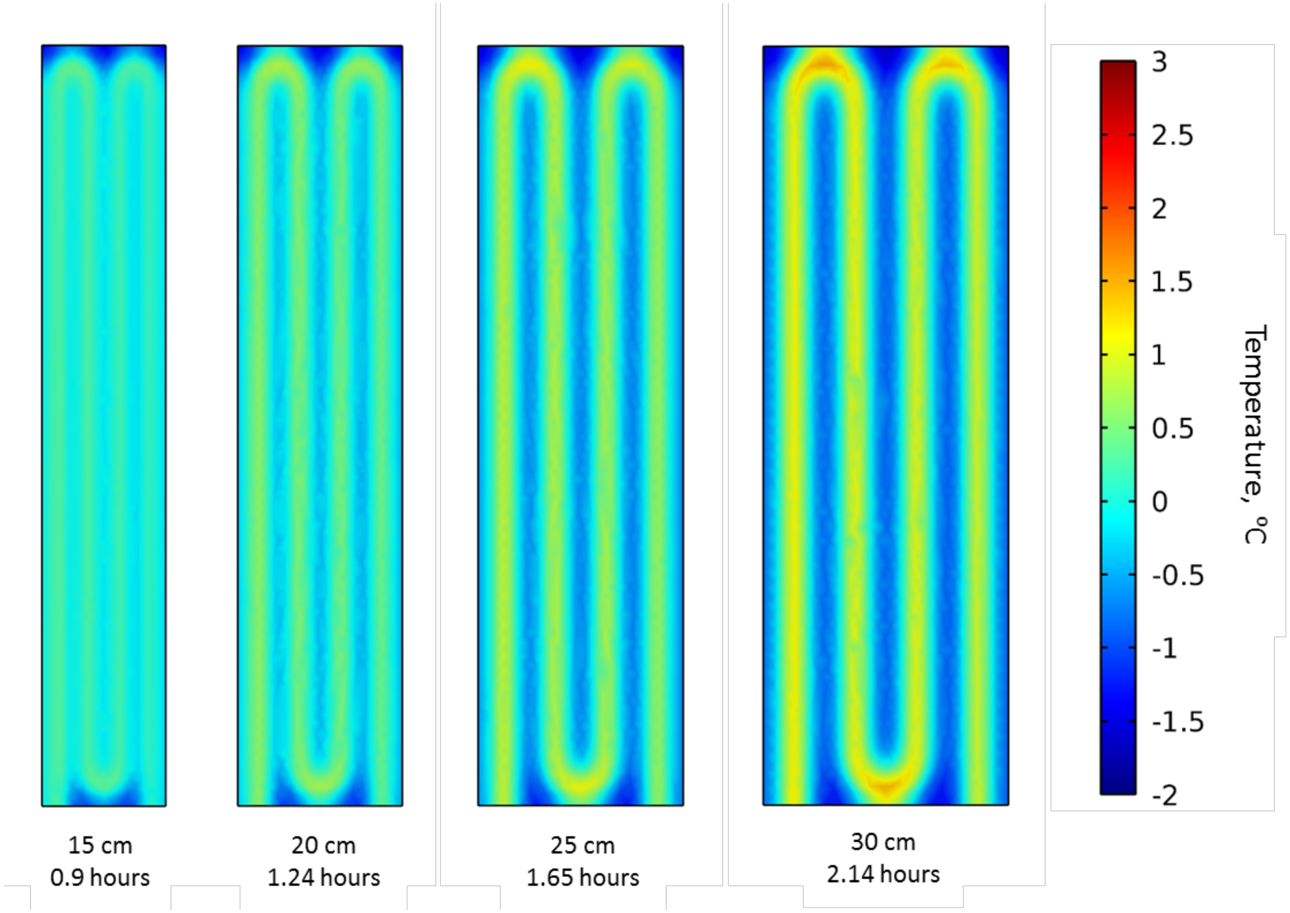


Understanding System Performance

- Time – how long does it take to heat?
- Temperature – can the bridge deck maintain a temperature above freezing?
- Energy – how much energy is this process requiring?
- Snow-Free – is the system able to keep the deck snow free? If not, is it able to melt it?
- Examined:
  - Ambient and initial temperature
  - Inlet fluid temperature
  - Wind speed
  - Rate of snowfall
  - Circulation tube spacing
  - Fluid flow rate
  - Concrete thermal conductivity
  - Concrete heat capacity
  - Insulation under the slab

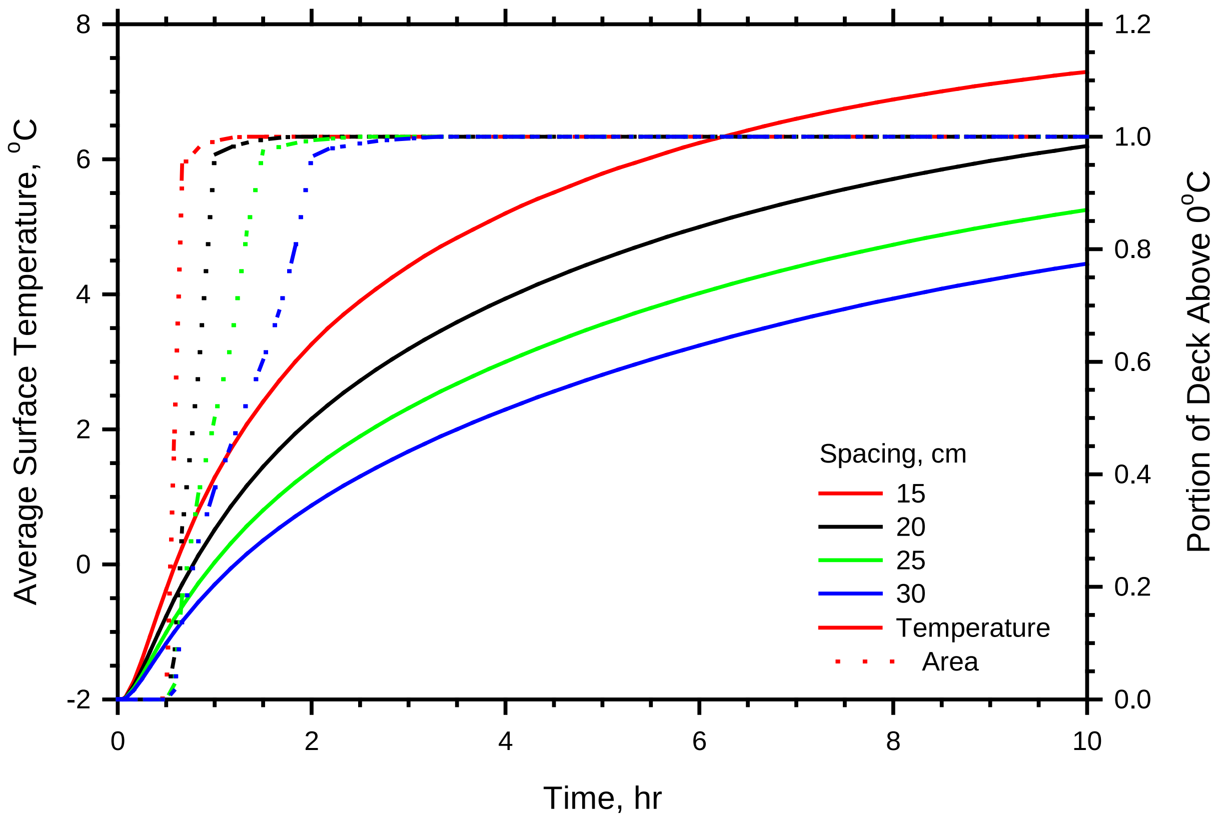
Parametric Study - Tube Spacing

- Surface temperature distribution for 15, 20, 25, and 30 cm tube spacing when the average surface temperature = 0^oC



Parametric Study - Tube Spacing

- Average surface temperature as compared to the total (top) surface area greater than 0°C



Summary of Numerical Research

- 3-Dimensional numerical models have been developed to simulate bridge deck deicing using geothermal energy
- Parametric analyses have showed the feasibility of these systems over a wide range of conditions
- The results from the analyses have been used to develop design tables that will be published

Summary and Conclusions

- Ground can be utilized as a renewable energy source as a result of its relatively constant temperatures and thermal storage capacity.
- Use of geothermal heat exchangers can be an environmental friendly and feasible way for heating and cooling of transportation facilities.
- There are a variety of geothermal heat exchange technologies including, borehole heat exchangers, geothermal energy piles, etc.
- The applications related to transportation infrastructure includes deicing of bridge decks and airport runways, heating and cooling of airport terminals, roadside facilities.
- Potential issues with long term performance of bridge deck deicing systems due to continued heat extraction. Thermal recharge may need to be utilized to provide supplemental heat energy.

Thank You!

Transportation Research Board

July 21, 2016

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Physicochemical and Biological Processes in Soils