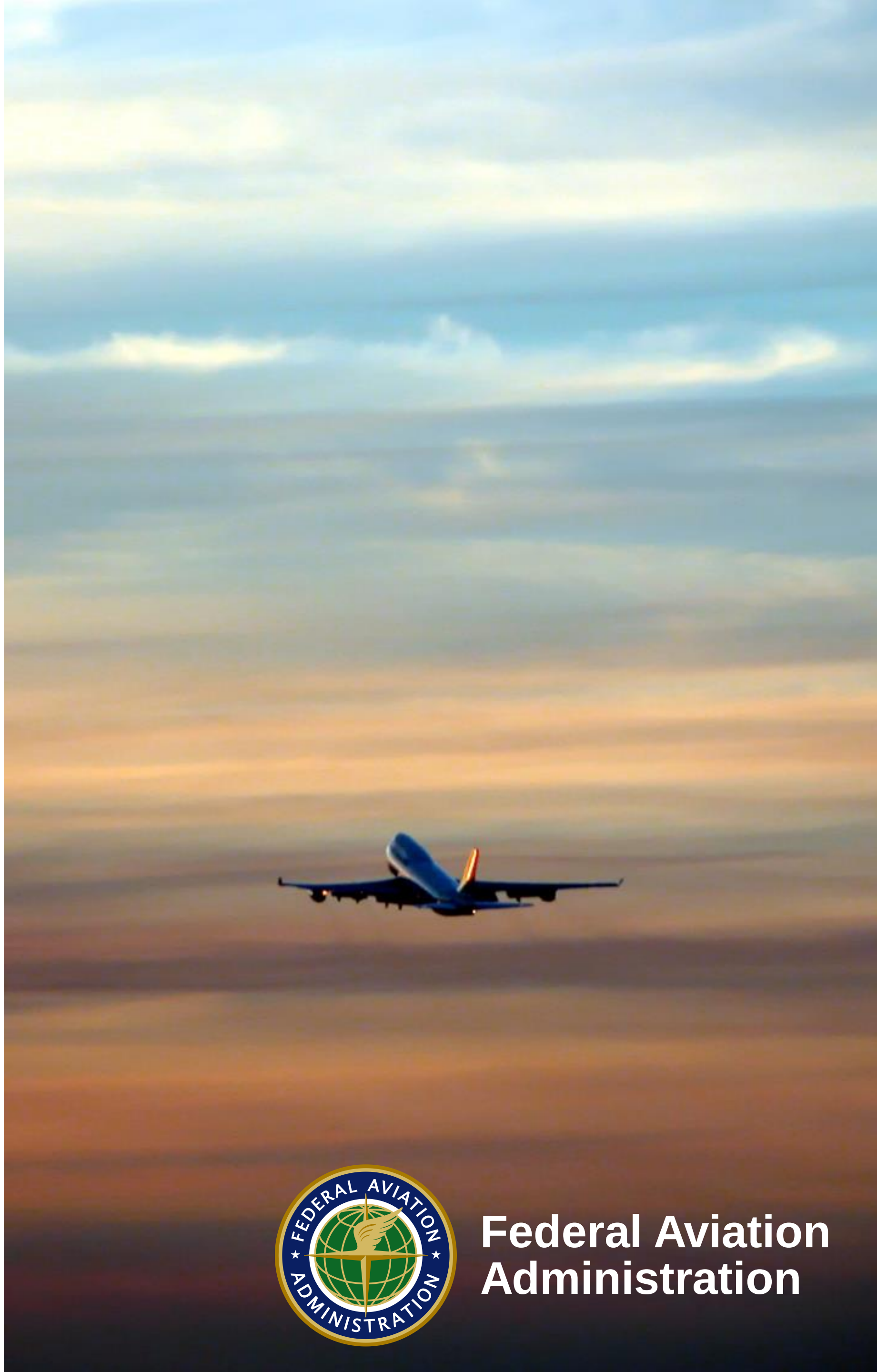
Heated Pavements & Nanotechnology for Airport Pavements



Presented to: **SWIFT Conference 2016**

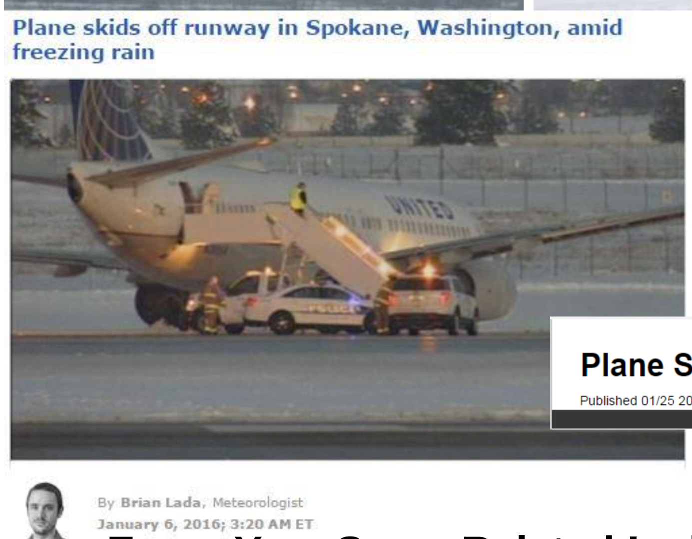
By: **David R. Brill, PhD., P.E.**

Date: **September 19-22, 2016**

Presentation Outline

- **Research Motivation**
- **Current Research Projects**
  - Airport Heated Pavement Projects – PEGASAS
  - Radiant Heating (Geothermal) for Airfield Pavements – Greater Binghamton Airport
- **Future Projects**
- **Questions**

Motivation



Every Year Snow Related Incidents at Airports Make Headlines & Cause Delays

Motivation

- **Ice and snow on transportation infrastructure systems cost the US economy in snow removal, damaged pavement and lost man-hours due to travel delay.**
- **Common practices for removing ice and snow:**
  - Anti-ice chemicals.
  - Snowplowing vehicles.
- **However, these methods are labor-intensive and have environmental concerns with possible contamination of nearby water bodies.**

PEGASAS

- **Partnership to Enhance General Aviation Safety, Accessibility and Sustainability.**
- **FAA Aviation Center of Excellence.**
- **https://www.pegasas.aero/**
- **Participating universities:**
  - Iowa State University (lead university)
    - PI: Halil Ceylan, Ph.D.
  - Purdue University
    - PI: John Haddock, Ph.D.

PEGASAS – Current Projects

- Energy and Financial Viability of Heated Pavement Systems (ISU)
- Hybrid Heated Pavement Systems Using Nanotechnology (ISU)
- Potential Use of Phase Change Materials to Store Heat in PCCP (Purdue)
- Advanced Construction Techniques for Heated Pavement Systems (ISU)
- Potential Use of Phase Change Materials to Store Heat in HMA (Purdue)

1A: Energy and Financial Viability

- **Objectives**:
  - Assess the amount of energy required to heat a pavement area.
  - Investigate the economic advantages of a heated pavement system.
  - Appraise the initial installation cost of a heating system.
- **Focus of the Study: Apron Areas**
  - Highly congested.
  - Snow removal is challenging and expensive.
  - Ground personnel working creates a safety concern.
  - Cost effective approach.
- **Approach**:
  - Identify Potential Airports Sites.
  - Collect Data on Energy and Cost Requirements.
  - Develop a Protocol to Enable Future Heated Pavement Systems to be Readily Evaluated.
  - Perform Cost/Benefit Analysis.

Energy and Financial Viability

Site Selection Criteria:

- Snow Fall Events (days)
- Max Snowfall Intensity (in/hr)

Commercial Service Airports (CS)

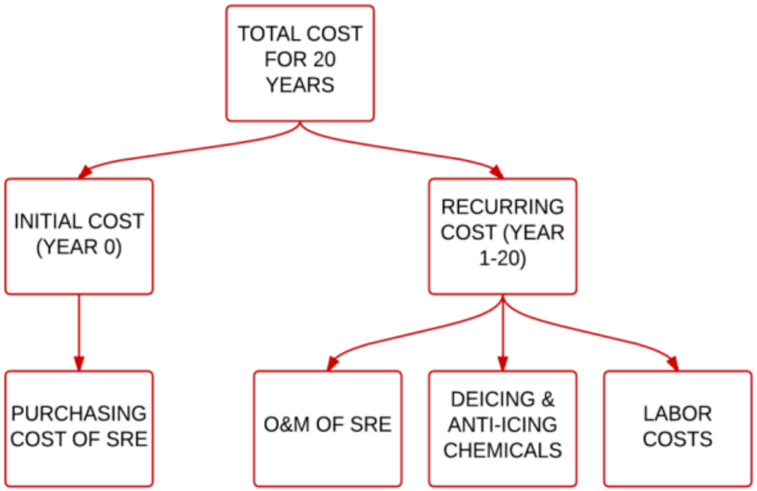
1. **MSP**: St. Paul Intl Airport, Minneapolis, MN
2. **CMH**: Port Columbus International Airport, OH
3. **DSM**: Des Moines Intl Airport, Des Moines, IA

General Aviation Airports (GA)

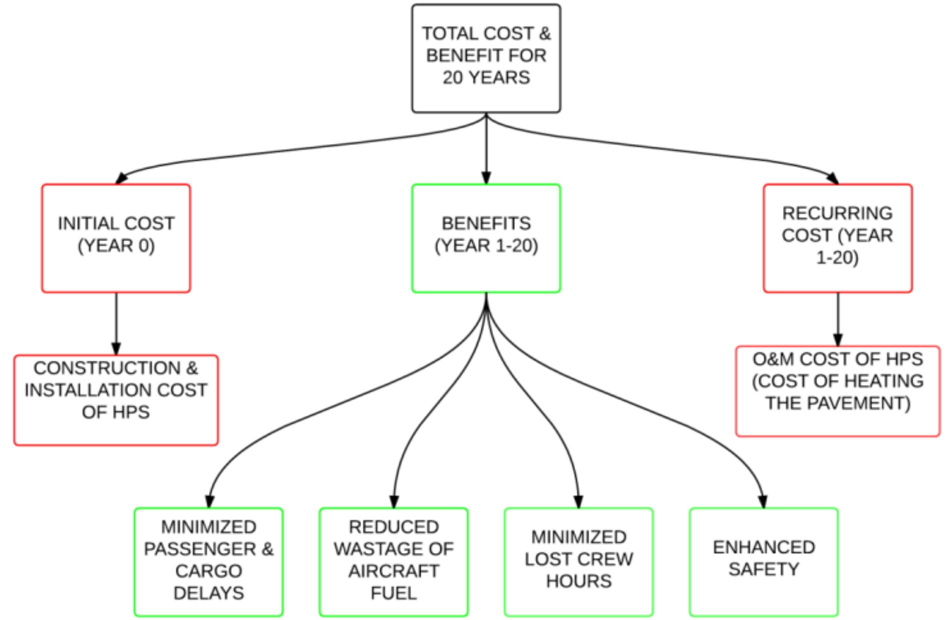
4. **MCW**: Mason City Municipal Airport, Mason City, IA
5. **1G3**: Kent State University Airport, Kent, OH

Energy and Financial Viability

Base Case: Conventional Methods



Alternative Case: Hydronic Heated Pavements with Natural Gas Heat Source



Net Present Value (NPV): Calculate ROI on a Project. Project is feasible if NPV > 0

Benefit/Cost Analysis (BCA): Economic Analysis for Evaluating a Project. B/C > 1

Sensitivity Analysis (SA): Method to determine how different values of certain variables impact BCA

Energy and Financial Viability

Net Present Value

Airport	Present Value of Cost	Present Value of Benefit	Net Present Value
MSP	$ 197,680,000	$ 354,000,000	$ 156,320,000
CMH	$ 79,911,564	$ 105,904,995	$ 25,993,431
DSM	$ 59,304,556	$ 62,727,377	$ 3,422,821
MCW	$ (23,721,826)	$ 683,485	$ (23,038,341)
1G3	$ (5,930,457)	$ 71,393	$ (5,859,064)

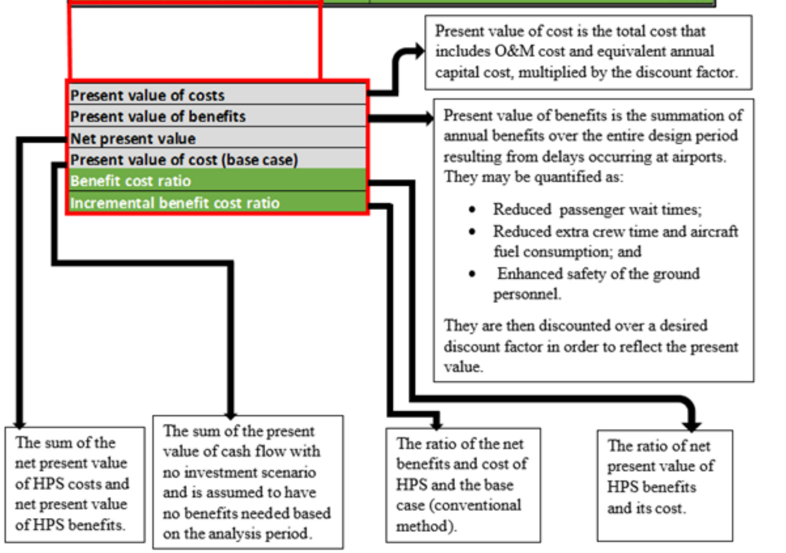
Benefit Cost Ratio

Airport	Present Value of Cost	Present Value of Benefit	Net Present Value
MSP	$ 197,680,000	$ 354,000,000	1.79
CMH	$ 79,911,564	$ 105,904,995	1.33
DSM	$ 59,304,556	$ 62,727,377	1.06
MCW	$ (23,721,826)	$ 683,485	-0.03
1G3	$ (5,930,457)	$ 71,393	-0.01

Energy and Financial Viability

Development of Economic Analysis tool

Cost parameters	Option 1.a: HPS by natural gas (area approach)
Analysis period	20
Capital cost	125,000,000
O&M costs (annual)	6,860,656
Benefits (annual)	27,478,817
Cost-benefit analysis of monetary costs and benefits for the entire analysis period	
Present value of costs	(197,681,885)
Present value of benefits	353,996,163
Net present value	156,314,278
Present value of cost (base case)	(17,053,768)
Benefit cost ratio	1.791
Incremental benefit cost ratio	1.960



Summary of Evaluated Parameters

Common input values			
Analysis year (year)	20		
Discount factor (%)	7%		
Area of aprons (ft2)	5,000,000		
Area of paved surfaces (ft2)	28,000,000		
Conventional methods cost			
SNOW REMOVAL EQUIPMENT			
Input	Quantity	Unit Price ($)	Labor hours (hours)
Multifunctional vehicle	4		
runway plows	23		
Rotary brooms	14		
Blowers	17		
Front end Loaders	25		
Sprayer	7		
Deicer truck	7		
Total	97		
Annual maintenance cost for SRE	600,000		
DEICING AGENTS			
potassium acetate	225,000	4.15	
sodium acetate	225,000	3	
LABOR			
Personnel	110	25.6	600
FUEL COST FOR SRE			
	97	14	600
HPS indirect benefits			
Input	Value		
Weather related delays (%)	2.00%		
Passenger growth rate	2.80%		
No. of seats in aircraft	150		
Operations in a day	1200		
Duration of delays (hour)	1		
Load factor	83.38%		
Incidence rate of injuries	5		
No. of full time workers in the airport	19,206		
HPS cost			
Input	Unit Price ($/ft2)		
Initial cost (construction)	25		
Maintenance cost	1%		
Average snowfall (in/h)	1		
Ambient temperature, Ta (0F)	20		
No. of snowfall events in a season	37		

Basic Input Parameters

Potential Benefits

- Reduces downtime required to clear ice and snow.
- Reduces adverse environmental impacts of using deicing chemicals.
- Reduces labor and equipment costs associated with using/applying deicing methods.
- Improves safety for ground crews servicing the aircraft at the gate areas.
- Mitigates pavement durability related failures.
- Advancements in HPS technology and construction practices are expected to bring down installation costs.

Sensitivity Analysis

- Benefit-to-cost ratios are greater than 1.0 for a large number of airports
- The BCR is highly sensitive to the duration of delays and percentage of delays.
- Increase in the initial cost reduces the BCR.
- The BCR strongly depends on the length of the analysis period.
- Snowfall rates have minimal effect on BCR.
- Natural gas had the highest BCR of the heating alternatives considered (natural gas, electric, geothermal).

Sustainability Assessment

- **Developed a sustainability assessment framework for the operation of airfield heated pavements by using life-cycle assessment (LCA) and carbon footprint analysis.**
- **Assessed energy consumption and greenhouse gas emissions (GHG) for:**
  - Traditional Snow Removal System (TSRS)
  - Hydronic Heated Pavement System using geothermal energy (HHPS-Geothermal - G)
  - Hydronic Heated Pavement System using natural gas furnace (HHPS-Natural Gas - NG)
  - Electric Heated Pavement System (EHPS)

Sustainability Assessment – Results

Snow Rate (in/h)	Total Energy Consumptions (MJ)						
	TSRS	HHPS-G COP=2	HHPS-G COP=2.5	HHPS-G COP=3	HHPS-G COP=3.6	HHPS-NG	EHPS
2	33,443	12,713	10,716	9,384	8,275	34,953	21,971
1.5	33,443	11,127	9,447	8,327	7,394	29,880	18,775
1	33,443	9,604	8,228	7,311	6,547	25,006	15,704
0.75	33,443	8,811	7,594	6,783	6,107	22,469	14,106
0.5	33,443	8,049	6,985	6,275	5,684	20,032	12,571

Snow Rate (in/h)	GHG Emissions (kgCO_2eq)						
	TSRS	HHPS-G COP=2	HHPS-G COP=2.5	HHPS-G COP=3	HHPS-G COP=3.6	HHPS-NG	EHPS
2.0	7,020	6,857	5,621	4,797	4,110	5,736	12,744
1.5	7,020	5,876	4,836	4,143	3,565	4,956	10,764
1.0	7,020	4,933	4,081	3,514	3,041	4,212	8,868
0.75	7,020	4,442	3,689	3,187	2,768	3,828	7,872
0.5	7,020	3,970	3,312	2,872	2,506	3,456	6,924

Sustainability Assessment

- Heated pavement systems enable effective snow removal with reduced energy consumption and GHG emissions.
- Energy demand and GHG emissions from the operation of heated pavement systems are significantly dependent on snowfall rate and snow period.
- From an environmental impact perspective, natural gas, with a relatively low emission factor, has the potential to replace electricity or diesel oil as a more environmentally-friendly energy source.
- With more data, the LCA models used in this study could be fully developed and calibrated to reflect realistic airport scenarios.

1B: Hybrid Heated Airport Pavement

Electrically Conductive Concrete (ECON)

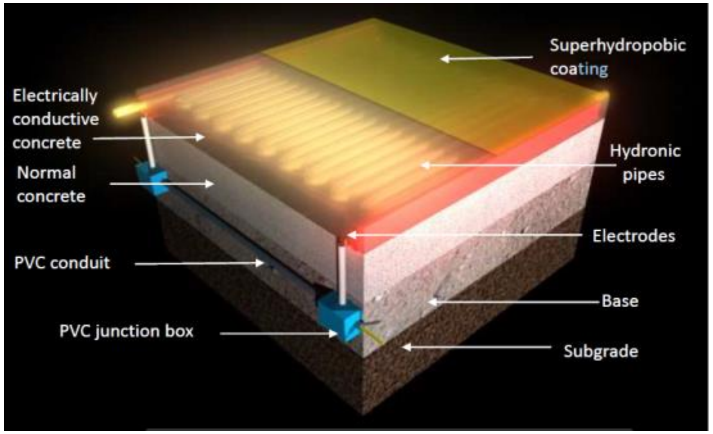
Conduct State-of-the-Art Review on Self-heating Electrically Conductive Concrete

Investigate Conductive Mortar Characteristics

Develop Self-heating ECON Mix Design

Demonstrate the Proof-of-concept: Slab Evaluation

Enhance Self-heating ECON Mix Design



Superhydrophobic Coatings

Identify Candidate Hydrophic Material

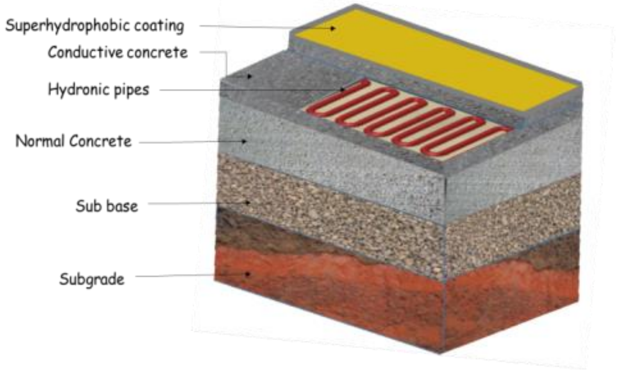
Develop Experimental Procedures for Effectively Depositing Superhydrophoic Coatings and Substrate

Assess Wettability of Coatings by Measuring Water Contact Angles

Measure Coating Durability

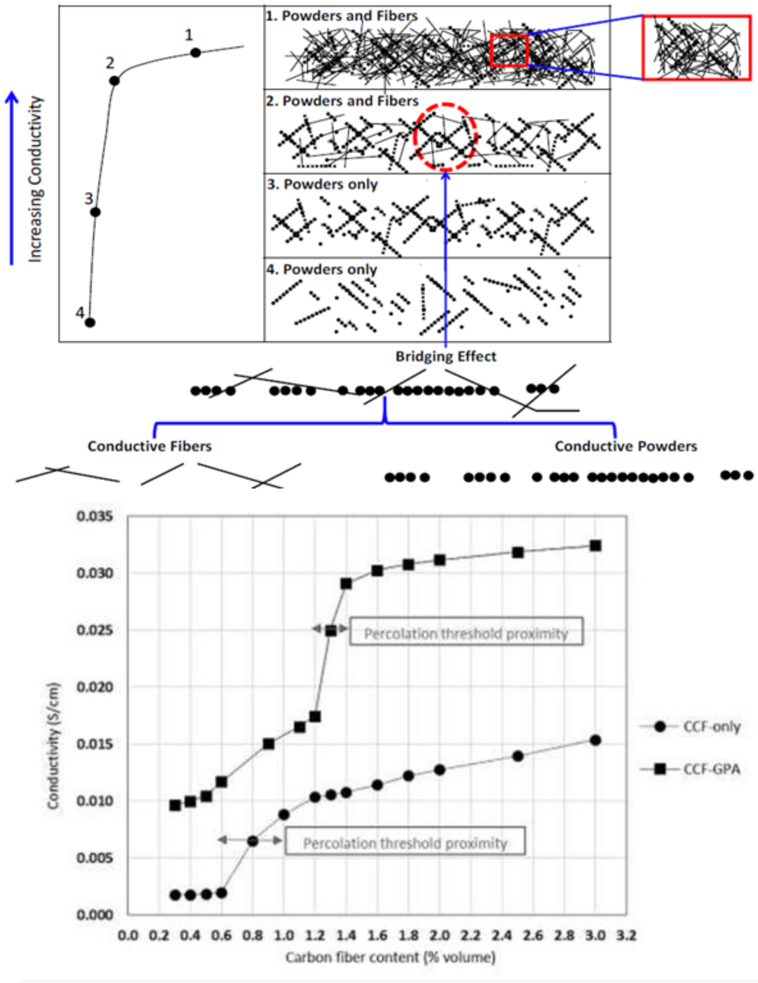
Compare Effectiveness of Candidate Coating Systems to Meet Desired Objectives.

Demonstrate Proof-of-concept



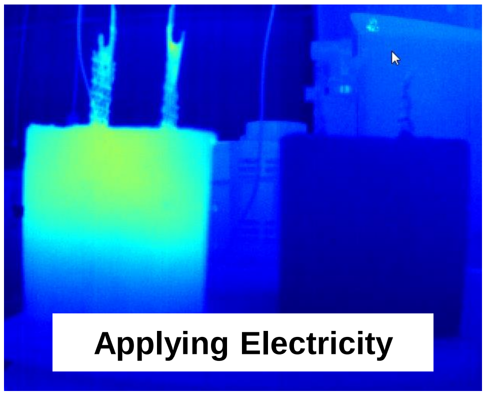
Hybrid Heated Airport Pavement

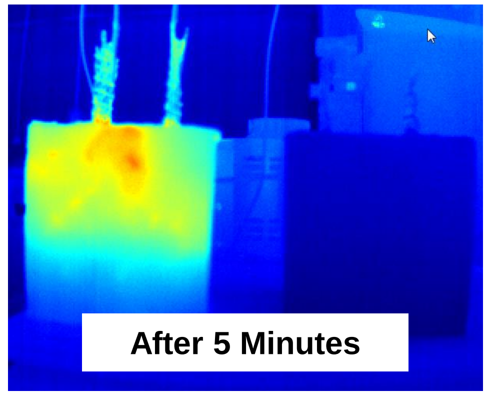
- **Characterize types and proportions of conductive materials for mix design**
- **<u>Percolation threshold</u> refers to the volume fraction above which the conductive material within the matrix touch one another to form a continuous electrical path.**
- **Significant improvement of conductivity can be achieved by:**
  - Increasing CCF Content.
  - Using a combination of Carbon Conductive Fibers (CCF) and Carbon Powders (CP) rather than CCF only but requiring significant amount of CP.

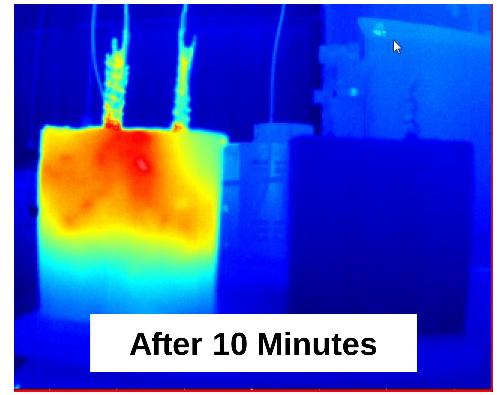


Hybrid Heated Airport Pavement

Investigate Conductive Mortar Characteristics: Infrared Thermographic Images







Developing an ECON Mix Design

- One Control
- Ten ECON Trial Mixes
  - CCF Volume, Consistency, Resistivity, and Compressive Strength
- Utilized CCF only
- Utilized fly ash Air Entraining Agent
- 0.4 water to binder ratio
- 1” Slump

PCC

Component	Content
Basic components	
Cement (Kg/m³)	333
Fly ash (Kg/m³)	83
Water (Kg/m³)	167
CA (Kg/m³)	1,011
FA (Kg/m³)	611
Admixtures	
Air entraining agent (ml/m³)	360
Fresh properties	
Slump (inch)	2.8
Air content (%)	4.9
W/C	0.4

ECON

Component	Content
Basic components	
Cement (Kg/m³)	305
Fly ash (Kg/m³)	76.2
Water (Kg/m³)	166
CA (Kg/m³)	1011
FA (Kg/m³)	611
CCF (Kg/m³)	13.6
Admixtures	
Methyl cellulose (%Wt of cementitious)	0.4
Air entraining agent (ml/m³)	360
HRWR (%Wt of cementitious)	3
Fresh properties	
Slump (inch)	1.2
W/C	0.44

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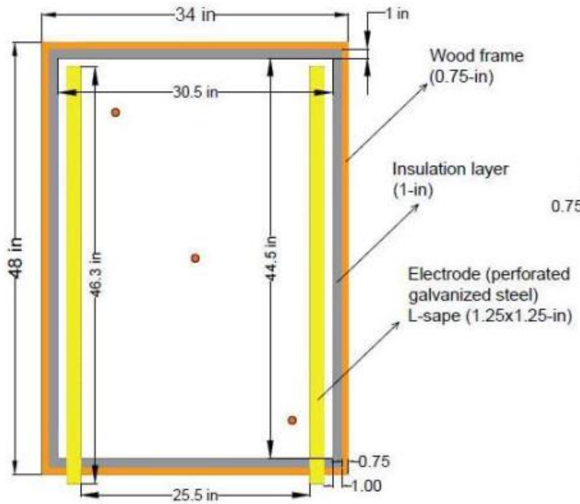
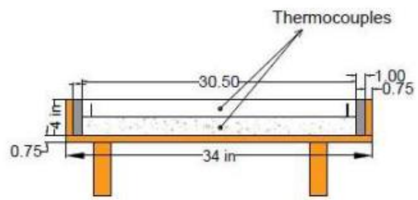
Hybrid Heated Airport Pavement

Demonstrate Proof-of-Concept:





Cross Section

Items	Length	Width	Thickness	Comments
Formwork	48-in	34-in	4.75-in	
Electrodes	46.3-in	1.25x1.25-in	0.125-in	L-Shape
Conductive Concrete	44.5-in	30.5-in	2-in	
Conventional Concrete	44.5-in	30.5-in	2-in	

Completed ECON Test Slab

2 Inches of Snow

After 20 Minutes

Snow Fully Melted

Hybrid Heated Airport Pavement

Defining Superhydrophobicity and Hydrophobicity

Requirements Considered

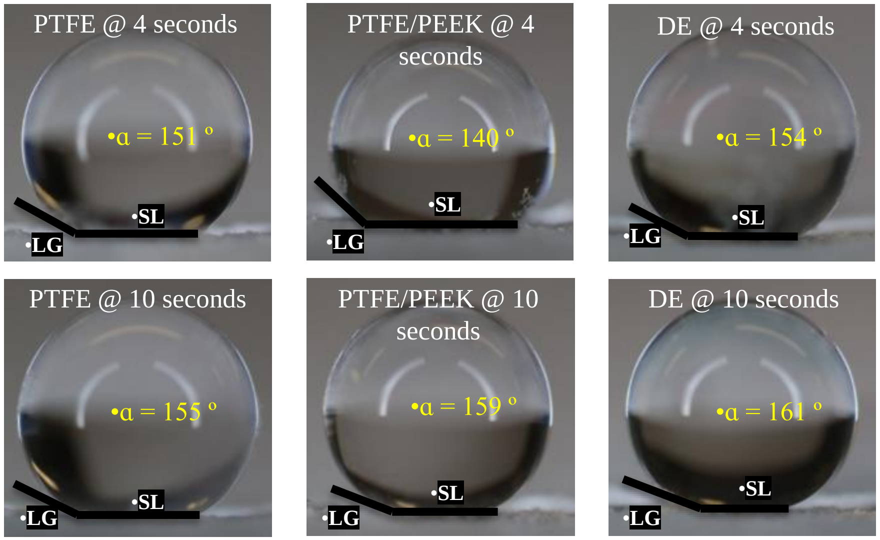
- Low Surface Energy (Hydrophobic)
- High Hardness and Melting Point
- Low Cost

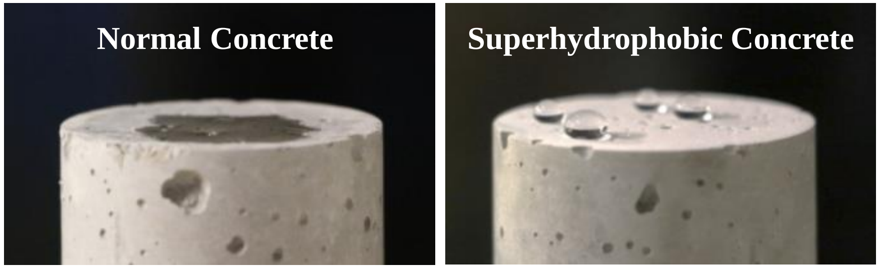
Coating Materials Identified

- Polytetrafluoroethylene (PTFE)
- Diatomaceous Earth (DE)
- Polyetheretherketone (PEEK)
- Zinc Oxide (ZnO)

Applied Using Layer-by-layer Application

- 4, 6, 8, and 10 Seconds

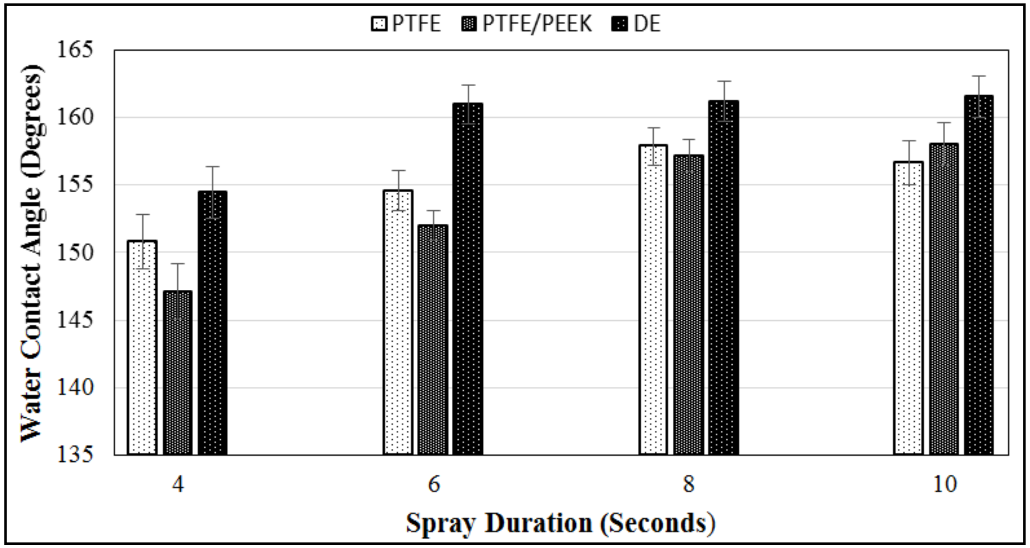




Hybrid Heated Airport Pavement

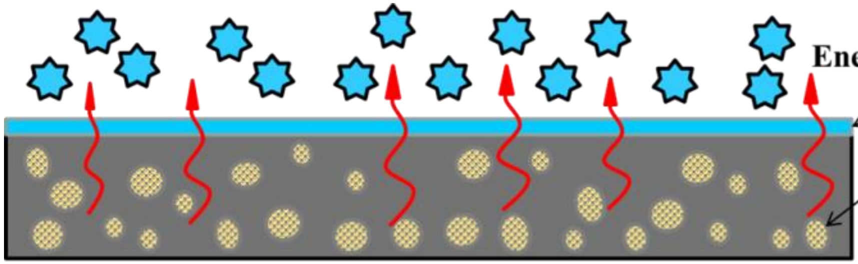
Initial Findings on Nano-Based Superhydrophobic Materials:

- Low surface energy materials (PTFE, PEEK, DE) may assist in achieving ice-repellant surfaces
- Amount of material applied to the PCC surface significantly effects the superhydrophobicity.
- Diatomaceous Earth (DE) resulted in the highest water contact angles (WCA), yielding excellent superhydrophobicity characteristics.



- Texturizing the surface of PCC can considerable enhance the dropped skid resistance.

1C: Phase Change Materials for PCC

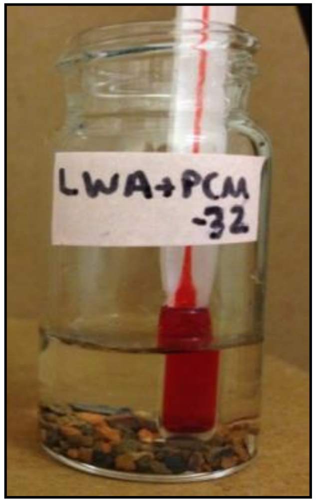


- **Advantages:**
  - PCMs can store thermal energy from the environment.
  - Stored energy can be released to melt ice and snow.
  - Improves anti-icing practices in airfield pavements.
  - Increases the safety of airport pavement.
  - Passive system.
- **Project Objectives:**
  - Determine the desired properties of the PCM-concrete composite.
  - Determine the PCM materials to use and how these PCMs can be manufactured.
  - Evaluate the performance of pavement containing PCM.

Phase Change Materials for PCC Pavements

- Lightweight aggregates (LWA) soaked in PCM are used to make concrete in the laboratory.
- The same procedure can be used in the field to make concrete pavement using conventional paving operations.
- Using lessons learned and tools developed this will be extended to HMA during the coming year.

Light Weight Aggregate (LWA)



Concrete with LWA + Paraffin Oil

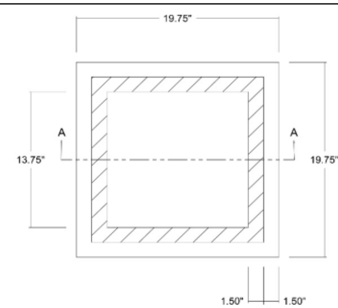
Phase Change Material in PCC Pavements

- **Concrete Slab Testing Complete**
- **Draft Report is Being Finalized**
- **Conclusions**
  - PCM may be used in concrete pavement to alter anti-icing practices
  - PCM can be successfully and economically used to delay or prevent ice formation.
  - Incorporation of PCM in LWA is a promising approach to mitigate ice formation in concrete pavement
- **Opportunities for Future Work**
  - Full Scale Testing of PCC Slabs at airports
    - Measure field properties of concrete using LWA PCM
    - Monitor concrete temperature and ice formation
  - Extend finite difference model to determine where use of PCM has the greatest Economic Viability.

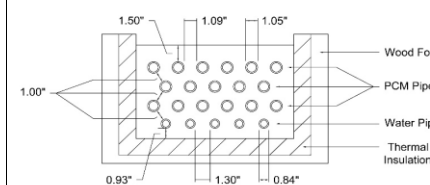
PCC Slab Type	PCM Type
Control	None
Embedded Pipes	Paraffin Oil
	Methyl Laureate
LWA Containing PCM	Paraffin Oil


Mold with Thermal Insulation


Mold with Embedded Pipes



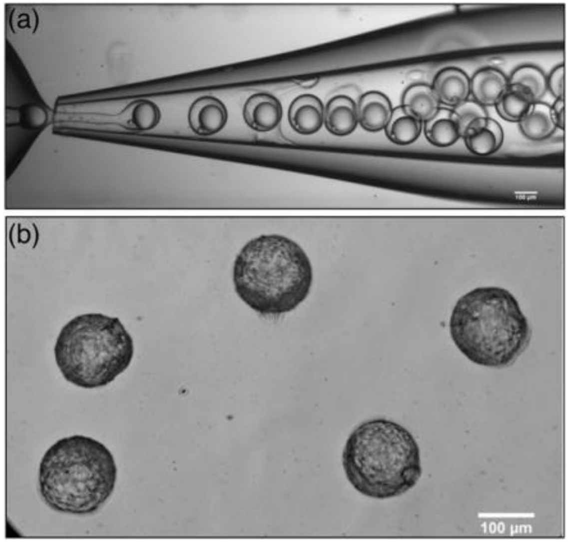
Top View



Section A-A
Cross Section View

PCM in Asphalt Pavements

- **Problem: PCM interacts with asphalt binder.**
- **Encapsulation required before incorporation into asphalt mixtures (M&M's) .**
- **Investigating methods to decrease the shell thickness below 100 µm to ensure heat is released properly.**



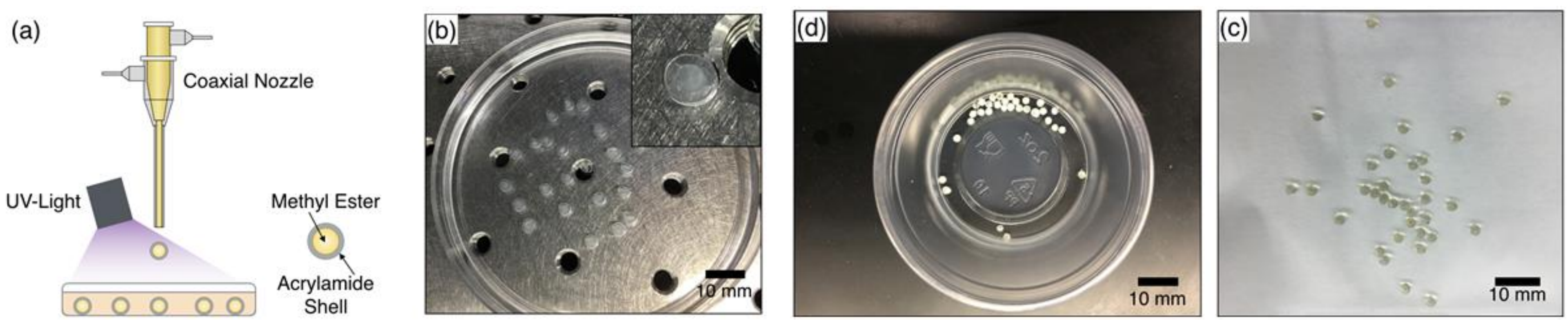
(a) Generation of double emulsion drops composed of a methyl laureate by a CNC-PEGDA shell.

(b) Dried capsules with a methyl laureate cores surrounded by a CHC PEGNA shell.

Investigating the Potential to Use Phase Change Material to Store Heat in Asphalt and Layered Pavement

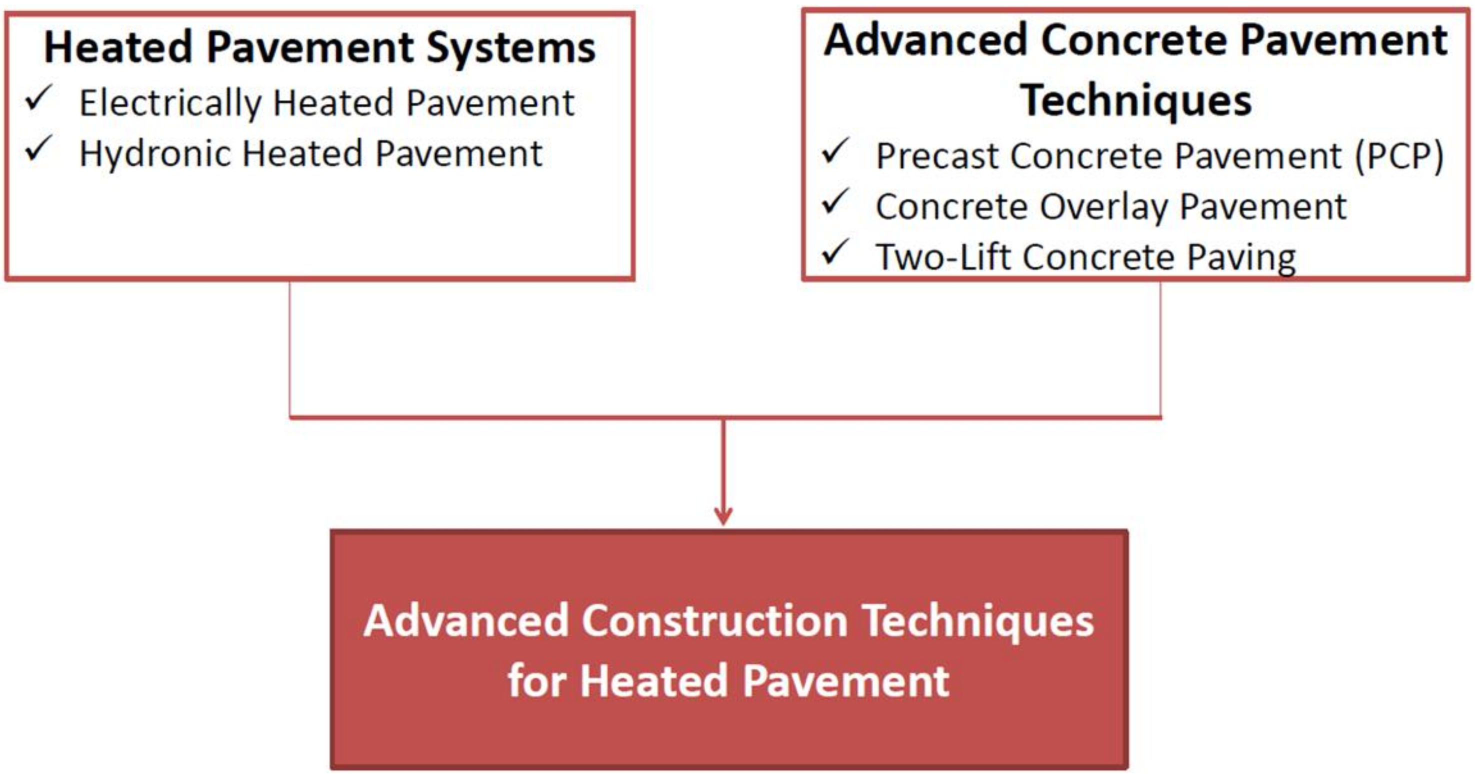
- Paraffin oil Interacts with Asphalt Binder
- Encapsulation Required before Incorporation into Asphalt Mixtures
- Two Possible Methods
  - Encapsulate PCM in LWA coated with Cement Paste

  - Encapsulate PCM in Acrylamide Coating



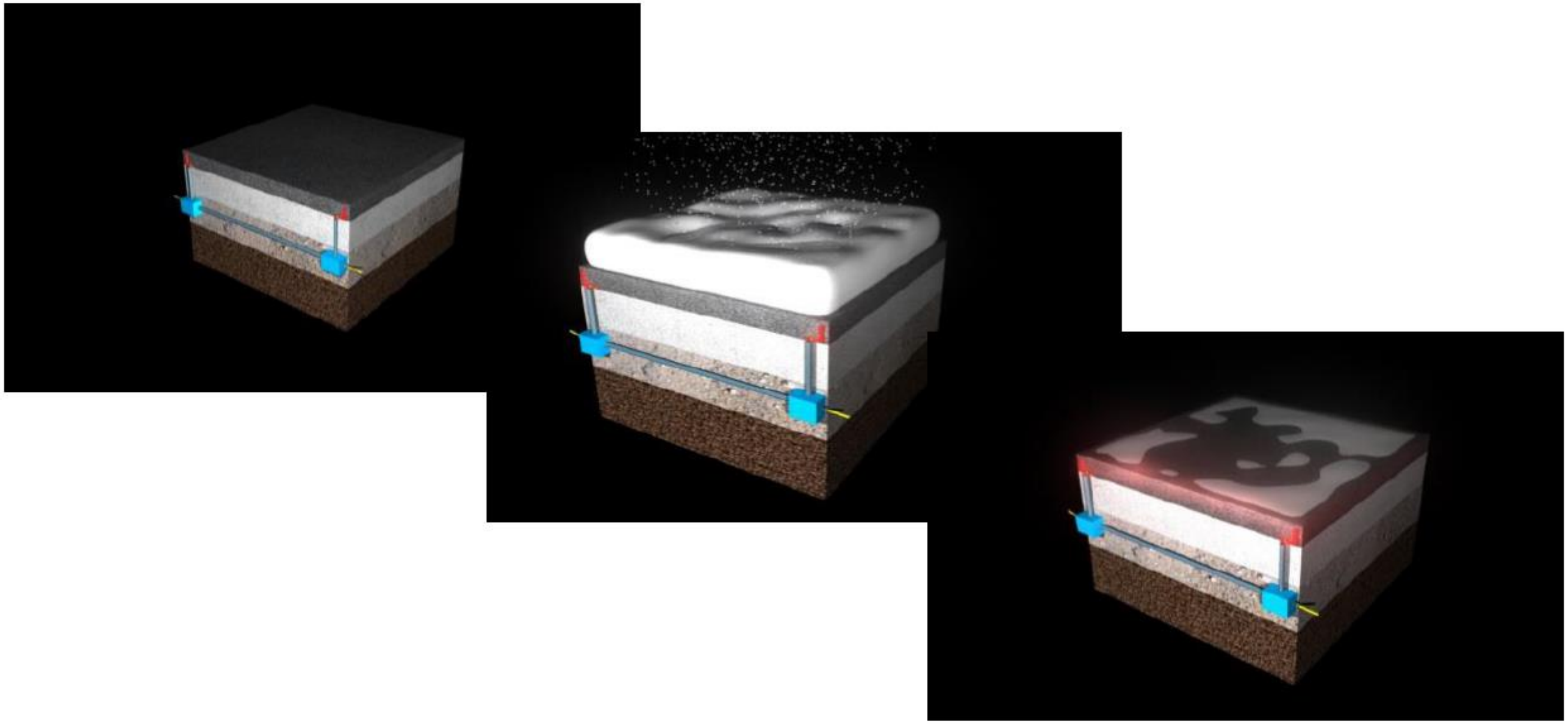
1D: Advanced Construction Techniques for Heated Pavements

<u>Objective</u>: Develop advanced techniques to automate and accelerate construction of large-scale heated pavements at airports.



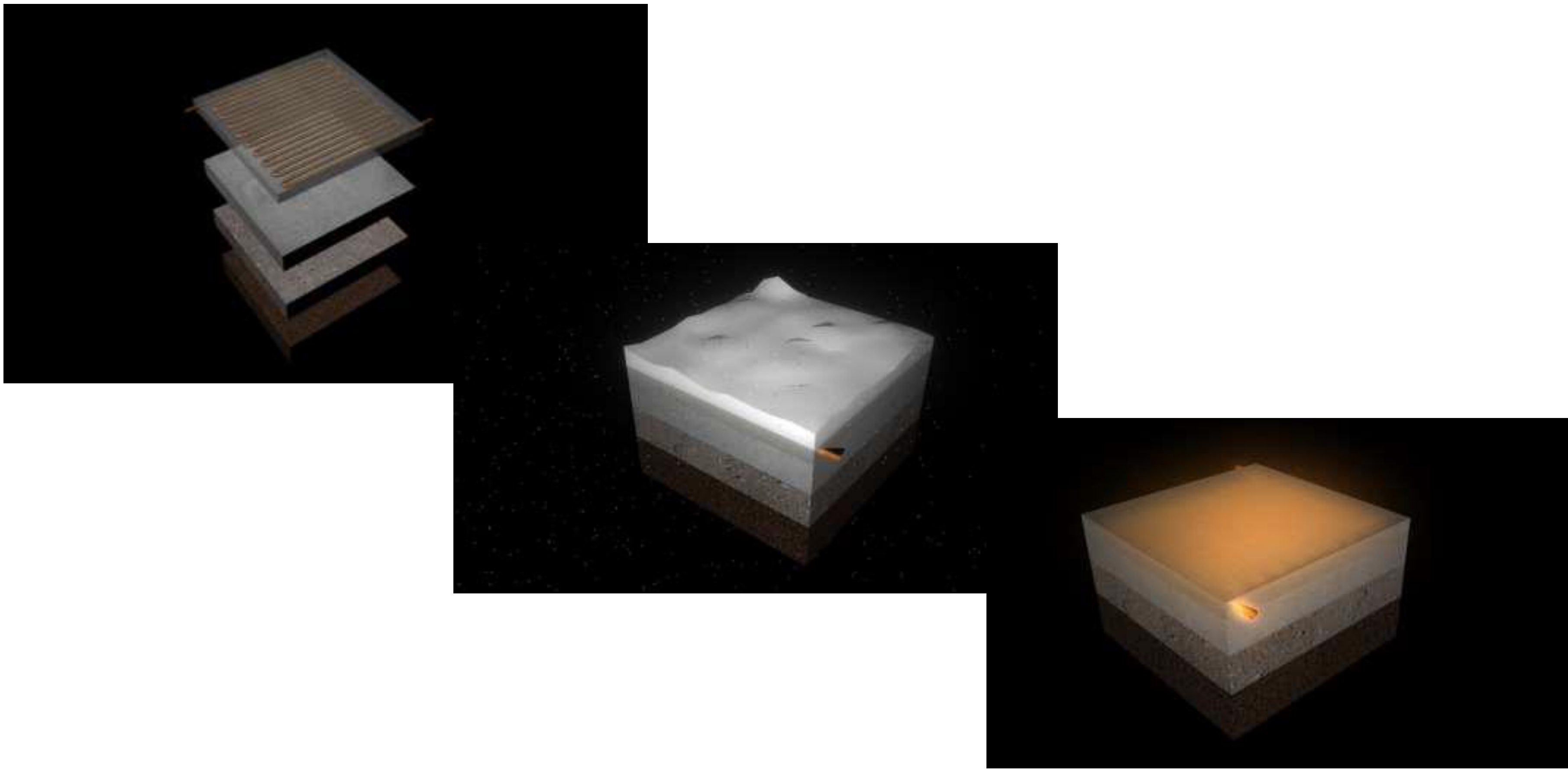
Advanced Construction Techniques for Heated Pavements

Conceptual design of heated pavement systems: 3D artist rendition and visualization of electrically conductive concrete



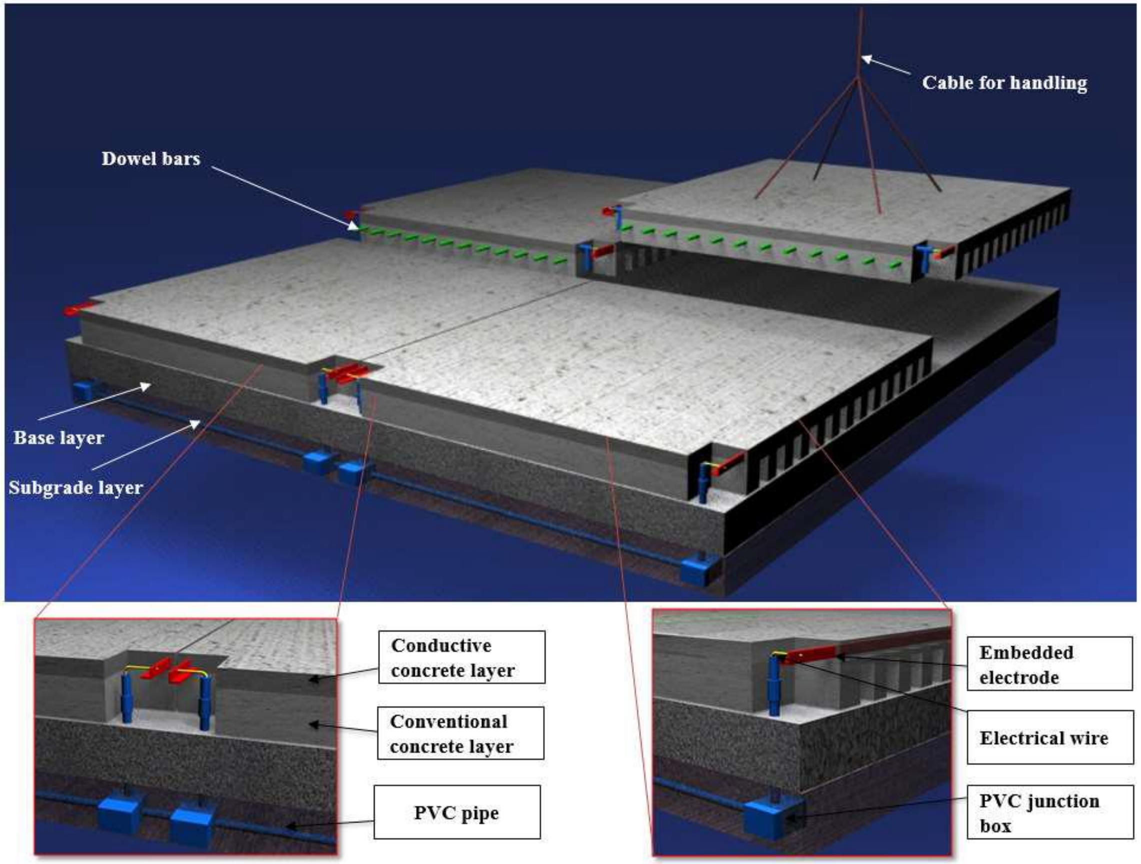
Advanced Construction Techniques for Heated Pavements

Conceptual designs of hydronic heated pavement system



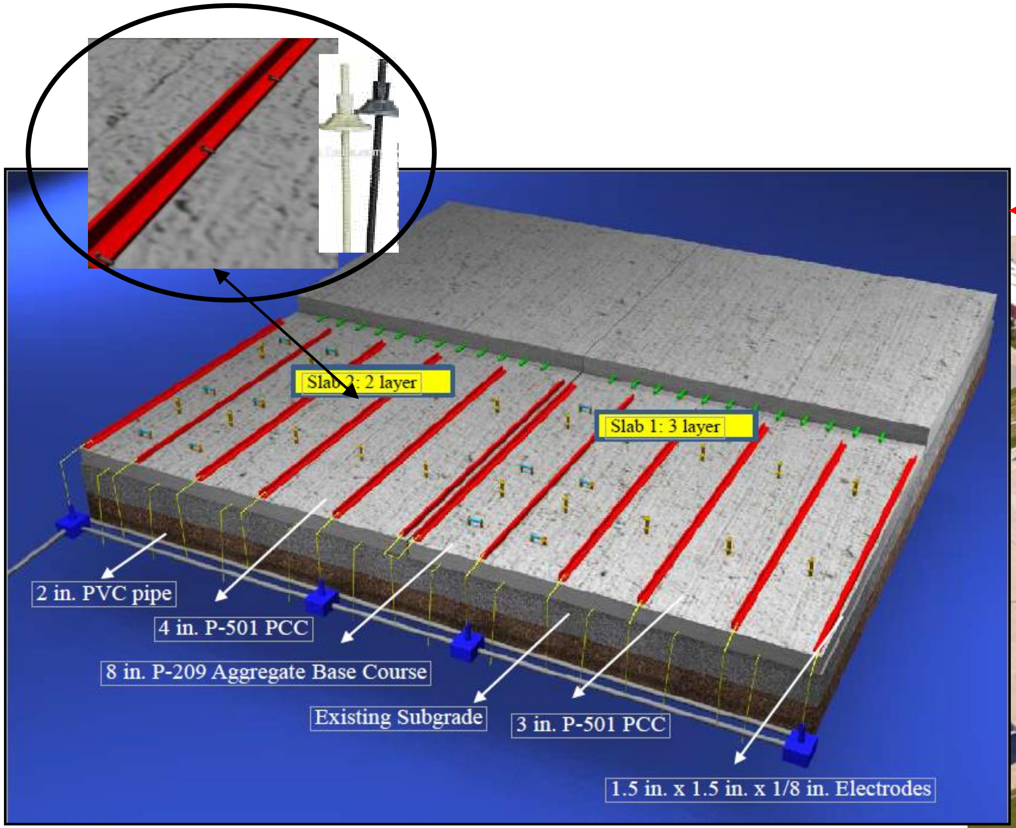
Advanced Construction Techniques for Heated Pavements

3D renderings for construction of ECON based HPS utilizing precast concrete techniques.

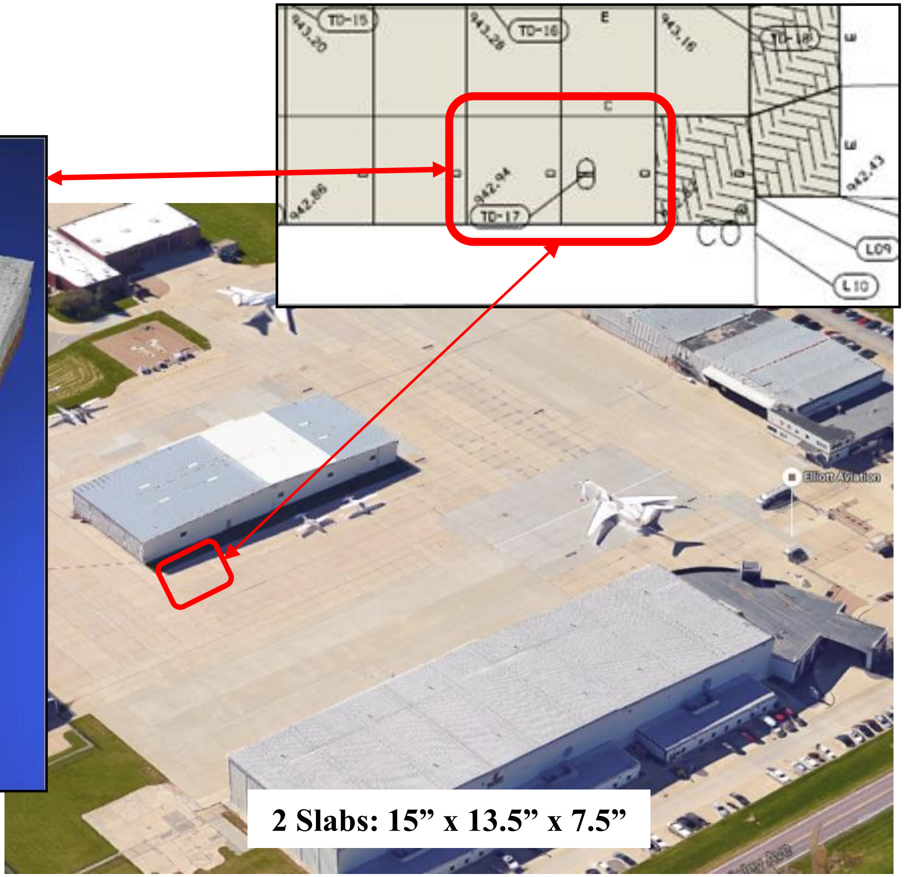


Advanced Construction Techniques for Heated Pavements

ECON heated pavement implementation at Des Moines International Airport



Proposed Slab Design



2 Slabs: 15” x 13.5” x 7.5”

Radiant Heating for Airfield Pavements
Greater Binghamton Airport, NY

- **PI – Prof. William Ziegler, Binghamton University.**
- **Objective: Design, construct and prototype geothermal heated pavement system to determine the viability of keeping airport pavements free from ice and snow.**
  - 8 slabs totaling 3200 SF
  - Geothermal heat-pump technology (glycol is pumped through embedded tubing).
  - Geothermal mechanical vault building.
  - Geothermal well field (20 vertical wells and 5 horizontal wells).
  - Sensors installed for data collection and monitoring.
  - Kiosk installed in the terminal building to educate flying public.

Greater Binghamton Airport

Greater Binghamton Airport - Timeline

- May 2009 – Binghamton Students Won National Design Competition for Universities
- July 2010 – Initial Grant Awarded (10-G-009) to Design & Build Prototype System
- April 2011 – Construction Begins on Radiant Heating System & Control Vault
- 2011 – 2012 Winter – Preliminary Test of System Conducted
- December 2013 – Heat Exchange Facility Construction Begins
- April 2014 – Geothermal Portion of System Construction Begins
- July 2014 – Heat Exchange Equipment Installed & Wells Drilled
- August 2014 – Well Field Control Vault Installed
- 2014 – 2015 Winter – Radiant Heating System Fully Functional
- March 2015 – Well-field is Connected to the Terminal Building
- April 2015 – Interactive Kiosk install in the Secure Passenger Facility
- May 2015 – Geothermal System Assist with Cooling the Terminal Building
- Present – Monitoring & Data Collection via Installed Sensors for Further Advancement

Greater Binghamton Airport

Construction of heated pavement system, 2011

Greater Binghamton Airport - Status

- **Draft report under review for publication.**
- **Research planned for 2017:**
  - System optimization:
    - Optimal supply line temperature vs. return line temperature.
    - Optimal buffer tank temperature.
    - Pump cycle efficiencies.
    - Vertical vs. horizontal well efficiency.
  - Economic feasibility validation:
    - Establish detailed breakdown of construction costs.
    - Validate financial viability using the financial viability study created by PEGASAS (ISU).
  - Establish a data management structure.

Questions?

Project Lead: Benjamin Mahaffay

benjamin.mahaffay@faa.gov