U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: AIRSIDE USE OF HEATED PAVEMENT SYSTEMS

Date: 3/29/2011

Initiated by:

AC No: 150/5370-17

Change:

1. PURPOSE. This Advisory Circular (AC) establishes minimum performance requirements for the design, construction, inspection, and maintenance of heated pavement systems for use in the Aircraft Operations Area (AOA). The AC includes:

a. Principles of operation and applications.

b. Design process, including heat requirements, formulas, and sample calculations.

c. Perspective locations and characteristics.

d. Design considerations for electric and hydronic systems, including system controls.

e. System performance requirements and specification template.

f. System construction requirements and specification template.

g. Inspection and maintenance requirements.

2. APPLICATION. The FAA recommends the guidelines and standards in this AC for heated pavement systems for airside applications. In general, use of this AC is not mandatory. However, use of the AC is mandatory for all projects funded with federal grant monies through the Airport Improvement Program (AIP) and with revenue from the Passenger Facility Charges (PFC) Program. See Grant Assurance No. 34, "Policies, Standards, and Specifications," and PFC Assurance No. 9, "Standards and Specifications." Airports certificated under Title 14 Code of Federal Regulations, Part 139, Certification of Airports (Part 139), must use the specifications in this AC for pavement construction projects involving heated pavement systems for airside applications.

3. PLANNING. All heated pavement system project requests, regardless of size and scope, must be coordinated with the Office of Planning and Programming for AIP eligibility determination.

4. COPIES OF THIS AC. This AC is available on the FAA website (www.faa.gov).

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Director of Airport Safety and Standards

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TABLE OF CONTENTS

LIST OF FIGURES

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CHAPTER 1. INTRODUCTION

1.1. Background.

Winter storm conditions typically negatively influence airport capacity through delays and/or cancellations, due in part to runway closures caused by pavement surface conditions. Winter contaminants, such as snow, slush, or ice, on pavement surfaces may also contribute to aircraft incidents.

Although the limits vary for types of aircraft, most transport category aircraft are prohibited from operating on runways covered by untreated ice or by more than ½ inch of snow or slush. Operators of air carrier airports follow specific guidance for the prompt removal of winter contaminants from the Aircraft Operations Area (AOA).

Airports should have sufficient resources to clear 1 inch of snow from priority areas of the AOA within a reasonable time[1]. The extents to which these undesirable effects from winter contaminants are minimized depend on the strategies implemented by the airport operator.

1.2. Traditional Strategies.

There are two strategies currently available to airport operators to alleviate hazardous conditions due to the presence of winter contaminants on pavement surfaces.

a. Mechanical Methods. These include plows, brooms, and sweepers for snow removal from priority areas. These pieces of equipment operate at relatively slow speeds and may interfere with aircraft operations. Wet snow and ice can develop a strong bond, making mechanical means of removal difficult or inefficient. A major drawback is that they are working from the surface down, not at the point of bonding. Mechanical methods can be damaging to the pavement and imbedded lighting fixtures.

b. Chemical Treatments. These include solid chemical dispersal and liquid spraying equipment for a variety of de-icing and anti-icing chemicals. This method can reduce or prevent the contaminant bonding to the pavement surface. Some airports are limited, however, in the use of chemical agents because of environmental restrictions, and environmental remediation efforts are costly. Other disadvantages include the downtime of the movement areas while the chemicals are applied and become effective; the detrimental effect on pavements, electrical systems, and aircraft braking performance; and the maintenance and calibration of the equipment.

Depending on the airport, the most effective strategies for alleviating the effects of winter contaminants in the AOA employ a combination of both methods.

1.3. Heated Pavement Strategies.

Heated pavement systems offer an alternative strategy for effectively mitigating the effects of winter contaminants by melting snow and preventing bonding to the pavement surface. Benefits can include:

- Efficient compliance with Part 139,
- Enhanced safety for aircraft and equipment operators,

[1] See the current version of FAA Advisory Circular 150/5200-30, Airport Winter Safety and Operations, table 1-1.

- Positive impact on capacity during winter operations,
- Reduction in environmental impacts of chemical deicers, and
- Significant decline in snow removal times required to clear priority areas.

The disadvantages of heated pavement systems typically involve high initial costs and complex installation procedures. Costs may be offset by a reduction in traditional strategies that use more equipment and personnel.

1.4. Principles of Operation.

Heating airfield pavements from within the pavement structure can be accomplished by passing electric current or circulating warm fluids through pipes, or tubes, in the pavement structure. The basic principles of these systems are described below.

a. Electrically Heated Pavements. Electrical current encounters resistance when flowing through a conductor. The resistance to current flow converts electrical energy to heat energy. The heat produced is proportional to the current flowing through the conductor and the composition of the conductor that offers resistance to the current flow. Two forms of electric heating are used for in-pavement snow melting applications.

- Insulated conductors are embedded in the pavement, such as heating cables or grid/mesh mats.
- Conductive materials are added to the pavement material mix, electrical energy is applied through uninsulated conductors, and the pavement serves as the heat source.

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b. Hydronic Pavement Heating. Hydronic refers to the use of heated fluid as the transfer mechanism. The heat is released by thermal conduction. Heated fluids flow through tubes, or pipes, embedded in the pavement structure. The cooled fluid is returned to the heat source and the cycle repeated. Heated fluids can come from a variety of sources.

- Direct-use of geothermal waters for the fluids is most efficient but may be limited to areas close to tectonic-plate boundaries.
- Other locations need to consider ground source heat pumps, heat exchangers, or boilers to boost efficiency and reduce the operational costs.
- Alternative heat sources, such as waste heat, may be utilized if a reliable supply over the whole design lifetime is guaranteed.

1.5. Applications.

a. Planning. All heated pavement system project requests, regardless of size and scope, must be coordinated with the Office of Planning and Programming for AIP eligibility determination.

b. Locations Factors. The FAA recommends heated pavement systems only for locations in the AOA where:

- Benefits will justify the cost of installation and operation,
- Mechanical methods are difficult,
- Use of chemicals may be limited,
- Operational safety is a factor, and
- Delays at critical locations cannot be tolerated.

c. Location Selection. Specific AOA locations may encompass an entire runway, taxiway, apron area, or any portion thereof, such as pavement areas surrounding edge lighting or aircraft service areas.

- The airport's Snow and Ice Control Plan (SICP)[2] should be consulted to identify high priority areas for the application of heated pavement systems.
- Compliance with Part 139, as it relates to obstacle clearances and safety areas, may restrict the type of system and location considered.

[2] See the current version of FAA Advisory Circular 150/5200-30, section 1-4.

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CHAPTER 2. DESIGN

2.1. Design Objectives.

This section describes minimum acceptable design requirements for heated pavement systems. These requirements are applicable to both electric and hydronic systems.

a. System Performance. The heating system must be capable of:

- Maintaining a surface condition of *"no worse than wet"*,
- Attaining surface temperature above the freezing point before the start of expected snow accumulation, and
- Maintaining surface temperature above the freezing point until snow accumulation has ceased.

b. Design Load. The required heat design load should be based on:

- Expected rate of snowfall, air temperature, humidity, wind speed, dimensions, and characteristics of the pavement;
- Calculations using established methodologies (for example, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), HVAC Applications Handbook 2007, Chapter 50);
- Consideration of back and edge losses; and
- Standard unit specifications (W/ft^2 or Btu/h/ft^2).

c. System Design. The design must comply with relevant sections of applicable ACs (current versions), including:

- AC 150/5300-13, Airport Design;
- AC 150/5320-5, Airport Drainage;
- AC 150/5320-6, Airport Pavement Design and Evaluation;
- AC 150/5320-12, Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces; and
- AC 150/5370-10, Standards for Specifying Construction of Airports.

d. Operation. The heated pavement must not cause electromagnetic interference (EMI) with aircraft navigational aid (NAVAID) systems or communication equipment and must be included in the Snow and Ice Control Plan (SICP).

e. Control of the System. The equipment control systems must include, as a minimum:

- Automated activation and de-activation,

- Ground fault protection devices, and/or
- Fluid temperature and pressure monitoring sensors.

2.2. Design Process.

The design of a heated pavement system includes three distinct phases as shown in Figure 1. The initial feasibility phase defines the parameters necessary for determining general performance requirements. The design phase defines specific requirements and results in design specifications and necessary approvals and funding request. The construction phase incorporates the design specifications into the construction standards. Securing a heated pavement system through a design-build, or design-bid-build, type of contract allows vendor integration into the project design phase.

2.3. Determine Heat Requirements.

The heat requirement, or design load, is required for sizing systems and equipment and depends on atmospheric factors, thermal conductivity, and classification of heat expectations. Appendix C contains industry accepted formulas for calculating the steady-state energy balance required for total heat flow per unit surface area, q_o. The ASHRAE 2007 Fundamentals Handbook, Chapters 1, 4, and 6, contains further guidance, tables, and examples.

a. Atmospheric Factors. The solution for the general equation requires simultaneous consideration of all four atmospheric factors:

- Rate of snowfall,
- Air temperature,
- Relative humidity, and
- Wind velocity.

It is necessary to investigate various combinations of the climatic factors and trends that might occur at a site over time to avoid over or under designing the system. The FAA recommends an average over three to five years.

b. Mass Transfer Rate. The dimensions of the heated pavement slab affect heat and mass transfer rates at the surface. Other factors such as back and edge heat losses should be considered in the system design.

c. Classification of Heat Expectations. Heat requirements for snow melting installations are classified as Class I, II or III[3]. Class II expectations are for areas that must be kept clear of accumulating snow, but the pavement may remain wet. To meet the expectations of Class II, heating requirements are generally in the 125 to 250 Btu/h/ft^2 (36 to 73 watts/ ft^2) range. When determining the solution for general equation q_o, the snow-free area ratio will be 1.

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[3] See ASHRAE 2007 HVAC Applications Handbook, Chapter 50, Snow-Melting and Freeze Protection.

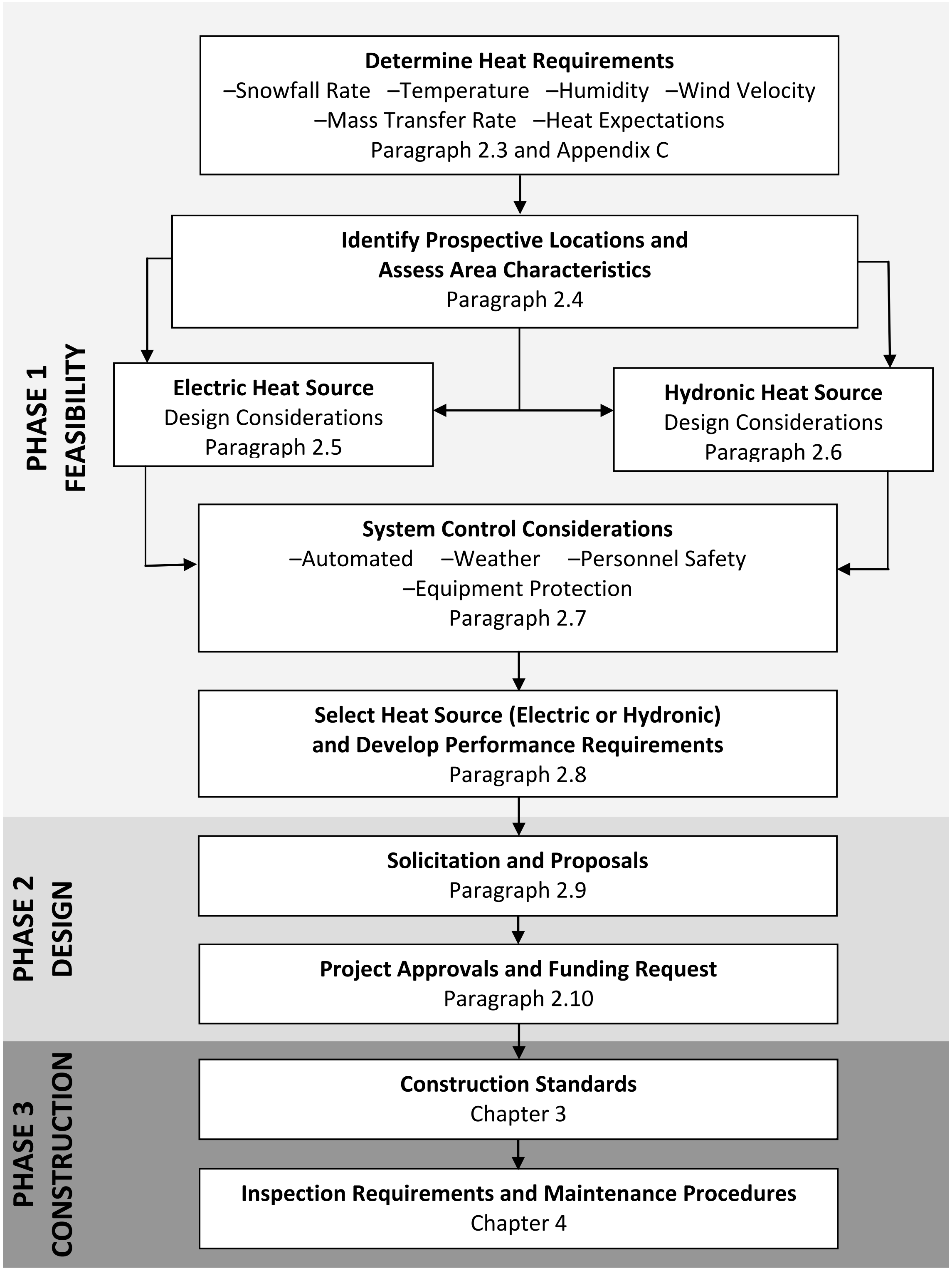

Figure 1. Process for Determining System Design Requirements

2.4. Identify Prospective Locations and Assess Area Characteristics.

The airport operator can limit interruption of service as much as possible by prioritizing the most critical portions of the aircraft movement area and supporting facilities and then taking care of other areas in their order of importance. These priority areas are typically defined in an airport's Snow and Ice Control Plan (SICP) and are a good source for identifying prospective locations.

a. Location Measurement. The area under consideration for installation of a heated pavement system must be measured and planned. The area surrounding the proposed location needs to be evaluated for feasibility of providing a heat source.

b. Power Source.

(1) For hydronic systems, examine the availability of a heated water supply.

- Is there nearby underground thermal water storage?
- Is a waste-water treatment plant close by?
- Are geothermal waters deep?
- Is there sufficient land available for horizontal loop systems or must the system be vertical wells?

(2) For electric systems:

- Is there accessible power in the vicinity or does installing new power lines need to be considered in the cost?
- Are there navigational aids or communication systems in proximity that could be impacted?

(3) For all systems:

- Consider renewable energy generation as a component of the system where feasible.

c. Pavement Characteristics. Composition of the pavement will affect the thermal conductivity, heat transfer, and evaporation rates in determining the required heat output.

- Is pavement flexible (asphalt) or rigid (concrete)?
- Is the requirement for edge to edge of the entire pavement area or is 50 feet each side of center satisfactory?
- Is the surface sloped or grooved?
- Consider the complexity and quantity of in-pavement lights, sensors, and other in-pavement penetrations.

d. Drainage Characteristics. Storm water collection systems are designed to provide adequate surface drainage for the geographical climatic conditions reflected in the design storm. Surface runoff from heated pavement systems will be disposed of without damage to facilities, undue saturation of the subsoil, or significant interruption of normal traffic. Consideration of the storm water drainage characteristics of the proposed area must be addressed. A detailed estimate of melted runoff and how it will be stored and/or removed from the operations area must be included in the design.

2.5. Electric Heat Source Design Considerations.

Heated pavement systems using electricity as an energy source have in-pavement heating elements in the form of resistive cables, grid-mesh/heat-mats, or conductive material mix designs for asphalt and Portland Cement Concrete (PCC). Heating element resistance and spacing of elements should be selected based upon manufacturer recommendations for design load and voltage.

a. Resistive Cables.

(1) **Type.** When voltage is applied to the cable, current flows through the conductor and generates heat. Power output per unit length varies with the applied voltage and circuit resistance. Cables are available with a wide selection of conductor resistances. The type of heating cable selected may vary from mineral-insulated to self-regulating or constant-wattage cables. Based on voltage and required cable length, select a specific conductor with a cable resistance that provides the required power output.

(2) **Depth.** Dependent upon the cable characteristics, placement depth is nominally 2.0 to 3.0 inches below the finished surface of asphalt or concrete to maintain the desired output.

(3) **Spacing.** Cable spacing is dictated primarily by the heat-conducting ability of the material in which the cable is embedded. Concrete has a higher heat transmission coefficient than asphalt, permitting wider cable spacing. Actual cable spacing may vary between 3 and 9 inches for proper heat output requirements.

b. Grid-mesh/Heat-mats.

(1) **Type.** Heated cable may be attached to plastic or fiber mesh to form a mat unit. Prefabricated factory-assembled mats are available in a variety of watt densities to match desired snow-melting capacities. Pre-fabricated mats are seldom made larger than 60 ft^2. Plastic or fiber-mesh heating mats can be tailored to follow contours and fit around objects.

(2) **Depth.** Mats should be installed 2.0 to 4.0 inches below the finished surface of asphalt or concrete.

(3) **Spacing.** The mats must be placed at least 12 inches from pavement edge. Adjacent mats must not overlap.

(4) **Slip Plane.** The grid-mesh/heat-mats must not create a slip plane between pavement layers.

c. Conductive Material Mixes. During the pavement material mixing process, conductive materials, such as graphite and carbon, are added to either asphalt or concrete mixes. Current mix designs use less than 25 percent conductive materials and are capable of meeting the appropriate FAA material specifications for strength and durability.

(1) **Type.** Material mixes area available for asphalt and PCC pavements. Both material mixes are capable of meeting FAA material specifications for strength and durability.

- Conductive asphalt pavements are typically installed in a "sandwich" type of design utilizing a modified Item P-401 mix for the conductive layer and the standard Item P-401 mix for the insulating surface course layer.

- Conductive concrete is installed as a thin concrete overlay, which is formulated to satisfy Item P-501 specifications.

(2) **Spacing.** The primary advantage of a conductive material mix is a reduction in the placement of wiring throughout the pavement structure. The cables imbedded in the pavement are a power source, not the heating element, and are capable of spacing up to 50 feet apart determined by the voltage available and the resistance of the material mix. Maximum circuit length will be specified based upon manufacturer's recommendations in accordance with national and local code requirements.

(3) **Installation.** The construction processes ensuring isolation of the conductive layer from imbedded pavement lights and cabling require multi-layered installation and layout. Caution must be exercised with respect to the conductive layers and electrical components embedded in the material mix when compacting asphalt or vibrating concrete.

(4) **Depth.** The conductive layer for asphalt installations must be completely insulated on the sides and above for personnel safety (see Figure 2). The insulating layer must be no less than 1 inch for personnel safety. Adjustments to the thickness of the insulating layer are necessary if the pavement surface is to be grooved. Conductive *concrete* may be operated at lower voltages and installations have been successful for thin surface course overlays.

(5) **Electrical Safety.** Use of the highest line voltage available is recommended to reduce current demand. Circuits supplying power to an electrical heating pavement system must comply with NEC Handbook, Article 426, Fixed Outdoor Electric Deicing and Snow-Melting Equipment. The system manufacturer must provide procedures for testing the integrity of electrical connections to be implemented during the construction process and immediately after placement of the pavement materials.

- Systems operating at less than 50 volts to ground and using approved over-current protection devices do not require de-energizing for personnel protection. Step-down transformers must be specified when designing low voltage systems.

- Systems operating at higher voltages, typically less than 600 VAC, should consider use of single-phase voltage. Complex lock-out/tag-out procedures and more frequent inspections are necessary to ensure the integrity of the insulating layer for personnel protection.[4]

[4] See NFPA 70E, Standard for Electrical Safety in the Workplace: Article 130.

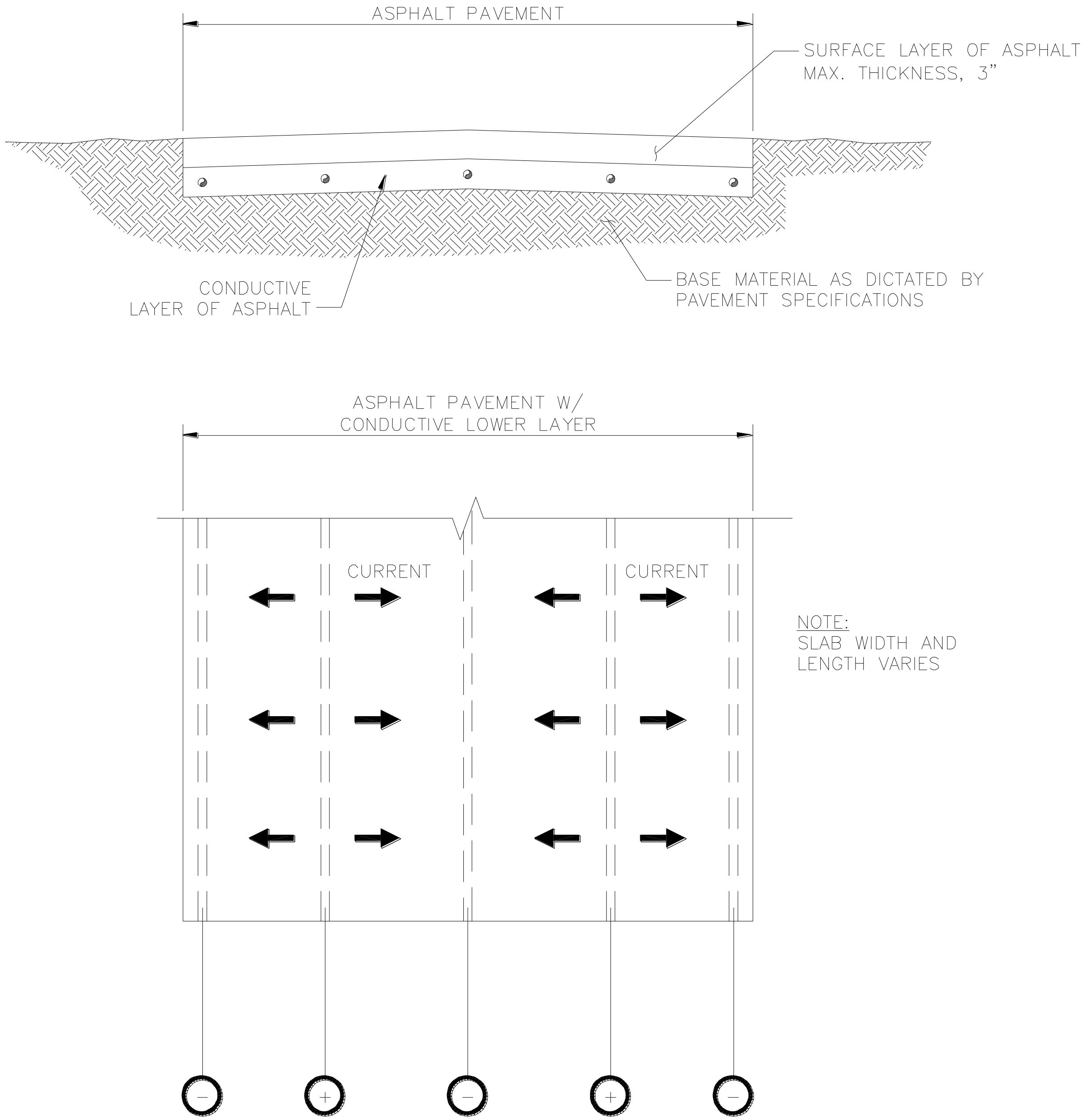

Figure 2. Electrically Conductive Asphalt Layered Installation

(6) **Additional Design Requirements.** Manufacturer recommendations for materials and components must be in compliance with industry accepted requirements as defined in ASHRAE 2007 HVAC Applications Handbook, Chapter 50, Snow Melting and Freeze Protection, and the Radiant Panel Association (RPA) 2009 RPA Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melt System, Section 300.5, Design Requirements – Electric.

- Heating elements may not run through any construction joint unless properly supported and protected.

- All ancillary electrical equipment and material requirements for providing power to the in-pavement heating system should comply with, and be installed per, applicable sections of AC 150/5370-10, Standards for Construction:

  - Item L-108, Underground Power Cable for Airports
    Sections 2.1 through 2.11

  - Item L-109, Airport Transformer Vault and Vault Equipment
    Sections 2.1 through 2.20

  - Item L-110, Airport Underground Electrical Duct Banks and Conduits
    Sections 2.1 through 2.8

  - Item L-115, Electrical Manholes and Junction Structures
    Sections 2.1 through 2.15

2.6. Hydronic Heat Source Design Considerations.

Geothermal sources, or heat pumps, can provide the energy to heat the fluids circulating through a hydronic system or in heat pipes. PCC or asphalt may be used with hydronic heated pavement systems, although pipe spacing and fluid temperatures will vary due to differences in thermal conductivity of asphalt and PCC.

a. Heat Sources. Various sources such as direct-use of geothermal hot water, Underground Thermal Energy Storage (UTES), boilers, and heat exchangers may be used. Because shallow ground temperatures are relatively constant throughout the United States, Geothermal Heat Pumps (GHPs) can be effectively used almost anywhere. However, knowledge of the specific geological and hydrological conditions and available land for the proposed site will help determine the best type of ground loop.

(1) **Geology.** Factors such as the composition and properties of soil and rock (which can affect heat transfer rates) require consideration when designing a ground loop. For example, soil with good heat transfer properties requires less piping to gather a certain amount of heat than soil with poor heat transfer properties. The amount of soil available contributes to system design as well. Areas with extensive hard rock or soil too shallow to trench may require installation of vertical ground loops instead of horizontal loops.

(2) **Hydrology.** Surface or ground water availability also plays a part in deciding what type of ground loop to use.

(a) Depending on factors such as depth, volume, and water quality, bodies of surface water can be used as a source of water for an open-loop system, or as a repository for coils of piping in a closed-loop system.

(b) Geothermal water can be supplied directly from shallow wells to the circulating pipes or through the use of heat exchangers at the ground source well heads.

(c) Ground water can also be used as a source for open-loop systems, provided the water quality is suitable and all ground water discharge regulations are met. Before consideration of an open-loop system, ensure the potential system manufacturer has investigated the site's hydrology to avoid potential problems such as aquifer depletion and groundwater contamination. Antifreeze fluids circulated through closed-loop systems generally pose little to no environmental hazard.

(d) Other areas may require deeper wells supplemented with the use of earth tubes, or down-hole heat exchangers. The heat from these wells can be extracted with heat pumps more efficiently than may be produced by conventional furnaces.

(e) Waste water from power plants or local industry may be viable alternatives for the heat source.

(3) **Land Availability.** The amount and layout of available land, landscaping, and the location of underground utility systems also contribute to system design. Horizontal ground loops (generally the most economical) are typically used for new construction with sufficient land. Vertical installations are often used because they minimize the disturbance to the landscape.

b. Piping. Piping, or tubing, may be metal, plastic, or rubber. Steel, iron, and copper pipes have long been used, but steel and iron may corrode rapidly. The use of salts for deicing and elevated temperatures may accelerate corrosion of components. A typical heat pipe installation is depicted in Figure 3.

The main disadvantage of plastic pipes embedded in asphalt is that the hot asphalt may damage the plastic pipes, as asphalt is usually placed at above 300°F in order to get adequate compaction. Also, the compaction process may deform and even break plastic pipes and their connections. Procedures for testing the integrity of piping and connections must be implemented during the construction process during and immediately after placement of pavement materials.

When plastic pipe is used, the system must be designed so that the fluid temperature required will not damage the pipe. One solution to temperature limitations is to decrease the pipe spacing. Closer pipe spacing also helps eliminate striping of snow (unmelted portions between adjacent pipe projections on the surface).

Selected materials for piping, or tubing, must be compatible with pavement materials and construction techniques. Pipe, or tubing, spacing will be specified by the manufacturer for the design heat requirements specified and must result in pressure drops within nominal capacities of circulators as dictated by standard industry/engineering practices.

Hydronic pipe or tube sizing should be selected to create flow velocities between 2 and 5 ft/s unless otherwise recommended by the manufacturer and in accordance with standard industry/engineering practices.

Use of a heat exchanger to separate the pavement piping circuitry from the fluid source may be advantageous to isolate additives, such as corrosion-inhibitors or anti-freeze additives, from effecting ground discharge waters.

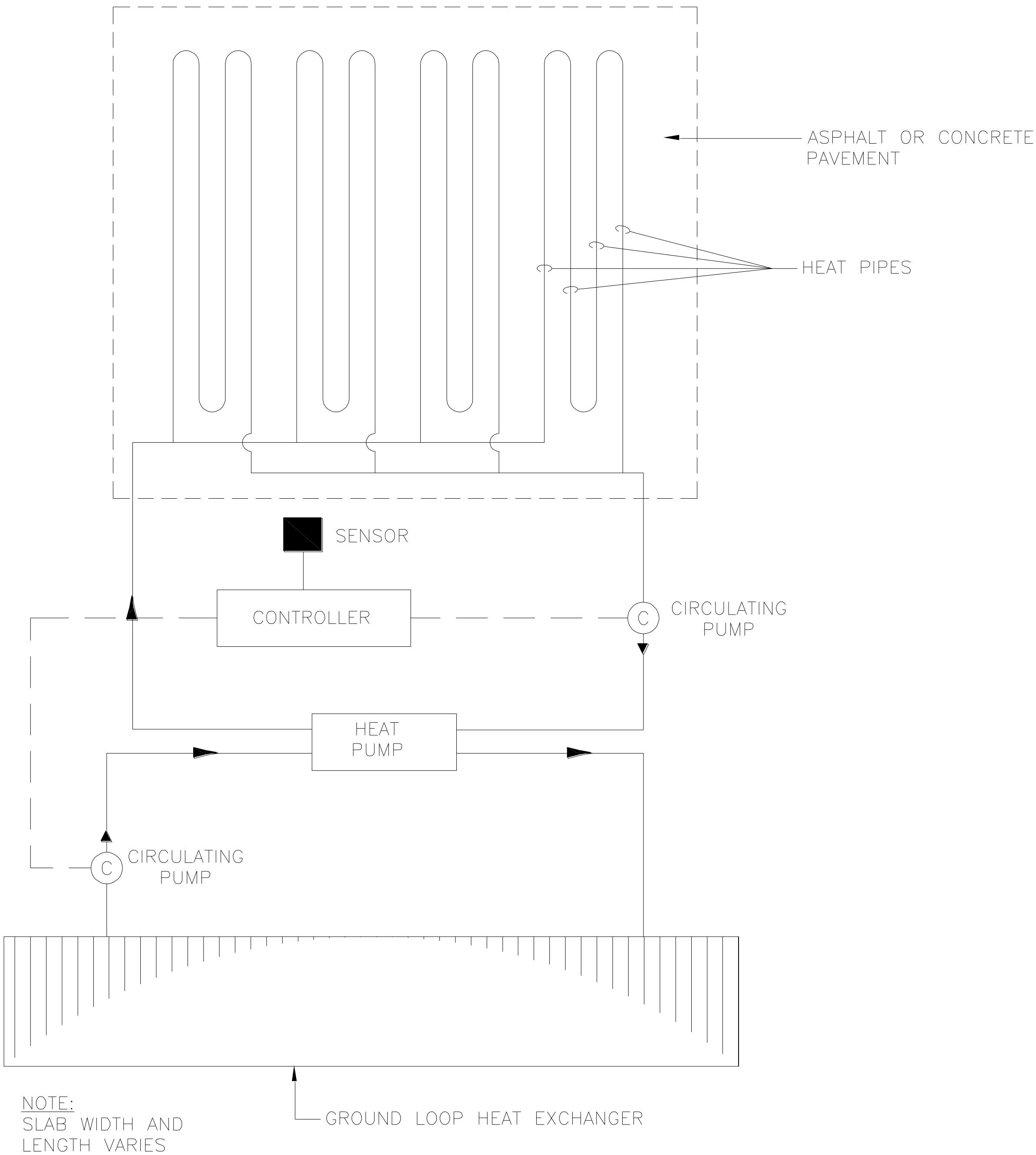

Figure 3. Heat Pipe System with Closed Loop Ground Source Heat

c. Heat Transfer Fluid. The fluid can be heated using various energy sources. A fluid heater can use steam, hot water, gas, oil, or electricity. Heat may be available from secondary sources, such as power plants and other waste heat sources. Alternative energy resources may also be used with or without heat pumps or heat pipes. The design capacity of the fluid heater is usually 200 to 300 Btu/h·ft^2, which includes back and edge losses. Design of the fluid heater should follow standard industry practice.

Heated fluid flow rates for operational design will be based on ΔT of 25°F unless otherwise specified by manufacturer. Total system flow will be calculated based on fluid density and heat capacities of fluid type mixture at the design ΔT.

The equation for the average fluid temperature to provide required heat output q_o is:

$$t_m = 0.5q_o + t_f$$

where:

t_m = average fluid temperature, °F

t_f = water film temperature (°F), accepted as 33°F

d. Heat Pumps. Heat pumps can circulate the ground source water provided by shallow wells or down-hole heat exchangers. The ground source water passes through the heat pump to extract the heat from the ground. The cooler, heat-extracted waters are returned back to the ground thus balancing this resource. The heat extracted, and that generated by the heat pump, combine to heat the closed-loop fluid flowing through the pavement. The proper pump is selected based on the fluid flow rate; energy requirements of the piping system; specific heat of the fluid; and viscosity of the fluid, particularly during cold start-up. Selection of the circulator will be determined by the system design flow rate and the differential pressure in the longest loop plus accumulated losses through valves, air separators, exchangers, etc. Select circulators based on the highest efficiency in mid-range performance.

e. Additional Design Considerations. Freeze protection is essential because most systems will not operate continuously in subfreezing weather. Without freeze protection, power loss or pump failure could cause freeze damage to the piping and pavement. Glycols (ethylene glycol and propylene glycol) are the most popular in heated pavement systems because of their moderate cost, high specific heat, and low viscosity. Ease of corrosion control is another advantage. The piping should be designed for periodic addition of an inhibitor. Glycols should be tested annually to determine any change in reserve alkalinity and freeze protection.

Manufacturer recommendations for materials and components must be in compliance with industry accepted requirements as defined in ASHRAE 2007 HVAC Applications Handbook, Chapter 50, Snow Melting and Freeze Protection, and the Radiant Panel Association (RPA) 2009 RPA, Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melt System, Section 200.5, Design Requirements – Hydronic.

2.7. System Control Considerations.

a. Activation. Sufficient lead time must be allowed for pavement temperature response if the ground has been below freezing before a storm event. Automating the activation of the heated pavement system before the accumulation of snow allows ample warm-up time and reduces the probability of thermal stress in pavement and equipment. For efficiency and reduction of operating costs, the following controls should be incorporated in the pavement heating system to provide this lead time.

(1) **Pavement Temperature Sensor.** Pavement temperature sensors will be installed in the heated pavement. A set point can be established to automatically cycle the system at pre-determined temperatures.

(2) **Snow Detectors.** Snow detectors monitor precipitation and temperature. They allow operation when snow is present. They may activate the heated pavement system when snow occurs at a temperature below a preset slab temperature.

(3) **Outdoor Thermostat.** The control system will include an outdoor thermostat that deactivates the system when the outdoor ambient temperature rises as automatic protection against accidental operation in summer or mild weather.

b. Safety.

(1) **Electric Systems.** For personnel safety and protection of equipment, the design of electric heated pavement systems is specified in Article 426 of the National Electrical Code (NEC) or National Fire Protection Agency (NFPA) Standard 70, which require that each electric heated pavement circuit be provided with ground fault protection devices. Equipment protection devices (EPD) with a trip level of 30 milliamps should be used to reduce the likelihood of nuisance tripping.[5]

(2) **Hydronic Systems.** Hydronic systems require fluid temperature and flow control for safety and component longevity. Slab stress and temperature limits of the heat transfer fluid, pipe components, and fluid heater need to be considered. Bypass flow and temperature controls may be necessary to maintain recommended boiler temperatures. If a primary control fails, a secondary fluid temperature sensor should deactivate the snow-melting system and possibly activate an alarm.

c. Separate Circuits. Planning for separate circuits should be considered so that areas within the system can be heated individually, as required.

2.8. Select Heat Source and Develop Performance Requirements.

a. The selection of the heat source is based on geographical and climatic location, local contractor and energy costs, drilling expenses, etc. As design and installation costs may be extensive and vary greatly, the airport sponsor should identify the preferred source of heat prior to fully developing performance specifications.

b. Consideration of all factors (i.e. calculating the heat required to meet expectations, selecting a prospective location, defining the level of system control, and identifying a source of heat) will allow the engineer to define performance requirements necessary for designing a system.

2.9. Solicitation and Proposals.

a. A template for design specifications for a Request for Proposal (RFP) is included in Appendix D. The solicitation will incorporate the performance requirements determined earlier in this chapter and will require vendors to include the following items:

(1) Certification of heated pavement system design to the capability of providing the defined heat requirements and that all materials or assemblies fully comply with design requirements.

(2) Detailed drawings and plans identifying the location of all proposed electrical or hydronic equipment, cables, and piping.

(3) Thorough maintenance and inspection programs must include procedures for emergency repairs and ensure compliance with existing drainage requirements and snow and ice control plans.

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[5] See NEC Article 426, Deicing and Snow Melting.

b. An evaluation of the submitted proposals will address technical merit as well as cost factors. The proposal should provide:

(1) A quality assurance (QA) program that ensures proposed construction, materials, and techniques are in accordance with system design requirements. A comprehensive quality assurance plan may also serve as certification for compliance with national and local codes as well as compliance to FAA standards.

(a) Successful experience designing and engineering heated pavement systems for transportation systems.

(b) Demonstration of in-depth awareness of heavy airplane pavement loading and stress effects, as well as maintenance and rehabilitation procedures.

2.10. Project Approvals and Funding Request.

The selected proposed system design must include all design assumptions and data utilized in its development, as well as proposed construction procedures and techniques. The proposal will also identify environmental requirement reporting procedures necessary for ground water discharge permitting.

a. Approvals.

(1) The airport engineer will incorporate the proposed design specifications into construction specifications and submit a quality assurance program to the responsible FAA Airports Regional/District Office for approval.

(2) The airport engineer will incorporate recommendations of regulatory agencies into the construction specifications to mitigate any environmental aspects.

(3) The airport sponsor will amend the airport's Storm Water Pollution Prevention Plan (SWPPP) if required by the National Pollution Discharge Elimination System (NPDES) and modify the airport base map depicting any incidental changes to the drainage plan.

b. Funding. The airport sponsor must follow accepted guidelines and procedures for obtaining funds for construction. However, any modification to an airport design standard that receives Federal aid requires further FAA approval. The request for modification should show that the modification will provide an acceptable level of safety, economy, durability, and workmanship.

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CHAPTER 3. CONSTRUCTION STANDARDS

3.1. Material Specifications and Construction Standards.

The following three ACs provide the basis for most of the standards applicable to the construction of heated pavement systems:

a. AC 150/5370-10, Standards for Specifying Construction of Airports, defines standards for pavement materials and installation techniques. Reference Part V for Flexible Surface Courses and Part VI for Rigid Pavement.

b. AC 150/5320-12, Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces, defines requirements of surface characteristics such as texture and grooving.

c. AC 150/5320-5, Surface Drainage Design, provides guidance to maintain compatibility and minimize interference with existing drainage patterns, control flooding of the pavement surface for design flood events, and minimize potential environmental impacts from storm water runoff.

3.2. Electric Heated Pavement System Construction Guidelines.

a. Installation of electrically heated pavement systems must be based on system design acceptance to provide the specific heat requirements for Class II operation.

b. Manufacturer recommendations for installation requirements of the in-pavement electric heating system must be in compliance with industry accepted requirements as applicable in ASHRAE 2007 HVAC Applications Handbook, Chapter 50, Snow Melting and Freeze Protection, and the Radiant Panel Association (RPA) 2009 RPA, Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melt System, Section 300.6, Installation Requirements – Electric.

c. Construction methods, testing, method of measurement, and basis of payment for all ancillary electrical equipment supplying power to the in-pavement heating system should comply with appropriate sections of AC 150/5370-10, Standards for Specifying Construction of Airports.

Item L-108 Underground Power Cable for Airports
Sections 3.1 through 5.1

Item L-109 Airport Transformer Vault and Vault Equipment
Sections 3.1 through 5.1

Item L-110 Airport Underground Electrical Duct Banks and Conduits
Sections 3.1 through 5.1

Item L-115 Electrical Manholes and Junction Structures
Sections 3.1 through 5.2

d. Heated Cable Installations.

(1) The heating cables and termination components must be UL listed specifically as electric deicing and snow-melting equipment. The heating cable must conform to IEEE Standard 515.1 Section 6.3.[6]

(2) Heating cable should be tested with a 2,500 Vdc megohmeter (megger) between the heating cable source and ground wiring. While a 2,500 Vdc megger test is recommended, the minimum acceptable level for testing is 1,000 Vdc.

NOTE: *The minimum acceptable level for the megger readings is 20 megohms, regardless of the circuit length.*

(3) The contractor or installer should perform this test a minimum of four times:

(a) Cable insulation resistance should be measured while the cable is still on the reel, before installation. Damage to the cable sheath is easily detectable with a field megohmeter. Cable with insulation resistance of less than 20 MΩ should not be used. Cable that shows a marked loss of insulation resistance after installation should be investigated for damage. Cable should also be checked for electrical continuity.

(b) After installation of cable and completion of circuit fabrication kits but before concrete or asphalt placement.

(c) During the placement of concrete or asphalt.

NOTE: *Should the cable be damaged during pavement material placement, the placement must stop, and the installer and contractor must locate the damaged cable, repair the cable with an approved splice kit, reinstall the cable in the original location or on rebar or wire grid where used, and retest the repaired cable before the placement can continue.*

(d) Upon completion of placement of concrete or asphalt.

(4) Results of the megger readings should be recorded and submitted to the airport engineer.

(5) When electric heating cable is installed in a concrete slab, the concrete slab must be placed in one layer.

(a) The heating cable is installed prior to placement of the concrete slab. Heating cables should be secured between 2 to 4 inches from the finished surface.

(6) Cable should not run through expansion, construction, or control joints. If the cable must cross such a joint, it should cross the joint as few times as possible and be protected at the point of crossing with 1 inch diameter rigid conduit or sleeve (see Figure 4). Burial below joint is the preferred option.

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[6] IEEE Recommended Practice for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Commercial Applications - Institute of Electrical and Electronic Engineers, Inc.

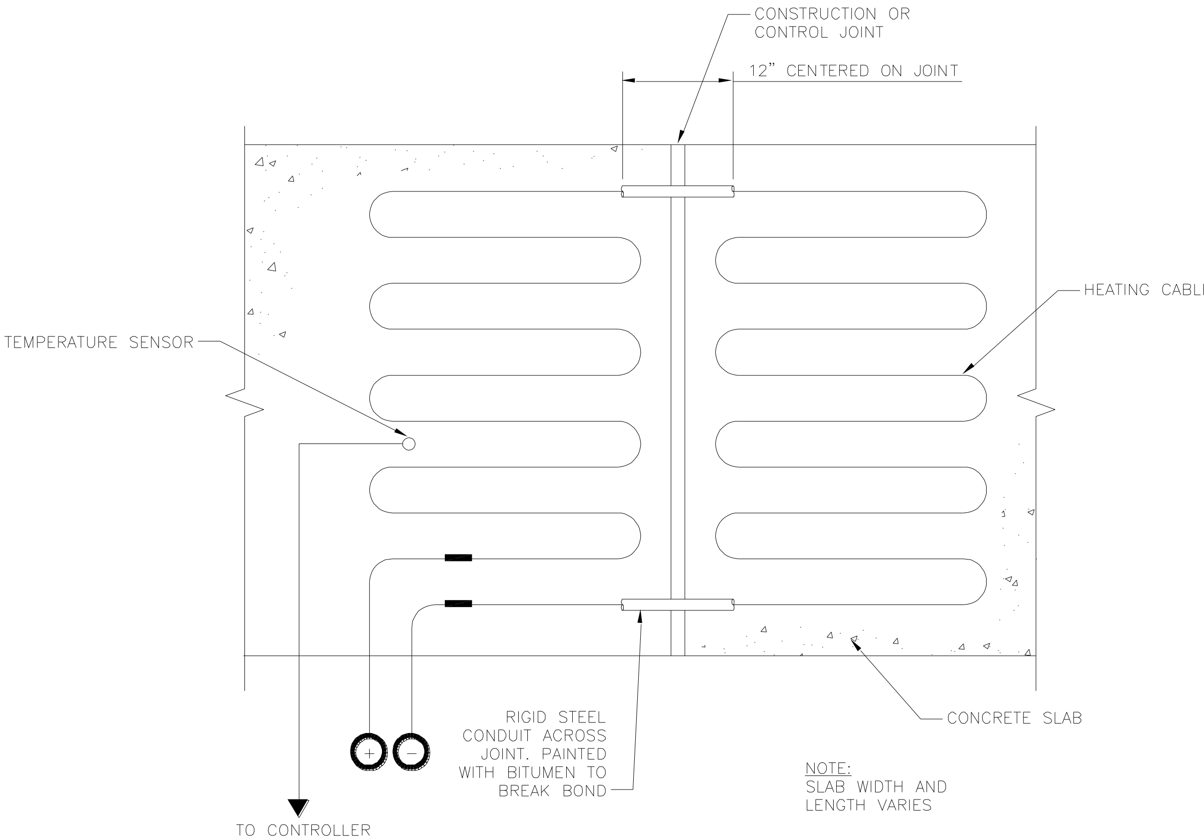

Figure 4. Typical Heating Cable Installation in Concrete Slab – ASHRAE

(7) The cold-lead cables should exit the slab underground in suitable conduits to prevent physical and chemical damage.

(8) In asphalt pavement installations, the cable may be fixed in place on top of the prepared base layer with pre-punched stainless steel strips or 6 inches by 6 inches wire mesh. A coat of bituminous binder is applied over the base and the cable to prevent them from floating when the top layer is applied. The layer of asphalt over the cable should be 2.0 to 4.0 inches thick.

(9) For uniform heating, cables should be arranged in a serpentine pattern. The heating cables should not be routed closer than 4 inches to the edge of the slabs, sensors, lights, or other items in the pavement.

(10) Heating cables are factory-fabricated with a non-heat-generating cold-lead cable attached. The cold-lead cable must be long enough to reach a dry location for termination and of sufficient wire gage to comply with local and NEC standards.

(11) The NEC requires a minimum cold-lead length of 6 inches within the junction box[7]. Cable junction boxes must be located such that the box remains dry and at least 3 feet of cold-lead cable is available at the end for any future service.

e. Grid-mesh or Mat Installations.

(1) Mats should be installed 2.0 to 4.0 inches below the finished surface of asphalt or concrete. Installing mats deeper decreases the snow-melting efficiency. Only mats that withstand hot-asphalt compaction should be used with asphalt pavements.

(2) Check the wire or heating mats with an ohmmeter before, during, and after installation.

(3) Temporarily lay the mats in position and install conduit feeders and junction boxes. Leave enough slack in the lead wires to permit temporary removal of the mats during concrete initial placement or asphalt first lift installation. Carefully ground all leads using the grounding braids provided.

(4) Place the base course and rough level to within 2.0 to 4.0 inches of the desired finish level. If units are to be installed on an existing asphalt surface, clean surface thoroughly. Apply a bituminous binder course to the lower base and install the mats. Secure all splices with approved water-tight connectors.

(5) Apply a second binder coating over the mats. Check all circuits with an ohmmeter to be sure that no damage occurred during installation.

(6) Place the top slab or asphalt lift over the mats while the rough slab is still wet, and cover the mats to a depth of at least 2.0 inches, but not more than 4.0 inches from the finished surface.

(7) Do not walk on the mats or strike them with shovels or other tools.

(8) Except for brief testing, do not energize the mats until the concrete is completely cured or the asphalt has completely hardened.

f. Conductive Material Mixes.

(1) The heated pavement system manufacturer must establish a material sampling and testing program in compliance with all applicable sections of AC 150/5370-10, Standards for Specifying Construction of Airports. Materials failing to meet these requirements can not be used.

(2) Power connections must be made in junction boxes. Power connections are not to be buried in concrete or asphalt.

(3) Cable sizing and connections must be made to conform to all applicable national and local code requirements.

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[7] See NEC Article 426, Fixed Outdoor Electric Deicing and Snow-Melting Equipment, Section II “Installation”.

(4) Where in-pavement lighting or other fixtures are incorporated in the pavement structure, the fixtures and wiring must be electrically isolated from the conductive layer of the pavement heating system.

(5) Installation of a conductive pavement must not interfere with cabling to the in-pavement fixtures.

(6) Installation of the standard asphalt mix for the insulating layer may be no less than 1.0 inch above and on the edges of the conductive layer for sufficient electrical insulation.

3.3. Hydronic Heated Pavement System Construction Guidelines.

a. Installation of hydronic heated pavement systems must be based on system design acceptance to provide the specific heat requirements for Class II operation.

b. Installation must follow manufacturer's recommendations for proper installation and layout methods.

c. Manufacturer recommendations for installation requirements must be in compliance with industry accepted requirements as applicable in ASHRAE 2007 HVAC Applications Handbook, Chapter 50, Snow Melting and Freeze Protection, and the Radiant Panel Association (RPA) 2009 RPA, Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melt System, Section 200.6, Installation Requirements – Hydronic.

d. Hydronic heated pavement systems are to be incorporated within the pavement structure.

e. All ancillary equipment must be constructed to maintain elements below grade within the confines of the runway and taxiway object free areas.

f. Installation of pipe within the pavement structure must be between 2.0 to 4.0 inches from the finished surface, dependent upon approved system design requirements.

g. With PCC pavements, the pipes, or tubing, can be attached over reinforcing mesh or dowels within the pavement (which may not always be used) but should have at least 2.0 inches of concrete above and below. Typical joint options are depicted in Figure 5.

h. In the case of thin concrete overlays, the piping is usually placed below the overlay in the existing pavement. In this case, the advantage of not placing the pipes, or tubes, in the overlay material is that future utility cuts or repairs can be made without damaging the pipes.

i. After pipe installation, but before slab installation, all piping should be air-tested to 100 psig or 1.5 times the operating pressure, whichever is greater. This pressure should be maintained for a minimum of 30 minutes or sufficient time until all seals and connections have been checked for leaks. Isolate the air pressure test to manifold and piping. Ancillary equipment, such as well heads, heat-exchangers, and boilers may have lower pressure test limits.

j. Testing *must not* be done with water because small leaks may not be observed during slab installation; water leaks may damage the concrete during installation; the system may freeze before antifreeze is added; and it is difficult to add antifreeze when a system is filled with water.

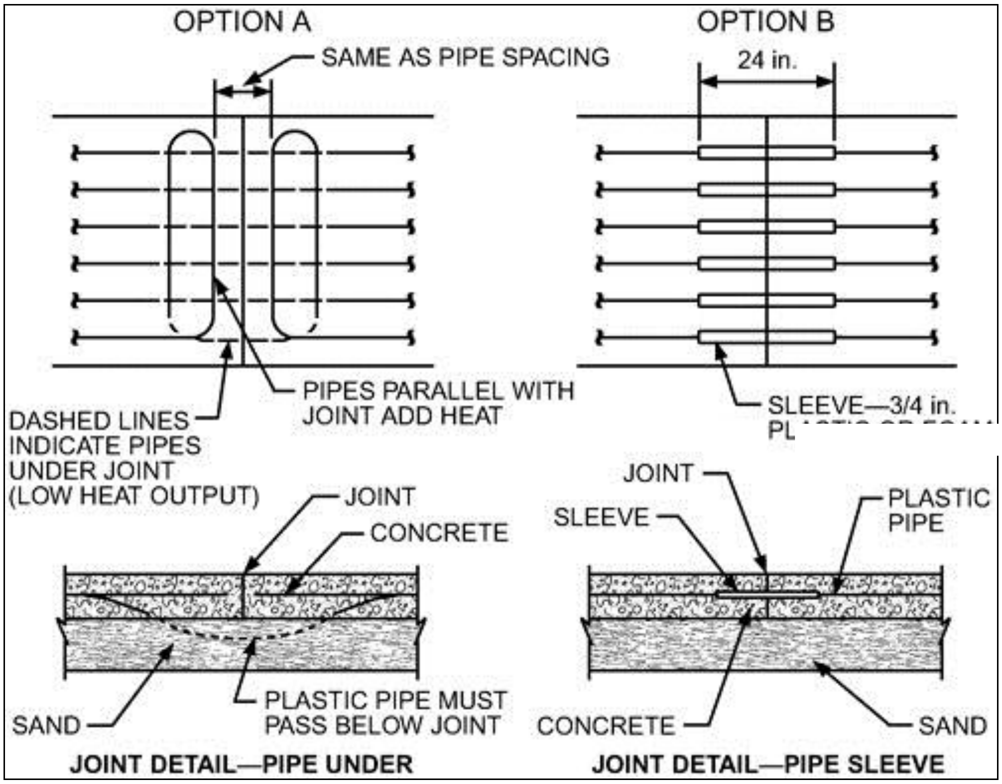

Figure 5. Piping Details for PCC Placement - ASHRAE

3.4. Quality Control/Quality Assurance.

a. The heated pavement system manufacturer, submitting through the construction contractor to the airport sponsor, will certify the heated pavement system design is capable of providing the defined heat requirements.

b. The system manufacturer, submitting through the construction contractor, will certify that all pre-fabricated materials or assemblies fully comply with the requirements of the contract. Such materials or assemblies delivered to the project site must be accompanied by the manufacturer's certificate of compliance in which all items are clearly identified.

c. The system manufacturer, submitting through the construction contractor, will furnish detailed drawings identifying the location of all proposed electrical or hydronic equipment, cables, and piping for review to the airport engineer.

d. A comprehensive quality assurance (QA) program must be implemented to ensure that installation/construction is in accordance with the approved heated pavement system design. The construction contractor and heated pavement system manufacturer will submit a QA plan to the airport sponsor for approval.

e. The quality assurance plan may serve as certification for compliance with national and local codes as well as compliance with FAA standards for construction specifications for materials and techniques.

f. The construction contractor will employ an independent testing organization to perform all manufacturer required tests during installation. The contractor will submit to the airport sponsor resumes on all testing organizations or individuals who will be performing the tests. All test data will be reported to the airport sponsor after the results are known. The contractor must submit a final report to the airport sponsor showing all test data reports, plus an analysis of all results showing ranges, averages, and corrective action taken on all failing tests.

g. The system manufacturer, or vendor, is responsible for liability of all costs to remove and remediate any systematic failure that affects the safety of aircraft operations or personnel.

h. The system manufacturer must demonstrate successful experience designing and engineering heated pavement systems for transportation systems with in-depth awareness of load effects, pavement maintenance, and rehabilitation procedures.

3.5. System Approval Procedures.

a. The system design must be prepared by the design engineer and the heated pavement system manufacturer for the airport sponsor. The airport sponsor must submit the heated pavement system design to the responsible FAA Airports Regional/District Office for review and approval.

b. The heated pavement system design must be certified by the manufacturer as meeting all the requirements of this AC, and the submittal must include all design assumptions and data utilized in its development as well as proposed construction procedures and techniques. The heated pavement system design must be submitted at least 45 days before award of contract.

c. The airport sponsor must submit the construction QA program to the responsible FAA Airports Regional/District Office for approval 14 days before the project notice to proceed. All modifications to FAA design and construction standards must be included in the submittal.

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CHAPTER 4. INSPECTION REQUIREMENTS AND MAINTENANCE PROCEDURES

4.1. General.

The heated pavement system manufacturer must submit plans for inspection requirements and maintenance procedures for each heated pavement system installation. Inspection and maintenance plans will provide general information, including a description of the heated pavement system and specialized equipment and materials descriptions necessary for maintenance or emergency repairs.

4.2. Inspection Plan.

Each year, inspection and operation of the heated pavement system will be conducted prior to the start of the winter season and after the last expected winter storm event.

Pavement surface condition inspections to discover and remediate cracks in the surface are necessary to prevent water infiltration from the pavement surface.

A well-documented inspection plan will include:

a. Type and frequency of required inspections;

b. Instructions on how to conduct each inspection;

c. List of typical problems, such as ponding water, and possible solutions;

d. Training of personnel;

e. Required documentation for inspections; and

f. Inspection forms.

4.3. Maintenance Procedures Plan.

A maintenance plan should be in place to maintain the heated pavement for the maximum expected life cycle. Procedures must be sufficiently detailed to allow emergency repair of the heated pavement system with the airport sponsor's staff. The plan should include the following maintenance and repair procedures:

a. List of approved materials and equipment.

b. Lock-out/tag-out procedures and training.

c. Description of repair procedures for preventing damage to a heated pavement system, such as repairing surface deteriorations, depressions/holes, abrasion damage, caulking/joint repair, etc.

d. Any unique requirements due to location and/or limitations, such as modifications to procedures in the SICP to assure clear paths to storm water drainage areas.

e. Contact information for warranty and emergency repairs.

4.4. Records.

The plans will include appropriate records to verify that all required inspections and maintenance have been performed. These records must be made available to the FAA upon request.

APPENDIX A. GLOSSARY

Advisory Circular (AC) – External FAA publication consisting of recommendations about a policy and guidance and information about a specific aviation subject.

Aircraft Operations Area (AOA) – For the purpose of this specification, the term aircraft operations area means any area of the airport used or intended to be used for the landing, takeoff, or surface maneuvering of aircraft, including all aprons and aircraft parking ramps.

Airport Improvement Program (AIP) – A Federal grant-in-aid program authorized by the Airport and Airway Improvement Act of 1982 that provides funding for airport planning and development.

Airport Sponsor – The entity that is legally responsible for the management and operation of an airport, including the fulfillment of the requirements of related laws and regulations. The term "sponsor", as used in this AC, includes all individuals or offices with delegation of authority on the airport's behalf, including the airport engineer and inspectors.

Airside – The portion of an airport that contains the facilities necessary for the operation of aircraft.

Apron – A specified portion of the airfield used for passenger, cargo, or freight loading and unloading; aircraft parking; and the refueling, maintenance, and servicing of aircraft.

Commercial Service Airport – A public airport providing scheduled passenger service that enplanes at least 2,500 annual passengers.

Navigational Aid (NAVAID) – A facility used as, available for use as, or designed for use as an aid to air navigation.

Notice to Proceed – A written notice to the contractor to begin the actual contract work on a previously agreed to date. If applicable, the Notice to Proceed will state the date on which the contract time begins.

Passenger Facility Charge (PFC) – Fees collected for every enplaned passenger at commercial service airports controlled by public agencies that are used to fund FAA-approved projects that enhance safety, security, or capacity; reduce noise; or increase air carrier competition.

Runway – A defined rectangular area at an airport designated for the landing and takeoff of an aircraft.

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APPENDIX B. REFERENCE AND RELATED READING MATERIALS.

FAA Advisory Circulars

Current versions of the following Advisory Circulars are available for viewing and/or printing on the FAA website at http://www.faa.gov/regulations_policies/advisory_circulars/.

AC 150/5200-30	Airport Winter Safety and Operations
AC 150/5300-13	Airport Design
AC 150/5320-5	Surface Drainage Design
AC 150/5320-6	Airport Pavement Design and Evaluation
AC 150/5320-12	Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces
AC 150/5340-18	Standards for Airport Sign Systems
AC 150/5340-30	Design and Installation Details for Airport Visual Aids
AC 150/5370-2	Operational Safety on Airports During Construction
AC 150/5370-10	Standards for Specifying Construction of Airports
AC 150/5380-7	Airport Pavement Management Program

Related Reading Material

Design Heat Requirements for Snow Melting Systems Canadian Building Digest – 160 G.P. Williams, 1974

Pavement Snow Melting, John W. Lund, Oregon Institute of Technology Geo-Heat Center (GHC) GHC Bulletin, June 2000

ASHRAE Fundamentals 2009 Handbook, Chapter 3, Fluid Flow; Chapter 4 Heat Transfer; Chapter 18.28, Heating Load Calculations*;* American Society of Heating, Refrigerating, and Air-Conditioning Engineers

ASHRAE HVAC 2007 Handbook, Chapter 50, Snow Melting and Freeze Protection, American Society of Heating, Refrigerating, and Air-Conditioning Engineers

RPA Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melt Systems, Radiant Panel Association, January 2009

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APPENDIX C. HEAT REQUIREMENT FORMULAS AND SAMPLE CALCULATIONS

C.1. Formulas

C.1.1. General Equations[8]

The general equation for required pavement heat output (q_o) in Btu/ h·ft^2 is:

$$q_o = q_s + q_m + A_r\,(q_e + q_h)$$

where:

- q_s = sensible heat transferred to the snow (Btu/ h·ft^2)
- q_m = heat of fusion (Btu/ h·ft^2)
- A_r = snow-free area ratio must equal 1 for areas with aircraft operations
- q_e = heat of evaporation (Btu/ h·ft^2)
- q_h = heat transfer by convection and radiation (Btu/h·ft^2)

The sensible heat (q_s) to bring the snow to 32°F is:

$$q_s = s\,c_p\,D\,(32 - t_a) / c_1$$

where:

- s = rate of snowfall (inches of water equivalent per hour)
- c_p = specific heat of snow (0.5 Btu/lb/°F)
- D = density of water equivalent of snow (62.4 lbs/ft^3)
- t_a = air temperature (°F)
- c_1 = conversion factor (12 in/ft)

The heat of fusion (q_m) to melt the snow is:

$$q_m = s\,h_f\,D / c_1$$

where:

- h_f = heat of fusion for water (143.5 Btu/lb)

The heat of evaporation q_e is:

$$q_e = P_{dry\ air}\,h_m(W_f - W_a)h_{fg}$$

where:

- $P_{dry\ air}$ = density of dry air (lb/ft^3)
- h_m = mass transfer coefficient, concrete slab (ft/h)
- W_f = humidity ratio of saturated air at film surface temperature @ 33° (lb_{vapor}/lb_{air})
- W_a = humidity ratio of ambient air @ 20° (lb_{vapor}/lb_{air})
- h_{fg} = heat of evaporation at the film temperature @ 33^0 (Btu/lb)

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[8] American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., (ASHRAE) 2007 HVAC Applications Handbook – Chapter 50, Snow-Melting and Freeze Protection

The heat transfer q_h:

$q_h = h_c(t_f - t_a) + \sigma\varepsilon_s(T^4_f - T^4_{MR})$ where:

where:

h_c = convection heat transfer coefficient for turbulent flow (Btu/h·ft^2·°R^4)
t_f = liquid film temperature, (°F) usually accepted as 33
t_a = ambient air temperature coincident with snowfall (°F)
σ = Stephan-Boltzmann constant (Btu/h·ft^2·°R^4)
ε_s = emittance of wet slab
T_F = liquid film temperature (°R)
T_{MR} = mean radiant temperature of surroundings (°R)

C.2. Sample Heat Requirement Calculations

C.2.1. Assumptions:

$S = .1$ - rate of snow-fall (inches of water equivalent per hour)
$T_a = 20°F$ - air temperature
17°F - Dew point temperature
$V = 20$ - wind speed (mph)

C.2.2. Result using the general equation for required pavement heat output (q_o) in Btu/ h·ft^2 is:

$q_o = q_s + q_m + 1(q_e + q_h)$
$q_o = 3.38 + 74.62 + 1(48.162 + 57.2)$
$q_o = 183.362$ Btu/ h·ft^2 or 53.74 W/ft^2

where:
$q_s = 3.38$ = sensible heat transferred to the snow (Btu/ h·ft^2)
$q_m = 74.62$ = heat of fusion (Btu/ h·ft^2)
$A_r = 1$ = ratio of snow free area to total area for AOA ops
$q_e = 48.162$ = heat of evaporation (Btu/ h·ft^2)
$q_h = 57.2$ = heat transfer by convection and radiation (Btu/h·ft^2)

The sensible heat (qs) to bring the snow to 32°F is:

$q_s = s\ c_p\ D\ (t_f - t_a) / c_1$
$q_s = .1 * .5 * 62.4(33-20) / 12$
$q_s = 3.38$

where:
$s = 0.1$ = rate of snowfall (inches of water equivalent per hour)
$c_p = 0.5$ = specific heat of snow (Btu/lb/°F)
$D = 62.4$ = density of water equivalent of snow (lbs/ft^3)
$t_f = 33$ = liquid film temperature, (°F) usually accepted as 33
$t_a = 20$ = air temperature (°F)
$c_1 = 12$ = conversion factor (inch/foot)

The heat of fusion (q_m) to melt the snow is:

$q_m = s\ h_f\ D / c_1$
$q_m = .1 * 143.5 * 62.4 / 12$
$q_m = 74.62$

where:
$s = 0.1$ = rate of snowfall (inches of water equivalent per hour)
$h_f = 143.5$ = heat of fusion for water (Btu/lb)
$D = 62.4$ = density of water equivalent of snow (lbs/ft^3)
$c_1 = 12$ = conversion factor (inch/foot)

The heat of evaporation q_e is:

$q_e = P_{dry\ air}\ h_m(W_f\text{-}W_a)h_{fg}$
$q_e = 14.696*1.7(.003947\text{-}.0021531)1074.64$
$q_e = 48.162$

where:

$P_{dry\ air}$ = 14.696 = density of dry air (lb/ft^3)
h_m = 1.7 =mass transfer coefficient, concrete slab (ft/h)
W_f = .003947 = humidity ratio of saturated air at film surface temperature @ 33^0 (lb_{vapor}/lb_{air})
W_a = .0021531 = humidity ratio of ambient air @ 20^0 (lb_{vapor}/lb_{air})
h_{fg} = 1074.64 = heat of evaporation at the film temperature @ 33^0 (Btu/lb),

The heat transfer q_h:

$q_h = h_c(t_f\text{-}t_a)+\sigma\varepsilon_s(T^4{}_f - T^4{}_{MR})$
$q_h = 4.4\ (33\text{-}20)+ 0.1712 \cdot 10^{-}8 \cdot .9(0)$
$q_h = 57.2$

where:
h_c = 4.4 = convection heat transfer coefficient for turbulent flow (Btu/h·ft^2·°R^4)
t_f = 33 = liquid film temperature, (°F) usually accepted as 33
t_a = 20 = ambient air temperature coincident with snowfall (°F)

APPENDIX D. DESIGN AND CONSTRUCTION SPECIFICATIONS

D.1. Design Specification. The Heated Pavement System Design Specifications should, as a minimum, include the following requirements and associated information:

a. Heat requirement (see Paragraph 2.3 and Appendix C): ___ per sq ft

b. Location (see Paragraph 2.4): i.e. Runway, Taxiway, Apron, Aircraft Parking area, etc.

(1) Coordinates:

(2) Size:

(3) Pavement condition:

c. Source of Heat - Electrical Pavement System

(1) Design (see Paragraph 2.2)

- One-line diagrams:
- Electrical service installation details:
- Panel schedules:
- Power plan:
- Materials list:

(2) System Control Requirements (see Paragraph 2.7)

- Activation/Deactivation:
  - Manual:
  - Automated:
- Warm-up time:
- Personnel safety:
- Ground fault protection devices:

(3) Plan to assure compliance with drainage requirements.

(4) Plan to assure no interference with navigational system.

(5) Plan to assure no interference with communication equipment.

d. Source of heat - Hydronic Pavement System (see Paragraph 2.6)

(1) Design

- Piping plans in the form of one-line diagrams:
- Fluid specifications including freeze specifications:
- Heat pumps specifications:
- Heat exchanger specifications:
- Boilers specifications:
- Other mechanical equipment specifications:
- Power plan specifications:
- Materials list:

(2) System Control Requirements (see Paragraph 2.7)

- Activation/De-activation:
  - Manual:
  - Automated:
- Warm-up time:
- Personnel safety:
- Ground fault protection devices:
- Other:

e. Project Plans

(1) Site plan: ___ copies

(2) Grading Plan: ___ copies

(3) Civil Details: ___ copies

(4) Cross Sections: ___ copies

(5) Electrical Layout Plan: ___ copies

(6) Electrical Schedules and One-Line Diagram: ___ copies

(7) Electrical Specifications: ___ copies

(8) Quality Assurance Plan: ___ copies

f. Site Visit: ________ Date/Time

g. Government Furnished Material (GFM): i.e. airport drawings, geotechnical data, Storm Water Pollution Prevention Plan (SWPPP)

h. Inspection and maintenance program: Procedures for:

(1) Inspection Requirements Plan: ___ copies

(2) Maintenance Procedures Plan: ___ copies

D.1.1. Design Cost Proposal:

D.2.1. Construction Specifications. The Construction Specifications should, as a minimum, include the following requirements and associated information:

a. FAA ACs:

(1) AC 150/5320-12, Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces

(2) AC 150/5370-10, Standards for Specifying Construction of Airport, including general provisions and technical specifications

(3) Other FAA ACs:

b. Specifications unique to Heated Pavement System

c. Specifications unique to Hydronic Pavement System

d. National Building Codes:

e. Local Building Codes:

f. Detailed drawings, specifications, and materials list of in-pavement requirements:

D.2.2. Construction Cost Proposal: