COVER PAGE

Title of Design: Radiant Heating of Airport Aprons

Design Challenge Addressed: Airport Operations and Maintenance

University name: Binghamton University – State University of New York

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Number of Undergraduates: 20

Number of Graduates: 0

Advisor(s) name: Professor William Ziegler

Airport Operations and Maintenance Challenge:

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Executive Summary

Title: Radiant Heating of Airport Aprons

Summary: Current methods of deicing and snow removal of paved surfaces are a significant expense for cold climate airports. Deicing is time-consuming, requires an array of heavy equipment, and demands expensive overtime work from the maintenance staff. Additionally, the use of sand can potentially cause damage to aircraft engines and deicing chemicals, i.e. potassium acetate, are thought to have adverse environmental effects. This project proposes a low-maintenance and environmentally friendly solution for ice and snow prevention on airport surfaces: a radiant snowmelt system powered by geothermal energy. The use of radiant heating will reduce staff workload, the need for heavy equipment, and the amount of sand and deicing chemicals used; geothermal heat pumps are roughly 300-400% more efficient than standard power sources and are topographically suited for installation at many airports. Our team analyzed successful commercial radiant system installations, expanded previous installations to a scale suitable to airports, and concluded that a radiant system installed during a routine pavement tear-up is a viable alternative to current deicing methods. Our proposal is limited to the concrete "aprons" and not the full runway of the airport. At this time, radiant heating systems are extremely costly to implement on the scale necessary to fulfill all snow and ice removal requirements of an entire airport; however, a life cycle cost analysis of our proposed system for the apron area revealed that though the initial installation is steep, a radiant system delivers unmatched convenience and becomes financially competitive with current deicing methods towards the end of its lifespan.

Participants: Twenty-three undergraduate students in the Department of Computer Science in the Thomas J. Watson School of Engineering and Applied Science at Binghamton University.

Table of Contents

Table of Figures

Figures

Tables

I. Problem Statement and Background

Climate factors have always been one of the most influential factors of aviation safety. Just recently, there was a devastating crash reportedly due to ice build up on an airplane in Buffalo, New York (Wald and Robbins, 2009). Weather conditions affect aircraft and airports around the world; the runways that planes land on need to be ice and snow free to ensure the safety of passengers, pilots, and aircraft, and airport facilities. Even small airports in areas with very harsh periods of cold weather budget upwards of hundreds of thousands of dollars towards the maintenance of airfield pavements (Chad Nixon, personal communication, February 10, 2009).

The current method of removing snow and ice from airport pavements involves the use of sodium acetate for melting ice, sand for increasing plane traction, and large specialty vehicles suited for blowing, brushing, and sweeping snow. These large vehicles are costly to maintain and replace, fuel inefficient, and are difficult to maneuver in tight areas. (Chad Nixon, personal communication, February 10, 2009) With mounting evidence suggesting anthropogenic global warming (United States Environmental Protection Agency, 2009), the amounts of carbon dioxide these machines emit are an environmental concern. Additionally, studies suggest that excess sand can erode plane engines (United States Department of Energy, 2008). From the issues that arise regarding the current methods of airport snow removal, it is evident that a more cost efficient, environment friendly solution is needed.

For the purposes of snow and ice removal and prevention, a radiant under-pavement heating system fueled by geothermal energy heat pumps is proposed. The radiant aspect of the system would elevate pavement temperatures to prevent snow and ice from forming (Uponor, 2009). Geothermal heat pumps are a clean energy alternative to standard plant supplied sources of energy (United States Department of Energy, 2009). The heat pumps take advantage of the relatively constant temperature underground, which can be tapped as both a heat source and heat sink.

The ability of radiant heat to melt snow (Uponor, 2009) lends itself to the idea of being used as an alternative method of snow and ice prevention and removal on all airfield pavements (Uponor, 2009). However, as will be shown, the required scale for energy and other associated costs for a system that heats all airport surfaces would make it impractical and generally unrealistic. Therefore, the emphasis herein is redirected to the usage of a radiant heating system from runways towards apron sections, specifically the terminal apron where planes park to load and unload passengers, and the areas under large jet bridges that restrict current methods of snow removal. These areas are of high aircraft and human traffic and therefore increase the risk of an accident. Further, a disproportionate amount of time and monetary resources are dedicated to snow removal in said locations (Chad Nixon, personal communication, March 6, 2009).

Figure 1 - Winter Conditions at Greater Binghamton Airport (BGM)

We have evaluated the practicality of our proposed system at the Greater Binghamton Airport (BGM), in Johnson City, New York (Fig. 1), and expanded our results into a per-acre cost that can be applied to any other airport with similar climate conditions.

II. Summary of Literature Review

II.1 Runway Deicing and Ice Prevention

Deicing and preventing the buildup of ice on runways is mission critical to ensuring the safe, expeditious operation of daily airport activities. As technological capacity has evolved, so too have the deicing techniques that maintain the safety of airport pavements; today, there are several standard techniques being used for de-icing.

According to Transport Canada (Transport Canada, 2008), larger Canadian international airports utilize three chemical compounds as runway deicing agents: sodium formate, potassium acetate and sodium acetate. This is opposed to the traditional use of Urea, which suffered two key limitations in that its practical low temperature effectiveness is considered to be about -7 degrees Celsius and it has a relatively high biological oxygen demand.

The San Diego based Cryotech (http://www.cryotech.com/) company manufactures both potassium and sodium acetate products, that can be used to de-ice runways. Both chemical compounds are used frequently within de-icing agents because they meet FAA-approved specifications for use by commercial airports and military bases. Primarily, these products are more environmentally friendly than other chemicals, are relatively inexpensive, and they perform at colder temperatures.

Cryotech's potassium acetate product (Cryotech, 2008) is a liquid runway de-icer that is applied by spraying the product directly onto the runway. The benefits include that it is biodegradable, non-persistent, and is effective to temperatures -7 degrees Celsius, with a freezing point of -24 degrees, Celsius; the use of acetate based products is generally considered more environmentally safe than the use of Urea.

Their sodium acetate product (Cryotech, 2007) is a solid runway de-icer that applies by spreading the pellets by truck onto the runway areas. The benefits include that is biodegradable at low temperatures, it gives off heat as it dissolves, has low toxicity to fish and mammals, and it is non-persistent. The drawbacks of this compound is that it loses its effectiveness as the temperatures decrease below zero Fahrenheit and that it must be reapplied “when new accumulation shows tendency to bond.”

Recently, according to the Transportation Research Board (Transportation Research Board, 2007) researchers have been investigating a potential link between potassium acetate and the wearing down of concrete runways. Preliminary findings of the Innovative Pavements Research Foundation “indicate that the deicers [containing potassium acetate] have potential to induce aggressive alkali-silica reactions in certain concretes.” Prolonged use and exposure of certain concrete runways to potassium acetate could thus reduce the durability in airfield pavements.

Additionally, in January of 2009, the United States Geological Survey released an article (Corsi, 2009) concerning the environmental effects of potassium acetate. They state that after collecting water samples from streams at four sites near the General Mitchell International Airport in Milwaukee between 1996 and 2006, “forty percent of the samples collected following the change (from urea to potassium acetate as a de-icing agent) had concentrations of potassium acetate at levels high enough to be detrimental to aquatic life.” The Center for Environmental Excellence (2009) highlights a few issues with acetate de-icers. Because it is granular in nature, the dust released from sodium acetate produces pollutants into the air, and is harmful if inhaled over an extended period of time. In runoff, “acetate ions are broken down by soil microorganisms and may result in oxygen depletion of the soil, which can impact vegetation.”

Furthermore, “acetate deicers also have the potential to cause oxygen depletion in rivers, streams and lakes.”

II.2 Methods of pavement heating

The basic premise behind radiant heating systems is that heated fluid circulates through tubing under a surface, radiating its energy evenly, thus heating a room, surface, or building.

Electric cable heating systems, often called line or high voltage systems, are ideal for heating smaller areas such as a bathroom, kitchen, or sunroom. These systems are comprised of a thermostat and a heating cable. These systems are usually less expensive, and provide the capacity to space the cables to maximize the amount of heated surface area (Butcher, 2008).

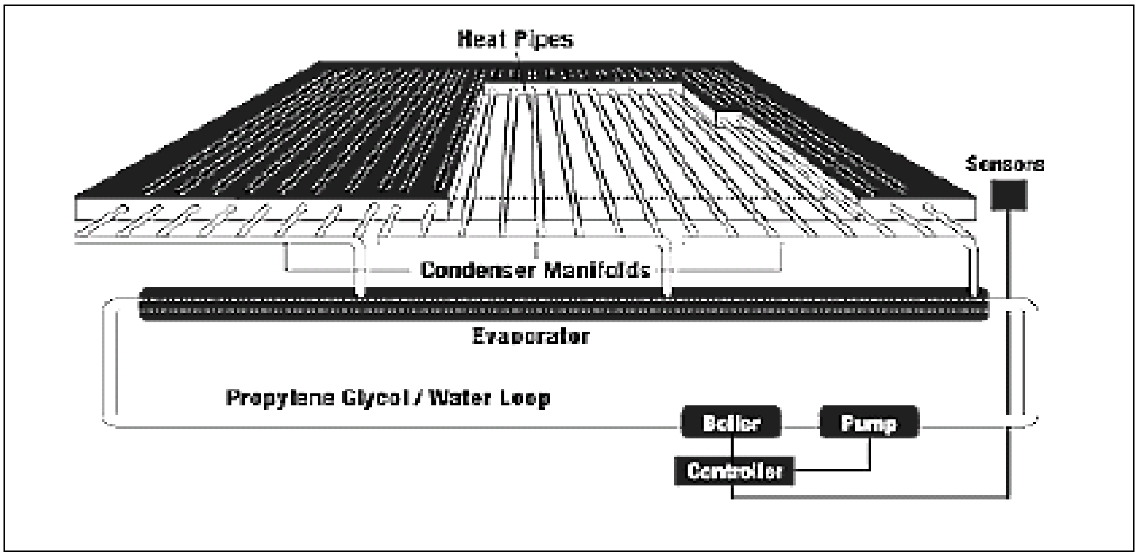

Figure 2 - Hydronic heating system

Hydronic heating systems as shown in Fig. 2 above are comprised of a boiler or hot water heater, pumps, manifolds, pex tubing, and a thermostat. Hydronic heating is the most complex of all radiant heat systems. These systems are most common in large areas and commercial use because of their expensive components and operational costs. Additionally, these systems afford the ability to be installed in almost any type of material, such as concrete, asphalt, etc., which makes them very versatile for use. The hydronic heating system tubing contains a glycol (antifreeze and water) solution that is heated in order to melt ice and snow (Butcher, 2008).

II.3 The Use of Geothermal Heat Pumps

Geothermal heat pumps (GTHP) do not generate energy, but provide a means of harnessing stored thermal energy in the ground. A GTHP requires a small amount of input energy to function, but is 300-400% more efficient than typical means of heating (i.e. gas or oil fired systems) (EPA: Geothermal Heat Pumps, pg. 1). The use of geothermal heat pumps is made possible by the stability of underground temperatures a few feet below the surface: in the summer, the relatively cool temperature of the ground (or body of water) is utilized as a heat sink and during the winter, the warmer ground (or body of water) is used as a heat source (Environmental Protection Agency, 2000, page 1). In addition to heating and cooling, a GTHP can often satisfy a residential home's demand for heated water (Toolbase: Geothermal Heat Pumps).

During winter, a GTHP collects thermal energy from beneath the earth's surface through a series of pipes, called a loop, installed below the surface of the ground or submersed in a body of water. A secondary pump circulates fluid, typically refrigerant or a glycol/water mixture, through the loop and carries the heat back to the main pump installation. An electrically driven compressor and a heat exchanger then concentrate the energy, making it available for use at a higher temperature (Consumer Energy Center, para. 3-10). In this way, a GTHP provides functionality similar to a conventional boiler.

In summer, the GTHP acts in a reverse cycle similar to a refrigerator, moving excess heat from a target location back underground into the relatively cool area under the earth's surface. By utilizing the earth as a heat sink in summer months, the (minimal) negative change to soil temperature sustained during winter months around the installation area of our loop is offset. In this way, a GTHP can satisfy both heating and cooling requirements for a given structure.

Geothermal heat pumps are generally divided into two systems, closed and open. The majority of closed loop systems are comprised of two loops: the refrigerant loop and the secondary (ground) loop. The refrigerant loop sits inside an appliance cabinet, within the building of installation, where it exchanges heat with a secondary loop; the secondary loop is constructed of polyethylene, an extremely durable plastic with high thermal conductivity (Consumer Energy Center, para. 20-24). The secondary loop is installed below the frost line, where it circulates a mixture of water and glycol in order to move heat between the ground and the heat pump.

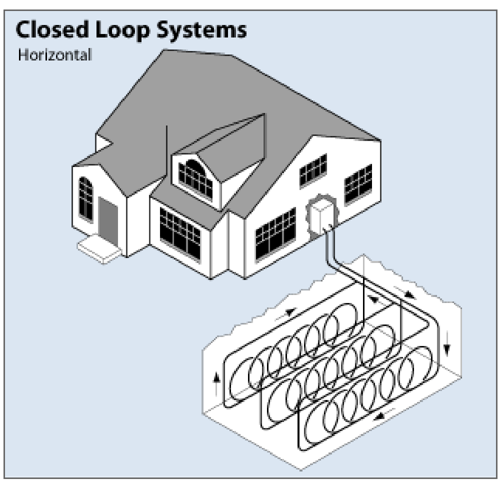

Figure 3 - Horizontal closed loop system (DOE: Types of Systems)

Horizontal closed loop systems are generally the most cost-effective systems for residential use (Proefrock, 2008); however, they require a significant amount of open space for installation. Typical loop length is between 400' and 600' per ton of heating and cooling (Consumer Energy Center, para. 26). Trenching for loop installation is dug equal to or greater than the depth of the frost line.

Vertical closed loop systems are typically installed in areas where horizontal systems are

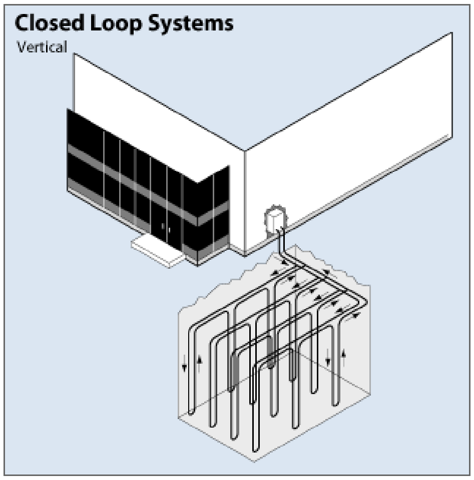

Figure 4 - Vertical Closed Loop System (DOE: Types of Systems)

impractical (DOE: Types of Systems, para. 3); vertical systems are used when space is limited, surface rocks make digging difficult, or landscape disturbance is unfavorable (Consumer Energy Center, para. 27). Vertical holes from 150'-450' are bored into the ground, and a pipe with a U-bend is inserted before sealing/backfilling the hole. Because of the cost of drilling, vertical looped systems are more expensive than their horizontal counterparts (Consumer Energy Center, para. 27).

Pond loop systems are notable in that they possess the most efficient mechanisms of heat transfer and the least expensive cost of installation; however, they work only in the presence of a sufficiently large body of water that meets quality considerations (DOE: Types of Systems, para. 4). Closed loop tubing is placed at a depth no less than 8' deep to avoid freezing.

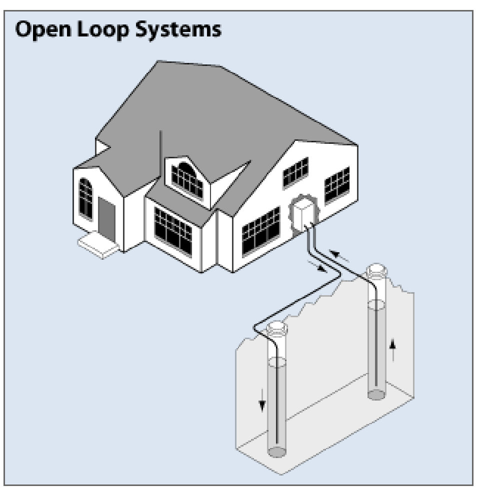

Figure 5 - Open loop system (DOE: Types of Systems)

In an *Open loop system,* water from a pond or aquifer is piped directly into a heat pump. After heat is exchanged, the water is pumped back to a discharge well located a suitable distance from the source. This ensures that a thermal recharge of the water body will occur. The feasibility for installation of an open loop system is dependent on the availability of clean water and local regulations regarding water use and discharge (DOE:

Types of Systems, para. 6). Additionally, the chemical composition of the water must be considered, as it is in direct contact with the heat exchanger, which could suffer corrosion as a result (Ground Loop, para. 5).

III. Problem Solving Approach

The Federal Aviation Administration (FAA) safety requirements state “snow, ice, and slush should be removed as expeditiously as possible” to keep the pavement surface in a “no worse than wet” condition (Federal Aviation Administration, 2008). Airports are to implement a snow and ice control plan (SICP) to identify and prioritize those aircraft pavement areas to be cleared of snow and/or ice within certain times (Federal Aviation Administration, 2008). In an effort to enhance the process of snow and ice removal, our team evaluated if a radiant melt system could meet FAA snow removal requirements.

First, our team met with experts at the Greater Binghamton Airport in Johnson City, New York to determine the feasibility of a radiant melt system powered by geothermal heat pumps. The choice of heating a one-acre area of apron pavement was made after careful research, consideration, and consultation with the experts from McFarland Johnson, Inc. including Chad Nixon, Aviation Director; and Don Harris, Professional Engineer. Also consulted was Carl Beardsley, Commissioner of Aviation for the Greater Binghamton Airport. A system based around one acre can be

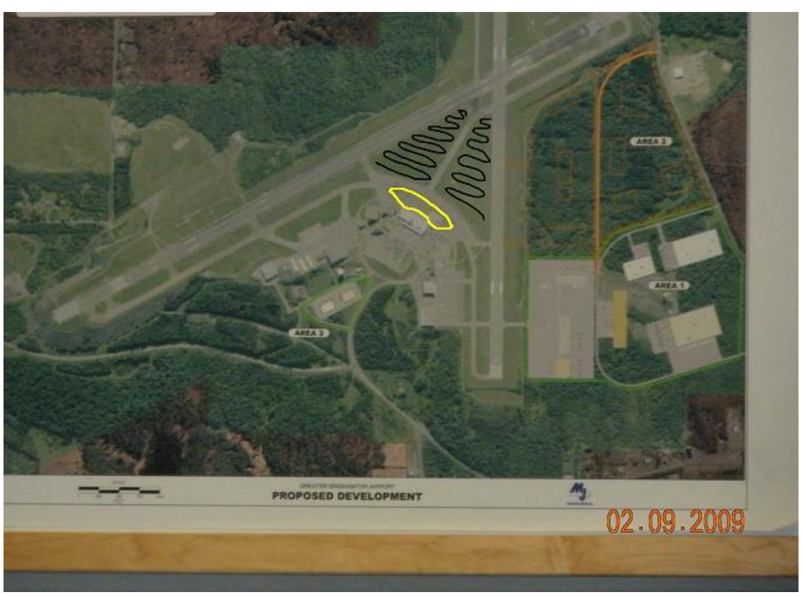

Figure 6 - Pavement to be heated and location of geothermal trenching at BGM

expanded to the needs of almost any airport worldwide, on an acre-by-acre basis. This decision was made after visiting the airport to see what areas represented the best possibilities to be heated. After researching the costs and risks of heating runways, the team determined that heating runways would be prohibitively expensive and would risk closing an entire airport in the event of a catastrophic system failure. It was determined that it would be more cost effective and of minimal risk to implement the system in a less critical, but high traffic area, specifically the apron area immediately in front of the terminal that surrounds the jetways, where most of the snow removal is done by hand with shovels. The highlighted oval area in Fig. 6 shows the area of the apron to be considered for radiant heating at BGM.

The next challenge was to determine the source of heat for the radiant system. Heat can be made available using a conventional boiler system with varying fuels such as electricity, coal, natural gas, propane, and solar power. The possibility of using geothermal heat pumps (GHPs) was also considered. GHPs are appropriate for use in warm or cold climates, and are more efficient than traditional heat pumps that exchange heat between a building and the outside air (United States Environmental Protection Agency, 2000). The benefits of GHPs include greatly reduced energy costs, reduced emissions of greenhouse gases and other pollutants, years of energy savings, quiet operation, low maintenance costs, and although the installation costs are high, they are paid for in just a few years (United States Environmental Protection Agency, 2000). For these reasons, geothermal heat pumps were selected over conventional methods of heating; GHPs were selected over photovoltaics because they are cheaper to implement on the scale necessary to satisfy or proposed systems energy requirement. Because BGM has wide tracts of open land, a horizontally trenched closed loop system was selected.

Given that our team is comprised of computer science majors, we discovered that we would need to expand our knowledge into the fields of engineering and physics to verify the validity of our proposed system. Our team worked closely with engineers at McFarland Johnson, who worked with us to evaluate field data from previously installed radiant systems. After analyzing said data, we approached engineers at KDF, who helped us to model our system and verify the field data. We expanded our modeling capabilities by seeking out Dr. Bruce Murray, a professor in the Mechanical Engineering department at Binghamton University.

As Computer Science students, most of the design process for the competition took us out of our comfort zone; however, we excelled at using computing tools to organize our team of twenty-four students. We created a website to post information regarding the project, connecting everyone on the team together and compiling the pieces of the project in one readily accessible place. Reference citations to written sections were recorded in a database, making sources available to everyone.

The team concluded the design process with a safety and risk assessment of the proposed system to ensure compliance with FAA safety regulations, and a life cycle cost analysis (LCCA) to evaluate the cost benefit of the radiant heating system in terms of the total cost of ownership over the life of the system.

IV. Safety and Risk Management

The main goal of the radiant heating system is to prevent ice and snow from accumulating on the apron; however, when the snow and ice are melted, the resulting water could remain on the apron unless a sufficient drainage system is present. If there is no proper drainage system installed, the ground around the apron could become saturated, which could impede the operation of the radiant heating system, create unstable pavement support conditions, and/or puddle water on the apron.

Wet surfaces can slow down the melting of the ice and snow, because “water is a poor conductor of heat” (Avison, 1989). Heat conduction occurs most rapidly through solids, slower through liquids and even slower through gases. The heat radiating from the concrete will travel slowly through the water before reaching the snow. This increases the time needed to clear the aprons. With a proper drainage system in place, the water can be displaced and the radiant heating system can function properly; typically, this is not a risk as pavements are pitched so water does not accumulate on their surface.

The climate conditions at BGM are typical of many northern areas of the United States and can be used as a model of similar climatic patterns elsewhere. According to the National Weather Service, winter weather conditions in Binghamton, New York occur usually between October 15 and April 15, and temperatures can be as low as -15 F. On average, Binghamton receives 67.4 inches of snow a year (see figure 7) with a record of 134 inches in 1995 (GoldenSnowball). To prevent ice and snow buildup, as well as to avoid a catastrophic failure of the radiant heating system, it is important to insure that the system is protected and operates without interruption. Underground tubing is typically filled with antifreeze to withstand extreme temperatures, otherwise there is a risk of the pipes freezing and shutting down the system. A failure in the radiant heating system could shut down the areas around affected heating surfaces at the airport. Additionally, the failure could be severe enough that a repair may disrupt air traffic for indefinite time periods. Closing of runways, taxiways, and/or aprons including a complete airport shutdown are an inherent risk. This risk is minimized by restricting radiant heating to aprons, where air and passenger traffic can be redirected without serious consequences to the operation of the airport. It should be noted that radiant melt systems are not generally prone to failure and have mechanisms already in place to minimize/eliminate the risk of freezing circulatory fluids.

Another risk is that the potential heat that can be extracted from the earth using geothermal technology can decrease over time from overconsumption. There is also the possibility of frost buildup around the pipes, which would slow the warming of the ground where heat is being extracted. One of the possible solutions to this problem would be to use the geothermal system to cool airport facilities during the warmer months, which will help to replace heat used from the ground. This can increase the life span of the geothermal system and maintain normal temperatures of the earth around the pipes significantly. Typically, in a properly researched and installed GHP system, this will never occur.

Given that each individual airport deals with slightly different climates, it is difficult to predict the success of geothermal and radiant technology at each airport; however, we conclude that our proposed system is within FAA guidelines, and if properly installed poses no risk to safe airport operation. As more data becomes available, the benefits of installing such a system will become clearer.

V. Technical Aspects Addressed

In this section, we have evaluated the implementation of a radiant melt system with a geothermal heat pump source, capable of meeting the FAA snow and ice prevention/removal requirements. The radiant melt system heats approximately one acre of pavement, because this is an adaptable metric that be expanded to the needs of a given airports.

V.1 Evaluation of Airport Conditions at BGM

The Greater Binghamton Airport (BGM) has served as a paradigm for other airports with similar snow and ice removal protocols throughout the development of our project. We have demonstrated that the conclusions drawn from our work at BGM can be adapted for use in airports with similar climate conditions.

V.1.1 Evaluation of airport finances

BGM budgets approximately $200,000 for snow removal annually; Beardsley states, "this figure includes the costs associated with sand, sodium acetate, employee snow removal related overtime and other expenses. Additionally, the airport spends $200,000 annually for electric use in the passenger terminal building and to light the main apron. Another $150,000 is spent heating the passenger terminal building annually." The airport utilizes ten snow removal vehicles, the average cost of each being approximately $450,000. Due to normal wear and tear from the operational tempo of snow removal in the Northeast, every 8-10 years each piece of equipment must be replaced (assuming a vehicle lasts 9 years, this averages out to an annual cost of approximately $500,000).

V.1.2 Evaluation of Airport Space and Climate

As discussed in the literature review and problem solving approach, airports with acres of unused open space, such as BGM (see figure 6), are prime candidates for installation of a horizontally trenched geothermal system (figures 2 and 3). Installation and maintenance of horizontal loops are less expensive than their vertical counterparts (Consumer Energy Center, para. 25).

The costs of installation and runtime of the proposed melt system are dependent on the average winter temperature and snowfall of a given airport. Monthly snowfall for BGM can be seen in Figure 7. The average wintertime temperature (see time in Figure 6) is approximately 33*F, dropping to about 22*F in January.

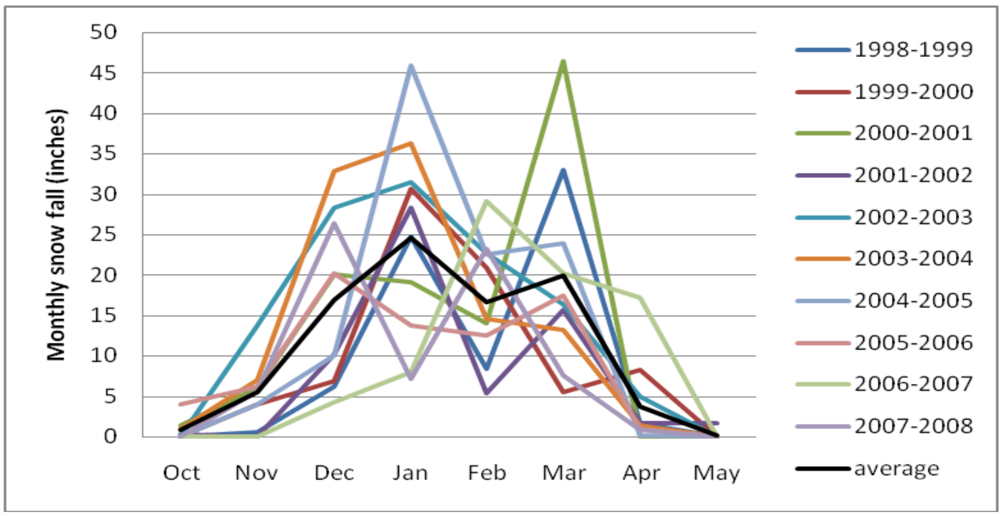

Figure 7 - Snowfall in inches per month 1998-2007; June – September is excluded because no snowfall occurred. Data is from a weather station located at BGM.

V.2 Application of radiant heating

In order to design a snowmelt system capable of meeting FAA requirements, an interdisciplinary approach was utilized. Heat transfer equations were used to model our theoretical system, and engineering field data from a previous successful installation of a radiant system was provided by McFarland Johnson, which we interpolated to design our proposed system.

V.2.1 Method via Physics modeling

The engineering data used in section 2.2 was performed under a set of specific constraints; using the physical properties of heat transfer, we confirm the validity of our data and demonstrate the impact of climate variation on the installation and melting capabilities of a radiant heating system.

The formulas in this section are basic heat transfer equations, which can be found in textbooks like Fundamentals of Heat and Mass Transfer. All equations have been discussed with Dr. Ammar Derraa, director of Technology at KDF, and Bruce Murray, a Professor of mechanical engineering at Binghamton University.

V.2.1a: Variables and Units

Variable	Value/Unit (SI)	Meaning
Heat (in)	*W*	The heat per unit time required to maintain T_s at a constant temperature.
Heat (out)	*W*	The heat per unit time lost from the slab to air.
Accumulated heat	*W*	Heat accumulated inside the slab
Q	$\frac{W}{m^3}$	Power per unit volume
Q_t	*W*	Total power input
A	2500 ft^2, 43560 ft^2 (232.26 m^2, 4046.86 m^2)	Area of the slab
h	3 – 200 $\frac{W}{m^2 * K}$	Convection heat transfer coefficient
T_s	42*F (279 K)	Temperature of the top of the slab
T_a	-10 – 32 *F (250K – 273K)	Temperature of air
T_b	52*F (284K)	Temperature of the bottom of the slab
k_1	$\frac{W}{m * K}$	Thermal conductivity (TC) of the slab (1.7 for concrete and .75 for asphalt)
k_2	$\frac{W}{m * K}$	Approximate TC of water/pipe (400 for copper or 15-200 for a modeled pipe/liquid hybrid)
D_1	3”-4” (.076m - .102m)	Thickness of slab above piping
D_2	10”-15” (.254m - .381m)	Thickness of slab
W	--	Watts
K	--	Kelvin

Table 1 - Variables in SI units

V.2.1b: Basic Model

The heating source should provide enough heat (in) for both the lost heat (out) to air and the accumulated heat in the slab (if any accumulation) (Ammar Derraa, personal communications, 3/27/09). Thus, *Heat (in)* is the heat per unit time required to maintain our surface temperature T_s at a desired constant temperature capable of melting snow and ice. We assume that heat is lost only in and through the slab (no other losses to the surrounding area). Additionally, a steady state for the heat flow is assumed (no initial heat-up time). In reality, there is a transition period from the time the heater is turned-on until the desired T_s is reached. The basic formula is as follows:

$$Heat\ (in) = Heat\ (out) + Accumulated\ heat$$

Where:

$$Heat(out) = h * A * (T_S - T_a)$$

$$Accumulated\ heat = \frac{(k * A * \ (T_b - T_s)\ )}{D}$$

The complexity of the formula is reduced by assuming the slab is uniformly heated (the homogenous case), the equation becomes:

$$Heat\ (in) = Heat\ (out)$$

If we are determined to model a simple heat gradient (the non-homogenous case), we account for heat (accumulated):

$$Heat\ (in) = h * A * (T_S - T_a) + \frac{(k * A * \ (T_b - T_s)\ )}{D}$$

This formula is the basis for estimating the energy requirement. The calculated number is lower than actual power because of the assumptions made. A small percentage (approximately 1-5%) could be added to the final power to account for the extra losses, which are not included in the formula (Amaar Derraa, personal communication, 3/27/09).

The basic model assumes that heating is occurring at the bottom of the slab and does not account for the properties or the location of the radiant tubing; however, the formula provides a simple method of calculating rough energy requirements and varying system conditions.
We solve for Heat (in) given variable values from section 2.2. Initially, the value of h is assumed to be relatively low (3) to minimize the convective losses due to wind. Given the homogenous case for an area of $2500 ft^2$, if we maintain the surface temperature of a 14" thick slab of concrete at 42* F (279K) and an air temperature of 2*F (256K), we determine Heat (in) to be: 16,025.94 W (54,729 BTU/hr). This estimate falls extremely short of the calculated requirement in section 2.2; however, if the value of h is increased to 14, the approximation becomes much more reasonable (74,788 W or 255,400 BTU/hr). To increase precision, the non-homogenous case was conducted assuming T_b is 52*F (284K) (Geoguys, para. 1) and h is 14: 80,272W (274128 BTU/hr).

The equations used thus far rely on broad assumptions; thus, our model was expanded, based on calculations from Professor Murray, to achieve greater accuracy.

V.2.1c: Expanded Model

The basic model is expanded to account for an approximate conductivity of the radiant tubing running through the slab:

$$Q_t = Q * A(D_2 - D_1)$$

$$T_s = T_a + \frac{k_1}{h}\left(\frac{T_b - T_a + \frac{Q}{2k_2}(D_2 - D_1)^2}{D_1 + \frac{k_1}{h} + \frac{k_1}{k_2}(D_2 - D_1)}\right)$$

This provides a method of solving for T_s; however, to solve for Q (and it follows that we can solve for Q_t) we have computed the following:

$$Q = \frac{2k_2 * \left(\left(\frac{h}{k_1}(T_s - T_a) \right) * \left(D_1 + \frac{k_1}{h} + \frac{k_1}{k_2}(D_2 - D_1) \right) + T_a - T_b \right)}{(D_2 - D_1)^2}$$

The thermal conductivity of the airport pavement in question (k_1) is known; it is assumed to be 1.7 for concrete and .75 for asphalt (Engineering ToolBox, 2005); however, the conductivity of k_2 varies according to the assumptions that are made regarding the simplification of the tubing model. In order to determine a value for k_2, one must determine a relation of k values between the piping, water, and glycol (Bruce Murray, personal communications, 3/25/09). In Figure 8, a plot is provided, indicating the effects of varying k_2 and h given the same assumptions as the basic model:

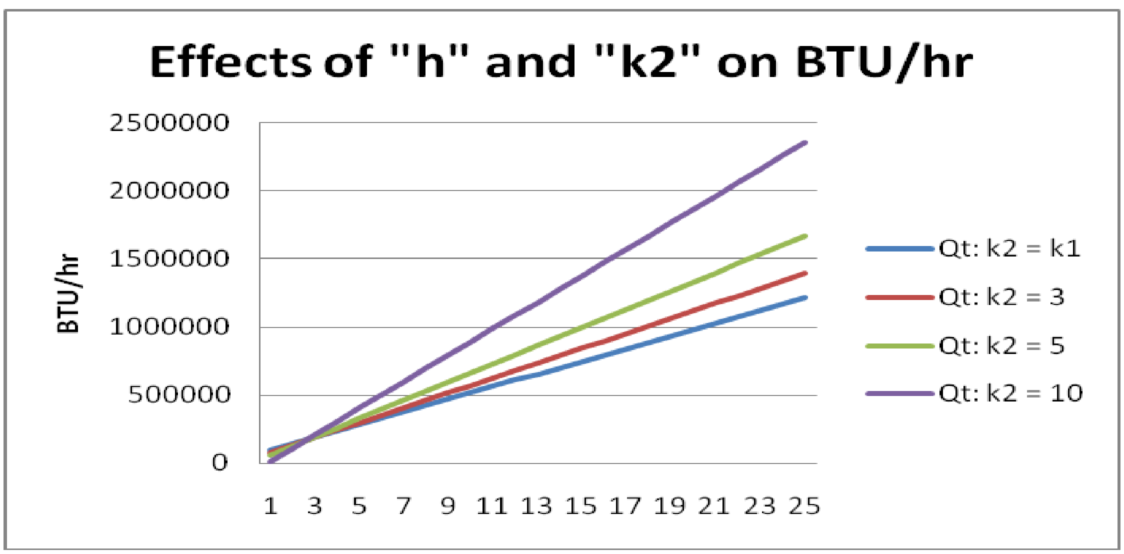

Figure 8 - Effects of scaling "h" and "k2" on BTU/hr, the x-axis representing h.

V.2.1d: Summary

In both the expanded and basic formula, our assumptions tend to neglect actual convective losses in an installed system. By increasing the value of the convection heat transfer coefficient (h), we combat the various losses in our system that we cannot accurately model. The models used in the previous section reveal that radiant systems are prone to heat losses due to wind (or other convective forcings), and that the same system in two different airports might requirement different amounts of input energy.

V.2.2: Method via Engineering Field Data

Working with engineers at McFarland Johnson, our team interpreted field data from a successful commercial installation of a RadiantWorks radiant heating installation and designed a radiant snowmelt system for use in airport pavements.

V.2.2a: Approximation of radiant panel power consumption

From a radiant system design report, supplied by McFarland Johnson, we derive the following:

- The radiant heating panel extends over an area of 2500 ft^2. This panel can be extended as warranted and is used as a standard measurement unit.
- Assumes a maximum 16 inches of snow fall a day, class II snow melt
- Average temperature of 2*F, wind speed of 10 miles per hour (MPH)
- Assumes heat pumps are run 125* F in, 100*F out, delta T 25*F
- Draws 267856 British Thermal Units per hour (BTU/h)

The system causes roughly .75" of melting an hour to occur. This falls under the category of a class II snow melt (area ratio .5), meaning there can be some accumulation in the form of slush, but not ice (Healthy Heating, para. 2). Achieving an AR greater than .5 requires more energy, thus, more heat pumps; an AR of .5 is acceptable for "less" critical areas where ice melt is to occur, specifically the terminal areas (Don Harris, personal communication, 3/18/09). Depressed melting requires roughly 80-125 BTU/ft^2, while keeping a surface completely slush/snow free or even completely dry can require from 120-450 BTUs (Systecore, para. 3-5); this particular radiant system requires 107.14 BTU/ft^2.

Certain GHPs are capable of producing the necessary 120*F+ temperatures necessary to operate a radiant system, but to ease calculations we calculate a system with a lower temperature in; we interpolate the data to account for heat pumps that operate on 100*F in, 75*F out (Don Harris, personal communications, 2/27/09). The design document assumes there is no insulation under the slab being heated; however, Kurt Flechsig, CEO of KDF, stated that he believes energy requirements and system efficiency could be improved through the combined use of insulating materials, heat storage tubs, and solar panels.

Heating data based around an acre is an adaptable metric suited to the installation of radiant systems in airport pavement (Chad Nixon, personal communication, 2/20/09). Conversion of 2500ft^2 to an acre (43560ft^2) can be achieved by multiplication of an approximate factor of 17.2. This multiplier is then applied to the field data panel load (268,000 BTU/h) to determine the approximate total energy cost per acre, 4,609,000 BTU/H.

V.2.2b: Heat pump selection

Considerations for heat pump selection should be based on tonnage, cost, and versatility. Given the energy requirements calculated in 2.2a, we choose a model with excellent tonnage (30) the Water Furnace model NXW360 (Water Furnace, 2008, pg. 23). Depending on an individual's energy requirements, the required output of a heat pump will vary. This particular model is reversible, meaning it can fill role of a chiller, readily able to turn our geothermal heat source into a heat sink; we will discuss the impacts of this later.

		LWPD			SOURCE 68.0 GPM						SWPD		SOURCE 90.0 GPM						SWPD	
ELT	EST	LGPM	PSI	FT HD	LLT	HC	KW	HE	COP	LST	PSI	FT HD	LLT	HC	KW	HE	COP	LST	PSI	FT HD
100	30	68.0	2.7	6.2	108.6	283.3	29.22	183.6	2.8	24.4	2.5	5.7	108.6	284.6	28.66	186.8	2.9	25.7	4.1	9.4
		90.0	4.2	9.8	106.6	289.3	29.34	189.2	2.9	24.3	2.5	5.7	106.7	290.5	28.75	192.4	3.0	25.6	4.1	9.4
	40	68.0	2.7	6.2	109.8	322.9	29.91	220.8	3.2	33.3	2.4	5.6	109.8	324.8	29.28	224.8	3.2	34.8	4.0	9.3
		90.0	4.2	9.8	107.6	331.7	30.01	229.3	3.2	33.0	2.4	5.6	107.6	332.9	29.38	232.6	3.3	34.7	4.0	9.3
	50	68.0	2.7	6.2	111.0	362.4	30.59	258.0	3.5	42.2	2.4	5.5	111.1	364.9	29.91	262.8	3.6	44.0	4.0	9.2
		90.0	4.2	9.8	108.6	374.1	30.69	269.3	3.6	41.8	2.4	5.5	108.6	375.3	30.01	272.9	3.7	43.7	4.0	9.2
	60	68.0	2.7	6.2	112.2	403.4	31.28	296.6	3.8	51.0	2.4	5.5	112.3	406.5	30.48	302.4	3.9	53.1	3.9	9.1
		90.0	4.2	9.8	109.5	415.5	31.38	308.4	3.9	50.7	2.4	5.5	109.6	418.0	30.60	313.5	4.0	52.8	3.9	9.1
	70	68.0	2.7	6.2	113.5	444.3	31.96	335.2	4.1	59.8	2.4	5.4	113.6	448.0	31.06	342.0	4.2	62.2	3.9	9.0
		90.0	4.2	9.8	110.5	456.8	32.07	347.4	4.2	59.5	2.4	5.4	110.6	460.6	31.19	354.1	4.3	61.9	3.9	9.0

Table 2 - Capacity Data for NXW360, full load, ELT = 100 (Water Furnace, 2008, pg. 23)

From the manufactures information, we determine the heating capacity (HC) of our model to be 283,300 BTU/h. In order to achieve said HC, the manufacture's data stipulates that the geothermal portion of the system run at a ΔT (change in temperature) of 5* F; 25*F out, 30* F return. We divide our energy cost per acre (4,609,000 BTUH) by the HC of our selected model (283,300 BTU/h) to determine our total number of heat pumps, 16.3. We take the ceiling of our calculation to obtain 17 heat pumps; we add in one additional heat pump so that we can take one heat pump off line for maintenance at any given time, so we require 18 heat pumps (Don Harris, personal communications, 3/3/09). The number of required pumps will increase if an airport chooses to replace existing means of heating with geothermal heat pumps.

V.2.2c: Heat pump housing

The rough size of a heat pump is assumed to be 5' long and wide (variable given different pump); this estimate allots additional size per heat pump to allow for ease of maintenance. The heat pumps are divided into four rows (18/4 * 5 = 22.5', rounded to 25' length and width), two rows hold four pumps and the others five. We allow for 6' of walk-around room on each end to bring the approximate length to 37'. We incorporate an electric room for wiring (15' length) and a pump room (24' length) to bring the building dimensions to 25' * 76', an approximate total of

$1900ft^2$ (Harris, personal communications, 3/10/09).

V.2.2d: Secondary pumps

After calculating power requirements and heat pumps, we determine how many secondary pumps we need to circulate water through our geothermal and radiant systems. The radiant portion requires 23.55 GPM per $2500ft^2$ panel, we scale this by 17.2 (our acreage factor) and determine the net GPM required to be 405. Harris suggests two 200 GPM pumps are adequate.

Our geothermal loop field requires roughly five times as much GPM as the radiant field minus roughly 33% due to the pump motor waste heat (Harris, personal communications, 3/3/09). We calculate the GPM required:

$$\left[Radiant\ GPM * \frac{\Delta\text{T radiant}}{\Delta\text{T geothermal}} * \frac{2}{3}\right] = Geothermal\ GPM = 1357\ GPM$$

V.2.2e: Geothermal Energy Collection

The energy requirements calculated in 2.2a are used to determine the size of the geothermal heat collection system. The method of heat collection varies based on airport geography; the wide-open tracts of land at the Greater Binghamton airport favor the installation of horizontally trenched piping (Carl Beardsley, personal communications, 2/25/09). Given the metric of 300 feet of loop per heat pump ton (DeVit, sec. 4-28), the number of heat pumps (i.e. 17 active at any given time) is multiplied by the tonnage of the heat pump being used (30 for the NXW360). The supply and return piping are laid in the same trench, thus the number is then divided by two:

$$Total\ piping\ (ft) = (Total\ active\ heat\ pumps * heat\ pump\ tonnage * 300')/2$$

From the formula above, we determine that 76,500 feet of trenching is required for our geothermal system. The trenching area can be seen in Figure 6, and lies northeast of the apron area to be heated.

V.3 Associated costs

Item	Sub-item	Cost	Rate
Geothermal loop field			
	trenching	$94,860	Once
	pipe	$459,000	Once
Radiant system			
	Radiant panels	$172,000	Once
	Installation	$86,000	Once
Pumps			
	Heat pumps	$342,000	Once
	Geothermal loop pumps	$18,000	Once
	Radiant pumps	$5600	Once
	Installation	$182,800	Once
Electricity			
	Rate	$47.22	Hourly
	Demand	$3976	Monthly
	Service cost	$30,000	Once
	Distribution cost	$23,000	Once
Other costs			
	Sensor array	variable	Once
	Pump housing	$142,500	once
Total:			
	1st year	$1,591,502	Once
	2nd year	$31741	Annual

Table 3 - Associated Costs – summary of the associated costs of heating one acre of airport pavement via geothermal heat source.

V.3.1: Explanation of costs

The table of associated costs provides a rough metric for determining the cost of installation for our proposed system per-acre. The explanation of costs is carried out in a manner to maximize ease of implementation in other airports.

V.3.1a: Geothermal loop field

We assume that for a ton, we require 300' of horizontal pipe and a 3.5' to 4' deep 2'wide trench (DeVit, sec. 4-28). Multiplying 300' by the number of heat pumps (17 active at any given time) by the tonnage of each heat pump (30), we determine that 153,000 feet of pipe is required; however, as supply and return tubing are laid in the same trench, we divide that number by two: 76500'. According to Nixon, a recent McFarland Johnson project determined trench cost to be approximately $1.24/foot and pipe cost to be $3/foot. Thus, trench cost is $1.24/ft * 76,500' = $94,860, and pipe cost is $3/ft * 153,000' =$ 459,860.

$$Total\ (horizontal)\ pipe = 300' * active\ heat\ pumps * tonnage\ per\ pump$$

$$Trenching = cost\ per\ foot_t * \left\lceil \frac{total\ pipe}{2} \right\rceil, \qquad Piping = cost\ per\ foot_p * total\ pipe$$

V.3.1b: Radiant System

The distributer design report mentioned in 2.2a specified the cost of their melt system to be $10,000 per panel (heating an area of roughly 2500ft^2). The 17.2 multiplier was applied to this number so that the cost reflects that heating is occurring over an acre; the total radiant panel cost is $172,000. According to Harris, a safe estimate of installation cost is 50% of equipment cost. The price of installation is calculated to be $86,000.

V.3.1c: Pumps

The heat pump detailed in table-2 costs $19,000 (Nixon, personal communications, 3/3/09), multiplied by the total number of heat pumps (18) results in a cost of $342,000. In section 2.2d we determine the required GPM for the geothermal and radiant sections; two 200 GPM pumps and 3 500 GPM pumps satisfy the requirements of the radiant and geothermal sections respectively. Harris estimated the cost of an adequate 200 GPM pump at $2800 ($5600 total) and a 500 GPM pump at $6000 ($18000 total). As in 3.1b, installation costs are 50% of the equipment cost, thus $182,800.

V.3.1d: Electricity

To calculate the operating cost per hour, we first determine the required operating energy of our collection of heat pumps. The number of active heat pumps (17) is multiplied by the energy draw per heat pump, 29.22 Kilowatt/hour (KW/hr) (Water Furnace, 2008), resulting in a 497 KW/hr requirement. The total KW/hr requirement is then multiplied by the cost of a single KW/hr (i.e. NYSIG, Municipal Power) and we obtain the cost/hr. At the BGM, the average cost per KW/hr is .095 and the demand rate for the airfield surfaces is $8.00 per KW/hr (Carl Beardsley, personal communications, 3/18/09). The cost/hr is calculated to be $47.22/hr; we calculate the charge for demand by multiplying our previous total KW/hr (497) by the demand rate ($8.00), resulting in a charge of $3976.

The electric service cost is assumed a 600-amp service from 50 feet away, totaling roughly $30,000; if the source of electricity is further away price will rise (Harris, personal communications, 3/10/09). Additionally, an estimate of the electric distribution cost can be obtained by multiplying the number of installed heat pumps and secondary pumps (18 + 3 + 2 = 23) by a rough rate of $1000; the cost of electric distribution is approximated to be $23,000.

V.3.1e: Other costs

The efficiency of the proposed melt system could be improved by monitoring climate conditions and forecasting weather events (Kurt Flechsig, personal communications, 3/15/09).

Climate senor controls are typically included in commercially available radiant heating packages, and will not be directly included in our total cost. Additionally, the initial cost of the system would rise if photovoltaics were used to provide the necessary circulatory energy to the GHPs; however, in the end this would be environmentally beneficial and may save money.

In section 2.2c, the approximate size of the heat pump housing was determined to be 1900ft^2. From Nixon's experiences with construction estimates, we assumed the rough cost of the housing to be $75 per ft^2. Thus, the approximate cost is $142,500 for the materials and construction of the building.

V.3.1f: Total

The total cost of the system is broken down into a one-time first year charge, and a recurring charge for every year following. The total cost is determined from table-2: $1,558,760; however, it is also necessary to concatenate this course with the annual cost of electricity.

The total cost of electricity per year is extremely sensitive to climate conditions, directly correlated with annual and monthly snowfall. From figure-1, the average annual snowfall of the BGM (86", see figure 6) is multiplied by the rate of snowmelt (.75"/hr) resulting in an approximate 115hrs of run time for the radiant system to melt the snow. A majority of radiant systems are run in idle mode for the duration of winter (turning up to full capacity when a storm is predicted), but this is difficult to compute; a reasonable assumption to ease calculations is that we can anticipate snowfall and warm up the system from rest two hours prior to accumulation. Given the weather patterns around BGM, we assume an average of six storms occur December-February, and two storms occur March, November, October, and April (this is approximately 26 storm events, totaling 52 hours of preheat time). The annual electric usage fee is determined to be the total run time (115 hrs + 52 hrs =167 hrs) multiplied by the cost/hr ($47.22), thus $7885.74. Annual demand is the product of the number of months with snow accumulation (6) and the demand charge per month ($3976), a total of $23856. Snowfall figures will vary from airport to airport.

Thus, the approximate total cost for installation and utilities is $1,590,502 and the recurring charge starting the next year is $31741 plus maintenance costs.

V.3.2 Life Cycle Cost Analysis

The life-cycle cost analysis has been performed in the Projected Impacts section of this proposal.

VI. Interactions with Airport Operators

On Tuesday, February 10, 2009 our team met at the Greater Binghamton Airport with Carl Beardsley, Commissioner of Aviation; and Chad Nixon, Aviation Director at McFarland Johnson Inc,. The team participated in a planning session to brainstorm potential solutions to the design challenge. Beardsley and Nixon took our group on a tour of the airport and discussed with us daily airport operation, snow removal and costs, and the annual budget. As shown in Figures 9, 10, and 11, the team carefully studied the apron area, snow removal vehicles, and sanding techniques.

Figure 9 - Inspecting the Apron at BGM

Mr. Beardsley informed us that one of the busiest times of year is snow removal season, meaning snow removal is mission critical to airport operation. Beardsley explained BGM's annual budget and indicated that snow removal costs are a time and money sink; he believed that airports would be open to new methods of removal that could reduce either cost. Winter costs at BGM include the purchase of sand, sodium acetate, employee snow removal related overtime and electricity/heating use in the passenger terminal building.

Figure 10 - Inspecting snow removal equipment at BGM

In addition to the previously mentioned costs, the airport budgets approximately $500,000 annually to the maintenance and replacement of a fleet of snow removal vehicles, a sample which can be seen in Fig. 10. It was noted during the meeting that equipment costs are eligible for Federal Aviation Administration grants at all air carrier airports such as Binghamton.

Beardsley noted growing snow removal and maintenance bills and stated that he hoped for a money saving, low maintenance alternative/aid to their current method of snow removal, which is the industry norm. Beardsley believes that a geothermal system could reduce the costs of heating passenger areas, and could be used to heat the aprons thus preventing icing from ever occurring.

Nixon suggested that the Binghamton airport and other airports could avoid much of the costs of retrofitting a radiant heating system by installing it during a (routine) pavement reconstruction. Beardsley informed us that the runway/apron pavement is annually evaluated for crack sealing and repairs, and in the next two to three years a full depth reconstruction will be performed, the last such time this occurred was 1994. This type of

Figure 11 – Inspecting the Sand storage facility at BGM

reconstruction often occurs between 10 and 20 years of age.

Not only would a radiant heating alternative reduce the cost of snow and ice prevention, Nixon and Beardsley believe that it could have the additional benefit of decreasing the likelihood that sand could damage airplane engines; it would benefit the airport and each individual airline if the amount of sand used could be decreased. Currently, the airport uses over 2500 tons of sand a year according to Nixon. The sand storage facility at BGM is shown in Fig. 11 above.

A discussion held February 20, 2009 with Nixon regarding energy sources for geothermal systems centered on the alternatives of trench-based versus deep-well systems. Nixon stated that a horizontal trench-based closed-loop geothermal system would likely be the most cost efficient option due to the availability of large open areas of most airports, including BGM, because of the trenching needed in such a system. Additionally, Nixon shared a geotechnical report of the terminal apron, which concluded the depth of the pavement section as shown in Table 4.

Section	Depth
Asphalt	10” to 12”
Concrete	13” concrete, 1.5” asphalt underneath

Table 4 - Apron Depth Breakdown

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Further consultation with McFarland Johnson led to a February 27, 2009 discussion with one of their engineers, Don Harris. During this discussion, rough numbers were calculated to determine the feasibility from a cost standpoint of the apron heating system (Harris, personal communications, February 27, 2009). Harris supplied basic energy requirement technical data and requested that we evaluate it and develop a costing tool, so that we might better understand the price of our system. Preliminary results suggested that radiant heating of runways would be prohibitively inefficient and expensive. Additionally, Harris felt that even an apron-based geothermal system might be expensive due to the potential energy demand and relatively costly construction. We decided to continue the research and meet again in a week.

As scheduled, on March 3, 2009 several students from our team reported to McFarland Johnson's Binghamton office to exchange technical data and ideas. After a tour of the engineering facility, we were led to a conference room where we met with Nixon and Harris; Harris had technical data in hand and was ready to review with us the conceptual energy requirements and cost of the proposed system. During his research, Harris came upon an internal company design document on similar systems. The report provided a basis from which we could determine the energy requirements of an Apron heating system, thus we were able to move on to the design and implementation of the radiant heating system inclusive of geothermal heat pumps and the closed loop system.

At this meeting, Nixon discussed the importance of a costing tool that could be adapted to the needs of many other airports. At this point, our team had created a rough design of such a tool and it was only a matter of applying the appropriate numbers to obtain the needed results. During the discussion the preliminary calculations were reviewed and refined. Ultimately it was determined that it would require approximately eighteen 30-ton heat pumps. Based upon the refined cost calculations the team was optimistic about the practicality of the system.

An analysis of possible improvements that could be made to the proposed system led to an exchange March 30, 2009 with Kurt Flechsig, CEO of KDF. Flechsig suggested several methods of reducing the energy cost associated with starting a radiant melt system from rest, including: reducing the demand cost of electricity by installing solar panels, incorporating hot water storage tanks into the loop, and investing in a computer system capable of monitoring climate conditions and varying the heat flowing through the radiant tubing. Additionally, we were introduced to another KDF employee Ammar Derraa, Director of Technology. Ammar guided us through the process of modeling our system so that energy requirements could be calculated given a variety of field conditions.

On March 6, 2009, the entirety of our team, as well as Nixon, Beardsley, and Faculty Supervisor William Ziegler, came together at Newing College of Binghamton University for a presentation of the current incarnation of the project, as shown in Fig. 12. This presentation was attended by various reporters and photographers for local news organizations. Here, Nixon presented the most up to date numbers for the cost of the prospective project, as well as a basic overview of the overall process for the news reporters. The data and specifications needed were at this point finalized in order, in order for our team to go ahead with the initial drafts of our proposal paper. In addition, samples of the manifold and tubing to be used in the project were available to gather a hand's on understanding of the technology.

Figure 12 - Design work taking place at Binghamton University

Working from the radiant system design report provided earlier in the month by Harris, our team had calculated the approximate energy requirements and installation details for our system. On March 17, 2009 several team members met with Harris and reviewed all work that had been done up until that point; figures were rethought, estimations made more precise, and a means of abstracting the design process for other airports was developed. The conclusions drawn from this meeting ultimately served as the basis for the technical aspects of our project.

On Friday March 20, 2009 several members of our team visited the Watson School of Engineering's Mechanical Engineering department to gain a better understanding of the physics behind the radiant heating of a surface. Dr. Bruce Murray, a professor of mechanical engineering, assisted with evaluating the heat transfer formulas provided earlier by Ammar. Murray further developed the formulas to account for varying wind conditions and the position of the radiant tubing inside the slab. He also provided a book entitled *Fundamentals of Heat and Mass Transfer* so we could continue formula refinement and analysis.

VII. Projected Impacts

When proposing a solution to a problem in a high traffic and wide scale area such as heating an airport pavement, it is imperative to review and understand all of the FAA goals outlined in the current FAA Flight Plan (Federal Aviation Administration, 2009). The four goals outlined by the FAA in this Flight Plan are increased safety, greater capacity, international leadership, and organizational excellence.

The FAA states in the Flight Plan that the “first commitment is to safety” (2009 - 2013 FAA Flight Plan). The purpose of the FAA's second goal, *greater capacity*, is to “work with local governments and airspace users to provide … better operational performance in the United States airspace system that reduces congestion and meets projected demand in an environmentally sound manner” (2009 - 2013 FAA Flight Plan). The third goal, *international leadership*, refers to the FAA's commitment to increasing “the safety and capacity of the global civil aerospace system in an environmentally sound manner” (2009 - 2013 FAA Flight Plan). The fourth FAA goal, *organizational excellence*, refers to the FAA mission for a “better-trained and safer workplace” and “enhanced cost measures” (2009 - 2013 FAA Flight Plan).

The proposed geothermal radiant heating system for airport aprons meets the criteria and standards set by the FAA Flight Plan. This system is expected to eliminate ice and snow more efficiently than manual snow removal, sand, and sodium acetate, and would lead to much safer pavement conditions. This would satisfy the first and most important goal, increasing the safety of passengers, crew, and everyone involved. Since the proposed system will be much more efficient than manual snow and ice removal, this is expected to promote traffic flow, which would decrease delays and congestion. In addition, since geothermal energy draws heat from the earth's surface, this new system is considered environmentally friendly (Geothermal Resources Council, 2005). Therefore, this project would also satisfy the second goal of setting a greater capacity. Aside from the aforementioned environmental benefits, implementing an efficient, yet technologically advanced radiant heating system with GHPs on airport pavement will set an example for airports around the world to follow. The proposed geothermal system will decrease the amount of workers needed to manually remove snow and ice, thus creating less opportunities for accidents and injuries to occur during the removal process. Additionally, if the GHP section of the system is expanded, an airport could replace all of their conventional heating and cooling methods with a cheap, environmentally friendly technology; this could offset some of the costs of our proposed system and help to satisfy the FAA's goals of environmental safety and "enhanced cost measures."

This project is based on the actual planning of a geothermal radiant heating system on the apron area of the Greater Binghamton Airport, located in Binghamton, New York; however, our proposed system has been designed to be adaptable to other airports with similar climate conditions. The Binghamton area is prone to frequent snowstorms, icy climates, and long winters.

According to Table 3 above (pg. 24), the total cost of installation and utilities for the first year is $1,591,502. The recurring annual cost beginning in the second year is $31,741. The financial analysis for the cost benefit of the new system would have to be a comparison between the Net Present Value (NPV) of the current system and the NPV of the new system. The calculation for NPV requires time of the cash flows, the discount rate, and the net cash flow at period t. The purpose of NPV is to figure out the cost of future cash flows in terms of money today. For example, the value today of $100 a year from now would be $104 based on an inflation rate of 3.8% (The 2008 U.S. Annual Average. 2008). The equation for NPV is as follows: $NPV = R_t /(1+i)^t$, where t is the time period, R is the net cash flow, and I is the discount rate.

Carl Beardsley in his presentation of the research project to the press stated that 80% of the cost for snow removal lay in removing snow from the apron, and half of that work is focused on the small areas around the jet ways, the area in which we propose to install the radiant heat system. From this statement, and Beardsley's previous estimation of an annual cost of $200,000 for snow removal, we estimate that the cost of the small area that we plan to update is approximately $80,000 a year. We will use the annual rate of inflation to be the discount rate, and we will calculate the costs over the next 20 years. Using the NPV equation, the value of the current system is a cost of $2,463,566.

As stated before, we have concluded that the up-front cost of this project would be $1,592,502, and the annual costs after installation would be $31,741, based on the information provided in the Technical Aspects section of this proposal. Using the same coupon rate and time period, our calculations came to show that the NPV for the new system would be $2,568,953. This is because our project is less affected by the inflation rate, since the majority of the costs occur upfront. These calculations assume a constant annual inflation rate over the next 20 years, an unlikely occurrence but a fair estimation of the actual present values of the costs.

	Geothermal Radiant System	Snow and Ice Removal
First Year	$1,591,502	$80,000
Recurring Annual Cost	$31,741	$80,000
Cost summary:		
Unadjusted total after 20 years:	$2,227,322	$1,600,000
NPV:	$2,568,953	$2,463,566

Table 5 - Comparative Cost Analysis

Cost alone should not be the deciding factor in regards to geothermal powered radiant heating systems. The current system of heavy equipment, labor, sand, and sodium acetate in mass quantities for ice and snow removal is undesirable on many levels. For example, large amounts of sand and sodium acetate may act as foreign object debris (FOD). FOD cause millions of dollars worth of damage to airlines and airports every year (Bachtel). One method of controlling these FOD would be manual sweeping, which may be an inefficient use of resources, relative to the downtime of the area being swept, along with the salaries of the workers who are sweeping. Besides the resources needed to sweep the FOD, the particles used for ice and snow removal, particularly sand, have been known to cause extensive damage to aircraft (Leib, 2008). Besides the physical damage incurred to the aircraft, long term exposure to FODs may negatively impact health.

Looking past cost, our proposed system offers conveniences that the standard methods of snow removal do not. First, it can decrease strenuous work in certain areas, such as manually shoveling snow in areas unreachable by large snowplow vehicles. In addition, since the geothermal radiant heating system would be able to distribute heat throughout the apron area, the new system would be able to clear ice and snow much more efficiently. This might help mitigate lawsuits due to people slipping and falling on ice and snow in the apron area. Another positive attribute of the proposed system is the environmental factor. As mentioned, geothermal energy is highly efficient and renewable, thus fitting the definition of green technology. By coupling the proposed GHP power source with photovoltaics, an airport could eliminate their heating related greenhouse gas emissions. In addition to this, a new, more technologically advanced radiant heating system would increase attraction to the Greater Binghamton Airport, and thus be advantageous for business. By taking into account all of the benefits associated with this proposed solution, it can be seen that an upgrade to a geothermal powered radiant heating system would be beneficial from an environmental and operational standpoint.

VIII. Summary and Conclusions

Our proposed system includes the use of a commercially available radiant snowmelt system supplemented by a horizontally trenched closed loop geothermal heat pump system. We hypothesize that the elevated cost, as compared to standard snow and ice removal techniques, of our proposed system is offset by the convenience, potential heating and cooling of terminal buildings, and environmental benefits that it delivers.

The Greater Binghamton Airport was evaluated to determine whether our proposed radiant system supplied by geothermal heat pumps is competitive or superior to current methods of snow and ice removal. This airport uses both sand and sodium acetate to prevent ice and snow from accumulating on runways and aprons areas; over 2500 tons of sand per year is spread onto the runways and aircraft aprons to increase the traction of airplanes and other vehicles at BGM. During a snowstorm, workers use heavy machinery for the removal of the snow, plowing and brushing the snow away from critical areas such as the runways and aprons; however, the sizes of the vehicles are prohibitive to cleaning certain areas. In order for snow removal to occur on such areas, workers are needed to forgo snow removal vehicles and manually remove the snow through means of shoveling, brushing, spreading sand and snowmelt, etc. Cold climate airports such as BGM are committed to the FAA's goals to seek improved methods for clearing snow and ice from their runways and aprons.

Research conducted by the team indicated that heating an entire runway with a radiant system is unrealistic in terms of cost; in consultation with the experts from McFarland Johnson, it was determined the most cost effective means of implementing our proposed system would be to heat a side apron area with the possibility of extending the GHP system to heat and cool the terminal building. Heating of this area would cut down the time required for snow removal, because this area requires cleaning by staff manually using snow shovels. If an installation of our proposed system in an apron is considered successful and the associated installation and runtime costs fall, full-scale implementation on airport runways should be considered.

The installation of GHPs is dependent on the topography of the airport in question; at BGM, there are wide acres of unused space that are suited to the installation of a horizontal closed loop system. The determination of which system to use, if any, must be made on an airport to airport basis; a radiant snow melt system is possible without the use of GHPs, but our team concludes they are preferable to conventional methods of heat delivery. GHPs are environmentally safe and can be coupled with a photovoltaic array to create a zero emission hybrid method for airport heating and cooling.

The implementation of our proposed system is feasible at BGM, but may not be for all other airports. The initial cost of implementation per acre is approximately $1.6 million as compared to $80,000 for the manual removal of the snow and ice (see Table 3); however, after the system is implemented, the cost of maintenance is approximately $32 thousand annually as compared to $80,000 annually for current snow and ice removal methods (see Table 5). A LCAA of our system revealed that our proposed system would be an expense to an airport implementing our system; however, a cost analysis of current snow removal methods should be performed at any airport interested in possibly adapting our proposed system.

The high initial cost of our system is offset by the fact that the components of our system require little maintenance and will outlast any of the heavy machinery that is currently used at airports. Machinery used for cleaning runways and aprons lasts an average of 8 to 10 years and require regular maintenance. Our system lasts at least twenty years (the tubing lasting over 50 years), and can be installed during a routine runway/apron tear up to further reduce cost. Our proposed system also has hidden value, as it eliminates overtime hours required for manual snow removal and reduces the chance of someone slipping on an icy surface.

An interdisciplinary approach utilizing heat transfer equations and radiant system field data confirms the benefits to using our proposed system. A radiant snowmelt system powered by GHPs is financially competitive with current removal methods, has a long lifespan, and is environmentally friendly. Although the system will incur additional cost (as compared to traditional removal methods), the benefits of this system outweigh the cost that is added. The proposed system accomplishes the FAA goals of improved airfield safety and minimizing an airport's negative environmental impact.

Appendix A:

List of complete contact information

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Appendix B: Description of the University

Binghamton University is a competitive and highly selective public university affiliated with the State University of New York. It serves as an institution of higher learning for over 11,500 undergraduate students, nearly 3,000 graduate students, and over 1,400 international students from around the world. Binghamton University consists of six separate schools and colleges, which are the Harpur College of Arts and Sciences, School of Management, Thomas J. Watson School of Engineering and Applied Science, Decker School of Nursing, School of Education, and the College of Community and Public Affairs. The university has been consistently rated among the best public universities in the country by such publications as Kiplinger's Personal Finance, Forbes, U.S News & World Report, Business Week, and the The Princeton Review. Greene's Guide has named Binghamton University a "public ivy." ("Binghamton at a Glance", 2008)

Binghamton University was originally founded in 1946 in the small town of Endicott, New York as Harpur College. In 1950, the college became affiliated with the State University of New York and became known as the State University of New York at Binghamton. Binghamton University moved to its current location in the city of Binghamton, New York in 1961, and did not take long to build its reputation as one of the premier public universities in the country. The name Binghamton University was added to the State University of New York title in 1992. The university places great emphasis on providing students with the best value in education they can get in the northeast by way of relatively low tuition and a highly accomplished faculty. Binghamton University is highly selective, with the average SAT scores of its admitted students falling within the 1190-1340 range and 84% having been in the top 25% of their high school class ("History", 2008).

Binghamton University's mission statement is “to provide an affordable, world-class education to high-caliber students from culturally and economically diverse backgrounds.” The university holds a “world wise” vision in which students can learn the lifelong benefits of cultural and intellectual exchange ("Mission, Vision, Values", 2008). Binghamton University strives to explore the rich diversity in artistic and cultural expression, while also the technical ideas of science and engineering. Thus, Binghamton University's real goal is to produce well-rounded, intelligent, and articulate individuals that can lead the world into the new millennium.

Appendix C: Description Of Non-university Partners Involved in the Project

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Greater Binghamton Airport (BGM), owned and operated by the Broome County Department of Aviation, is located eight miles north of the Binghamton Metropolitan area. BGM satisfies the transportation needs of the Greater Binghamton Area and the surrounding communities in Southern New York and Northern Pennsylvania, offering the services and conveniences expected from a five star airport. The services and conveniences are: free WIFI, business center access, national franchised concessions, electronic airline check-in kiosks, strong air services, and a congestion-free facility.

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"McFarland Johnson is an employee-owned, multi-disciplined consulting firm, providing innovative and economical solutions to engineering, planning and environmental service needs since 1946. The firm is dedicated to continuing its tradition of establishing long-term relationships with clients through ethical, responsive and quality service. McFarland Johnson aggressively pursues planned growth, new technologies and visions for the future. The company is committed to providing a work environment which fosters professional and personal development through challenging opportunities and employee involvement." (http://mjinc.com/)

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"KDF is a global leader in engineering, manufacturing, and supporting physical vapor deposition tools around the world for more than 20 years. In 2007, KDF launched the Cluster Intelligence tool, which has complimented their growing product line of sputter and etch equipment. KDF has positioned itself to serve a host of markets including Compound Semiconductor, Solar PV, Flat Panel, Medical Devices, Telecommunication, RF Power, Photo mask and a host of other critical military and commercial applications. KDF is the sole source OEM for the MRC batch product line of equipment." (http://kdf.com/) Kurt and several of his engineers researched a radiant system for commercial and residential use and shared with our group their accumulated knowledge.

"As director of technology, Dr. Derraa assumes responsibility for all KDF technology, with a particular emphasis on research and development. This includes overseeing the development of new KDF technology, including advancements upon the company's series of sputtering tools, and service and customization of pre-owned MRC systems. Prior to joining KDF, Dr. Derraa worked for NanoOpto Corp., where he led a nanotechnology project developing new nano-devices with dimensions smaller than the wavelength of light. Previously he was at Micron Technology, where he worked on many projects focused on the development of new technologies, including flat panel displays and various computer memory devices. Dr. Derraa has a rich background in academic and commercial research. He holds a PhD in physics from the University of Toronto, an MSc in physics from Queen's University, and a BSc in physics from the University of Constantine. His achievements include the Reginald Blyth Award (1994-94), the E. Burton Fellowship (1990-93), and the John Nadeau Award (1990). He has filed 54 patents (36 awarded, 18 pending) and has more than a dozen technical and conference publications to his credit." (KDF, 2004)

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Appendix D: Design Submission Form

University: Binghamton University

Design Developed by: ○ Individual Student ◉ Student Team

If Student Team:

Student Team Lead: Justin Flechsig

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Competition Design Challenge Addressed:

Airport Operation and Maintenance

I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed: ________________________ *Date: April 15, 2009*

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University/College: Binghamton University

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Appendix E: Evaluation of the educational experience provided by the project

For the Students:

1. *Did the FAA Airport Design Competition provide a meaningful learning experience for you? Why or why not?*

The primary educational benefit that we derived from this project was the exposure to technical writing and communication. Unlike other engineering disciplines, computer science undergraduates are not required to write substantial technical reports as part of the standard curriculum, and so this project helped to fill that gap. In particular, the nature of the report and the size of our team necessitated our learning how to use collaboration software and collaborative features of desktop software.

2. *What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?*

Since we are a class of computer science students, it was a bit of a reach for us to be working on a project that was primarily a physics/engineering problem. To compensate for our inexperience we researched the topic and received assistance from Carl Beardsley, the Greater Binghamton Regional Airport's Commissioner of Aviation, Chad Nixon, the Aviation Director of McFarland Johnson, Inc., and Don Harris, an employee of McFarland Johnson, Inc.

Another challenge was getting companies to cooperate with us. Companies were not obliging because we were only a class working on a project or they did not service our area. Once we started to work with Don Harris, he became our intermediary and companies were more forthcoming with information. Kurt Flechsig and his firm, KDF, were also helpful.

Finishing by the competition's deadline was difficult since we did not start until the beginning of the Spring 2009 semester which began at the end of January. To make the project less daunting, we split it into smaller jobs.

As a team of over 20 people, communication among that many people could be an issue. Nonetheless, as computer scientists we knew of and had several options. Binghamton University has an Internet application called Blackboard, which allows the sending of email to the entire class in an easy manner. We also wanted to have documents viewable for everyone, so an account to a website, specifically PBwiki, was created for each of us. The website allowed us to upload our documents and sent out emails to everyone in the class so that we knew when there had been alterations to the site.

Finally, since this is a large research paper with many sources of information used and viewed, we needed a method to keep track of our citations. However, Microsoft Word does not handle bibliographies when written in a team approach. We used Open Office for some of our work to take advantage of its bibliography capabilities.

3. *Describe the process you or your team used for developing your hypothesis.*

Prof. Ziegler was somewhat familiar with geothermal heating. Then with research and consultation with our competition partners, we were able to define our hypothesis. As a group, we decided to go forth with Prof. Ziegler's idea.

4. *Was participation by industry in the project appropriate, meaningful and useful? Why or why not?*

When we were able to get responses from people in industry, we found it quite useful. There were a few people whose assistance was crucial to our completion of the project, Don Harris, an employee of McFarland Johnson, Inc., Carl Beardsley, the Greater Binghamton Regional Airport's Commissioner of Aviation, and Chad Nixon, the Aviation Director of McFarland Johnson, Inc.

5. *What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?*

We all learned about geothermal heating, radiant heating, and airports. In addition, communication was a very important lesson. It was important to collaborate with people from the Greater Binghamton Regional Airport and McFarland Johnson and understand the airport requirements. We learned that with the right tools and cooperation, communication amongst a large group does not have to be difficult. In general, the collaboration of the class was a useful experience. The complexity of working in a team increases exponentially with each additional person. However, with meetings every week and our good communication we were able to avoid the catastrophes associated with working in large groups.

For the Faculty:

1. *Describe the value of the educational experience for your student(s) participating in this Competition submission.*

Real world experience can never be gained by sitting in a classroom. Most of my students participating in this competition have never even been on a plane; most have never consulted with experienced professionals, nor ever had to solve an engineering problem that did not come out of a textbook. They have never had to perform real research on a topic they began knowing nothing about, they have rarely worked in teams, and they have never had to collaborate with so many individuals. When they can learn and experience all of those lifelong skills in one semester, then they truly have had an educational experience that is simply immeasurable in value.

2. *Was the learning experience appropriate to the course level or context in which the competition was undertaken?*

The competition was undertaken as a class project in a required senior level undergraduate course titled Professional Communication and Ethics. The course is intended to bridge academe and professional practice within the themes of communication and ethical decision making. The learning experience presented by the FAA competition is exactly what is expected in this course.

3. *What challenges did the students face and overcome?*

There were two primary challenges. First, the students are all undergraduate Computer Science seniors with no experience relating to air travel, airports, aviation, etc. However, they are experienced at problem solving, research, and communication, which are the foundations of the competition. Their lack of experience relating to the aviation industry took them far from their comfort zone and that was quite a challenge for them. However, the biggest challenge was that of communication. The student team consisted of 24 students, far too many for such a project. However, as the students learned, sometimes you have to seize the moment when opportunity arises, and the FAA competition was such a moment. As I tried to explain to the students, you do not always get to work on the ideal team, the perfect team size, or the perfect project; the idea is to learn and adapt as you go. They will realize later that the technical and communication challenges they faced on the FAA project prepared them well for the future.

4. *Would you use this Competition as an educational vehicle in the future? Why or why not?*

I am already making plans to enter my students in the competition next year. This has been a fabulous experience for not only the students, but also our aviation partners who assisted us in the competition, and of course for me. I have reviewed and analyzed every action and decision throughout the competition with the goal of making the experience for my students even better the next time around.

5. *Are there changes to the Competition that you would suggest for future years?*

The FAA competition is by far the best-organized competition I have seen in my 30 years in higher education. Because my students are computer scientists, this competition was quite a stretch for them. However, the educational value and experiences presented by participating in the competition is simply unmatched anywhere else, so I am willing to go the extra effort to bring my students up to speed, just to be able to participate.

My only concern is that it seems that most of the suggested topics had been covered in previous years, so it was difficult to come up with a twist on a topic because we did not want it to appear that we were copying ideas that had already been presented at some earlier time.

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Appendix G: Biographies

Conrad Weykamp

- Conrad Weykamp grew up in Latham, New York, a suburb fifteen minutes away from downtown Albany. His first experience with computers was during the fifth grade, and he has been enthralled ever since. He took all the programming classes Shaker High School offered and received an award for his work in AP Computer Science. Currently, Conrad is expected to graduate from Binghamton University in May.

Dan Jones

- Dan Jones is currently a senior in the computer science program at Binghamton University. He is currently enrolled in the Watson School/School of Management Fast Track MBA program, taking MBA courses this year and will receive an MBA within one year of receiving his bachelor's degree. His areas of interest in computer science are in consulting and security, and he hopes to join a law enforcement agency with a focus on cyber crime. He is a former martial arts instructor and is proficient in multiple styles of martial arts.

Danny Dang

- Danny Dang was born on July 5, 1986 in Vietnam, and immigrated to the United States 15 years ago. He currently attends Binghamton University as a computer science major, and plans on pursuing a career in computing following his graduation in May 2009.

Giovanni Torres

- Giovanni Torres grew up in Manhattan, New York City around Washington Heights. He went to high school at Mount St. Michael Academy located in the Bronx, NY. He currently attends college in Binghamton University located in Vestal, NY. He has held various jobs at the university including the position of Monitor Supervisor for Off Campus College Transport, the local student run bus company. He is currently a resident assistant and a coop for the Endicott branch of IBM, working with the Hardware Management Console for IBM Z series mainframes. He plans to have a career in information technology or technology consulting. He also plans to pursue an MBA. His hobbies include watching soccer, going to concerts, and repairing computers. His areas of interests in computer science are operating systems, architecture, and web development. He has been on the dean's list multiple times, most recently for the semester of Spring 2008.

Jacob D'Agostino

- Jacob D'Agostino grew up in Pittstown, NY and is scheduled to get his B.S. in Computer Science at the end of the current (Spring '09) semester. He is a member of Upsilon Pi Epsilon. He will be working for Northrop-Grumman in the fall.

James Wong

- James Wong is currently a senior expecting to graduate from Binghamton University in spring 2009 with a BS in Computer Science. He does not currently have a specific area of interest in CS, so he plans acquire working experience after graduation, and then figure out in which areas he excels. He has previously interned at Lockheed Martin, and will continue working there full time following his graduation. After working for several years, he may consider applying for a fellowship program to earn an MS degree.

Jordan Messina

- Jordan Messina is from Syracuse, NY. He went to high school at Fabius-Pompey High School in Central New York, and currently attends Binghamton University. He is currently an intern at the Bank of New York Mellon in Syracuse, and in June he will be working full time for them in their Leadership Development Program in Pittsburgh. He also plans to attend graduate school at the University of Pittsburgh next spring. His areas of interest in Computer Science include operating systems and networks.

Justin Flechsig

- Justin Flechsig was born December 20th, 1986 in Pascack Valley Hospital, Westwood, New Jersey. For as long as he can remember his father had made an effort to get him involved with technology; the earliest such memory he has is, at the age of 5, doodling on KidPix on his father's computer. As he progressed through high school, he kept with him the hope of working in some field of computers, particularly computer graphics; however, plans change and he declared his major as "computer science" when he applied to Binghamton. Initially it seemed computer science might not be a good fit for him, but as his years spent at Binghamton have progressed so has his knowledge of programming; where once he was convinced he was in over his head, he is now graduating with honors and a Scholar's minor. He is not sure a career in computer science is what the future has in store for him, but his time spent as a programmer has shown him that he can excel even in his weakest areas if he only puts forth the effort. After he graduates from Binghamton, he hopes to attend NYU Stern and get his MBA.

Nate Trick

- Nate Trick grew up in Port Crane, NY and currently attends Binghamton University. He previously studied at Broome County Community College, and was placed on the Dean's List there. His future plans involve moving south and working as a programmer.

Ryan Boris

- Ryan Boris is a senior at Binghamton University and will be graduating in the spring of 2009 with a B.S. in Computer Science. He has worked and created websites for a few companies in the past. Once he graduates he plan on going back to school at Binghamton University to receive his Masters degree in Computer Science. So far there is no specific field of Computer Science that he enjoys over the rest, although he does enjoy programming, working with robotics, and software engineering. His current hobbies are playing baseball and soccer, and drumming on his drum set.

Ryan Zielinski

- Ryan Zielinski is a senior computer science major expecting to graduate in May 2009. He is from Oriskany Falls, NY and has attended Herkimer County Community College, SUNY Oneonta, and Binghamton University. His interests are game development and RC helicopters, and he plans a career in developing XNA games.

Amanda Lannie

- Amanda Lannie is from Central Square, New York. She currently attends Binghamton University as a computer science major, with an interest in mathematics and applied computer science. She is currently the president of the computer science honor society Upsilon Pi Epsilon chapter at Binghamton. She was awarded the Lockheed Martin scholarship and was an intern at the Air Force Research Lab in Rome, NY.

Benjamin Kreuter

- Benjamin Kreuter was born on May 5, 1987, and grew up in New York City. He is currently a senior computer science and electrical engineering major at Binghamton University, with plans to pursue a Ph. D. beginning in the Fall semester of 2009. His interests include mathematics, formal language theory and programming language design, and topics related to electrical engineering. He is a contributor to the Fedora Linux project and is currently an intern at Red Hat, Inc.

Jason Wong

- Jason Wong is a senior computer science major attending Binghamton University. He was born and raised in Bayside, which is located in the borough of Queens in New York City. He attended Townsend Harris High School before being admitted into Binghamton University. His interests in computer science are in networks, databases, and information technology. In his free time, he loves to follow and play sports, as well as spending time with friends and family members.

Lauren Sutcliffe

- Lauren Sutcliffe was born and raised in Newburgh, NY. She went to school at NFA where she did cross-country and played soccer. At age 15, she coached a children’s soccer team for her town recreation department and has been doing it ever since; she also became a referee for children’s soccer games. In the past, she has set up and organized the Town of Newburgh Town Hall's inventory system by setting up a program called Info Track and she goes back periodically to keep it updated. She is currently a senior at SUNY Binghamton graduating in the spring with a BS in Computer Science. Upon graduation, she hopes to pursue a career in network security.

Nathan Gagnon

- Nathan Gagnon is a senior year Computer Science major at Binghamton University, set to graduate this May. He was born and raised in Vermont, and has spent the last four years as a full-time student at Binghamton. The areas of computing that he is most interested in are embedded systems and data mining, and he is especially interested in the real-world applications of these fields. His pastimes include backpacking, snowboarding, listening to music, watching movies, and reading. This summer, he will begin employment at BAE System in their Engineering Leadership Development Program, in which he will be simultaneously working, developing leadership abilities, and earning a Master's degree in a field that has yet to be decided.

Appendix H: Photographs

Working with Carl Beardsley and Chad Nixon at the Greater Binghamton Airport

Inspecting the Apron at the Greater Binghamton Airport

Studying the Effects of Sand and Sodium Acetate on the Apron

Working with Carl Beardsley and Chad Nixon at Binghamton University

Appendix I: Ethical Considerations

In both the development and the implementation of an airport radiant heating system, there are important ethical considerations that should be recognized and addressed. It is important to understand the ethical implications associated with any technical endeavor, especially when said endeavor has the potential for widespread implementation. This project carries large financial implications, and its externalities extend to the environment.

In order to evaluate the ethical issues related to this project, it is important to establish what exactly constitutes an 'ethical issue'. 'Ethics' are moral codes that serve to guide the actions of humans, and help determine whether something is 'right' or 'wrong'. We imply from this that an 'ethical issue' is any sort of human action that with a relation to morality that has social, environmental, and legal implications.

In the development of the radiant heating project, the team researched airports and airport pavements, radiant heating, geothermal heat pumps and other areas relevant to developing the plan. Almost all of the information that has served as a basis for our project is derived from the knowledge of others. The use of other individuals' research is an issue that holds both social and legal ethical implications. Namely, the two major issues associated with this activity are plagiarism and honesty. When information gained during research is used, it is both American law and commonly accepted professional ethical behavior to give credit to the author of the sources used. It is a point of ethical consideration in terms of honesty and respect, and one that should be considered seriously by all persons participating in the development of written documents, new science, engineering designs, etc.

Another issue relating to honesty involves the student assigned as the airport liaison; the liaison is tasked with facilitating discussion between the project managers and the aviation experts with whom we are corresponding. All communication is to be logged for possible future reference. It is important that the liaison is accurate when recording dialog; incorrect or ambiguous paraphrasing risks misrepresenting the statements of individuals we are in contact with. It is also important that in the event of little or no correspondence, that the liaison does not falsify information to make it appear that communication is occurring more often than it actually does.

The implementation of our proposed system carries its own ethical and environmental issues. The plan being proposed uses geothermal heat pumps to power a radiant heating system to melt snow and ice on runways. Geothermal energy is considered to be an environmentally responsible heating option, because it is more efficient (and thus contributes less emissions) than standard methods of heating. The use of radiant melting as opposed to standard methods of ice and snow removal is considered environmentally friendly, but carries a higher price tag for implementation. A balance of cost against damage to the environment is something that needs to be considered, as an extreme in either direction may be an ethical issue.

Geothermal systems utilize heat energy (generally indirect solar energy) extracted from the earth, but depend on a secondary source of energy to power the associated heat pumps. Gas, propane, electric, coal, and photovoltaics are all viable sources of energy. This raises an important ethical issue regarding the environmental impact of the secondary energy source. Going back to the issue of cost vs. environmental responsibility, standard plant electricity may prove cheaper, but photovoltaics are emission free.

Another ethical environmental impact to be considered is the creation of permafrost. By taking energy from the ground surrounding the airport, the ground may be negatively affected in ways that cause it to be consistently below freezing. The permafrost would be difficult to reverse, and as such, the risk of this change needs to be considered as one of the ethical effects of this project. The creation of the permafrost may negatively affect airport architecture, and could lead to changes to our natural environment that would not have occurred otherwise. The issue of permafrost creation can be avoided completely if the heat pumps are properly installed.

On the technical aspect of the project, many pipes need to be laid down which contain a glycol solution. In high concentrations, this solution can be hazardous, potentially posing a threat to the environment and to wildlife. If the system failed and pipes ruptured, the antifreeze solution could seep into the ground and be absorbed into the water and soil. Additionally, a geothermal system can inflate the natural temperature highs and lows of the earth or water used as its energy source creating a negative environmental impact. This project is one that has many potentially hazardous effects to the environment, and taking all of these effects into consideration is something that is deeply ethical in nature.

Traditionally, the process of manually deicing runways has created job opportunities. Implementing our proposed low-maintenance system would eliminate a portion of the need for manual labor. While the initial building of the geothermal system may create more jobs, in the long run there are responsibilities, and thus jobs, that are no longer necessary. The possibility for airport employee job loss is a consideration for airport management.

Overall, the primary ethical considerations for this project fall in four categories: honesty, safety, environmental and social. Ethical considerations regarding honesty are inherent in the creation of any report or proposal, and are thus universal and broad. Safety and environmental considerations are unique to this project, as the costs versus the effects of the project must be weighed not only issue by issue, but also for each airport and the unique risk levels posed by each situation. The social implications are due to the large-scale nature of this project, and its affect on human lives and human interactions with the environment. All of the ethical considerations listed in this section should be considered by all participants in this project, as they are all relevant to the members involved in the development of this plan.