COVER PAGE

Title of Design: _LED Runway and Taxiway Lighting Powered with On-Site Solar Panels__

Design Challenge addressed: _III Airport Environmental Interactions, Part C: Increasing____ Energy Efficiency in the Management of Airfields___

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1. Executive Summary

Reducing energy consumption and greenhouse gas emissions has become a prevalent issue for the transportation industry, including airports. The goal of Colorado Sustainable Energy Consulting (CSEC) was to improve the energy efficiency in airfield management at Grand Junction Regional Airport (GJRA). As a class one airport, and the third largest in Colorado, we feel our design can easily be replicated and scaled to other airports. In the next ten years Grand Junction Regional Airport plans to construct a new runway 10,500 feet by 200 feet replacing the existing taxiway and runway. Our proposed improvements will impact the new taxiway stretching 6000 feet and the new runway. They are intended to be implemented in conjunction with construction of this new runway.

After close consultation with GJRA Master Electrician, Brian Harrison, and other stakeholders, we assessed in detail options for improved runway and taxiway lighting, alternative energy generation for this lighting, and geothermal heating for the runway. Weighted criteria, including initial cost, payback period, social impacts, and environmental impacts were used to determine the best alternatives. Following the detailed decision process, CSEC and GJRA decided that the installation of 729 Light Emitting Diode (LED) runway lights without heaters would be the focal point of the final design. With a payback period of roughly one year and a capital investment of $703,000 these lights will be a sound investment. Also included in the final design is a solar photovoltaic array that will annually generate 49 MWh of electricity, which is just enough to power the lights. With government incentives the capital investment of the solar panels is $140,000 with a payback period of 19 years. These designs are intended to improve energy needs at GJRA and to be replicated at similar airports throughout the country.

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2. Problem Statement

Colorado Sustainable Energy Consulting (CSEC) assessed ways to improve energy efficiency in the management of airfields. After consulting many experts in the Federal Aviation Administration (FAA), Colorado Department of Transportation (CDOT), and airport representatives, CSEC decided to work with the Grand Junction Regional Airport (GJRA) to increase its airfield energy efficiency. We conferred with other airport officials to help make our designs more replicable for other airports in the region. After evaluating several methods for improving energy efficiency and reducing environmental impacts, excluding methods in airport terminals and buildings, a criteria-weighted decision matrix was used to determine the best option. This report outlines the background, alternatives evaluation process, and details of the selected design.

3. Background

3.1 Energy Consumption in US Airports

Reliance on fossil fuels is a primary contributor to climate change because of the release of large amounts of greenhouse gases into the atmosphere. Major greenhouse gases include carbon dioxide, methane, particulate matter, water vapor, nitrous oxides, and carbon monoxide (Hinkle Charitable Foundation, 2013). Implementation of sustainable, energy efficient practices in airports can help reduce greenhouse gas emissions and the general effects of climate change. Figure 1 shows a graph from the U.S. Department of Transportation detailing which industries are mainly responsible for emissions, and details of emissions within transportation. With over 15,000 airports in the United States, the aviation industry accounts for more than 10% of all transportation emissions (Reed, 2006). Of that, airports themselves account for five percent of the aviation sector's carbon emissions (Air Travel and Efficiency, 2012).

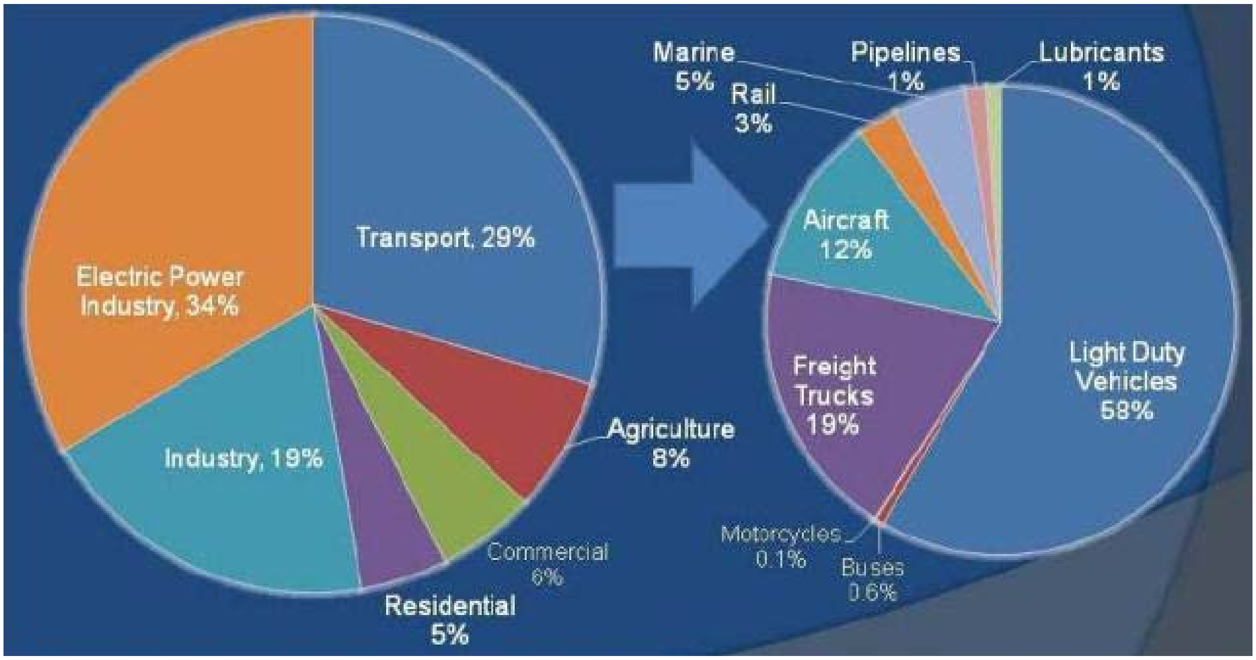


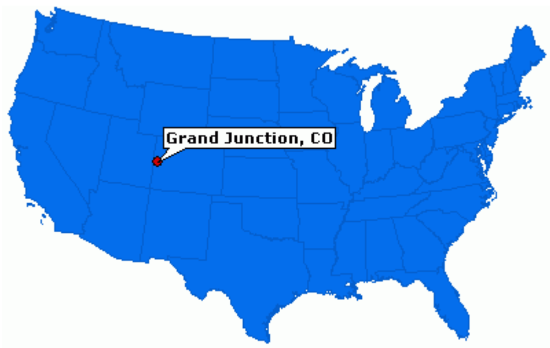
Figure 1: U.S. Greenhouse Gas Emissions by End Use (Ehl, 2010)

The United States government states that it is committed to addressing the climate change impacts of commercial aviation and is pursuing a multi-pronged approach to achieve greenhouse gas emission reductions (FAA, 2012). Airports may be distinctly positioned to use renewable energy technology due to large areas of open land within airport property boundaries (Airport Cooperative Research Program, 2010). The United States government has set an ambitious overarching goal of achieving carbon-neutral growth for commercial aviation by 2020, using 2005 emissions as a baseline (FAA, 2012).

Many airports have already implemented energy efficient technologies and significantly reduced energy consumption. The majority of electricity use is associated with terminal buildings; however, there still remain many areas in airfield management that consume large amounts of energy (Allee, 2011). Since the FAA Design Competition is aimed at energy improvements in non-terminal areas, CSEC investigated ways to improve energy efficiency and management in these sectors.

3.2 Grand Junction Airport Energy Use

GJRA is a public airport located about three nautical miles northeast of the business district of Grand Junction, on Colorado's western slope. The airport covers an area of approximately 2,357 acres and sees about 140 aircraft operations per day. Airfield usage consists of 60% general aviation, 30% air taxi, 7% military, and 3% commercial (AirNav, 2013).



GJRA, on average, uses 1.17 GWh of energy each year. Figure 3 describes the airport's total energy use by sector (Harrison, 2013).

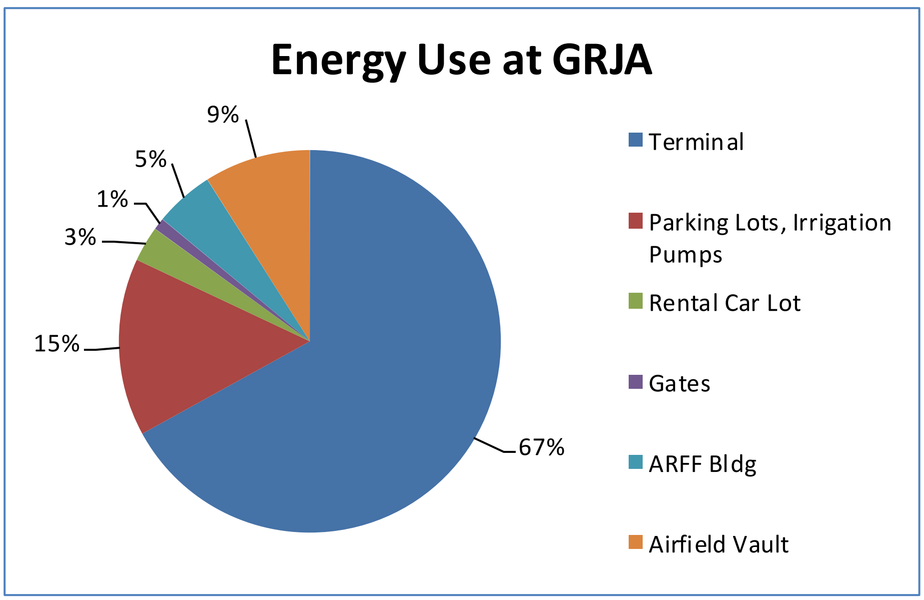


Figure 3: Electricity Use Distribution of Grand Junction Regional Airport (Harrison, 2013)

GJRA is currently undergoing a $20 million renovation. This renovation will upgrade much of the terminal and fire building. In addition, it aims to replace the primary runway and taxiway with a new runway and larger taxiway to be completed by 2019 (Harrison, 2013). The reason for this new runway is the anticipated military and commercial flights, and the current asphalt has reached the end of its lifespan (Harrison, 2013).

Figure 4: Current Aerial View of GJRA (Google Maps, 2013)

Since the FAA Competition limits improvements for the competition to non-terminal and non-airport buildings, CSEC will focus its efforts on improving energy efficiency and management in other areas. One area which CSEC can improve for GJRA is lighting for the airfield. Electricity for lighting is routed through the airfield vault. This electricity amounts to 9% of the total energy consumed at the airport. Lighting uses an average of 105,000 kWh of electricity, which costs $18,000 per year (Harrison, 2013). The airfield vault meter reading represents airfield lighting as well as ramp lighting, a pivot gate, and a small heating unit. Reducing this energy use will not only benefit GJRA financially, but also the environment via the reduction of greenhouse gas emissions. Figure 4 shows the current Terminal, Ramp, and Apron areas of GJRA. GJRA's 50-year runway and taxiway expansion plan is shown in Figure 5.

Figure 5: 50-year Plan View of GJRA (Google Maps, 2013)

4. Regulations

Grand Junction Regional Airport is subject to Regulations from the FAA, CDOT, and the city of Grand Junction. The airport authority board of Grand Junction is charged with setting policy and overseeing the operations of GJRA. "The board ensures compliance with its By-laws, the State of Colorado Public Airport Authority Law and with FAA regulations" (Grand Junction Airport Regional Authority, 2013, para. 2). Regulations for airport design are primarily found in Advisory Circulars (ACs) published by the FAA. The ACs used in this report include

Table 1: Regulations Quoted Directly from FAA Advisory Circulars (FAA AC, 2012) (FAA Engineering Briefs)

	Details and Document	Requirements
Runway Lighting		The light units and battery must perform under the following environmental conditions: • Exposure to any temperature from -4°F to +122°F (-20°C to +50°C). • Exposure to wind speeds up to 150 mph (240 km/h) from any direction. • Exposure to a salt-laden atmosphere. • Exposure to solar radiation. • Exposure to all normal weather conditions including exposure to blowing dirt and sand (up to 150 mph), rain, snow, ice, sleet, and hail.
Geothermal	FAA approval method, other regulations found in AC 150/5370-17 chapter	• The airport engineer will incorporate the proposed design specifications into construction specifications and submit a quality assurance program to the responsible FAA Airports Regional/District Office for approval. • The airport engineer will incorporate recommendations of regulatory agencies into the construction specifications to mitigate any environmental aspects. • The airport sponsor will amend the airport's Storm Water Pollution Prevention Plan (SWPPP) if required by the National Pollution Discharge Elimination System (NPDES) and modify the airport base map depicting any incidental changes to the drainage plan.
Alternative Energy	Solar power supplies for lighting	• Ensure the total power demand of the lighting system is known. This information can be calculated from the light manufacturer's specification sheets.
	Batteries	• Based on paragraph 2.2c, the daily amp-hour requirement for the light is 16.1 amp-hours. • Per the system specification, the batteries must power the system for 7 days with no or reduced sunshine • The impact of high and low temperature on the battery capacity should also be considered.

AC numbers 150/5370-17, 150/5070-6B, 150/5345-46D, 150/5345-50B, 150/5300-13, and 150/5320-6. The regulations in these reports are mandatory for all projects funded through the Airport Improvement Program (AIP) or the Passenger Facility Charges (PFC) Program (FAA, 2012). Additional requirements from the FAA include Engineering Briefs. Specifically utilized in this report are Engineering Briefs 67 and 76, for alternative lighting and solar power respectively. These requirements are highlighted in Table 1.

5. Interactions with Airport Operators

Table 2 details the various staff, faculty, and experts that we have contacted throughout the duration of our design process. They include FAA personnel, Airport Officials, and Industry Experts. The initial communications were meant to determine which energy issues are most prevalent at airports in Colorado, and to determine a partner airport for the project. After deciding to work primarily with GJRA, CSEC maintained regular communication with the master electrician at GJRA, Brian Harrison. This communication included contact over phone, email, and a visit to GJRA. Mr. Harrison informed CSEC that potential solutions to improving environmental conditions at GJRA include alternate lighting, energy generation, and snow removal (Harrison, 2013). CSEC has made sure to work closely with stakeholders throughout the design process.

Table 2: Experts Consulted

Contact	Position	Employer	Phone	Email	Date(s) Contacted	Information Discussed
Timothy Head	Airport Manager	Boulder Airport	303-441-3108	headt@bouldercolorado.gov	2/14/2013	Airport Energy Consultation
Bruce Jacobson	Senior Vice-President	Crawford, Murphy & Tilly, Inc.	312 401-8055	bjacobson@cmtengr.com	2/15/2013	Project Inquiry
Laura Sakach	Engineer	Crawford, Murphy & Tilly, Inc.	217 572-1046	lsakach@cmtengr.com	2/15/2013	Project Inquiry
Chris Babb	Project Manager	Landrum-Brown	513 530-1275	cbabb@landrum-brown.com	2/12/2013	Project Inquiry
John E. Joyner III	Manager-Electrical & NavAid Design	Delta Airport Consultant	919 840-7604	ejoyner@deltaairport.com	2/12/2013	Project Inquiry
Brian Harrison	Master Electrician	Grand Junction Regional Airport	970-201-3036	bharrison@gjairport.com	2/14/2013 2/20/2013 2/25/2013 2/27/2013 3/4/2013 3/8/2013 3/28/2013 4/3/2013 4/9/2013	Airport Energy Consultation
Mark Lovin	Director of Aviation	Pueblo Airport	719-553-2760	mlovin@pueblo.us	2/14/2013	Airport Energy Consultation
Woods Allee		DIA	303-342-2632	woods.allee@flydenver.com	2/13/2013	Airport Energy Consultation
Craig Shilenger	Assistant Manager	DIA	303-342-2834		2/13/2013	Airport Energy Consultation
Brett Miller	Operations Manager	Rocky Mountain Airport	303-271-4850	bamiller@co.jefferson.co.us	2/13/2013 2/20/2013 3/5/2013	Airport Energy Consultation
Nick Condon	Operations Specialist	Rocky Mountain Airport	303-271-4873	ncondon@co.jefferson.co.us	2/14/2013	Airport Energy Consultation
Amy Jordan		Grand Junction	970-244-9100	ajordan@gjairport.com	2/14/2013	Airport Energy Consultation
David Gordon	Director	CDOT	303-512-5254	davidc.gordon@state.co.us	2/14/2012	Airport Energy Consultation
Jenell Barilleaux	Environmental Program Manager	FAA	425-227-2611		2/14/2013	Project Inquiry
Duane Holliman	Northwest Director	FAA	303-342-1254		2/14/2013	Project Inquiry
Agnes Blachut	Public Affairs Cordinator	Colorado Springs	719-550-1902	ablachut@springsgov.com	2/13/2013 3/5/2013	Airport Energy Consultation
Jim Elwood	Airport Director	Aspen Airport	970-429-2851	jim.elwood@co.pitkin.co.us	2/28/2013	Airport Energy Consultation
Debra Ross	Program Specialist	Virginia Space Grant	757 766-5210	dross@odu.edu	3/3/2013	Project Inquiry
Tim Winkelman	Sales Engineer	ADB Lighting	614-573-8283	Tim.winkelman@adb-air.com	4/12/2013	Price Inquiry

6. Team's Problem Solving Approach

CSEC strived to incorporate systematic engineering approaches to find the best method to improve energy efficiency at Grand Junction Regional Airport. This process included a five step approach leading to a final design by defining a problem, generating possible solutions, evaluating those solutions, modifying our design, and communicating our preliminary design to the client.

CSEC was given a request for proposal from the FAA design competition requesting a design for increasing energy efficiency in the management of airfields, specifically excluding consideration of terminal and other airport buildings (FAA Airport Design Competition, 2012). Given this request, the team contacted several airport officials, members of the FAA, and Colorado Department of Transportation (CDOT) to help determine an airport energy problem. Also, a proposal was written to do a preliminary analysis of current and new technologies that improve energy efficiency and offer these services to several airport clients. After consulting with these airports and suggesting the methods derived in the proposal, CSEC determined that working with Grand Junction Regional Airport to reduce energy consumption for their planned new runway would offer the most environmental benefit within competition constraints.

A discussion with the airport master electrician Brian Harrison defined the scope of the problem to include improved airfield lighting, alternative energy generation for the lighting, and geothermal heating for the runway. An alternatives assessment was composed to explore possible solutions and determine which of them would best meet the needs of GJRA. CSEC used a literature review to generate possible solutions, and a weighted decision matrix to evaluate them. The criteria used to weight these options included technical, environmental, social, and financial categories. By working with several airport administrators, CSEC was able to better determine which criteria to use and how to weigh the importance of each criterion.

It was important to focus on achieving long term gains for GJRA, which is why CSEC considered specific concerns for environmental engineering. The designs in this report are proven solutions with built-in sustainability (Bielefeldt, 2013). Also considered were post construction concerns such as start-up costs, growth of airport facilities, changing regulations, and operating and maintaining these facilities (Bielefeldt, 2013).

To ensure the quality of work and monitor progress, CSEC completed weekly timesheets meant to follow a developed work plan for each member of the team. This work plan was created to define team roles and ensure these roles were being fulfilled and that deliverables were completed on time. This also acted as a method of quality assurance by incorporating in members' schedules time to review work done by others.

7. Alternatives Summary

This section of the report describes the decision process behind choosing the best alternative for GJRA. Of the alternatives considered several were eliminated as possibilities without the need for thorough investigation. Four alternatives were chosen to be evaluated in more detail which included a literature review of possible technologies, technical analysis of possible designs, and a financial analysis of the designs. The four alternatives chosen include solar power energy generation, LED lighting, geothermal heating, and fuel cells for backup power.

7.1 Preliminary Screening of Alternatives

CSEC primarily analyzed alternatives for approaching problems in energy generation, alternate lighting, energy storage, ground fleet vehicle conversion, and snow removal methods and solid waste management. Because GJRA has a relatively small and modern ground fleet CSEC decided not to pursue options of more energy efficient vehicles. The cost would not justify the benefits, and the technologies have not yet been developed enough to implement on a large scale for an airport of GJRA's capacity. Another alternative was improving solid waste management though it was determined early on that the relatively small amount of waste generated at GJRA would not validate the environmental benefits of creating a new protocol for waste removal.

Within energy generation CSEC evaluated solar power, wind energy, and algal hydrogen production. The implementation of an algal farm was not feasible because the technology is too expensive and has not been implemented in enough locations. Wind power was an attractive option but because the average wind speeds in Grand Junction are only three to five meters per second, wind turbines would not function properly (USGS, 2012).

7.2 Fuel Cells

7.2.1 Summary

Grand Junction Regional Airport does not currently have a backup power system. Because of this CSEC has decided to review alternative backup power systems as a way to improve energy needs. Fuel cells are an attractive option as a backup power system at GJRA.

7.2.2 Literature Review

The Department of Energy (DOE) suggests fuel cells as a less costly option for backup power in areas where pumped-hydro or compressed air storage is not feasible (Department of Energy, 2013). The DOE also asserts that fuel cells offer longer continuous runtime, less maintenance, and more durability than batteries. (Department of Energy, 2013). In 2003 the FAA was awarded a grant from the DOE to install fuel cell backup systems at twenty-six airports for emergency power to terminal buildings (Zilis, 2013). The FAA decided to expand this to another twenty-six sites in 2009 (Zilis, 2013). Distributors such as Eagle Fuel Cells markets systems that are already FAA approved (Eagle Fuel Cells, 2013). Methanol fuel cell systems are available and are attractive due to their high efficiency and ability to use liquid fuel as opposed to gas. Hydrogen fuel cells, on the other hand, produce no carbon emissions and hydrogen gas production is easily integrated with wind and solar generation (Department of Energy, 2013). Both types can provide a reliable way to address the problem of intermittent supply of solar and wind resources (Department of Energy, 2013).

7.2.3 Technical Aspects

On their website, Eagle Fuel Cells states "bladder fuel cells are an assembly of flexible fuel resistant polymers, fabric materials, metal items and fittings. A cross section of a fuel cell wall construction consists of a fuel resistant polymer (typically liquefied nylon, Neoprene, Buna-N / Nitrile or Urethane) laminated to a fabric substrate (typically polyester or nylon) which provides structural support and puncture resistance" (Eagle Fuel Cells, 2013).

The DOE funded the FAA with a $465,000 grant to buy fuel cells, and the FAA was expected to cover their installation. Once purchased, fuel cells are relatively low cost, requiring the air filter be changed "every 400 run hours and running the machine once every four to six weeks are the two maintenance requirements, and running the machine remotely can be scheduled with automatic self-cycles" (Zilis, 2013).

7.2.4 Financial Analysis

Shown in the Table 3 is a rough estimate of the cost and payback period for a 100 kW fuel cell system. The size and capacity of these systems was estimated to produce more than enough electricity used by runway lighting in one year. A life-span of ten years was assumed for this system, however many sources claim longer lifetimes for fuel cells.

Table 3: Fuel Cell Costs (Eagle Fuel Cells, 2013)

Capacity	100	kW
Installed Cost	2000	$/kW
Maintenance	200	$/yr
Lifespan	10	yrs
Total Cost	22,000	$
Payback Period	16	yrs

7.3 Solar Energy

7.3.1 Summary

Using the sun's energy to generate electricity is not a new idea. Solar photovoltaic (PV) technology started to increase in feasibility in the mid-1900s, and PV cells have increased in conversion efficiency ever since (DOE, 2002). They produce electricity by chemically converting the energy carried by the photons from the sun into electric potential at the cell's terminals. This electricity is either used directly, as in an off-grid system, or fed to the electrical grid, as in an on-grid system. Most large installations are connected to the grid, though off-grid large systems could be useful at remote locations where the airport may not necessarily be grid-tied.

7.3.2 Literature Review

One possible use for PV at the Grand Junction Regional Airport is for lighting individual runway lights, with each light having its own dedicated panel. Such an implementation would eliminate the need for a large-scale system to be installed and would also not require as large of an open space. Having a dedicated panel for each light could be more aesthetically pleasing and would eliminate the need for extensive infrastructure overhaul. Several companies including Flight Light Incorporated and ADB Lighting already offer several solar LED light models that meet all FAA requirements (Flight Light, ADB, 2013). Not only do the lights have reduced power consumption when compared to incandescent, but they also take advantage of solar PV. Individual solar panels or several panel clusters spread across the airport grounds could be used to generate the power required for inset lights, marker lights, and others.

Solar power generation has been used successfully in many sectors, including airports. Denver International Airport has the highest generating capacity of any airport, and Chicago's airports also implement both off and on-site solar generation (Meyers, 2011).

Solar PV systems have fallen in price by a factor of seven in the past 20 years (SolarBuzz, 2012). Currently, a large PV system of capacity greater than 100kW has an installed cost of under $5/W, and that price will surely fall in the coming years (Chen, 2012). Cash incentives for installing solar PV systems have also been falling in recent years, and their current median pre-tax value ranges between $0.90 and $1.20 depending on location (Chen, 2012). Despite the drastic drops in price over the past years, a preliminary calculation using National Renewable Energy Laboratory's System Advisor Model (SAM) modeling a 60kW system and assuming $0.13/kWh is charged by Xcel Energy (Harrison, 2013), the payback period for a system of that size is just over 22 years (NREL, 2013). However, if funding can be secured under the FAA's Airport Improvement Program and Voluntary Airport Low Emission Program (Harris, Miller, Miller, and Hanson Inc, 2010) at the amount of 50% of the installed cost of this project, the payback period becomes much shorter at about 7.18 (NREL, 2013).

7.3.3 Technical Aspects

The installation of a solar farm requires several criteria to be met. First and foremost, they require a relatively large area of open space. Two areas at GJRA have been tentatively given approval for the installation of a solar farm. One of these is on the western edge of the property, and the other is northeast of the planned new runway 11/29. Both of these sites meet the size requirements of a solar array.

There are three main components of a solar generating system. These typically include the solar modules themselves and necessary mounting hardware, a device known as a grid-tie inverter to convert the direct current output by the panels to alternating current used by the grid and most modern technology, and the necessary cables, etc. These components are available from many different sources worldwide, and vary in capacity as well as price.

A solar array installation project begins with choosing a location for the array. In our case, the location northeast of the new runway was chosen due to its proximity to the possible future location of the airfield vault, which houses the various lighting components that the solar array would power. In addition, GJRA's 50-year plan includes the installation of another runway parallel to 11/29 a few hundred yards north of the new runway. Positioning the solar array and airfield vault in this location would facilitate expansion north to the second runway. Once the location has been chosen, the array needs to be sized appropriately. The first step in sizing the array is determining the current or planned electricity use that will be offset by the array. Then, NREL's SAM tool can be used with Typical Meteorological Year data to estimate output of an array. The desired size is then specified such that the array's yearly output most closely matches the electricity to be offset. An appropriately sized inverter(s) is then selected to convert DC from the panel to AC used on the grid. SAM does not, however, model cables used to connect the various components, so those must be chosen according to the location of the array and local codes. Once the components of the system have been appropriately sized, they may be purchased from a number of suppliers and shipped to the site.

7.3.4 Energy Storage

One of the largest drawbacks in alternative energy generation is that most sources are intermittent. To overcome this issue, a storage system should be integrated to provide a reliable and consistent energy supply. Pumped hydro and compressed air are cost-effective options to store energy where the resources are available. Compressed air can be stored in underground formations such as old mines, aquifers, and oil wells, which could be convenient and inexpensive if drilling is already taking place on-site (i.e. geothermal heating of runways) (Woodbank Communications, 2013). Pumped hydro might be useful at the Grand Junction location due to its proximity to the mountains.

7.3.5 Financial

To analyze the cost of installing solar panels in differing sized arrays CSEC utilized a cost model from NREL (SAM) to determine the cost and payback of differing arrays given state and corporate incentives, and specific module and inverter prices. The smaller array was selected (shown in black in Table 4) because it does not rely on FAA funding. Also, it will provide slightly more energy than that which will be required by the new runway lights, i.e. it is not oversized for the application.

Operations and Maintenance costs are nearly negligible for a solar array, as it is a solid-state system with few to no moving parts. Costs would consist of cleaning supplies to clean the glass on the array and the periodic replacement of parts that may break, and are estimated by SAM to be only $20/kW/year. (NREL, 2013)

Table 4: Cost Analysis for Solar Arrays (NREL, 2013)

Case	Total Installed Cost ($)	Annual Energy Produced (MWh)	LCOE Real (¢/kWh)	25-year expense with system ($)	25-year expense without system ($)	Net Savings ($)	Payback (years)
58.1 kW (With 50% FAA Funding)	137900	96	4.75	-1,200	-13,700	12,500	7.2
58.1 kW (Without FAA Funding)	275800	96	9.56	-1,200	-13,700	12,500	22.2
29 kW (No FAA Funding)	137800	49	12.26	-7,300	-13,700	6,400	18.7

7.4 Alternative Lighting

7.4.1 Summary

There are six different areas where we can assist GJRA in improving their lighting: runway edge, threshold, end, exit, centerline, and taxiway lighting. Currently, GJRA uses incandescent lamps to light their landing strip and taxiway. We have determined that improvements can be made in order to increase energy efficiency and management.

7.4.2 Literature Review

We found four alternative light sources that can help Grand Junction Airport increase energy efficiency. These alternatives include halogen lamps, fluorescent lamps, high intensity discharge lamps, and light-emitting diodes. **Halogen lamps** are incandescent lights with a small amount of halogen, such as iodine, added, which results in a higher luminous efficacy and color temperature. In general, halogen lamps use less energy than incandescent bulbs, but have a higher initial cost that outweighs its overall benefits (Best Replacement Bulbs, 2012). As a result, we will not consider halogen lamps as a lighting solution.

Fluorescent lamps are gas-discharge lamps that use electricity to excite mercury vapor (Fluorescent Lamp Definition, 2008). Upgrading from incandescent lighting to fluorescent lamps can greatly increase overall energy efficiency. Fluorescent lamps have a greater luminous efficacy and emit less heat and carbon dioxide than incandescent bulbs; however, these lights also contain mercury, which can pose an environmental threat if the light is broken. Economically speaking, fluorescent lamps have slightly higher capital costs but much lower operating costs, making them a viable option (Energy Efficient Lighting, 2012). **High Intensity Discharge (HID) lamps** produce light by striking an electrical arc across tungsten electrodes. These lights are typically used when high levels of light over large areas are needed, such as in lighting roads. These lamps have a longer lifespan, but a much higher initial cost. Because of this, the payback period versus incandescent bulbs is longer than the actual lifespan of the HID bulb (Aviation Light Bulb, 2012). Therefore, HID lamps will not be implemented at GJRA.

Light-Emitting Diode (LED) is a lighting technology that is extremely energy-efficient and provides only directional light, not diffused light. By providing only directional light, the light is more intense, but only in one direction. Therefore, more modern designs use diffuser lenses and reflectors to disperse the light more like an incandescent bulb. Overall, LEDs are approximately 80% more efficient and can emit different colors depending on their voltage drop and semiconductor material. While capital costs are several times larger than incandescent, the low operating cost makes these lights a convincing alternative.

7.4.3 Technical Aspects of Design

Fluorescent lamps operate much differently than incandescent bulbs and have many benefits. The lifespan is far greater than incandescent at about 6,000-20,000 hours (Understanding the Difference, 2012). The luminous efficacy is also greater as fluorescent lamps can convert about 60 lumens per watt, which is four times greater than incandescent bulbs. On average, fluorescents emit around 20 BTUs of heat per hour, while incandescent bulbs emit around 56 BTUs per hour to produce the same amount of light.

An important consideration for implementing **LED lights** is their performance in cold regions. Because LED lights are more efficient, they do not produce as much heat as traditional incandescent bulbs. To date, there have been no field tests that prove what the threshold in terms of weather conditions is for the need of heaters. The FAA, however, does require that for medium intensity approach lights, the "energized LED light source shall prevent the accumulation of ice on the face of the light source when exposed to an ambient air temperature of -10°C ± 2°C and water droplet temperature of 0°C to 3°C" (FAA, 2012). Many airports in cold climates have reported success with LED fixtures that do not contain heating units; however, most airports have not performed experimental analyses to determine whether heaters might potentially be needed in their climates (Bullogh, 2012). Grand Junction Airport is in a region prone to freezing rain and snow accumulation.

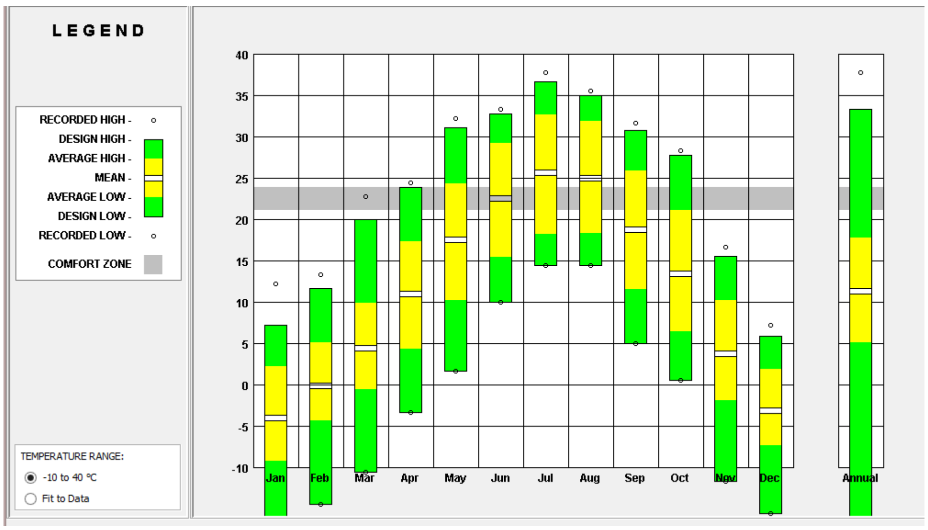


Figure 6: Seasonal Temperatures in Grand Junction (USGS, 2012)

7.4.4 Financial Analysis

A financial comparison of the five types of lighting options is presented in Table 5. It was determined that halogen lamps and HID lamps are not financially advantageous for GJRA. On the other hand, fluorescent lamps and LED lamps can save the airport considerable amounts of money over time (Building Energy Software Tools Directory, 2011).

In general, **fluorescent lamps** have higher capital costs than incandescent bulbs, but maintain lower operating costs. The most important statistic to consider is the payback period, which can be calculated using the EnergyStar calculator. Assuming Grand Junction wants to replace 60 watt incandescent bulbs with 50 watt fluorescent lamps at a maximum price of $5 per fluorescent bulb, a lifespan of roughly 25,000 hours operating 12 hours a day, and about ten cents per kilowatt-hour, Grand Junction Airport would save about $4.10 per bulb (EnergyStar, 2012). The payback period would be approximately 15 months and the airport would also eliminate 44 kWh per bulb of electricity use per year. Therefore, this option is economically sustainable because it saves the airport money in operation costs, it reduces carbon emissions, and it cuts down on energy use, which increases overall energy efficiency.

In addition to fluorescent lamps, **LED lamps** also have higher capital costs and lower operating costs than incandescent bulbs. According to the company Elemental LED, LED bulbs cost around $25 per bulb versus $0.84 per incandescent bulb (Understanding the Difference, 2012). The operating cost is a lot lower due to the increased lighting efficiency. The payback period depends on the amount of watts used, lifespan of the LEDs, and average hours of operation. If we use the initial prices above and replace each 60 watt incandescent bulb with a 6 watt LED that lasts on the low end of 50,000 hours and operates 12 hours per day at about ten cents per kilowatt-hour, LED lamps at Grand Junction Airport would become a better financial investment after the tenth month (Light Bulb Energy Savings Comparison Calculator, 2013).

Since some experts say that LEDs require a heater in order to be functional in colder conditions, we will use financial data from ADB Airfield Solution's LED L-850B model as an example to determine the economic difference between LED systems with and without heaters. From ADB Airfield's online calculator, an LED system without a heater will save the airport around $1,365 per year per fixture (ABD Airfield Solutions, 2012). An LED system with a heater will save the airport approximately $1,342 per year per fixture (ABD Airfield Solutions, 2012). These data show that introducing a heater into the system will only cost about $20 more per fixture each year. Sensors ensure that the heaters turn on only when the outdoor temperature is below 40 ^{0}F and only function to keep the glass of the lighting fixture above freezing temperatures. With Grand Junction being a cold-climate airport, this option is advantageous to keep airport operations running and does not inflate annual operation costs too much.

Table 5: Cost comparison of Differing Lights (Light Bulb Calculator, 2013)

	Incandescent	Halogen	Fluorescent	HID	LED w/o Heater
Capital Cost (Per Bulb)	$0.84	$4	$5	$150	$25
Average Lifespan (hours)	1,000	2,000	25,000	40,000	100,000
Payback Period (years)	----	No Payback	1.25	No Payback	0.83
Savings per Year	----	No Savings	$4.10 per bulb	No Savings	$1,365 per fixture

7.4.5 Preliminary Analysis

Implementing LED lights at GJRA would be the most advantageous option available. Based on input from our contact, Brian, at GJRA, only the flush mount LED lights will require heaters to operate in snowy conditions. Environmentally, production of LEDs emits the least amount of greenhouse gases into the atmosphere (Understanding the Difference, 2012). Also, when in operation, they require the least amount of energy in order to produce the same amount of light, further decreasing environmental impacts. While every other option requires some sort of filtering device to change the color, LEDs do not require a color filter, which otherwise could detract from their efficiency and lighting power. Economically, LEDs may be the most expensive in capital costs, but they have the fastest payback period. Additionally, LEDs last up to ten times longer and do not degrade in color over time, which cuts down the annual maintenance cost. On the social side, LEDs meet EnergyStar standards because they are at least three times more efficient and their luminous efficacy is greater than 20 lumens per watt (EnergyStar, 2012). Also, the state of Colorado has incentives for businesses that replace incandescent bulbs with LED lights. In conclusion, LEDs would provide the airport with the highest quality lighting that is more socially, environmentally, and economically sustainable.

7.5 Geothermal Heating

7.5.1 Summary

One important consideration for the new runway at Grand Junction Regional Airport is snow removal. Prevention of snow and ice buildup on runways is critical to ensure safe and timely operation of daily procedures. Airport operations managers have traditionally relied on chemical and mechanical methods including plows, brooms, sweepers, solid chemical dispersal, and liquid spraying equipment to clear snow and ice from runways and taxiways (Jane, 2012). Heated pavement systems could offer GJRA an alternative method of preventing snow and ice buildup on the newly constructed runway. Benefits of heated pavement systems include enhanced safety for aircraft and equipment operators, positive impact on capacity during winter operations, reduction in environmental impacts associated with chemical deicers, and a noticeable reduction in snow removal times required to clear priority areas (FAA AC 150/5370, 2011). However, these systems have high installation costs and complex installation procedures. The FAA recommends installing these systems at airports where: benefits will justify the cost of installation and operation, mechanical methods are difficult, use of chemicals may be limited, operational safety is a factor, and delays at critical locations cannot be tolerated (FAA AC

150/5370, 2011). Although these parameters don't directly apply to GJRA, CSEC has performed this analysis at the specific request of our client.

7.5.2 Literature Review

Passing electric current or circulating warm fluids through pipes in the pavement structure can be an effective method of heating airfield runways from within the pavement (FAA AC 150/5370, 2011). Resistive components such as cables, mats, and aggregates can be poured in the asphalt or concrete for electrically heated systems (FAA AC 150/5370, 2011). The electrical energy is converted to heat by the resistive material. Depending on how much electricity is flowing through the system, and the resistivity through the pavement, the heat generated will vary. Heating pavement through the use of electrically conductive materials is more expensive and is usually only used for small-scale projects. Because of this our team has decided to rule out this option for GJRA, and examine hydronic heat source designs.

Hydronic is defined as the use of fluid as a heat transfer mechanism through conduction (Lund, 2012). The fluid is cycled through pipes lying underground and buried in the pavement.

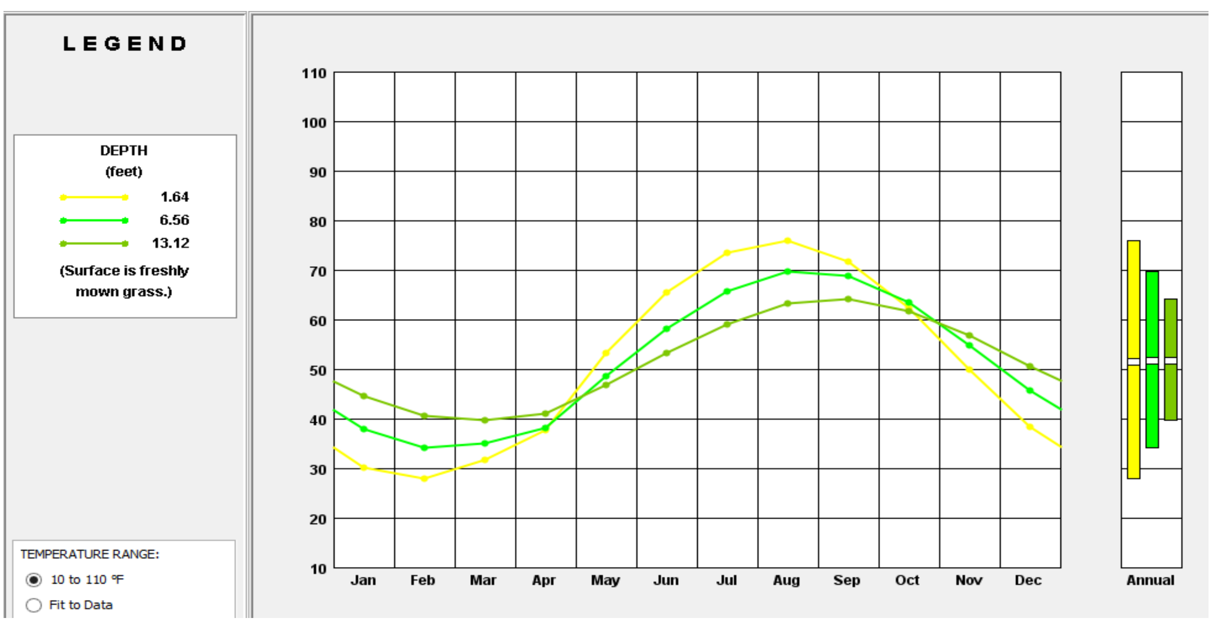


Figure 7: Average ground temperatures at specified depth for Grand Junction in 2008 (USGS, 2012)

"Various sources such as direct-use of geothermal hot water, Underground Thermal Energy Storage (UTES), boilers, and heat exchangers may be used for hydronic heating" (FAA AC 150/5370, 2011, pg 4). Because Grand Junction's monthly average ground temperature is around 35 degrees Fahrenheit (shown in figure 7), and because of lower costs, we have decided to pursue geothermal heat exchangers for this location.

7.5.3 Technical Aspects of Design

Our design goals are to meet FAA minimum design requirements for heated pavement systems using conservative estimates for system variables. The calculations used are those of American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) (ASHRAE, 200). To design a proper GHP system it is important to design parameters for the "heat transfer fluid, piping, fluid heater, pump(s) to circulate the fluid, and controls" (ASHRAE, 2007, pg 2).

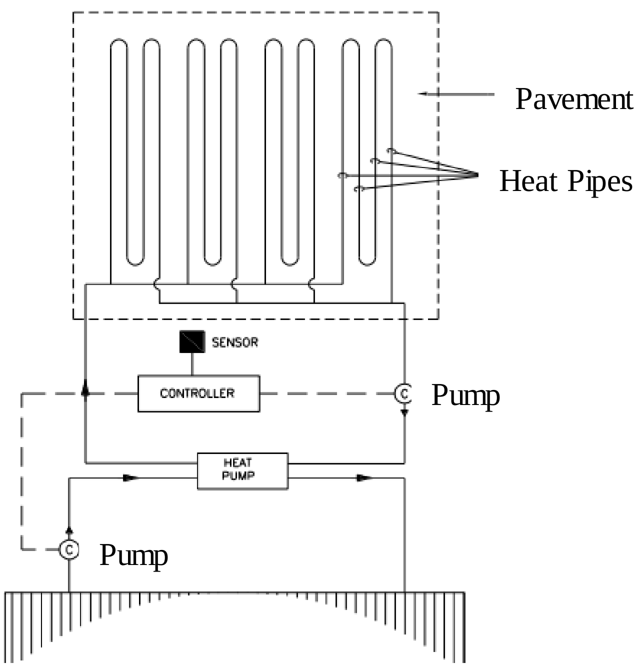


Figure 8: General Layout for Closed Loop Runway Heating (ASHRAE, 2007)

Our initial step in defining the design criteria for a geothermal heat pump for the new runway at GJRA was to assess the initial feasibility and define parameters necessary for general performance requirements. A list of these parameters and their values can be found in Appendix G. Some of these parameters include rate of snowfall, air temperature, relative humidity, and wind velocity (FAA AC, 2012).

Once a geothermal system was deemed feasible for implementation, we calculated the type and quantity of system components necessary. Tubing for the system is a major expense and critical to the longevity of the system. Of the two options for pipe, metal or plastic, plastic is more commonly used. Commonly used plastic pipes include cross-linked polyethylene (PEX), (Lund, 2012). However, to allow for an asphalt runway the temperatures need to withstand 300 ^{0}F, the normal temperature of asphalt when poured, which is above the range of PEX pipes. Because the typical pipe does not meet these temperature requirements, and because metal pipe is more expensive, we have elected to use High Density Poly Ethylene (HDPE) tubing. The diameter of the tubing required to accommodate the needed flow rate is ¾ inch.

Our team is assuming the proposed runway at GJRA will be the same size of the current main runway. GJRA would require 550 million BTU/hr to heat the runway, which equates to 45,833 tons of refrigerant needed. Choosing a horizontal slinky design requires 45,833 loops and accounts for 110 miles of underground tubing. The amount of tubing required to pass through the runway itself is 591 miles.

It is important to use a working fluid that is resistant to freezing in order to avoid damage to the system when the pumps are not running. The pumps could potentially be dormant due to power loss or pump failure (ASHRAE, 2007). Certain fluids including brine, oils, and glycol-water are acceptable for exchanging heat from fluid heater to the slab (FAA AC, 2012). Of these options our team has elected to use ethylene glycols, which are the most popular option because of their “moderate cost, high specific heat, low viscosity, and corrosion resistance” (Lund, 2000, pg. 5). Our team will follow standard practice and dilute the mixture to have 25% ethylene glycol and 75% water.

7.5.4 Financial

A financial analysis of the system was conducted to include initial costs and yearly costs for the system. The initial cost includes all costs of materials used, as well as installation costs. The net capital cost included accounts for government rebates and incentives. These results can be seen in Table 6. Once CSEC conducts a more thorough evaluation of current snow removal costs we will be able to provide a payback period for the system. Based on common snow removal practices for airports of similar sizes we predict a net capital cost payback period of 80 years.

Table 6: Cost Estimate for Geothermal (NRSE, 2013)(York, 2007)

Material	Description	Amount	Cost per unit	Total Cost
Pipes	¾" HDPE	740 miles	$3.25/ft pipe	$12,700,00
Antifreeze	Ethylene glycol	89624.6	$11.70/gal	$1,043,000
Pumps	York Titan (6167 tons each)	7 pumps	$9,044,933/ heat pump	$63,000,000
Electricity	12.5 kW/pump	7 pumps	$10,950/pump	$109,500
Drilling	Excavating trench standard 1 CY	740,000 BCY	$5.35/BCY	$3,960,000
Total Cost				$67,100,000
Annual Cost				$109,500
Total Net Cost				$37,100,000

Table 7: Incentives for Geothermal Heat Pumps (DSIRE, 2013)

Organization	Program	Incentive	Total Incentive
Xcel Energy	Business Energy Efficiency Program	Ground Source Heat Pump: $1500	$15,000
Xcel Energy	Ground Source Heat Pump Rebate	$300/ton	$13,750,000
Federal Government	Business Energy Investment Tax Credit	10% of project cost	$9,500,000
Federal Government	Renewable Electricity Production Tax Credit	$0.0202/kWh	$9,000
Federal Aviation Administration	Airport Improvement Program	75% of applicable costs	As much as $15,000,000

8. Alternatives Comparison and Decision

In order to choose the most effective energy solution for GJRA, we screened a multitude of possible alternatives, and ran the five best options through a weighted decision matrix to quantify the pros and cons of each solution. Through this process we defined specific criteria that help assess the relevance and effectiveness of each alternative. By applying scores that correlate to the strength of the alternative in each category, we are able to objectively compare each alternative to ensure that it maximizes its potential benefit to the airport.

One aspect of the decision matrix is a financial category to assess the economic strain of each alternative. A summary of the costs of each main alternative can be seen below in Table 8.

Table 8: Financial Comparison of Alternatives

Primary Option	Capital Cost	Payback Period (Years)
Fuel Cells	$22,000	15.91
Solar Array	$138,000	19
LED Lighting	$703,000	0.83
Geothermal Heating	$67,100,000	80

The criteria established for use in our decision matrix (Table 9) were developed by CSEC in collaboration with our faculty advisors, Rocky Mountain Metropolitan Airport's Nick Condon, and GJRA's Brian Harrison. Criteria were chosen within the categories of technical, economic, environmental and social factors. Within each category are multiple subcategories that help define which aspects of that category are most important. These criteria are catered directly towards affordable, energy-efficient and environmentally conscious designs for airport operations.

Each criterion has its own weighting factor to standardize its importance relative to the other criteria. These weights were determined initially through the consideration of practical factors influencing our design, as well as through discussion with our faculty advisor. Using feedback from our client at GJRA, some of our weights were changed to ensure the airport's wants and needs were being carefully addressed, and guarantee a final product that adopts GJRA's individual desires for an energy solution. Category and criteria weights can be found in the decision matrix (Table 9).

In order to objectively compare our energy solutions, a score is applied to each alternative for each specific criterion. Scores were distributed on a scale of zero to one, with one being the best score possible, and zero being the worst. Scores were assigned through careful evaluation of our literature review of each alternative, along with input from industry experts and airport officials. The product of this score and the overall weight of the criterion yields a weighted score, and the sum of all weighted scores gives the total score for that alternative. The highest total score indicates the solution that has the potential to provide the most benefit to our client at GJRA. This is the solution we will suggest to our client, but we will also consider parallel implementation of several designs that could provide additional synergetic value.

Table 9: Weighted Decision Matrix

Category	Category Weight	Specific Criteria	Criteria Weight	Solar Array	LED Lighting	Fluorescent Lighting	Geothermal Runway Heating	Fuel Cells
Technical	40%	Replicability	25%	0.75	0.75	0.75	0.75	0.75
		Resource Availability	32%	0.75	0.75	0.75	0.75	0.75
		Construction Feasibility	43%	0.5	0.75	0.75	0.5	0.5
Economic	40%	Payback Period	40%	0.25	0.75	0.75	0.25	0.25
		Initial Cost	35%	0.75	0.25	0.5	0.25	0.5
		Net Present Value	13%	1	1	1	0.75	1
		Grants and Incentives	12%	1	0.25	0.25	0.75	0.75
Environmental	4%	Emissions During Tech Production	50%	0.75	1	0.75	0.5	0.5
		Greenhouse Gas Reduction	50%	1	1	1	0.75	1
Social	16%	Safety	75%	1	1	0.25	1	0.5
		Aesthetically Pleasing	25%	0.5	1	1	1	1
TOTAL		**Satisfaction**		**0.642**	**0.784**	**0.624**	**0.592**	**0.585**

As shown in Table 9, implementing LED lights is the most beneficial option, followed by solar panel energy generation. Because of these scores, CSEC has created a preliminary design to implement LED lights in conjunction with a solar array to offset the energy use of the lights.

9. Safety Risk Assessment

A safety risk assessment is applicable to all design alternatives, and played a sizeable role in determining which alternatives were chosen. Safety is paramount in all airport operations and must be considered when assessing our design solution. The FAA promotes this protocol to a high degree, and as a result, has made travel by air one of the safest and most reliable sources of transportation. The FAA mandates an assessment of potential hazards using the Safety Management System (SMS), prior to implementation of any new designs. Determining the risk level of a given solution is achieved through the five phases of Safety Risk Management (SRM), as detailed in the FAA's Safety Management System Manual (FAA, 2008). This process is used to describe the system, identify hazards, analyze the risk, assess risk, and finally, alleviate the risk through alternative strategies or preventative measures (FAA, 2008).

Installation of LED runway lighting poses a large safety risk at higher latitude airports that receive snowfall during winter months. As opposed to conventional runway lights, LED's don't produce enough heat to melt snow that falls on the lights (ADB, 2012). If the lights are covered up it may prove difficult to locate the runways and land an aircraft. One potential remedy to this hazard would be to install heaters to melt any snow accumulation on the lights. Officials at GJRA have informed CSEC that the elevated taxiway and runway lights at GJRA do not receive enough snow accumulation to justify heaters; however, the flush mount lights will require heaters (Harrison, 2013). Another potential hazard associated with LED runway lighting is the fact that they don't emit light in the infrared wavelength. Some aircraft use infrared sensing to locate the runway and autonomously land the vehicle, so lack of this wavelength of light could prove dangerous (Williams, 2012). Pilots will have to be properly notified before attempting to land on the proposed new runway.

When considering solar power generation, we encountered a problem with reflection of sunlight off of concentrated solar mirror surfaces. This poses a threat to incoming pilots that may be flash blinded by the reflected rays, and therefore, unable to land the aircraft (FAA, 2008). Reflected light could also be mistaken for runway lighting, and cause a misguided landing. As a result of this hazard, we are not going to consider concentrated solar applications, and will focus our energy on photovoltaic solar power. These panels have a very low reflectivity, but still pose a threat if mounted on top of pre-existing structures (FAA, 2010). The airport "must submit to the FAA a Notice of Proposed Construction Form 7460 under part 77 to ensure the project does not penetrate the imaginary surfaces around the airport or cause radar interference" (FAA, 2010). CSEC has ensured that the proposed designs meet FAA regulations for safety requirements.

10. Final Design

10.1 Overall Recommendation

Based on the results of our weighted decision matrix, LED lighting technology is the most cost-effective and direct way to reduce emissions and energy use at Grand Junction Regional Airport. An LED system installed with solar generation will not only enhance these reductions, they will also make GJRA a model for other airports across the nation. Since our design for the solar array is a grid tied system we will not need to implement a battery bank. The solar array will be installed northeast of the current runway in a location recommended by Brian Harrison. This location will allow for future renovations to the runways and taxiways without hindering solar power generation.

10.2 Design Detail

10.2.1 Solar Array

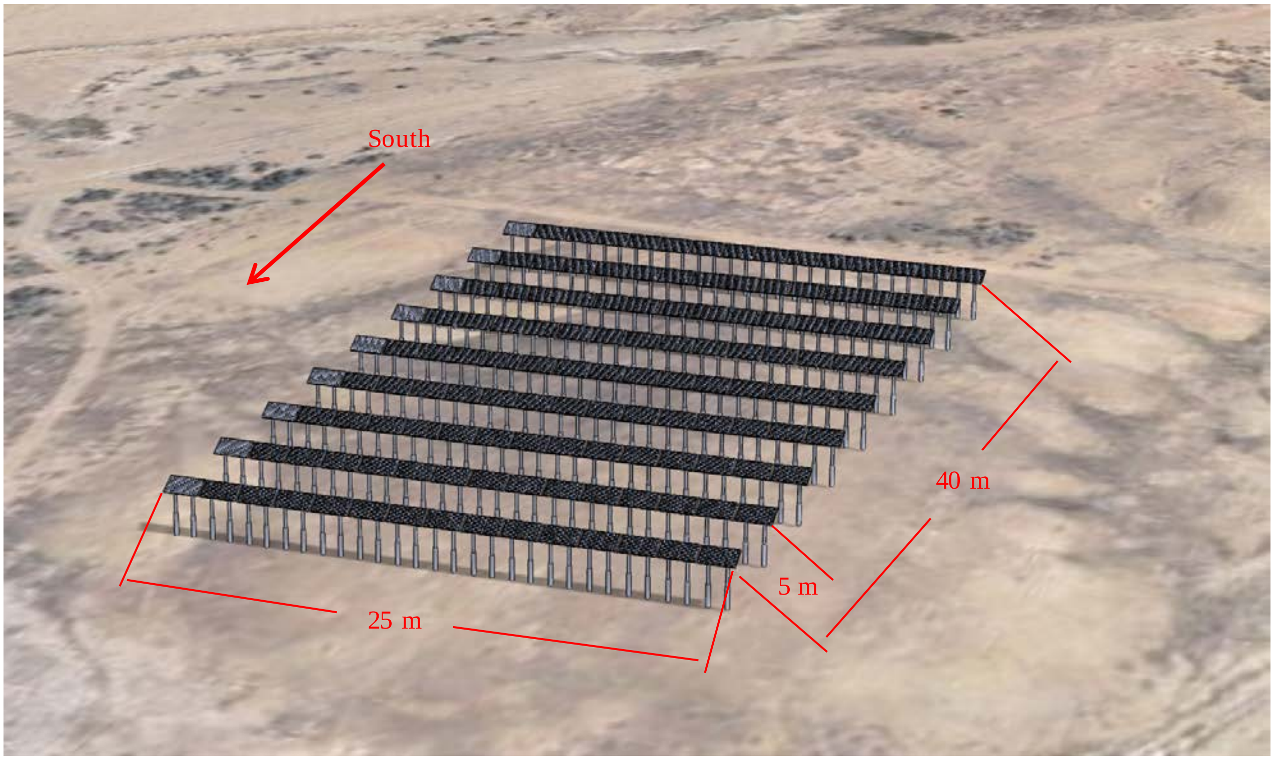


Figure 9: Solar Panel Array Configuration on Site (Module by Fabijanic, 2011)

The solar array will consist of 135 SunPower SPR-210-BLK-U solar modules laid out in 9 rows of 15 modules. The modules will be mounted in each row such that they are as close to each other as possible to minimize land footprint. This array can be seen in Figure 9 created by CSEC using a standard solar panel model. The array will have an Open Circuit Voltage of 429.3V that feeds to a single Ideal Power Converters IPV-

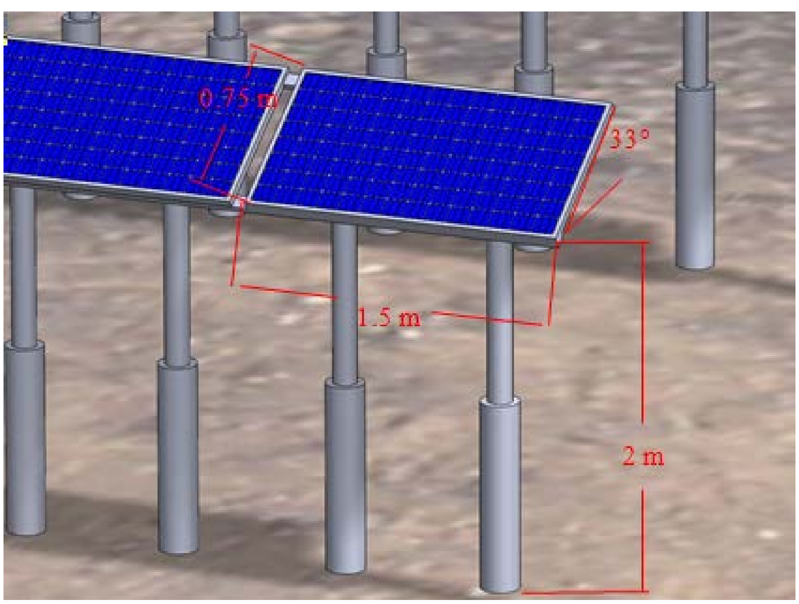


Figure 10: Solar Panel Dimensions (Fabijanic, 2011)

30kW-480 grid-interacting inverter that will supply 480VAC to the airfield vault, where the electricity will be fed to the utility mains through a net meter. The amount of electricity fed to the grid will be slightly more than that used by the proposed LED Lighting system, effectively offsetting the electricity used for airfield lighting and the associated greenhouse gas emissions. The array will eliminate between 49.7 and 52.1 tons of CO_2 emissions per year (DOE, 2013).

10.2.2 LED Runway/Taxiway Lights

The Plans for building the new runway 11/29 at GJRA include the complete demolition of the existing runway 11/29 and its associated taxiways and ramp, as the asphalt has reached the end of its lifespan and the runway's crown is no longer at the centerline. A new ramp area, taxiways, and runway will be constructed near the current location. The new runway will be shifted north and slightly east in order to eliminate conflicts at the corner where runways 11/29 and 4/22 meet. The new taxiway will therefore be slightly larger than the current taxiway, and will have more infield areas. As such, a greater number of taxiway edge light fixtures will be needed, but due to the fact that they will use LED bulbs instead of incandescent bulbs, the overall energy required to light the airfield will be roughly 55% of the current energy required.

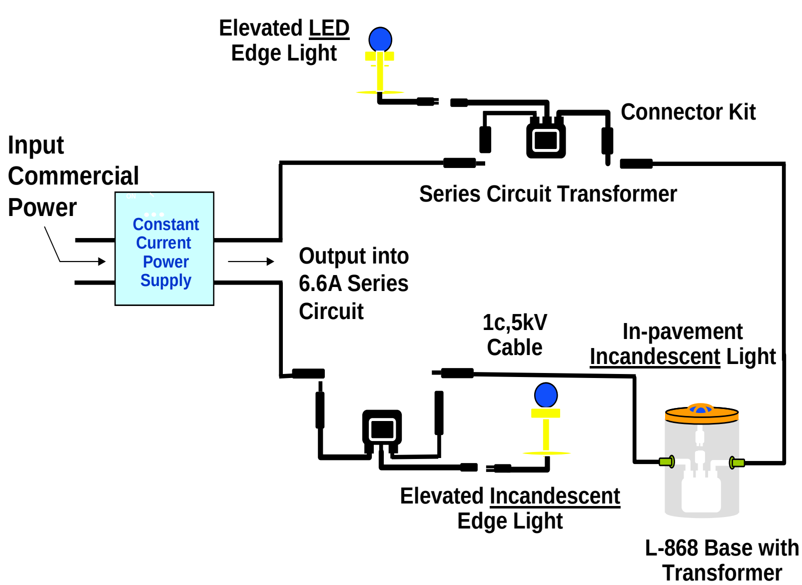


Figure 11: General Circuitry in Taxiway (Rainey Ford, 2006)

Since the infrastructure will be replaced, retrofitting existing conduit, etc. will not be necessary. Warranties for lights, transformers, etc. also require that new cable be pulled from the airfield vault to the lights (Harrison, 2013).

Table 10: Detail of Lighting Fixtures to be Installed (ADB Lighting, 2013)

	SWCS	SSS	L-850B	L-850C	L-861/E	L-861T	PAPI
General Description	Solar Wind Cone System (SWCS)	Solar Sign System (SSS)	TDZ	Flush Mount Runway Edge Lights	Elevated Runway Edge Lights	Elevated Taxiway Edge Lights	Precision Approach Path Indicator
Number of Units	3	Double: 34 Triple: 18	90	9	L-861: 157 (93&64) L-861E: 8 (4&4)	400	8
Isolation Transformer (W)	PV: 95 W	100	25	65	L-861: 45 L-861E:45	45	Connected to Solar kit
Fixture Load (VA)	N/A	100	15	15	L-861: 20 L-861E: 12	12	280
Lifetime Hours	Battery: 4,000 cycles; PV:10 years	10 years	150,000	150,000	150,000	180,000	43,800
Average Annual Operating Hours	2738	2738	2738	2738	2738	2738	2738
Total Annual Power consumed (kWh)	N/A	14238	3696	370	L-861: 8,598 L-861E: 263	13142	6133
Total Fixture Cost ($)	$1,500	$54,000	$54,000	$5,400	$33,000	$70,000	$3,200
Total Operating Cost ($)	$0	$27,410	$7,238	$885	$26,862	$38,790	$0
Total Life Cycle Cost ($)	$1,500	$81,410	$61,238	$6,285	$59,862	$108,790	$3,200
Estimated Emission Reduction (metric Tons of CO2)	N/A	N/A	94	9	106	513	N/A

Figure 12: Proposed Three New Circuits for New Runway and Taxiway (Harrison, 2013)

The cables from the airfield vault will run through the ground in 2” PVC conduit buried 2’ below the surface. Each lighting circuit will have a dedicated conduit so that bleeding between the systems does not occur in the event of a short to ground. At the site of each light, an aluminum recessed can will be buried such that it is flush with the ground. This can will house the isolation transformer for each light and serve as the mounting point for the fixture. The transformers and Constant Current Regulators currently in operation at the airfield can be reused for the LED lights on the lowest setting of 2.8 Amps, eliminating the need for the purchase of new equipment.

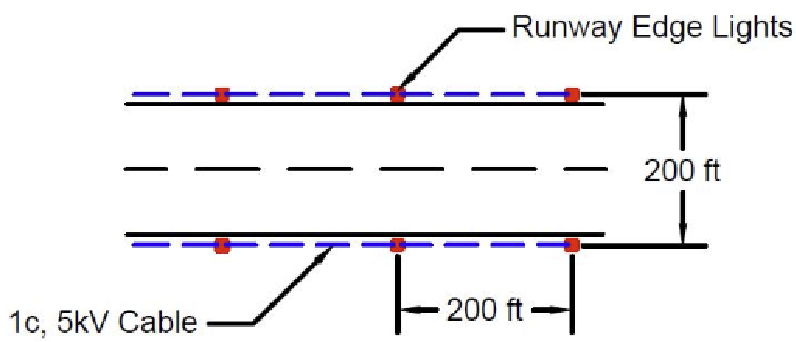


Figure 13: Runway Edge Light Spacing Dimensions

Table 11: Required LED Light Fixtures for New Taxiway and Runway

Fixture Type	Quantity	Unit Cost	Total Cost
SWCS (L-806/7 wind cone with solar power supply)	3	$6,500	$19,500
SSS (L-858 Y/R/L/B with solar supply)	Double: 34 Triple: 18	$5,750	$299,000
L-850B (TDZ)	90	$990	$89,100
L-850C	9	$1,325	$11,925
L-861/E	173	$575	$99,475
L-861T	400	$400	$160,000
PAPI	2	$12,000	$24,000
Total	729		$703,000

10.3 National Applicability

There are 64 commercial airports in the United States that are comparable to GJRA servicing 100,000-300,000 passengers per year (Federal Aviation Administration, 2013). Assuming passenger load correlates to airport size, a majority of these airports could benefit from at least one aspect of the design proposed in this document, depending mainly on the location and climate of each airport.

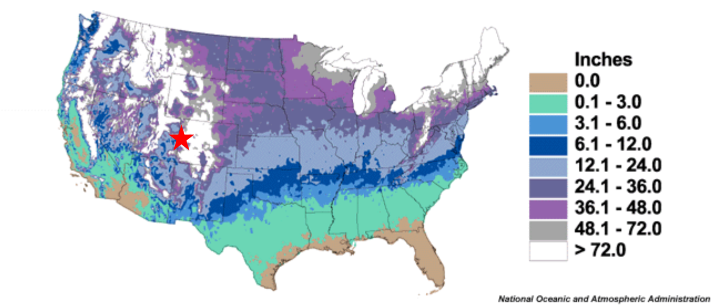


Figure 13: Annual Snowfall in USA (NOAA, 2013)

Grand Junction is located in a region with under twenty-four inches of snow per year and does not require heaters for the proposed elevated LED runway installation, only the flush mount installations. Based on first-hand observations of the current light fixtures, heaters are not required. Brian Harrison, the Master Electrician at GJRA, stated that heaters would definitely not be needed, as he has not seen any snow sticking to the current lights when they were off, which indicates that even with the diminished heat output of the LED lights, snow will not obstruct view of the lights. However, Airports in areas that receive more than twenty-four inches of snow per year or that have significant ice accumulation should consider installing heaters with all of the LED lights (Harrison, 2013). This will slightly increase the capital cost and operations cost for this design.

GJRA is also situated in a region with moderate to high incident solar radiation. With surface irradiation of over 5 kWh/m^2/day, Grand Junction is an appealing site for solar energy implementation. Airports in regions with less than 4.5 kWh/m^2/day of incident radiation can still benefit from a solar array; however, less energy will be produced per solar panel. This will affect

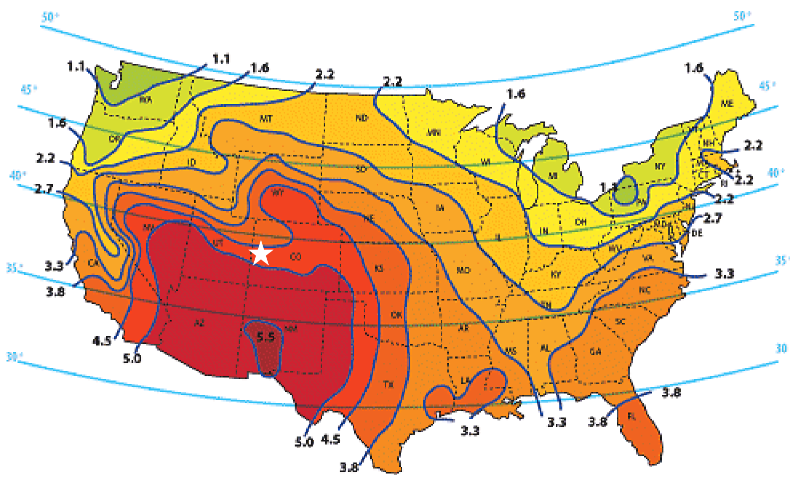


Figure 14: Incident Solar Radiation (Energy, 2009)

the capital cost and payback period for this technology, so a detailed cost analysis will be required at each location. Of the 64 airports of comparable size to GJRA, seven of them lie in regions with more than 5 kWh/m^2/day, and can gain added benefit from a solar array. They can either install fewer panels, therefore reducing the economic strain of installation, or produce more energy from a similar-sized array.

11. Conclusion

In this report CSEC assessed several potential methods to improve energy needs for Grand Junction Regional Airport. This review was conducted in response to the FAA design competition to improve energy efficiency in airfield management. CSEC analyzed several alternatives including solar power, geothermal heating LED lighting, and fuel cells. After an assessment of all alternatives it was deemed best to use LED lighting with a solar panel array. These systems can be installed with the new runway and taxiway to offset costs even further. The designs included in this report should help GJRA reduce its carbon emissions and reduce energy needs.

12. Appendix A: Contact Information

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13. Appendix B: Background of the University of Colorado

The University of Colorado at Boulder is the largest University in the state, and is one of only thirty-four U.S. public institutions belonging to the prestigious Association of American Universities (AAU) (CU Boulder, 2013). The school offers bachelors, masters, and doctoral degrees in over 150 different fields of study with strong programs in the sciences, engineering, education, music, business and law, among others (CU Boulder, 2013). Since opening in 1877, the university has developed a proud tradition of academic excellence, as well as an outstanding alumni community that has contributed in all factions of society.

The CU Boulder College of Engineering and Applied Sciences was established in 1893 and since then has been one of the top-ranked engineering programs in the country (CU Boulder, 2013). The new-age curriculum offered integrates the benefits of hands-on learning with the professional expertise and structure of a highly qualified staff. The ITL Laboratory offers students the chance to use state-of-the-art machining equipment to synthesize components for design and research projects. The collaboration of students across multiple cultural backgrounds and engineering disciplines; including Mechanical, Environmental, Civil, Biological, Chemical, Aerospace, Architectural, Computer Science and Electrical Engineering; provides a well-rounded and highly adaptable education. Within the Environmental Engineering program, students can choose one of six options to focus on. These include energy, water quality, air quality, waste management, soil remediation, and ecology. Each member of our team is following the energy option within CU's Environmental Engineering program. As representatives of this University, our group aims to raise the standards even higher through the culmination of this design project.

14. Appendix C: Description of Non-University Partners

Before selecting an airport, our team spoke with Bruce Jacobson and Laura Sakach (competition representatives for the FAA) to discuss competition details and ask for assistance in finding a suitable airport as a client. Bruce put us in touch with the Aspen airport, but the project there did not conform to competition requirements. David Gordon from CDOT also provided assistance in airport selection, and through our personal research we came into contact with administrators from Grand Junction Regional Airport.

The primary contact between our team and Grand Junction was Brian Harris, the Master Electrician. He provided advice and guidance about our design and how to tailor it to the needs of Grand Junction Regional Airport. Through the course of the design process, we have been in contact through phone and email, and two members visited the site to meet with Brian in person and survey the current and planned runway/taxiway sites. In addition, they gained valuable knowledge of lighting circuits, fixtures, and other components. The team liaison has maintained weekly communication by e-mail, and biweekly communication over the phone. Brian has supplied us with a large amount of client-specific information including runway maps, circuit information/diagrams, airport energy usage, and more.

Since we aimed to scale our project to match the needs of other airports, we have also remained in touch with Nicholas Condon, the operation specialist from Rocky Mountain Airport. He has provided input on both our design and our approach to this project. Interactions with him have been limited to phone and email. We have also sought advice from officials in the FAA as well as CDOT.

16. Appendix E: Evaluation of Educational Experience

Student Response

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

The FAA Design Competition did provide a meaningful learning experience because it encouraged us to understand the scope of an engineering project with real deliverables and real clients. The FAA has provided many resources to help us with the design process and encourages high quality results. Our team has become much more familiar with technical details surrounding airports in Colorado. This design has helped allow our team to develop professional engineering skills that lectures alone could not deliver.

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

Our team initially struggled to find a partner airport. In order to overcome this challenge we contacted many experts available to students in the FAA design competition by phone and email. Bruce Jacobson and Laura Sakach provided us with valuable information on how to contact airport administrators and where to find literature on energy efficiency in airfield management. After contacting eight airports in the Colorado region we decided to work with Grand Junction Regional Airport.

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

Our team developed our hypothesis by first working closely with Grand Junction Regional Airport to assess their energy needs. We then produced a literature review comparing possible solutions to the energy problems faced by the airport. Next, we consulted other airports to gauge whether they had similar energy problems and asked for their opinions of the proposed solutions. We then created an alternatives assessment to compare the solutions in more detail. Initial cost and payback period were of primary importance to most airports, which was a focal criterion to our hypothesis.

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

Our team was fortunate to have dedicated industry partners and cooperation from experts. Our stakeholders at Grand Junction Airport played an active role in the creation of our preliminary design and were in weekly communication with our team. We also received input from other airport officials and administrators allowing our design to be more replicable.

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?

This project helped us learn a great deal about a systematic engineering design approach. We learned how to manage ourselves and create deliverables the client can utilize. More specifically we learned professional skills including communication, professionalism, time management, and producing higher quality work. Our research abilities were greatly improved and we feel much more confident in where to find credible and applicable resources for a specific research question. These improved skills should assist us in our future careers both in academia and industry. By working with industry experts and professionals we were able to absorb what is expected of each member working on a project. This competition has helped our ability to succeed in our future careers by enabling us with these new skills.

Faculty Response

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

This competition has provided an opportunity for students to experience what it is like to work in a structured team and coordinate activities and tasks. The students have learned many skills in problem formulation, information collection, task and role delegation, technical details of design, and self-reflection on positive and negative aspects of their work and the work of their teammates.

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

Yes – the learning is supposed to be in approaching an open ended problem and this was accomplished through the FAA competition.

3. What challenges did the students face and overcome?

Initial challenges were in formulating the precise theme for their project. This included challenges in finding an airport to work with, making contact with appropriate people to provide them information needed and making sure their approach and project fit into the rules of the competition. There were numerous challenges in the technical aspects of the report including how to narrow down their options, deciding between energy generating and energy efficiency as a theme, and how to properly weight their decision and decide on a single design solution. All of these challenges were met and overcome.

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

Yes. This competition provides the students with opportunity to work on a concrete problem of current interest. It is a chance to interface with professionals. It provides clear guidelines to follow which can be instructive in developing a design report. Having a competition provides a certain level of motivation for the students to perform to their best ability for something in addition to a good grade.

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

While the rules are good and clear, the topics are quite broad. Perhaps a more detailed statement of request for proposal would help to get focused more quickly. Having partner airports set up might also help streamline the student work.

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