# SUSTAINABLE CLIMATE CONTROL FOR A MID-RISE OFFICE BUILDING IN THE SALT LAKE VALLEY

By

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## Executive Summary

This report examines the sustainability of Trane's EarthWise™ climate control systems in the Salt Lake Valley (and the United States Mountain West in general). A simulation is performed to determine the best climate control system for a LEED Silver, 5-story tenant office building. This new building is a duplication of a pre-existing building. The climate control system installed at the preexisting building is used as a baseline against which three (3) alternative systems are compared. The social, ecological, and economic impact of each alternative is examined to determine which is the most sustainable. Since the baseline system is a proven option for LEED, and therefore ecologically sustainable, emphasis is given to the economic viability of the alternatives.

The first alternative reduces temperature of the air supplied to the conditioned space. The theory is that by supply cooler air, less of it can be delivered, which should result in smaller equipment with lower installation and operation costs. This system would save approximately $8,000 per year in utility costs. The second alternative adds thermal storage to the baseline. With this system, ice can be produced at nighttime, when electricity is cheap and plentiful, and then melted during the day to offset some of the cooling requirements for the building. By shifting the time the energy is consumed to off-peak hours, this alternative saves over $18,000 a year in electricity costs. The final alternative combines the first two alternatives with a new high efficiency chiller running a more efficient refrigerant. In the end, despite the increased installation cost of the fourth alternative, it is selected as the favored system because of its low cost of operation (saving over $26,000 a year) which results in a payback period of less than 3 years. These savings result in a 44.5% return on investment, which makes this particular alternative a highly attractive climate control system for the given building, and one that is worth considering for other buildings in similar climates.

# Introduction

Although commonly looked at as a burden of doing business in the modern era, green building and sustainable production can actually provide a business advantage. Green building, in particular, can result in substantially higher construction costs as steps are taken to mitigate the environmental impact of new construction. However, building green may not always a burden. There may be instances in which energy saving options may not only reduce environmental impact, but may also positively affect the bottom line for the builder. If such a system lowered the overall environmental impact of a building while at the same time reducing expenses, it would be well on its way to be considered not just green, but sustainable.

Sustainability can be simply defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (NGO Committee on Education 1987). So, in order for an HVAC system to be considered a sustainability improvement, it needs to reduce environmental impact, while lowering costs or increasing profits, and beneficially impacting the community into which the system is installed. Only when something meets all three of these requirements, does it qualify as sustainable. This project examines the five-story “Thanksgiving Park II” office building in Lehi, Utah to determine if an energy saving (and therefore more-green) heating, ventilation, and air-conditioning (HVAC) system would provide both a business advantage and a more positive community impact than a traditional system.

As one might imagine, the highly conservative Salt Lake Valley is not quick to adopt anything simply because it is green. In order for a green HVAC system to be installed in a new building, it needs to be proved as sustainable. In the summer of 2010, the Rocky Mountain division of the Trane Company was given the opportunity to help select the HVAC system to be installed at Thanksgiving Park II. The building will be a five story office building of identical design to a pre-existing building. The HVAC system

will bid late in 2010 with a selection being made by the owner and engineers by the end of the year. Rocky Mountain Trane decided to use this opportunity to evaluate some new, supposedly much more efficient, technology. This seeks to determine the most sustainable (economically, ecologically, and socially) system to present for possible installation.

## Scope and Deliverables

Within the six-month time frame, an entire heating, ventilation, and air-conditioning system needs to be laid-out to service the new 250,000 square foot building. Starting with the system installed in the pre-existing building as a baseline, multiple alternatives will be analyzed to establish the best recommendation based on the criteria. The analysis aims to find the most sustainable air-conditioning and ventilation system available from Trane. The heating system of the building will not be analyzed as Trane has not introduced any major changes to heating equipment since the installation of the system in the pre-existing building. The main technologies to be analyzed are low-temperature low-flow air, thermal storage, and "free-cooling" economizers. Once the analysis is complete, a final recommendation will be made for the most sustainable system.

The analysis will be carried out using the TRACE 700 software package from Trane. The program will be given the dimensions and exposures of the building, then using a highly specialized weather data package, TRACE will determine the exact heating and cooling load experienced by the building for every day of the year. Once the loads have been determined, various HVAC systems can be simulated in the building to find the one with the lowest economic, environmental, and social impact. Of particular importance is the economic impact. It is necessary to determine if it is possible to see a return on the investment in a newer (and potentially more expensive) HVAC system. This process will be discussed in further detail in the Methodology section of this report.

## Organization

The report will be organized as follows:

- A case is made by presenting related coursework that finding the solution to this problem is in-fact an ideal Industrial Engineering project.
- The background of sustainability as it relates to green building, and in particular heating, ventilation, and air-conditioning, is presented.
- A review of pertinent academic and professional literature to support the assumptions and conclusions of this report.
- The project organization and design will be established.
- A detailed description of the process by which the conclusions are reached.
- The conclusions of the analysis and final recommendations of the Rocky Mountain Trane sales office to the builders is described in detail, along with supporting reasoning.
- Finally, conclusions and pertinent generalizations are presented to the reader.

## Applied Coursework

As a Senior Project, this report will draw upon material from the following Industrial Engineering courses offered at California Polytechnic State University, San Luis Obispo:

IME 239 – Industrial Costs & Controls provides the foundation of business practices that will allow this project to be successfully implemented by Rocky Mountain Trane at Thanksgiving Park II.

IME 314 – Engineering Economics has laid out the financial decision-making system which proves that this system is a financially wise investment.

IME 319 – Human Factors Engineering principles are applied to define comfortable working environments.

IME 401 – Sales engineering skills are used to research and recommend the solution. Consultative sales abilities are utilized to present the solution to the decision-making engineering firm.

IME 301/405/407 – The ability to optimize the competing economic, ecological, and social factors is essential to a successful system selection.

IME 420 – The TRACE 700 program is an analytical simulation technology that requires careful tuning in order to achieve accurate results.

## Background

The HVAC system to be analyzed is destined for the Thanksgiving Park II office building. The owner of the Thanksgiving Park office building complex prides itself on green building. According to the website, Thanksgiving Park I is the first Class-A office building in Utah to be certified as LEED Silver. The building owners claimed to emphasize "state-of-the-art strategies for sustainable site development, water savings, energy efficiency, materials and resources selection, and indoor environmental quality" (Thanksgiving Park 2010). As such, the owners desire to implement the most environmentally responsible systems feasible in Thanksgiving Park II. For this reason, the owner's engineers approached Rocky Mountain Trane with a request for a highly efficient air-conditioning system. Although not an abnormal request, given the current economic climate, most builders are requesting the least expensive installed HVAC option, often at the expense of efficiency and life-cycle costs. The climate of 129,000 square feet of tenant office space can be very expensive and difficult to maintain even with the best equipment; using a bargain priced option may make it impossible. Because of the scale and prominence of the Thanksgiving Park II building, the leadership at Rocky Mountain Trane has determined to spend extra time selecting the most sustainable system possible.

This decision fits nicely with Trane's recent push into the green building market. Dubbed "EarthWise™" systems, Trane recently introduced a line a HVAC systems aimed at reducing environmental impact while potentially lowering overall life-cycle costs. A typical EarthWise™ system employs the so-called "low-temperature, low-flow" central chiller plant paired with a high efficiency chiller. In this system, the central chiller plant produces supply air for the air-conditioning system at 48°F rather than the standard 55°F. As a result, a smaller volume of cold air is required. Therefore smaller fans, coolant pumps, and ductwork can be used. The result, in theory, is that less energy is required to keep the conditioned space at a comfortable level. The problem is, these systems were designed by corporate engineers, and the possibility exists that the new systems are not the as sustainable as they are purported to be in all regions and climates. Thus, the system selection for Thanksgiving Park II is not just another opportunity for the office to close a large deal, but also to test the viability of the EarthWise™ systems in the Salt Lake City market. The climate of Salt Lake City is similar to much of the mountain west with cold winters and hot, dry summers. Monsoonal rains are common in the summer as are temperatures far in excess of 100°F. So, proving the EarthWise™ systems in Salt Lake City could lend credibility to these systems throughout the Rocky Mountain States. But, in order to close the deal (which remains the number one goal), the EarthWise™ system needs to live up to its reputation as an economically wise decision, not just an ecologically sound one. This is where the analysis begins.

## Literature Review

The system analysis begins by reviewing the pertinent literature on a variety of topics, from sustainability and green building to various energy saving technologies, optimizing HVAC systems, refrigerants, and occupant comfort. Studies linking employee comfort and productivity are reviewed as well. The owners of the Thanksgiving Park corporate park claim that their goal is to be sustainable and that to that end, they have built the first LEED building in Utah (Thanksgiving Park 2010). They assert that every effort has been made to reduce energy use. Specifically, the building complex uses the most

efficient air-cooled chillers available. This is important because “buildings are some of the largest consumers of natural resources and the largest generators of carbon emissions” (Hsieh 2007). According to some estimates, buildings are responsible for 39% of all $CO_2$ emissions and use 70% of all electricity in the United States. Globally, buildings consume 15trillion gallons a water a year and consume 40% of all raw materials (Hsieh 2007). Thankfully, Hsieh also points out that “green buildings use 36% less energy … and reduce CO2 emissions by [up to] 50%.” Reducing energy consumption is the first step in the process for a building to become LEED certified.

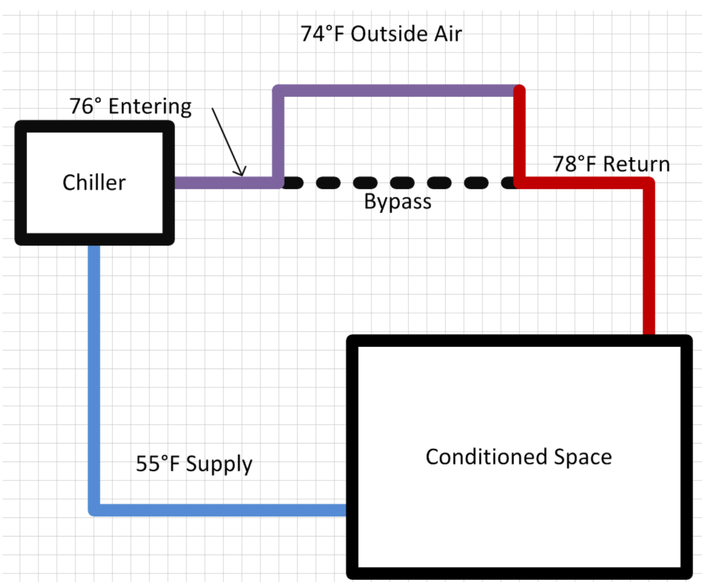
The first rule in saving HVAC energy is to reduce the building load. This can be accomplished through proper orientation of the building to minimize thermal gains at peak times, by glazing exterior glass, and by proper construction techniques that limit the amount of unconditioned outside air leaking into the building (Biesterveld 2008). Once the building itself is as efficient as possible, it is necessary to begin work on the HVAC system itself. There are a number of different technologies for reducing climate control costs. The trick is to find which options will optimize the system for a particular climate, and more importantly, for a specific building.

One of the most important considerations in the selection of HVAC equipment is which refrigerant to use. Currently, two refrigerants are used in central chilling plants, HCFC-123 and HCFC134-A, better known as R123 and R134-A, respectively. R123, though more efficient than R134-A, is actually slated to be phased out over the next 20 years while R134-A has no official phase-out date at this time. According to the Kyoto Protocol, R123 will not be allowed in new HVAC equipment after 2020, but the refrigerant itself can continue to be produced until 2030 (Thompson 2009). After 2030, R123 can only be replaced through the recycling of existing refrigerant. Because R134-A has no specific phase-out date and a lower global warming potential than R123 may companies view R134-A as preferable to R123. However, R134-A systems run at higher pressures (R123 actually run under a vacuum) and so the

leakage rate of R134-A is much higher than the leakage rate for R123. This means that although the global warming potential for each gram of R123 is higher than the potential for each gram of R134-A, more R134-A leaks into the environment than does R123, which results in R134-A causing more environmental damage. As a result of this, Europe has already banned the use of R134-A in all new cars as of 2011 (Thompson 2009). And, because R123 systems run at much lower pressures, they are actually much more efficient. The research therefore seems to support the use of R123 to achieve the most efficient (green) system possible, which is convenient for the Trane sales office, since Trane chillers use R123 almost exclusively.

One of the oldest concepts for saving energy on building climate control is what is known as "free cooling." The simple idea is to use the ambient environment (outside air) to provide as much cooling as possible. Because of the heat load generated inside of a building by office equipment, people, lighting, etc. most large office buildings require year-round cooling in order to maintain a comfortable working environment. Free cooling utilizes a heat sink that is below the return temperature to reduce the load on the cooling system. Figure 1 shows a simplified free cooling system. In this system, cool air flows from the chilling plant at 55°F to the conditioned space which is maintained at 72°F. As the supply air warms it is sent back to the chiller at the return temperature of 78°F. But, if there is a natural heat sink (outside air, incoming domestic water, etc) that is below the return temperature, then some of the heat energy in the return can be absorbed by the natural heat sink. In the figure, this is depicted as the 74°F outside air that absorbs 2°F off the return,

**Figure 1 - Simplified Free Cooling Diagram**



allowing a 76°F entering temperature. This means that instead of having to lower the temperature of the return by 23°F, the chiller only has to lower it 21°F. This may not seem like a lot, but every little bit helps. "Not surprisingly, truly free cooling is a myth. Just as there is no free lunch, free cooling is a concept, not a reality" (Trane Company 1991). There is always a cost. In this example, extra energy is needed for the fans to push the supply air through a longer loop exposed to the outside air. Another type of free cooling is known as an airside economizer. An airside economizer uses outdoor air instead of the return air as long as the outside air is cooler than the return air. The most common cost associated with an airside economizer is the loss of control over humidity levels. This is generally not an issue in dry climates, but can be problematic in more humid climates.

Another common method of saving energy is to employ a variable primary flow (VPF) system. In a VPF system, two or more small chillers are linked to the same system in such a way that when only a little cooling is required, only one chiller needs to operate. Then, for the short periods of the day when cooling loads are very high, both chillers can be run to meet the needs of the building. This method can be highly effective and often has a lower installed cost than a single chiller that produces the same maximum cooling capacity (Schwedler 1999). However, a VPF system is not right for every situation. These systems often require more floor-space because two (or more) chillers are being installed rather than one, and if the building has a level cooling load throughout the day, a single large chiller operating at its maximum efficiency will be more cost-effective to operate than two chillers that cycle on-and-off throughout the day.

The final energy saving technique examined is the use of a thermal storage medium, typically ice. Thermal ice storage "does for cooling what a domestic water heater does for hot water… ice storage utilizes plentiful nighttime-produced electricity to generate and store daytime cooling" (Tarcola 2009). According to PSEG (2010) electricity is generated at approximately the same rate during the day and the

night. But significantly less electricity is used during the nighttime than is used during the day. As a result, nighttime electricity rates are much lower than daytime rates. In order to take advantage of this phenomenon, an HVAC system can be used to produce ice during the off-peak hours and then melt the ice to reduce the load on the chiller during the peak hours. The ice that was made very inexpensively during the night can be used like free cooling, which was previously discussed. For example the University of Arizona installed a massive ice storage system in 2005 and was able to save over $38,000 a month simply by shifting when energy was used from the middle of the day to the middle of the night, when electricity is much less expensive (Tarcola 2009). While ice storage itself does not lower the energy usage of a building (in fact, it may increase it slightly) it does reduce the demand on the electric grid during peak times, and often reduces energy cost because the electricity being used is purchased at a cheaper rate. LEED looks at energy cost in addition to energy usage, so ultimately, "an ice-storage system may help the overall building design receive points from the "LEED Energy & Atmosphere credit 1" based on the building energy savings beyond ASHRAE Standard 90.1-2004" (Solberg 2007). Armed with these techniques and technologies a "green" HVAC system should be achievable.

But, just because a building is green does not mean that it is sustainable – nor will it qualify for LEED simply by reducing energy costs. As stated in the report on Dutch green homes, "sustainable building has developed … towards a discipline comprising various practical and scientific issues" (Bossink 2007). Often, a social component is examined as well as ecological issues. So, in order to be sustainable, the owners have installed showers in the building as a way to encourage employees to exercise while on lunch breaks, thereby improving the health and wellbeing of the occupant employees. This is where the building moves from just being green (or energy efficient) into being sustainable. This practice, of weighing not only economic concerns, but also ecological concerns and the comfort and health of the employees is at the crux of a truly sustainable building. It is actually possible to apply a weighted metric system to any building project that can help to balance these three "pillars" of sustainability (Avgelis

2009). By giving a weighted value to the comfort of the employees, the builders of Thanksgiving Park came to the conclusion that valuable floor space should be used for employee showers rather than additional rental space. They also were willing to accept a more expensive climate control system in order to reduce the building's impact on the environment. These decisions could be very different for another owner, but for the owners of Thanksgiving Park, these sustainability issues were given a priority over a purely economic view.

Although a great start, the showers were only one small thing the owners of Thanksgiving Park could do to improve the condition of the employees that would one-day occupy the building. What else could, or should, have been done to increase occupant comfort? One study out of Japan found that giving employees the ability to control the climate in their immediate space resulted in employees being on-task, in their assigned work areas, as much as twice as often as those without this ability. Across the board, these employees preferred a cooler, drier work area than the standard climate provided to the building as a whole (Akimoto et al 2010). Another Japanese study confirmed that participants preferred a lower humidity environment. But, not only were employees more comfortable in a lower humidity environment, but they were less tired, and took longer to become fatigued. In other words, a lower humidity environment was linked to increased productivity (Harigaya et al 2007). Interestingly, HVAC specialist have been advocating the delivery of cooler, drier air as a way to improve indoor air quality through the reduction of mold spores for at least the last decade (Eppelheimer 2000).

In order to achieve the increased comfort of a low humidity environment, and indoor air quality improvements, low-temperature low-flow supply-air systems typically deliver air to the conditioned space at 48°F rather than 55°F(Eppelheimer 2000). With the reduced temperature of the incoming air, the volume of air needed to cool the space to the same temperature is also reduced. Because of the improved comfort of a drier environment, the conditioned space can actually be kept at a slightly higher

temperature, which again reduces the amount of supply air needed to maintain a comfortable working environment. All of these reductions in airflow result in smaller air handlers, which in turn use less energy and have improved acoustics. Table 1, borrowed from Eppelheimer (2000), compares a conventional system to a "cold air" system.

**Table 1 – Conventional and Cold Air Systems**

| | Conventional | Cold Air[a] |
|---|---|---|
| Supply air | 55°F | 45°F |
| Room set point | 75°F | 78°F |
| Room humidity | 55–60% RH | 40–45% RH |
| Cooling-coil ΔT | 20°F | 33°F |
| Airflow rate for space sensible cooling load | 553 cfm/ton | 335 cfm/ton |

[a]This phenomenon is described by the equation, $Q = 1.085 \times cfm \times \Delta T$.

There are other advantages to the cold air system as well. According to Eppelheimer, because of the reduced supply air requirements, the size of the air handler can be reduced. Smaller air handlers are easier to install, run quieter, and are more easily and cheaply maintained, thus providing both economic benefits to the building owner(s) and further increasing comfort for occupants. Additionally, smaller ductwork can be used to supply the air to the conditioned space, and return it to the chiller. As with the air handlers, smaller ductwork is much easier, and therefore much less expensive, to install and maintain. Although not the case with Thanksgiving Park, larger buildings could actually realize additional floor space (or even an extra floor) due to the shorter floor-to-floor height allowed by the reduced ductwork sizing. Certainly "a comfort system that reduces building cost, and lowers energy cost while improving comfort and indoor air quality makes sense in today's competitive marketplace" (Eppelheimer 2000).

This is not to say that cold air is always the best solution. There are certain factors that need to be considered including the design of the building and the layout of the HVAC ductwork, which is the purpose of this project. Additionally, lower temperature supply air should be paired with more heavily insulated ductwork to prevent excessive heat transfer while the air is in transport. Mr. Eppelheimer (2005) puts it this way, "it's tempting to rely on ARI standard rating conditions … But, as valuable as

these benchmarks are for verifying performance, they are unlikely to reflect optimal conditions for the entire system … especially as mechanical efficiencies improve and customer requirements change." In other words, each building needs to be evaluated as an individual, and an optimal system selected for each particular building (Biesterveld 2008). This evaluation needs to be done not just for peak load times, but for an entire year, or a number of years, in order to accurately reflect the true level of sustainability achieved by the building (James et al 2010). This is especially true when seeking LEED certification – which is a true measure of sustainable development. The need to individually analyze each climate zone, and each building for that matter, is the impetus for this project.

# Design

## Objectives

The new building at Thanksgiving Park needs a sustainable HVAC system. The ideal system will provide a low first cost, a low operating cost, reduced environmental impact, and improve the comfort of all occupants. In order to achieve these four goals a high efficiency, low cost refrigerant will be utilized in the central chilling plant. The first and lifecycle costs of high efficiency and standard chillers will be examined. Fresh-air economizers will be used to supply the required fresh air to the system and an optimal on/off temperature will be determined. Additionally, a low-flow, low-temperature supply air system will be analyzed to determine its feasibility for this project and for the Salt Lake Valley in general.

## Climate

Positioned at the junction of the Utah and Salt Lake Valleys, Lehi, Utah sits at the intersection of "Bsk" and "Dfa" Köppen Climate Zones. These zones denote a dry, hot, continental climate. In particular, the summers are hot, the winters cold, and the rate of precipitation is lower than the rate of evaporation. (See appendix B for more detailed climate information and sources.) This has three

significant impacts on the selection of an HVAC system. First, hot summers require high levels of cooling. Second, cold winters require more heating than temperate winters. Lastly, a dry climate reduces the need for supply air dehumidification. Since this project is intended to find the optimal cooling system, the high summer temperatures and humidity control requirements will significantly impact the final equipment selection. Summer temperatures in Lehi typically exceed 90°F from June through August with high temperatures reaching 110°F or more for short periods of time. Although humidity levels average between 40% and 50% during the summer months, it can be as low as 10% on the hottest days, while climbing above 80% during thunderstorms which frequent the valleys. Typically, 40% relative humidity is considered the low-end threshold for office buildings. Below this level, static electricity can become problematic. Therefore, the HVAC system will need to be able to handle the high temperatures as well as the swings in relative humidity.

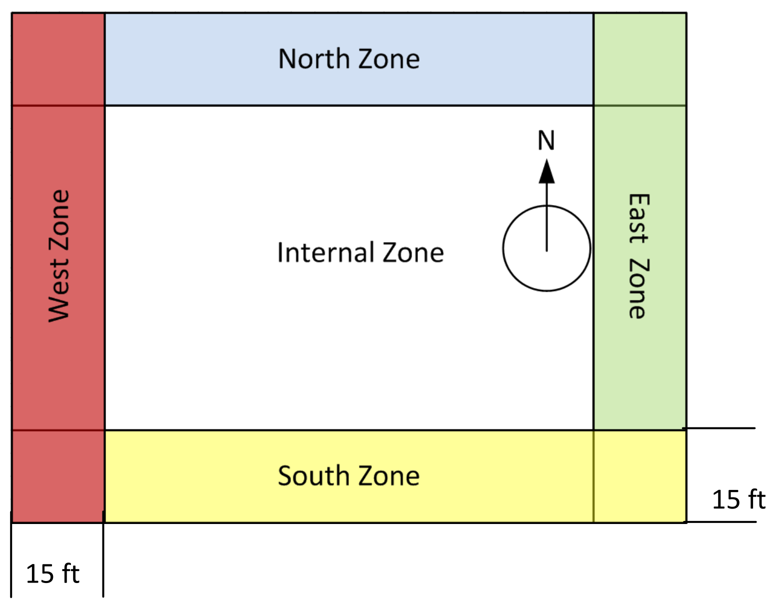
## Requirements

There are four main ways in which heat energy is transferred to a conditioned space: conduction, radiation, infiltration, and internal loads. Conduction is the heat gained by a conditioned space due to one of its boundaries being warmer than the conditioned space. A good example of conduction is wall in direct sunlight – the wall will heat-up and transfer some of that heat into the conditioned space. Radiation is the heat gain produced by sunlight shining through glass and directly warming the conditioned space. Infiltration refers to unconditioned air that leaks into the conditioned space through poorly sealed doors, windows, and the through the natural respiration of porous materials. The internal heat load is produced by people, equipment, and lighting inside the conditioned space. As was discussed in the literature review, the number one rule of energy efficiency (for an HVAC system) is to reduce the load.

In an effort to reduce the load due to solar radiation, Thanksgiving Park II will be oriented 45° counter-clockwise from true north. This orientation takes advantage of a large mountain range to the north and east of the building to minimize morning-time heat-gain. It also minimizes the true westward exposure of the building which is important in reducing the load due to solar radiation. The highest solar load generally occurs at 4 o'clock in the afternoon as the afternoon sun streams in through west-facing glass. Since as much as 86% of each floor will have glass walls, this orientation offset must be factored in to the calculations for selecting the best cooling system.

In order to calculate the total cooling requirements for the building it is necessary to break each floor into zones that can be individually analyzed and then summed together. The simplest building zoning system calls for the building to be broken into five zones. The first four zones cover the area that extends 15 feet into the conditioned space from each of the walls facing in the four cardinal directions. The fifth zone covers everything inside of this area and is simply called the "internal" zone. While this simplified zoning system, depicted in Figure 2, is adequate for most small scale buildings, it will not suffice for the Thanksgiving Park II building.

**Figure 2 - Simple Climate Zones**




Thanksgiving Park II is a large building. With 129,000 square feet of conditioned office space spread across 5 floors, a much more detailed approach to zone determination is needed. The simplified zones shown above assume that the entire interior of the building has a uniform heat load, but this will not be the case with this building. Additionally, large buildings require a certain amount of outdoor air to

be vented into the conditioned space in order to prevent the air from becoming stale. This fresh air also helps to flush out pollutants that can significantly reduce indoor air quality. So, accurately calculating the buildings loads by hand would be a prohibitively time consuming process. Therefore, the TRACE 700 program will be utilized to determine the cooling and fresh-air required for the building.

## Setting up the Simulation

TRACE 700 is a powerful simulation tool developed by the Trane Company. It is able to take into account the specific climate of the new building's location – it even comes pre-loaded with 30 years of historical climate data for every major area in the United States. The program requires the user to input the exposures of the building, which includes the height, amount of glass, construction material, and direction of every external surface. Next, the user specifies the number of floors and enters the basic parameters to which the system should be designed, such as desired indoor air temperature and relative humidity. After defining the building basics, the user inputs the internal divisions of each floor into Trace by defining rooms, hallways, etc. This information allows TRACE 700 to output the total heating and cooling requirements for the building.

Armed with the knowledge of the total heating and cooling requirements for the building, the sales engineer then proceeds to choose a baseline set of HVAC system components through the use of generalizations. Rooms and zones are then assigned to be serviced by the different equipment. Utility rates are established and an estimate of the installed equipment cost is also entered into TRACE. Once all these parameters are established, the sales engineer runs the simulation and receives preliminary results. This is when the ingenuity and creativity of the Sales Engineer comes into play. S/he must take the baseline system and begin to tweak it through iterative changes to find the best system for the building. This process can take anywhere from hours to weeks depending on the size of the building and

the competiveness of the bid. The more competitive the bid process, the more optimized the final system must be.

## Existing System

The Thanksgiving Park II simulation benefits from the fact that an identical building already exists at the site. Because of this, the process of selecting an optimized HVAC system can begin from a baseline with an acceptable track record rather than from scratch. The existing system employs a 350 nominal-ton, air cooled water chiller running on R134-A, an air-handler for each floor, fresh-air economizers that activate when outside air is below the set-point, and Variable Air Volume (VAV) reheat boxes in zone, to provide 250 tons of cooling and 115,000 CFM of air to the building. A VAV reheat box receives the cold air from the air handler via ducting and then using an electric heating-coil, reheats the air (if it is too cold) before distributing it to each of the diffusers in the zone. Although the VAV box may sound inefficient, cooling the air below the desired delivery temperature is often done to reduce humidity and improve the quality of the air being delivered to the space. The chiller installed at Thanksgiving Park I (which is the baseline) achieving an 8.6 Energy Efficiency Ratio (EER) – which is a ratio of the output cooling to the input energy. Although it may seem strange to have an efficiency rating greater than one, EER does not use the same units for input and output. An EER of 12 means that a chiller is capable of producing one ton of chilling for every KW consumed. So, an 8.6 EER chiller consumes about 1.4 KW for each ton of chilling it produces.

## Alternative Systems

Given the baseline system and the research performed, several good opportunities exist to improve the efficiency of the HVAC system for Thanksgiving Park II over the baseline system. One option will be to take advantage of the concept of low-flow low-temperature supply air. Another option is to incorporate thermal-ice storage to help reduce the cost of operating the system. An EER of 8.6 is rather

low, most R-123 centrifugal chillers can reach 12.5 EER, and therefore a more efficient chiller may be a good option as well. At the direction of the sales manager in the sales office the following three alternatives will be examined:

- Alternative 1 will be the baseline, as-installed, system.
- Alternative 2 will utilize a low-flow low-temperature supply air configuration with the baseline equipment.
- Alternative 3 will make add thermal-ice storage to the existing system without changing the supply air flow rate or temperature.
- Alternative 4 will be an EarthWise™ system that utilizes low-flow low-temperature supply air, thermal-ice storage, and a more efficient R-123 chiller rated at 12.5 EER.

## Methodology

The process began by determining the exposures and dimensions of Thanksgiving Park II. This was a time consuming process that required some estimation. Using scale plans of the building, the total exposure for each wall was determined. Then, using an engineering scale, the percentage of glass on each wall was estimated. Shading factors for the glass (amount of solar radiation screen out) and insulation factors for the walls were provided by CCI Mechanical, the contracting engineer. This process was repeated for each of the five floors. Once the floors and walls were established, internal zones were developed based on the planned rental pattern of the building. Some floors, such as floor four, were to be rented out as a single large office space, so no internal divisions were made. However, the first floor consisted of five different rental spaces, three hallways, a set of showers/lockers, and an entry way, that would each need their own climate controls. This information, along with the climate data and building type (Mid-rise office building) were entered into TRACE 700.

With the zones established it was time to add the baseline equipment to the simulation. The sales records from Thanksgiving Park I were used to select identical equipment to be used as a baseline in the simulation for Thanksgiving Park II. After selecting the equipment, each piece needed to be assigned to its service zones and told how to service them – in this case, a Variable Air Volume (VAV) reheat-box per zone was selected. VAV boxes adjust the amount of supply air coming into the conditioned space to keep the space at the correct temperature. VAV reheat boxes will also heat the supply air if it is too cold to allow into the space in the volume required for adequate ventilation. The baseline system made use of fresh-air economizers which had to be defined in the TRACE simulation. This took some doing, but after several emails to and from technical support, the economizers were established in the simulation and appeared to be working properly. Next, the chilled water pumps needed to be defined. These were very difficult to define as the size of the pumps would vary with the equipment selections and sizing of the components. Eventually, a way was found to force the pumps to vary with the type of equipment selected. With all of the baseline equipment selected it was time to run the simulation. The results of this first run were then fed back into the simulation each time an alternative system was added. In this way, the first run became the baseline for comparison.

One of the first details to be added back into the system was the selection of a utility rate plan. Rocky Mountain Power, which supplies electricity to the state of Utah, suggested one of two rate plans. The first was plan 6A and the second 6B. Schedule 6A (a usage-based plan) had varying rates per kilowatt-hour used based on the time of day and time of year the electricity was consumed. Schedule 6B (a demand-based plan) had varying rates based on the peak kilowatts demanded by the building again based on time of day and time of year. The demand-based schedule was eventually chosen for its moderate charge for electricity usage (kWh) at any time of day and its zero-cost for demand occurring during off-peak hours. The specifics of Schedule 6B can be found in Appendix A. The process of determining the best electricity rate structure to use was, like the rest of the simulations, an iterative

process of adding an alternative and fine tuning the simulation until the desired results were obtained. The iterative steps went as follows:

1. Exposures, zones, chiller, air-handlers, and regional climate were established.
2. Fresh-air economizers were added.
3. Chilled water pumps were added along with ducting for supply and return air.
4. The results of the baseline were fed back into the system to better determine what equipment should be selected. Utility rates were investigated; ultimately the most cost effective plan was selected.
5. Installed cost and maintenance were determined and added.
6. The first alternative was added by specifying supply air temperature, which took several attempts. It was finally determined that using a value below 48°F for the supply air would “break” the simulation resulting in massive loads as the heating system would try to constantly reheat the space while the chiller kept attempting to reduce the temperature of the space.
7. The second alternative was added by adding thermal storage equipment to the baseline chiller and defining an operating schedule for this equipment. This was highly dependent on the utility rate structure selected.
8. The third alternative was established by building-off the first alternative and adding thermal storage and a high-efficiency chiller. Again, the utility rate structure played a major role in defining a valid set of selections.
9. Economics were finally established for all four builds including installed cost, utility rates, depreciation, taxes, and maintenance costs.
10. Technical support was contacted to assess the validity of the model. After several fine-tuning issues, the simulation was complete.

## Results

After numerous runs and refinements, the simulation had finally yielded results that seemed reasonable, were verifiable, and hopefully valid. Figure 3 shows the annual electric utility cost of each of the four systems.

Figure 3 - Annual Electricity Cost of the Four Systems


From these results it is clear that the EarthWise™ system with thermal storage has the lowest operating cost of any of the systems. However, there were trade-offs to consider. The more efficient system might be substantially more expensive to install. The additional cost of not only the more efficient chiller, but also the thermal storage tanks, could very-well eat-up the $28,000 in annual electric savings. The EarthWise™ system delivers the more comfortable cooler, drier air, but is it really more sustainable than any of the other system? An economic analysis shows that the EarthWise™ system not only saves money annually, and produces a more comfortable environment, but is in-fact, a wise long-term economic choice. Table 2 details the economic comparison. Because the system uses smaller

piping for chilled water and smaller ducts for supply air the EarthWise™ system only costs about $42,000 more to install than the baseline system. This is paid back in less than three years.

**Table 2 - Economic Comparison of Alternative Systems**

| | Yearly Savings ($) | First Cost Difference ($) | Cumulative Cash Flow Difference ($) | Simple Payback (yrs.) | Net Present Value ($) | Life Cycle Payback (yrs.) | Internal Rate of Return (%) |
|---|---|---|---|---|---|---|---|
| Alt 2 vs Alt 1 | 8,186 | -203,860 | 280,995 | 0.0 | 232,271 | No Payback | 1,000.0 |
| Alt 3 vs Alt 1 | 18,465 | 177,480 | 267,285 | 9.6 | -15,110 | No Payback | 8.9 |
| Alt 4 vs Alt 1 | 26,603 | 42,140 | 509,935 | 1.6 | 159,399 | 2.9 | 44.5 |
| Alt 3 vs Alt 2 | 18,465 | 381,340 | -13,710 | 37.1 | -247,381 | No Payback | Does Not Payback |
| Alt 4 vs Alt 2 | 26,603 | 246,000 | 228,939 | 13.4 | -72,872 | No Payback | 6.0 |
| Alt 3 vs Alt 4 | 18,465 | 135,340 | -242,650 | -1.0 | -174,509 | No Payback | Does Not Payback |

The final question is whether or not this EarthWise™ system is more efficient that the baseline. Although the baseline system is capable of qualifying the building for LEED Silver, a more ecological choice would be nice. Table 3 shows the ecological impact for the baseline, while Table 4 details the ecological impact of the EarthWise™ system. And the answer is, yes – The EarthWise™ alternative is a more ecologically sound choice than the baseline system.

**Table 3 - Ecological Impact of the Baseline System**

| Energy Consumption | | |
|---|---|---|
| Building | 45,118 | Btu/(ft2-year) |
| Source | 120,047 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| $CO_2$ | 3,611,040 lbm/year |
| $SO_2$ | 3,267 gm/year |
| NOX | 6,513 gm/year |

**Table 4 - Ecological Impact of the EarthWise™ System**

| Energy Consumption | | |
|---|---|---|
| Building | 43,271 | Btu/(ft2-year) |
| Source | 115,152 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| $CO_2$ | 3,463,263 lbm/year |
| $SO_2$ | 3,134 gm/year |
| NOX | 6,246 gm/year |

*A complete set of results are available to the reader in Appendix C

## Conclusions

The EarthWise™ system examined is a more sustainable choice than the baseline system analyzed. As a result, the Trane Sales Office should recommend the EarthWise™ system to the owners of the new building at Thanksgiving Park as it will increase profits while reducing environmental impact and improving the quality of life (or air at least) for the occupants of the building. Because of the location of Thanksgiving Park II it can be assumed that a similar system should provide similar results for other buildings in the Salt Lake and Utah Valleys. Although, a thorough analysis should be performed for every building, the results of this analysis can be used as support for the recommendation of other EarthWise™ systems in the region. Ultimately, the new climate control technologies available from the major companies, Trane in particular, can provide more sustainable options than those available even a few years ago. Since building climate control uses up such a large proportion of all electricity, these systems should be considered for all buildings of even moderate size.

To expand the validity of these results a more thorough comparison of just the EarthWise™ system and the baseline should be evaluated. More accurate values should be obtained for the installed cost of the EarthWise™ system. Additionally, examining the varying technologies from companies other than Trane could lend validity to the concept of sustainable HVAC in general.

## Works Cited

1. Akimoto, Takashi, Masato Sasaki, Shin-ichi Tanabe, and Takashi Yanai. "Thermal comfort and productivity - Evaluation of workplace environment in a task conditioned office." Building and Environment. 45-1. (January 2010): 45-50. Science Direct. Engineering Village II. Cal Poly State University, San Luis Obispo. 31 Oct. 2010 http://www.engineeringvillage2.org
2. Avgelis, A., A.M. Papadopoulos. "Application of multicriteria analysis in designing HVAC systems." Energy and Buildings. 41-7 (July 2009): 774-780. Science Direct. Engineering Village II. Cal Poly State University, San Luis Obispo. 31 Oct. 2010 http://www.engineeringvillage2.org
3. Biesterveld, Matt, Jeanne Harshaw, and John Murphy. "Energy Saving Strategies for LEED Energy and Atmosphere Credit 1." Trane Engineer's Newsletter 37-2 (2008): 1-8
4. Bossink, Bart A.G. "The interorganizational innovation processes of sustainable building: A Dutch case of joint building innovation in sustainability." Building and Environment. 42-12 (December 2007): 4086-4092. Science Direct. Engineering Village II. Cal Poly State University, San Luis Obispo. 31 Oct. 2010 http://www.engineeringvillage2.org
5. Eppelheimer, Don. "Cold Air Makes Good $ense" Trane Engineer's Newsletter 29-2 (2000): 1-6
6. Eppelheimer, Don. "Selecting Cooling Towers for Efficiency: Range or Approach?" Trane Engineer's Newsletter 34-1 (2005): 1-4
7. Harigaya, Junkichi, Shin-ichi Tanabe, Yasuo Iguchi, Gen Nakamura, and Hitomi Tsutsumi. "Effect of Humidity on Human Comfort and Productivity After Step Changes from Warm and Humid Environment." Building and Environment. 42-12. (December 2007): 4034-4042. Science Direct. Engineering Village II. Cal Poly State University, San Luis Obispo. 31 Oct. 2010 http://www.engineeringvillage2.org
8. Hsieh, Chris. "Top Ten Frequently Asked Questions on LEED and HVAC." Trane Engineer's Newsletter 36-4 (2007): 1-8

9. James, Geoff, Jiaming Li, Ronxin Li, Glenn Platt, Geoff Poulton, and Josh Wall. "Adamptive HVAC Zone Modeling for Sustainable Buildings." Energy and Buildings. 42-4 (April 2010): 412-421. Science Direct. Engineering Village II. Cal Poly State University, San Luis Obispo. 31 Oct. 2010 http://www.engineeringvillage2.org

10. NGO Committee on Education. "Our Common Future, Chapter 2: Towards Sustainable Development." UN Documents. 1987. 31 Oct. 2010. <http://www.un-documents.net/ocf-02.htm>

11. PSEG. "While You Were Sleeping: Thermal Energy Storage (TES)." EnergE Link. 31 Oct. 2010 <http://www.calmac.com/documents/UtilityNewsletter-WhileYouWereSleepingThermalEnergyStorage.pdf>

12. Rocky Mountain Trane. "Thanksgiving Park: HVAC Alternatives Analysis." 2010: 1-9

13. Schwedler, Mick. "Variable Primary Flow Systems" Trane Engineer's Newsletter 28-3 (1999): 1-4

14. Solberg, Paul. "Ice Storage as Part of a LEED Building Design." Trane Engineer's Newsletter 36-3 (2007): 1-6

15. Tarcola, Al. "Fire and Ice: University of Arizona increases turbine efficiency with ice storage." Distributed Energy March-April 2009: 1-4. 6 Aug. 2010 http://www.distributedenergy.com/forms/print-29196.aspx

16. Thanksgiving Park. 2010. 30 Oct. 2010 <http://www.thanksgivingpark.com>

17. Thompson, Mike. "What Lies Ahead." HPAC January/February 2009: 40-41

18. The Trane Company. "A New Era of Free Cooling." Trane Engineer's Newsletter 20-3 (1991): 1-7

## Appendix A

Appendix A contains the executive summary report that was presented by the Rocky Mountain Trane sales office to CCI Mechanical on 9 September 2010.


THANKSGIVINGPARK

HVAC Alternatives Analysis

The Trane Company

TRANE

Last update:

8 September 2010

This report outlines four alternative HVAC equipment selections for the Thanksgiving Park office building. Thanksgiving Park is a five-story, "low rise" office building with approximately 128,000 sq-ft of tenant office space. The first alternative is an attempt to model the equipment currently installed in the Thanksgiving Park Phase 1 building. The second alternative is a typical low-flow, low temperature system. The third alternative reuses the currently installed equipment with the addition of thermal ice storage. The fourth, and final alternative, represents an advanced Trane EarthWise™ system which incorporates low-flow, low-temperature supply air with thermal storage (ice), and a high efficiency air-cooled chiller. Critical to this analysis is the use of Rocky Mountain Power's Schedule 6B, which provides time-of-day based peak and off-peak pricing for power demand (KW).

**Alternative 1 – Baseline (as installed)**

Chiller: 250 Ton Trane Air Cooled Rotary Chiller

Efficiency: 8.5 EER

Supply Air Temperature: 55°F

Chiller Water ΔT: 12°F

**Alternative 2 – Low-Flow, Low-Temp**

Chiller: 250 Ton Trane Air Cooled Rotary Chiller

Efficiency: 8.5 EER

Supply Air Temperature: 48°F

Chiller Water ΔT: 16°F

**Alternative 3 – Baseline w/ Thermal Storage**

Chiller: 250 Ton Trane Air Cooled Rotary Chiller

Efficiency: 8.5 EER

Supply Air Temperature: 55°F

Chiller Water ΔT: 12°F

Thermal Storage: 2000 Ton·Hr

**Alternative 4 – EarthWise™ Low-Flow, Low-Temp w/ Thermal Storage**

Chiller: 250 Ton Trane Air Cooled Rotary Chiller

Efficiency: 12.8 EER

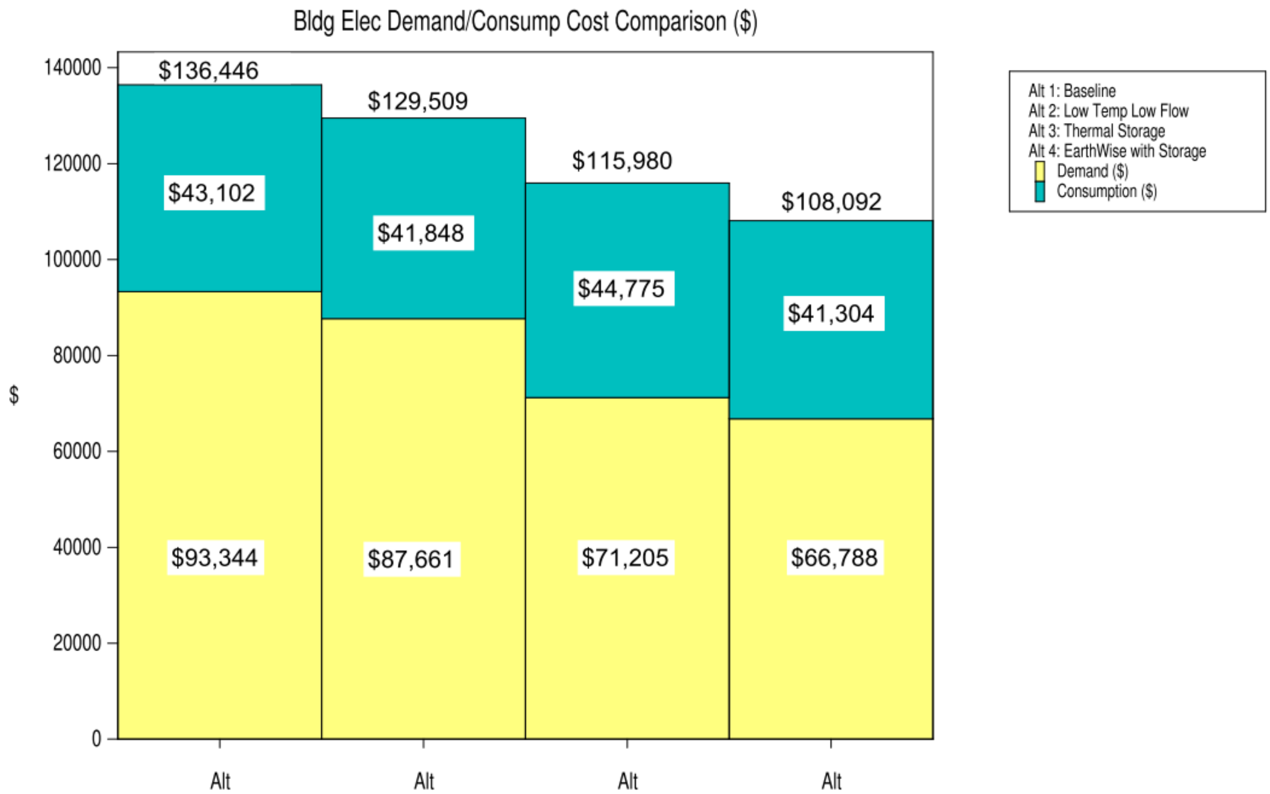
Supply Air Temperature: 48°F

Chiller Water ΔT: 16°F

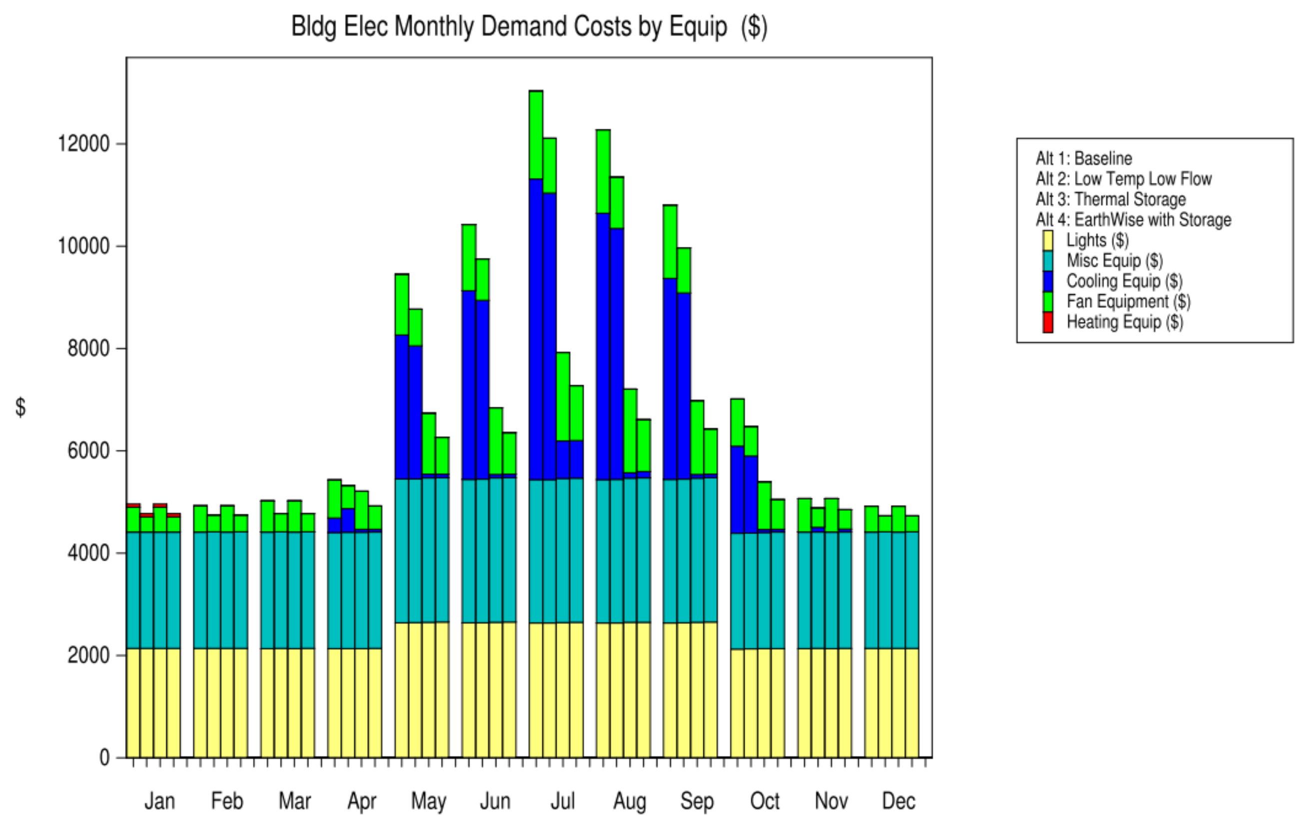
Thermal Storage: 2,000 Ton·Hr

**Rocky Mountain Power Schedule 6B**

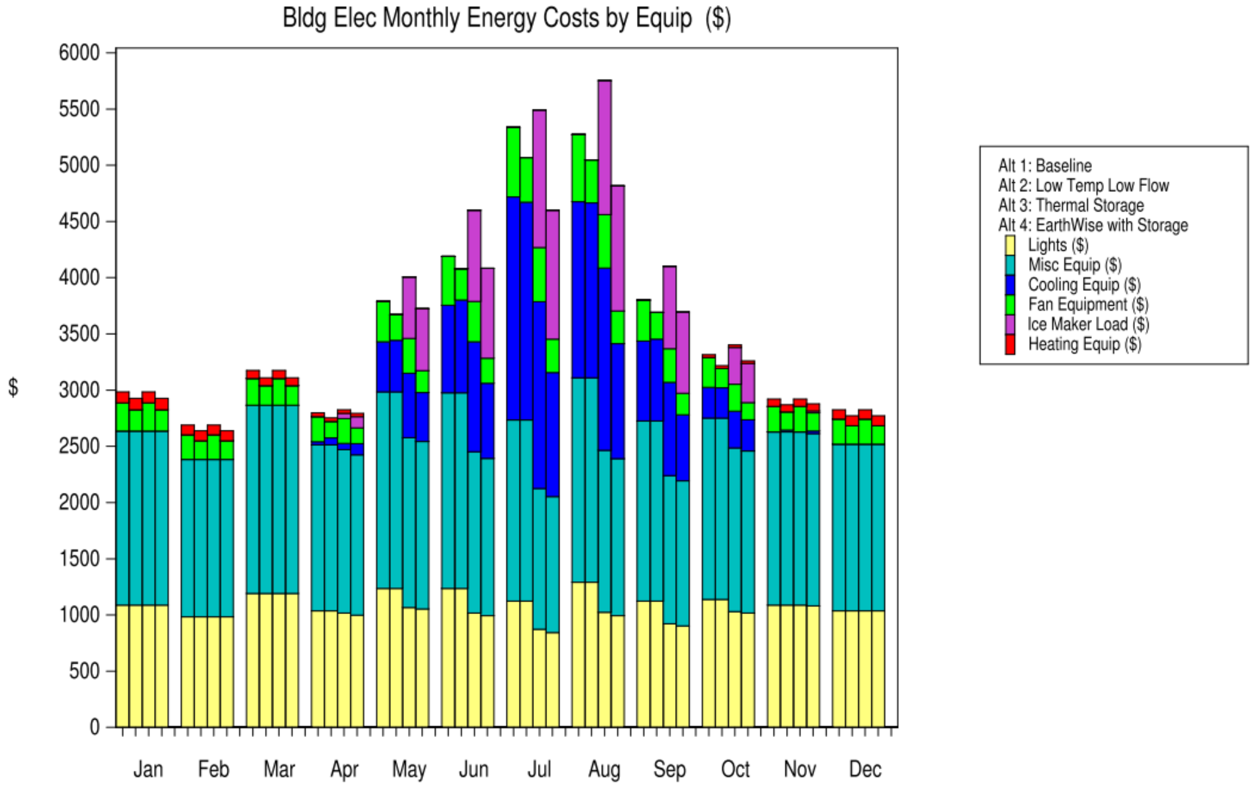
| | On-Peak Demand (7 a.m. 11 p.m.) | Off-Peak Demand (11 p.m. – 7 a.m.) | Usage |
|---|---|---|---|
| May – September | $15.16 / kW | $0.00 | 3.1907¢ / kWh |
| October - April | $12.17 / kW | $0.00 | 2.9416¢ / kWh |




This graph displays the net result of the electricity demand and usage charges for each of the four alternatives. Note that the demand charge accounts for the largest portion of the total bill. As such, anything that can shift electric demand from the peak to the off-peak times will result in substantial savings. For example, the installation of thermal storage reduces the total utility bill by over $20,000/year, even though the total usage went up, it occurs during off-peak hours.




This graph shows the monthly electric demand cost for each type of equipment by alternative. By making use of thermal storage (ice) alternatives 3 and 4 are able to reduce the cooling equipment demand charges to almost zero, even during the peak months.




This graph depicts the monthly electricity usage cost for the first year of operation for the various alternatives. Note that during the peak months the thermal storage systems use a significant amount of power. But, because this power is utilized during off-peak hours, only the usage is charged, at roughly 3¢/kWh, while the demand is not billed at all.

**The next two pages break out the monthly charges for electric demand and usage for all four alternatives.**

**Demand Charges**

| | Alt 1 | | | | | Alt 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Lights | Misc | Cooling | Fan | Heating | Lights | Misc | Cooling | Fan | Heating |
| | $ | $ | $ | $ | $ | $ | $ | $ | $ | $ |
| Jan | 2139.26 | 2274.96 | 0 | 486.98 | 60.79 | 2140.76 | 2276.55 | 0 | 296.55 | 62.94 |
| Feb | 2139.49 | 2275.21 | 0 | 516 | 0 | 2141.04 | 2276.85 | 0 | 327.71 | 0 |
| Mar | 2138.71 | 2274.38 | 0 | 614.51 | 0 | 2140.8 | 2276.6 | 0 | 358.49 | 0 |
| Apr | 2135.81 | 2271.29 | 283.4 | 742.9 | 0 | 2136.56 | 2272.09 | 462.25 | 453.6 | 0 |
| May | 2641.65 | 2809.22 | 2812.77 | 1189.95 | 0 | 2643.62 | 2811.31 | 2597.8 | 716.97 | 0 |
| Jun | 2639.28 | 2806.69 | 3682.48 | 1293.25 | 0 | 2640.87 | 2808.38 | 3493.96 | 808.09 | 0 |
| Jul | 2634.68 | 2801.81 | 5875.15 | 1721.76 | 0 | 2636.1 | 2803.31 | 5601.66 | 1068.74 | 0 |
| Aug | 2635.82 | 2803.02 | 5204.06 | 1629.5 | 0 | 2637.4 | 2804.7 | 4903.28 | 1004.33 | 0 |
| Sep | 2638.46 | 2805.83 | 3926.96 | 1433.06 | 0 | 2640.35 | 2807.84 | 3637.48 | 879.43 | 0 |
| Oct | 2127.75 | 2262.72 | 1700.83 | 924.49 | 0 | 2130.05 | 2265.17 | 1503.11 | 577.36 | 0 |
| Nov | 2138.44 | 2274.09 | 0 | 655.67 | 0 | 2139.89 | 2275.63 | 89.22 | 379.65 | 0 |
| Dec | 2139.56 | 2275.28 | 0 | 506.46 | 0 | 2141.17 | 2276.99 | 0 | 314.53 | 0 |

**Usage Charges**

| | Alt 1 | | | | | Alt 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Lights | Misc | Cooling | Fan | Heating | Lights | Misc | Cooling | Fan | Heating |
| | $ | $ | $ | $ | $ | $ | $ | $ | $ | $ |
| Jan | 1087.48 | 1548.1 | 0 | 251.17 | 98.25 | 1087.48 | 1548.09 | 0 | 190.78 | 101.65 |
| Feb | 983.91 | 1400.33 | 0 | 219.07 | 85.99 | 983.9 | 1400.31 | 0 | 164.93 | 88.96 |
| Mar | 1191.06 | 1675.4 | 0 | 237.42 | 71.42 | 1191.06 | 1675.41 | 0 | 172.39 | 71.65 |
| Apr | 1035.7 | 1477.63 | 27.84 | 223.62 | 32.61 | 1035.69 | 1477.61 | 62.66 | 145.85 | 30.6 |
| May | 1235.75 | 1748.24 | 446.94 | 358.74 | 0.63 | 1235.74 | 1748.22 | 459.44 | 228.94 | 0.65 |
| Jun | 1235.76 | 1740.85 | 777.5 | 435.3 | 0 | 1235.75 | 1740.84 | 824.68 | 278.43 | 0 |
| Jul | 1123.41 | 1610.15 | 1985.06 | 619.28 | 0 | 1123.4 | 1610.14 | 1938.76 | 396.39 | 0 |
| Aug | 1291.93 | 1817.29 | 1566.1 | 598.08 | 0 | 1291.91 | 1817.26 | 1556.57 | 380.46 | 0 |
| Sep | 1123.42 | 1602.77 | 709.8 | 366.31 | 0 | 1123.39 | 1602.74 | 727.97 | 236.3 | 0 |
| Oct | 1139.27 | 1611.74 | 274.1 | 264.11 | 25.68 | 1139.25 | 1611.72 | 269.98 | 172.22 | 25.22 |
| Nov | 1087.47 | 1541.26 | 0 | 225.65 | 66.22 | 1087.48 | 1541.27 | 16.07 | 160.81 | 65.38 |
| Dec | 1035.69 | 1484.44 | 0 | 221.81 | 84.26 | 1035.68 | 1484.42 | 0 | 163.93 | 88.06 |

| | Lights | Misc | Cooling | Fan | Heating | Lights | Misc | Cooling | Fan | Heating |
|---|---|---|---|---|---|---|---|---|---|---|
| **Annual Total** | **$41,719.76** | **$49,192.70** | **$29,272.99** | **$15,735.09** | **$525.85** | **$41,739.34** | **$49,213.45** | **$28,144.89** | **$9,876.88** | **$535.11** |

## Demand Charges

| | Alt 3 | | | | | Alt 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Lights | Misc | Cooling | Fan | Heating | Lights | Misc | Cooling | Fan | Heating |
| | $ | $ | $ | $ | $ | $ | $ | $ | $ | $ |
| Jan | 2139.26 | 2274.96 | 0 | 486.98 | 60.79 | 2140.76 | 2276.55 | 0 | 296.55 | 62.94 |
| Feb | 2139.49 | 2275.21 | 0 | 516 | 0 | 2141.04 | 2276.85 | 0 | 327.71 | 0 |
| Mar | 2138.71 | 2274.38 | 0 | 614.51 | 0 | 2140.8 | 2276.6 | 0 | 358.49 | 0 |
| Apr | 2137.35 | 2272.92 | 57.39 | 743.44 | 0 | 2139.57 | 2275.29 | 54.81 | 454.23 | 0 |
| May | 2651.9 | 2820.12 | 71.21 | 1194.57 | 0 | 2654.63 | 2823.02 | 68 | 719.96 | 0 |
| Jun | 2651.37 | 2819.55 | 71.2 | 1299.18 | 0 | 2654.07 | 2822.42 | 67.99 | 812.13 | 0 |
| Jul | 2646.56 | 2814.44 | 731.59 | 1729.51 | 0 | 2649.28 | 2817.33 | 735.02 | 1074.08 | 0 |
| Aug | 2649.57 | 2817.64 | 104.89 | 1638 | 0 | 2652.6 | 2820.86 | 126.33 | 1010.11 | 0 |
| Sep | 2650.65 | 2818.79 | 71.18 | 1439.68 | 0 | 2653.67 | 2822 | 67.97 | 883.86 | 0 |
| Oct | 2136.11 | 2271.61 | 57.36 | 928.12 | 0 | 2138.59 | 2274.25 | 54.78 | 579.68 | 0 |
| Nov | 2138.44 | 2274.09 | 0 | 655.67 | 0 | 2140.16 | 2275.92 | 54.82 | 379.7 | 0 |
| Dec | 2139.56 | 2275.28 | 0 | 506.46 | 0 | 2141.17 | 2276.99 | 0 | 314.53 | 0 |

## Usage Charges

| | Alt 3 | | | | | | Alt 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lights | Misc | Cooling | Fan | Ice | Heating | Lights | Misc | Cooling | Fan | Ice | Heating |
| | $ | $ | $ | $ | $ | $ | $ | $ | $ | $ | $ | $ |
| Jan | 1087.48 | 1548.1 | 0 | 251.17 | 0 | 98.25 | 1087.48 | 1548.09 | 0 | 190.78 | 0 | 101.65 |
| Feb | 983.91 | 1400.33 | 0 | 219.07 | 0 | 85.99 | 983.9 | 1400.31 | 0 | 164.93 | 0 | 88.96 |
| Mar | 1191.06 | 1675.4 | 0 | 237.42 | 0 | 71.42 | 1191.06 | 1675.41 | 0 | 172.39 | 0 | 71.65 |
| Apr | 1018.25 | 1452.73 | 55.21 | 219.85 | 47.6 | 32.06 | 999.12 | 1425.44 | 99.88 | 140.7 | 98.64 | 29.52 |
| May | 1067.26 | 1509.87 | 572.55 | 309.82 | 546.26 | 0.54 | 1052.84 | 1489.48 | 436.83 | 195.06 | 551.54 | 0.55 |
| Jun | 1017.99 | 1434.07 | 977.78 | 358.59 | 810.37 | 0 | 993.59 | 1399.7 | 666.66 | 223.87 | 800.28 | 0 |
| Jul | 873.31 | 1251.7 | 1661.8 | 481.42 | 1222.27 | 0 | 843.5 | 1208.97 | 1104.01 | 297.63 | 1146.2 | 0 |
| Aug | 1024.08 | 1440.53 | 1622.15 | 474.09 | 1192.85 | 0 | 993.22 | 1397.11 | 1021.97 | 292.49 | 1114.21 | 0 |
| Sep | 922.99 | 1316.83 | 828.66 | 300.96 | 731.66 | 0 | 903.55 | 1289.09 | 588.67 | 190.06 | 723.03 | 0 |
| Oct | 1029.39 | 1456.3 | 327.31 | 238.64 | 328.24 | 23.2 | 1017.77 | 1439.86 | 278.08 | 153.86 | 347.6 | 22.53 |
| Nov | 1087.47 | 1541.26 | 0 | 225.65 | 0 | 66.22 | 1081.14 | 1532.28 | 23.75 | 159.87 | 16.77 | 64.99 |
| Dec | 1035.69 | 1484.44 | 0 | 221.81 | 0 | 84.26 | 1035.68 | 1484.42 | 0 | 163.93 | 0 | 88.06 |

| | Lights | Misc | Cooling | Fan | Ice | Heating | Lights | Misc | Cooling | Fan | Ice | Heating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Annual Total** | **$40,557.85** | **$47,520.55** | **$7,210.28** | **$15,290.61** | **$4,879.25** | **$522.73** | **$40,429.19** | **$47,328.24** | **$5,449.57** | **$9,556.60** | **$4,798.27** | **$530.85** |

**The following tables display the total monthly energy consumptions for each alternative.**

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 1** | **Baseline** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 92,606 | 83,780 | 100,816 | 89,141 | 113,603 | 125,714 | 153,230 | 156,723 | 113,083 | 107,007 | 92,158 | 87,749 | 1,315,610 |
| Off-Pk Cons. (kWh) | 8,869 | 7,643 | 7,129 | 5,957 | 5,188 | 5,586 | 14,065 | 8,550 | 6,084 | 5,684 | 7,130 | 8,329 | 90,213 |
| On-Pk Demand (kW) | 400 | 398 | 406 | 439 | 618 | 682 | 854 | 804 | 707 | 569 | 409 | 397 | 854 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 41 | 46 | 48 | 235 | 142 | 48 | 41 | 41 | 46 | 235 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,977 | 2,132 | 1,438 | 293 | 1 | 0 | 0 | 0 | 0 | 240 | 1,250 | 1,800 | 10,131 |
| On-Pk Demand (therms/hr) | 16 | 16 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 15 | 15 | 16 |

| Energy Consumption | | |
|---|---|---|
| Building | 45,118 | Btu/(ft2-year) |
| Source | 120,047 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| $CO_2$ | 3,611,040 lbm/year |
| $SO_2$ | 3,267 gm/year |
| NOX | 6,513 gm/year |

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 2** | **Low Temp Low Flow** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 90,684 | 82,048 | 98,737 | 87,735 | 109,745 | 121,962 | 144,562 | 149,333 | 109,484 | 103,650 | 90,492 | 85,912 | 1,274,345 |
| Off-Pk Cons. (kWh) | 8,854 | 7,635 | 7,004 | 5,834 | 5,372 | 5,899 | 14,297 | 8,822 | 6,178 | 5,762 | 7,109 | 8,328 | 91,093 |
| On-Pk Demand (kW) | 385 | 383 | 385 | 430 | 573 | 637 | 793 | 743 | 651 | 525 | 394 | 381 | 793 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 41 | 46 | 49 | 214 | 146 | 47 | 45 | 41 | 46 | 214 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,930 | 2,052 | 1,345 | 261 | 1 | 0 | 0 | 0 | 0 | 210 | 1,185 | 1,721 | 9,705 |
| On-Pk Demand (therms/hr) | 15 | 15 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 14 | 15 | 15 |

| Energy Consumption | | |
|---|---|---|
| Building | 43,717 | Btu/(ft2-year) |
| Source | 116,488 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| $CO_2$ | 3,498,916 lbm/year |
| $SO_2$ | 3,166 gm/year |
| NOX | 6,310 gm/year |

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 3** | **Thermal Storage** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 92,606 | 83,780 | 100,816 | 88,658 | 101,173 | 103,526 | 101,605 | 112,089 | 93,073 | 98,708 | 92,158 | 87,749 | 1,155,940 |
| Off-Pk Cons. (kWh) | 8,869 | 7,643 | 7,129 | 7,402 | 24,388 | 40,606 | 70,474 | 68,237 | 35,459 | 16,979 | 7,130 | 8,329 | 302,646 |
| On-Pk Demand (kW) | 400 | 398 | 406 | 421 | 439 | 445 | 517 | 470 | 455 | 436 | 409 | 397 | 517 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 188 | 316 | 377 | 461 | 438 | 376 | 271 | 41 | 46 | 461 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,977 | 2,132 | 1,438 | 293 | 1 | 0 | 0 | 0 | 0 | 240 | 1,250 | 1,800 | 10,131 |
| On-Pk Demand (therms/hr) | 16 | 16 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 15 | 15 | 16 |

| Energy Consumption | | |
|---|---|---|
| Building | 46,516 | Btu/(ft2-year) |
| Source | 124,242 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| $CO_2$ | 3,722,942 lbm/year |
| $SO_2$ | 3,369 gm/year |
| NOX | 6,715 gm/year |

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 4** | **EarthWise with Storage** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 90,684 | 82,048 | 98,737 | 86,489 | 97,258 | 98,677 | 95,070 | 105,333 | 89,092 | 95,763 | 90,410 | 85,912 | 1,115,475 |
| Off-Pk Cons. (kWh) | 8,854 | 7,635 | 7,004 | 8,470 | 19,528 | 29,324 | 49,109 | 45,699 | 26,694 | 15,052 | 7,456 | 8,328 | 233,152 |
| On-Pk Demand (kW) | 385 | 383 | 385 | 397 | 407 | 413 | 474 | 430 | 418 | 407 | 391 | 381 | 474 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 207 | 218 | 248 | 306 | 285 | 246 | 207 | 80 | 46 | 306 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,930 | 2,052 | 1,345 | 261 | 1 | 0 | 0 | 0 | 0 | 210 | 1,185 | 1,721 | 9,705 |
| On-Pk Demand (therms/hr) | 15 | 15 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 14 | 15 | 15 |

| Energy Consumption | | |
|---|---|---|
| Building | 43,271 | Btu/(ft2-year) |
| Source | 115,152 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| $CO_2$ | 3,463,263 lbm/year |
| $SO_2$ | 3,134 gm/year |
| NOX | 6,246 gm/year |

# Appendix B

## Climate Data

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ututah

**UTAH LAKE LEHI, UTAH (428973)**

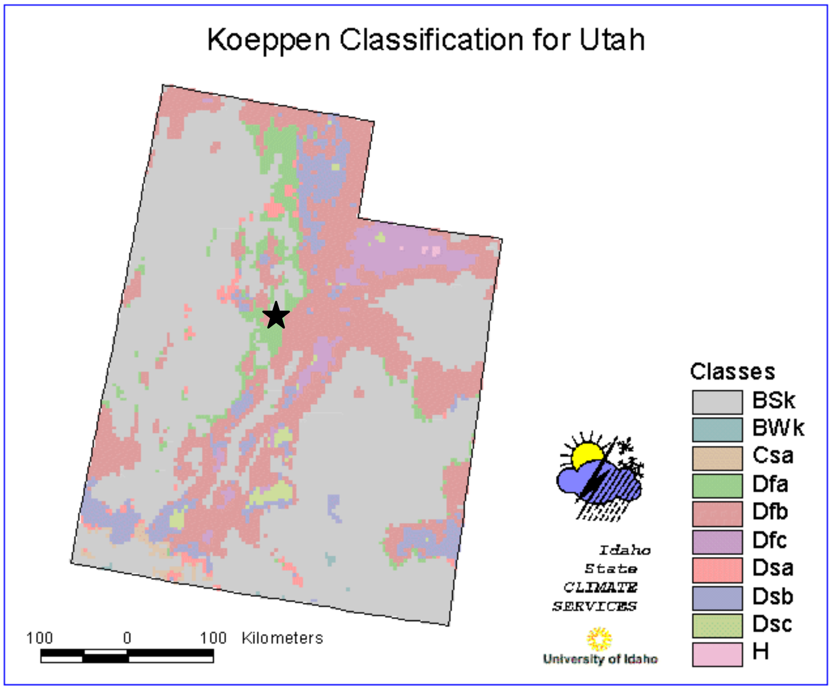
Period of Record Monthly Climate Summary

Period of Record: 1/ 1/1928 to 11/30/2003

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 36.2 | 42.0 | 50.4 | 61.3 | 71.4 | 81.7 | 90.0 | 87.6 | 78.1 | 65.0 | 48.3 | 38.8 | 62.6 |
| Average Min. Temperature (F) | 15.0 | 20.3 | 27.2 | 34.0 | 41.4 | 48.2 | 55.6 | 54.1 | 44.2 | 34.3 | 24.9 | 18.0 | 34.8 |
| Average Total Precipitation (in.) | 0.91 | 0.90 | 1.04 | 1.17 | 1.10 | 0.72 | 0.66 | 0.91 | 0.84 | 1.08 | 1.00 | 0.85 | 11.18 |
| Average Total SnowFall (in.) | 8.1 | 4.2 | 3.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 3.4 | 6.8 | 26.8 |
| Average Snow Depth (in.) | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

Percent of possible observations for period of record.
Max. Temp.: 98.1% Min. Temp.: 98.1% Precipitation: 97.1% Snowfall: 93.9% Snow Depth: 83.3%
Check Station Metadata or Metadata graphics for more detail about data completeness.

## Koppen Climate System




http://snow.cals.uidaho.edu/clim_map/images/ut.gif

An excellent discussion of the Koppen Climate System can be found on Wikipedia* at the following link:

http://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification#GROUP_D:_Continental.2Fmicrothermal_climate

*According to a study conducted by *Nature* Journal, Wikipedia is an accurate source of technical information, containing on average, about half as many errors as the Encyclopedia Britannica.

http://science.slashdot.org/science/05/12/15/1352207.shtml?tid=95

# Appendix C – Complete Results

## Design Airflow Quantities

Alternative 1 describes the airflow for the baseline and the thermal storage alternative.

Alternative 2 describes the airflow for the low temperature supply air and EarthWise$^{TM}$ alternatives.

**SYSTEM SUMMARY**

**DESIGN AIRFLOW QUANTITIES**

By Trane

| | | MAIN SYSTEM | | | | | Auxiliary System | Room |
|---|---|---|---|---|---|---|---|---|
| System Description | System Type | Outside Airflow cfm | Cooling Airflow cfm | Heating Airflow cfm | Return Airflow cfm | Exhaust Airflow cfm | Supply Airflow cfm | Exhaust Airflow cfm |
| **Alternative 1** | | | | | | | | |
| 01-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 3,248 | 24,211 | 9,449 | 24,211 | 24,211 | 0 | 0 |
| 02-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 3,215 | 22,570 | 9,352 | 22,570 | 22,570 | 0 | 0 |
| 03-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 3,215 | 25,822 | 9,352 | 25,822 | 25,822 | 0 | 0 |
| 04-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 2,862 | 23,484 | 8,322 | 23,484 | 23,484 | 0 | 0 |
| 05-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 2,757 | 19,487 | 8,016 | 19,487 | 19,487 | 0 | 0 |
| Totals | | 15,298 | 115,575 | 44,490 | 115,575 | 115,575 | 0 | 0 |
| **Alternative 2** | | | | | | | | |
| 01-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 3,183 | 16,479 | 9,449 | 16,479 | 16,479 | 0 | 0 |
| 02-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 3,116 | 15,440 | 9,352 | 15,440 | 15,440 | 0 | 0 |
| 03-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 3,192 | 17,487 | 9,352 | 17,487 | 17,487 | 0 | 0 |
| 04-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 2,852 | 15,886 | 8,322 | 15,886 | 15,886 | 0 | 0 |
| 05-AHU | Parallel Fan Powered VAV, Htg Coil on Mixing Box Outl | 2,697 | 13,873 | 8,016 | 13,873 | 13,873 | 0 | 0 |
| Totals | | 15,040 | 79,164 | 44,490 | 79,164 | 79,164 | 0 | 0 |

**Note:** Airflows on this report are not additive because they are each taken at the time of their respective peaks. To view the balanced system design airflows, see the appropriate Checksums report (Airflows section).

Project Name: Thanksgiving Park
Dataset Name: TG PARK STD 62.TRC

TRACE® 700 v6.2.5 calculated at 10:58 AM on 09/08/2010
Design Airflow Quantities Report Page 1 of 1

# Economic Cash Flows

Alternative: 1
Life Cycle Cost: $2,332,756.66

| Year | Utility Cost ($) | Maint. Cost ($) | Interest Cost ($) | Principal Cost ($) | Property Taxes ($) | Insurance Cost ($) | Revenue Penalty ($) | Replace. Expenses ($) | Deprec. Tax ($) | Cash Flow Effect ($) | Present Value ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1,500,000 | 0 | 0 | 0 | 0 | 0 | 1,500,000 | 1,500,000 |
| 1 | 142,456 | 3,000 | 0 | 0 | 0 | 0 | 0 | 0 | 75,000 | 57,273 | 52,067 |
| 2 | 149,578 | 3,090 | 0 | 0 | 0 | 0 | 0 | 0 | 71,250 | 63,101 | 52,150 |
| 3 | 157,057 | 3,183 | 0 | 0 | 0 | 0 | 0 | 0 | 67,688 | 69,069 | 51,893 |
| 4 | 164,910 | 3,278 | 0 | 0 | 0 | 0 | 0 | 0 | 64,303 | 75,192 | 51,357 |
| 5 | 173,156 | 3,377 | 0 | 0 | 0 | 0 | 0 | 0 | 61,088 | 81,484 | 50,595 |
| 6 | 181,814 | 3,478 | 0 | 0 | 0 | 0 | 0 | 0 | 58,034 | 87,961 | 49,652 |
| 7 | 190,904 | 3,582 | 0 | 0 | 0 | 0 | 0 | 0 | 55,132 | 94,639 | 48,565 |
| 8 | 200,449 | 3,690 | 0 | 0 | 0 | 0 | 0 | 0 | 52,375 | 101,533 | 47,366 |
| 9 | 210,472 | 3,800 | 0 | 0 | 0 | 0 | 0 | 0 | 49,757 | 108,661 | 46,083 |
| 10 | 220,995 | 3,914 | 0 | 0 | 0 | 0 | 0 | 0 | 47,269 | 116,038 | 44,738 |
| 11 | 232,045 | 4,032 | 0 | 0 | 0 | 0 | 0 | 0 | 44,905 | 123,684 | 43,350 |
| 12 | 243,647 | 4,153 | 0 | 0 | 0 | 0 | 0 | 0 | 42,660 | 131,616 | 41,937 |
| 13 | 255,830 | 4,277 | 0 | 0 | 0 | 0 | 0 | 0 | 40,527 | 139,853 | 40,511 |
| 14 | 268,621 | 4,406 | 0 | 0 | 0 | 0 | 0 | 0 | 38,501 | 148,416 | 39,083 |
| 15 | 282,052 | 4,538 | 0 | 0 | 0 | 0 | 0 | 0 | 36,576 | 157,324 | 37,662 |
| 16 | 296,155 | 4,674 | 0 | 0 | 0 | 0 | 0 | 0 | 34,747 | 166,599 | 36,257 |
| 17 | 310,963 | 4,814 | 0 | 0 | 0 | 0 | 0 | 0 | 33,010 | 176,262 | 34,873 |
| 18 | 326,511 | 4,959 | 0 | 0 | 0 | 0 | 0 | 0 | 31,359 | 186,338 | 33,515 |
| 19 | 342,836 | 5,107 | 0 | 0 | 0 | 0 | 0 | 0 | 29,791 | 196,850 | 32,186 |
| 20 | 359,978 | 5,261 | 0 | 0 | 0 | 0 | 0 | 0 | 566,030 | -7,269 | -1,080 |

Alternative: 2
Life Cycle Cost: $2,100,485.70

| Year | Utility Cost ($) | Maint. Cost ($) | Interest Cost ($) | Principal Cost ($) | Property Taxes ($) | Insurance Cost ($) | Revenue Penalty ($) | Replace. Expenses ($) | Deprec. Tax ($) | Cash Flow Effect ($) | Present Value ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1,296,140 | 0 | 0 | 0 | 0 | 0 | 1,296,140 | 1,296,140 |
| 1 | 135,270 | 2,000 | 0 | 0 | 0 | 0 | 0 | 0 | 64,807 | 56,439 | 51,308 |
| 2 | 142,034 | 2,060 | 0 | 0 | 0 | 0 | 0 | 0 | 61,567 | 61,830 | 51,099 |
| 3 | 149,135 | 2,122 | 0 | 0 | 0 | 0 | 0 | 0 | 58,488 | 67,359 | 50,608 |
| 4 | 156,592 | 2,185 | 0 | 0 | 0 | 0 | 0 | 0 | 55,564 | 73,041 | 49,888 |
| 5 | 164,422 | 2,251 | 0 | 0 | 0 | 0 | 0 | 0 | 52,786 | 78,889 | 48,984 |
| 6 | 172,643 | 2,319 | 0 | 0 | 0 | 0 | 0 | 0 | 50,146 | 84,918 | 47,934 |
| 7 | 181,275 | 2,388 | 0 | 0 | 0 | 0 | 0 | 0 | 47,639 | 91,142 | 46,770 |
| 8 | 190,339 | 2,460 | 0 | 0 | 0 | 0 | 0 | 0 | 45,257 | 97,576 | 45,520 |
| 9 | 199,856 | 2,534 | 0 | 0 | 0 | 0 | 0 | 0 | 42,994 | 104,236 | 44,206 |
| 10 | 209,848 | 2,610 | 0 | 0 | 0 | 0 | 0 | 0 | 40,845 | 111,137 | 42,848 |
| 11 | 220,341 | 2,688 | 0 | 0 | 0 | 0 | 0 | 0 | 38,802 | 118,296 | 41,462 |
| 12 | 231,358 | 2,768 | 0 | 0 | 0 | 0 | 0 | 0 | 36,862 | 125,731 | 40,062 |
| 13 | 242,926 | 2,852 | 0 | 0 | 0 | 0 | 0 | 0 | 35,019 | 133,459 | 38,658 |
| 14 | 255,072 | 2,937 | 0 | 0 | 0 | 0 | 0 | 0 | 33,268 | 141,498 | 37,261 |
| 15 | 267,825 | 3,025 | 0 | 0 | 0 | 0 | 0 | 0 | 31,605 | 149,869 | 35,877 |
| 16 | 281,217 | 3,116 | 0 | 0 | 0 | 0 | 0 | 0 | 30,025 | 158,590 | 34,514 |
| 17 | 295,278 | 3,209 | 0 | 0 | 0 | 0 | 0 | 0 | 28,523 | 167,683 | 33,175 |
| 18 | 310,041 | 3,306 | 0 | 0 | 0 | 0 | 0 | 0 | 27,097 | 177,169 | 31,865 |
| 19 | 325,543 | 3,405 | 0 | 0 | 0 | 0 | 0 | 0 | 25,742 | 187,072 | 30,588 |
| 20 | 341,821 | 3,507 | 0 | 0 | 0 | 0 | 0 | 0 | 489,103 | 11,555 | 1,718 |

Alternative: 3
Life Cycle Cost: $2,347,866.70

| Year | Utility Cost ($) | Maint. Cost ($) | Interest Cost ($) | Principal Cost ($) | Property Taxes ($) | Insurance Cost ($) | Revenue Penalty ($) | Replace. Expenses ($) | Deprec. Tax ($) | Cash Flow Effect ($) | Present Value ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1,677,480 | 0 | 0 | 0 | 0 | 0 | 1,677,480 | 1,677,480 |
| 1 | 121,991 | 5,000 | 0 | 0 | 0 | 0 | 0 | 0 | 83,874 | 42,645 | 38,768 |
| 2 | 128,090 | 5,150 | 0 | 0 | 0 | 0 | 0 | 0 | 79,680 | 48,072 | 39,729 |
| 3 | 134,495 | 5,304 | 0 | 0 | 0 | 0 | 0 | 0 | 75,696 | 53,601 | 40,271 |
| 4 | 141,219 | 5,464 | 0 | 0 | 0 | 0 | 0 | 0 | 71,911 | 59,245 | 40,465 |
| 5 | 148,280 | 5,628 | 0 | 0 | 0 | 0 | 0 | 0 | 68,316 | 65,018 | 40,371 |
| 6 | 155,694 | 5,796 | 0 | 0 | 0 | 0 | 0 | 0 | 64,900 | 70,934 | 40,041 |
| 7 | 163,479 | 5,970 | 0 | 0 | 0 | 0 | 0 | 0 | 61,655 | 77,008 | 39,517 |
| 8 | 171,653 | 6,149 | 0 | 0 | 0 | 0 | 0 | 0 | 58,572 | 83,252 | 38,838 |
| 9 | 180,236 | 6,334 | 0 | 0 | 0 | 0 | 0 | 0 | 55,644 | 89,684 | 38,035 |
| 10 | 189,247 | 6,524 | 0 | 0 | 0 | 0 | 0 | 0 | 52,862 | 96,318 | 37,135 |
| 11 | 198,710 | 6,720 | 0 | 0 | 0 | 0 | 0 | 0 | 50,218 | 103,170 | 36,161 |
| 12 | 208,645 | 6,921 | 0 | 0 | 0 | 0 | 0 | 0 | 47,708 | 110,257 | 35,131 |
| 13 | 219,077 | 7,129 | 0 | 0 | 0 | 0 | 0 | 0 | 45,322 | 117,595 | 34,063 |
| 14 | 230,031 | 7,343 | 0 | 0 | 0 | 0 | 0 | 0 | 43,056 | 125,202 | 32,970 |
| 15 | 241,533 | 7,563 | 0 | 0 | 0 | 0 | 0 | 0 | 40,903 | 133,096 | 31,862 |
| 16 | 253,610 | 7,790 | 0 | 0 | 0 | 0 | 0 | 0 | 38,858 | 141,296 | 30,750 |
| 17 | 266,290 | 8,024 | 0 | 0 | 0 | 0 | 0 | 0 | 36,915 | 149,822 | 29,641 |
| 18 | 279,604 | 8,264 | 0 | 0 | 0 | 0 | 0 | 0 | 35,069 | 158,693 | 28,542 |
| 19 | 293,585 | 8,512 | 0 | 0 | 0 | 0 | 0 | 0 | 33,316 | 167,932 | 27,458 |
| 20 | 308,264 | 8,768 | 0 | 0 | 0 | 0 | 0 | 0 | 633,003 | -62,982 | -9,362 |

Alternative: 4
Life Cycle Cost: $2,173,357.55

| Year | Utility Cost ($) | Maint. Cost ($) | Interest Cost ($) | Principal Cost ($) | Property Taxes ($) | Insurance Cost ($) | Revenue Penalty ($) | Replace. Expenses ($) | Deprec. Tax ($) | Cash Flow Effect ($) | Present Value ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1,542,140 | 0 | 0 | 0 | 0 | 0 | 1,542,140 | 1,542,140 |
| 1 | 113,853 | 5,000 | 0 | 0 | 0 | 0 | 0 | 0 | 77,107 | 40,469 | 36,790 |
| 2 | 119,546 | 5,150 | 0 | 0 | 0 | 0 | 0 | 0 | 73,252 | 45,517 | 37,617 |
| 3 | 125,523 | 5,304 | 0 | 0 | 0 | 0 | 0 | 0 | 69,589 | 50,661 | 38,062 |
| 4 | 131,799 | 5,464 | 0 | 0 | 0 | 0 | 0 | 0 | 66,110 | 55,914 | 38,190 |
| 5 | 138,389 | 5,628 | 0 | 0 | 0 | 0 | 0 | 0 | 62,804 | 61,288 | 38,055 |
| 6 | 145,309 | 5,796 | 0 | 0 | 0 | 0 | 0 | 0 | 59,664 | 66,797 | 37,705 |
| 7 | 152,574 | 5,970 | 0 | 0 | 0 | 0 | 0 | 0 | 56,681 | 72,454 | 37,180 |
| 8 | 160,203 | 6,149 | 0 | 0 | 0 | 0 | 0 | 0 | 53,847 | 78,273 | 36,515 |
| 9 | 168,213 | 6,334 | 0 | 0 | 0 | 0 | 0 | 0 | 51,154 | 84,266 | 35,737 |
| 10 | 176,623 | 6,524 | 0 | 0 | 0 | 0 | 0 | 0 | 48,597 | 90,450 | 34,872 |
| 11 | 185,455 | 6,720 | 0 | 0 | 0 | 0 | 0 | 0 | 46,167 | 96,838 | 33,941 |
| 12 | 194,727 | 6,921 | 0 | 0 | 0 | 0 | 0 | 0 | 43,858 | 103,446 | 32,961 |
| 13 | 204,464 | 7,129 | 0 | 0 | 0 | 0 | 0 | 0 | 41,666 | 110,289 | 31,947 |
| 14 | 214,687 | 7,343 | 0 | 0 | 0 | 0 | 0 | 0 | 39,582 | 117,385 | 30,911 |
| 15 | 225,421 | 7,563 | 0 | 0 | 0 | 0 | 0 | 0 | 37,603 | 124,749 | 29,864 |
| 16 | 236,692 | 7,790 | 0 | 0 | 0 | 0 | 0 | 0 | 35,723 | 132,400 | 28,814 |
| 17 | 248,527 | 8,024 | 0 | 0 | 0 | 0 | 0 | 0 | 33,937 | 140,355 | 27,769 |
| 18 | 260,953 | 8,264 | 0 | 0 | 0 | 0 | 0 | 0 | 32,240 | 148,634 | 26,733 |
| 19 | 274,001 | 8,512 | 0 | 0 | 0 | 0 | 0 | 0 | 30,628 | 157,257 | 25,713 |
| 20 | 287,701 | 8,768 | 0 | 0 | 0 | 0 | 0 | 0 | 581,932 | -54,892 | -8,159 |

## Economic Comparisons

### Alternative 2 vs Alternative 1

| | |
|---|---|
| First Cost Difference | -203,860.00 |
| Down Payment Difference | -203,860.00 |
| Net Present Value of Incremental Cash Flows | 232,270.96 |
| Life Cycle Cost Difference | 232,270.96 |
| Revenue Penalty Difference | 0.00 |
| Simple Payback on Investment | 0.0 years |
| Life Cycle Payback on Investment | 0.0 years |
| Internal Rate of Return | Over 1,000 % |
| Cost of capital (%) | 10.0 |

| Year | Cash Flow Difference | Cumulative Cash Flow Difference | Present Value of Flow Difference | Net Present Value |
|---|---|---|---|---|
| 0 | 203,860.00 | 203,860.00 | 203,860.00 | 203,860.00 |
| 1 | 834.10 | 204,694.10 | 758.27 | 204,618.27 |
| 2 | 1,271.53 | 205,965.63 | 1,050.85 | 205,669.12 |
| 3 | 1,710.08 | 207,675.70 | 1,284.81 | 206,953.93 |
| 4 | 2,150.82 | 209,826.52 | 1,469.04 | 208,422.96 |
| 5 | 2,594.81 | 212,421.33 | 1,611.17 | 210,034.14 |
| 6 | 3,043.14 | 215,464.47 | 1,717.77 | 211,751.91 |
| 7 | 3,496.87 | 218,961.34 | 1,794.45 | 213,546.36 |
| 8 | 3,957.10 | 222,918.44 | 1,846.01 | 215,392.37 |
| 9 | 4,424.92 | 227,343.35 | 1,876.60 | 217,268.97 |
| 10 | 4,901.45 | 232,244.81 | 1,889.72 | 219,158.69 |
| 11 | 5,387.83 | 237,632.64 | 1,888.40 | 221,047.09 |
| 12 | 5,885.21 | 243,517.85 | 1,875.21 | 222,922.30 |
| 13 | 6,394.77 | 249,912.62 | 1,852.34 | 224,774.64 |
| 14 | 6,917.72 | 256,830.34 | 1,821.65 | 226,596.29 |
| 15 | 7,455.28 | 264,285.62 | 1,784.73 | 228,381.02 |
| 16 | 8,008.73 | 272,294.35 | 1,742.93 | 230,123.96 |
| 17 | 8,579.36 | 280,873.71 | 1,697.38 | 231,821.34 |
| 18 | 9,168.52 | 290,042.23 | 1,649.04 | 233,470.37 |
| 19 | 9,777.59 | 299,819.82 | 1,598.71 | 235,069.09 |
| 20 | -18,824.39 | 280,995.44 | -2,798.12 | 232,270.96 |

### Alternative 3 vs Alternative 1

| | |
|---|---|
| First Cost Difference | 177,480.00 |
| Down Payment Difference | 177,480.00 |
| Net Present Value of Incremental Cash Flows | -15,110.04 |
| Life Cycle Cost Difference | -15,110.04 |
| Revenue Penalty Difference | 0.00 |
| Simple Payback on Investment | 9.6 years |
| Life Cycle Payback on Investment | Does not pay back |
| Internal Rate of Return | 8.9 % |
| Cost of capital (%) | 10.0 |

| Year | Cash Flow Difference | Cumulative Cash Flow Difference | Present Value of Flow Difference | Net Present Value |
|---|---|---|---|---|
| 0 | -177,480.00 | -177,480.00 | -177,480.00 | -177,480.00 |
| 1 | 14,628.63 | -162,851.37 | 13,298.76 | -164,181.24 |
| 2 | 15,029.10 | -147,822.26 | 12,420.75 | -151,760.50 |
| 3 | 15,468.07 | -132,354.20 | 11,621.39 | -140,139.11 |
| 4 | 15,946.58 | -116,407.62 | 10,891.73 | -129,247.38 |
| 5 | 16,465.80 | -99,941.82 | 10,223.96 | -119,023.42 |
| 6 | 17,026.98 | -82,914.84 | 9,611.29 | -109,412.13 |
| 7 | 17,631.49 | -65,283.35 | 9,047.74 | -100,364.39 |
| 8 | 18,280.79 | -47,002.55 | 8,528.12 | -91,836.27 |
| 9 | 18,976.47 | -28,026.08 | 8,047.87 | -83,788.39 |
| 10 | 19,720.21 | -8,305.88 | 7,602.99 | -76,185.40 |
| 11 | 20,513.82 | 12,207.94 | 7,189.97 | -68,995.44 |
| 12 | 21,359.23 | 33,567.17 | 6,805.71 | -62,189.73 |
| 13 | 22,258.51 | 55,825.68 | 6,447.50 | -55,742.23 |
| 14 | 23,213.85 | 79,039.53 | 6,112.93 | -49,629.30 |
| 15 | 24,227.57 | 103,267.10 | 5,799.89 | -43,829.42 |
| 16 | 25,302.14 | 128,569.25 | 5,506.48 | -38,322.94 |
| 17 | 26,440.19 | 155,009.44 | 5,231.05 | -33,091.89 |
| 18 | 27,644.48 | 182,653.92 | 4,972.10 | -28,119.79 |
| 19 | 28,917.96 | 211,571.88 | 4,728.31 | -23,391.47 |
| 20 | 55,713.35 | 267,285.23 | 8,281.43 | -15,110.04 |

## Alternative 3 vs Alternative 2

| | |
|---|---|
| First Cost Difference | 381,340.00 |
| Down Payment Difference | 381,340.00 |
| Net Present Value of Incremental Cash Flows | -247,381.00 |
| Life Cycle Cost Difference | -247,381.00 |
| Revenue Penalty Difference | 0.00 |
| Simple Payback on Investment | 37.1 years |
| Life Cycle Payback on Investment | Does not pay back |
| Internal Rate of Return | Does not pay back |
| Cost of capital (%) | 10.0 |

| Year | Cash Flow Difference | Cumulative Cash Flow Difference | Present Value of Flow Difference | Net Present Value |
|---|---|---|---|---|
| 0 | -381,340.00 | -381,340.00 | -381,340.00 | -381,340.00 |
| 1 | 13,794.53 | -367,545.47 | 12,540.48 | -368,799.52 |
| 2 | 13,757.58 | -353,787.89 | 11,369.90 | -357,429.62 |
| 3 | 13,757.99 | -340,029.90 | 10,336.58 | -347,093.04 |
| 4 | 13,795.76 | -326,234.14 | 9,422.69 | -337,670.35 |
| 5 | 13,870.99 | -312,363.15 | 8,612.79 | -329,057.56 |
| 6 | 13,983.84 | -298,379.31 | 7,893.52 | -321,164.04 |
| 7 | 14,134.62 | -284,244.69 | 7,253.30 | -313,910.75 |
| 8 | 14,323.70 | -269,920.99 | 6,682.11 | -307,228.64 |
| 9 | 14,551.55 | -255,369.44 | 6,171.28 | -301,057.36 |
| 10 | 14,818.75 | -240,550.68 | 5,713.27 | -295,344.09 |
| 11 | 15,125.98 | -225,424.70 | 5,301.56 | -290,042.53 |
| 12 | 15,474.02 | -209,950.68 | 4,930.50 | -285,112.03 |
| 13 | 15,863.74 | -194,086.94 | 4,595.16 | -280,516.87 |
| 14 | 16,296.13 | -177,790.81 | 4,291.28 | -276,225.59 |
| 15 | 16,772.29 | -161,018.52 | 4,015.15 | -272,210.44 |
| 16 | 17,293.41 | -143,725.11 | 3,763.55 | -268,446.89 |
| 17 | 17,860.83 | -125,864.28 | 3,533.67 | -264,913.22 |
| 18 | 18,475.96 | -107,388.32 | 3,323.06 | -261,590.16 |
| 19 | 19,140.37 | -88,247.95 | 3,129.60 | -258,460.56 |
| 20 | 74,537.74 | -13,710.21 | 11,079.55 | -247,381.00 |

## Alternative 3 vs Alternative 4

| | |
|---|---|
| First Cost Difference | 135,340.00 |
| Down Payment Difference | 135,340.00 |
| Net Present Value of Incremental Cash Flows | -174,509.15 |
| Life Cycle Cost Difference | -174,509.15 |
| Revenue Penalty Difference | 0.00 |
| Simple Payback on Investment | Does not pay back |
| Life Cycle Payback on Investment | Does not pay back |
| Internal Rate of Return | Does not pay back |
| Cost of capital (%) | 10.0 |

| Year | Cash Flow Difference | Cumulative Cash Flow Difference | Present Value of Flow Difference | Net Present Value |
|---|---|---|---|---|
| 0 | -135,340.00 | -135,340.00 | -135,340.00 | -135,340.00 |
| 1 | -2,175.73 | -137,515.73 | -1,977.94 | -137,317.94 |
| 2 | -2,555.20 | -140,070.94 | -2,111.74 | -139,429.68 |
| 3 | -2,940.11 | -143,011.04 | -2,208.95 | -141,638.62 |
| 4 | -3,331.40 | -146,342.44 | -2,275.39 | -143,914.01 |
| 5 | -3,730.04 | -150,072.49 | -2,316.06 | -146,230.08 |
| 6 | -4,137.02 | -154,209.50 | -2,335.24 | -148,565.32 |
| 7 | -4,553.31 | -158,762.82 | -2,336.57 | -150,901.88 |
| 8 | -4,979.95 | -163,742.77 | -2,323.18 | -153,225.07 |
| 9 | -5,417.98 | -169,160.75 | -2,297.75 | -155,522.82 |
| 10 | -5,868.45 | -175,029.20 | -2,262.54 | -157,785.36 |
| 11 | -6,332.47 | -181,361.67 | -2,219.49 | -160,004.85 |
| 12 | -6,811.16 | -188,172.83 | -2,170.24 | -162,175.10 |
| 13 | -7,305.68 | -195,478.50 | -2,116.19 | -164,291.29 |
| 14 | -7,817.23 | -203,295.73 | -2,058.52 | -166,349.81 |
| 15 | -8,347.04 | -211,642.77 | -1,998.21 | -168,348.02 |
| 16 | -8,896.39 | -220,539.16 | -1,936.11 | -170,284.14 |
| 17 | -9,466.62 | -230,005.78 | -1,872.92 | -172,157.06 |
| 18 | -10,059.08 | -240,064.86 | -1,809.21 | -173,966.27 |
| 19 | -10,675.21 | -250,740.07 | -1,745.48 | -175,711.75 |
| 20 | 8,090.51 | -242,649.56 | 1,202.60 | -174,509.15 |

## Alternative 4 vs Alternative 1

| | |
|---|---|
| First Cost Difference | 42,140.00 |
| Down Payment Difference | 42,140.00 |
| Net Present Value of Incremental Cash Flows | 159,399.11 |
| Life Cycle Cost Difference | 159,399.11 |
| Revenue Penalty Difference | 0.00 |
| Simple Payback on Investment | 1.6 years |
| Life Cycle Payback on Investment | 2.9 years |
| Internal Rate of Return | 44.5 % |
| Cost of capital (%) | 10.0 |

| Year | Cash Flow Difference | Cumulative Cash Flow Difference | Present Value of Flow Difference | Net Present Value |
|---|---|---|---|---|
| 0 | -42,140.00 | -42,140.00 | -42,140.00 | -42,140.00 |
| 1 | 16,804.37 | -25,335.63 | 15,276.70 | -26,863.30 |
| 2 | 17,584.30 | -7,751.33 | 14,532.48 | -12,330.82 |
| 3 | 18,408.17 | 10,656.84 | 13,830.33 | 1,499.51 |
| 4 | 19,277.98 | 29,934.82 | 13,167.12 | 14,666.63 |
| 5 | 20,195.84 | 50,130.67 | 12,540.03 | 27,206.66 |
| 6 | 21,164.00 | 71,294.67 | 11,946.53 | 39,153.18 |
| 7 | 22,184.81 | 93,479.47 | 11,384.31 | 50,537.50 |
| 8 | 23,260.75 | 116,740.22 | 10,851.31 | 61,388.80 |
| 9 | 24,394.45 | 141,134.67 | 10,345.62 | 71,734.43 |
| 10 | 25,588.66 | 166,723.32 | 9,865.53 | 81,599.96 |
| 11 | 26,846.28 | 193,569.61 | 9,409.46 | 91,009.42 |
| 12 | 28,170.39 | 221,740.00 | 8,975.95 | 99,985.37 |
| 13 | 29,564.19 | 251,304.19 | 8,563.69 | 108,549.06 |
| 14 | 31,031.08 | 282,335.26 | 8,171.45 | 116,720.51 |
| 15 | 32,574.61 | 314,909.87 | 7,798.10 | 124,518.61 |
| 16 | 34,198.54 | 349,108.41 | 7,442.59 | 131,961.20 |
| 17 | 35,906.80 | 385,015.21 | 7,103.97 | 139,065.17 |
| 18 | 37,703.56 | 422,718.77 | 6,781.31 | 145,846.48 |
| 19 | 39,593.17 | 462,311.94 | 6,473.80 | 152,320.28 |
| 20 | 47,622.84 | 509,934.79 | 7,078.83 | 159,399.11 |

## Alternative 4 vs Alternative 2

| | |
|---|---|
| First Cost Difference | 246,000.00 |
| Down Payment Difference | 246,000.00 |
| Net Present Value of Incremental Cash Flows | -72,871.86 |
| Life Cycle Cost Difference | -72,871.86 |
| Revenue Penalty Difference | 0.00 |
| Simple Payback on Investment | 13.4 years |
| Life Cycle Payback on Investment | Does not pay back |
| Internal Rate of Return | 6.0 % |
| Cost of capital (%) | 10.0 |

| Year | Cash Flow Difference | Cumulative Cash Flow Difference | Present Value of Flow Difference | Net Present Value |
|---|---|---|---|---|
| 0 | -246,000.00 | -246,000.00 | -246,000.00 | -246,000.00 |
| 1 | 15,970.27 | -230,029.73 | 14,518.42 | -231,481.58 |
| 2 | 16,312.78 | -213,716.96 | 13,481.63 | -217,999.94 |
| 3 | 16,698.10 | -197,018.86 | 12,545.53 | -205,454.42 |
| 4 | 17,127.16 | -179,891.70 | 11,698.08 | -193,756.33 |
| 5 | 17,601.03 | -162,290.67 | 10,928.85 | -182,827.48 |
| 6 | 18,120.86 | -144,169.81 | 10,228.75 | -172,598.73 |
| 7 | 18,687.94 | -125,481.87 | 9,589.87 | -163,008.86 |
| 8 | 19,303.65 | -106,178.22 | 9,005.29 | -154,003.57 |
| 9 | 19,969.53 | -86,208.69 | 8,469.03 | -145,534.54 |
| 10 | 20,687.21 | -65,521.48 | 7,975.81 | -137,558.73 |
| 11 | 21,458.45 | -44,063.03 | 7,521.05 | -130,037.67 |
| 12 | 22,285.18 | -21,777.85 | 7,100.74 | -122,936.93 |
| 13 | 23,169.42 | 1,391.56 | 6,711.35 | -116,225.58 |
| 14 | 24,113.36 | 25,504.92 | 6,349.80 | -109,875.78 |
| 15 | 25,119.33 | 50,624.25 | 6,013.37 | -103,862.42 |
| 16 | 26,189.81 | 76,814.06 | 5,699.66 | -98,162.75 |
| 17 | 27,327.44 | 104,141.50 | 5,406.59 | -92,756.17 |
| 18 | 28,535.04 | 132,676.54 | 5,132.28 | -87,623.89 |
| 19 | 29,815.58 | 162,492.12 | 4,875.08 | -82,748.81 |
| 20 | 66,447.23 | 228,939.35 | 9,876.95 | -72,871.86 |

# Monthly Utility Costs

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ------- Monthly Utility Costs ------- | | | | | | | | |
| **Alternative 1** | | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 2,724 | 2,464 | 2,966 | 2,622 | 3,625 | 4,011 | 4,889 | 5,001 | 3,608 | 3,148 | 2,711 | 2,581 | 40,350 |
| Off-Pk Cons. ($) | 261 | 225 | 210 | 175 | 166 | 178 | 449 | 273 | 194 | 167 | 210 | 245 | 2,752 |
| On-Pk Demand ($) | 4,917 | 4,886 | 4,983 | 5,388 | 9,409 | 10,377 | 12,988 | 12,227 | 10,759 | 6,971 | 5,023 | 4,876 | 92,804 |
| Off-Pk Demand ($) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 540 |
| Total ($): | 7,947 | 7,620 | 8,203 | 8,231 | 13,244 | 14,611 | 18,371 | 17,546 | 14,607 | 10,331 | 7,989 | 7,748 | 136,446 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 1,767 | 1,273 | 860 | 156 | 0 | 0 | 0 | 0 | 0 | 128 | 747 | 1,076 | 6,009 |
| Monthly Total ($): | 9,714 | 8,893 | 9,063 | 8,387 | 13,244 | 14,611 | 18,371 | 17,546 | 14,607 | 10,459 | 8,736 | 8,824 | 142,456 |

Building Area = 128,800 ft²
Utility Cost Per Area = 1.11 $/ft²

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ------- Monthly Utility Costs ------- | | | | | | | | |
| **Alternative 2** | | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 2,668 | 2,414 | 2,904 | 2,581 | 3,502 | 3,891 | 4,613 | 4,765 | 3,493 | 3,049 | 2,662 | 2,527 | 39,068 |
| Off-Pk Cons. ($) | 260 | 225 | 206 | 172 | 171 | 188 | 456 | 281 | 197 | 169 | 209 | 245 | 2,781 |
| On-Pk Demand ($) | 4,732 | 4,701 | 4,731 | 5,279 | 8,725 | 9,706 | 12,065 | 11,305 | 9,920 | 6,431 | 4,839 | 4,688 | 87,121 |
| Off-Pk Demand ($) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 540 |
| Total ($): | 7,705 | 7,384 | 7,886 | 8,077 | 12,443 | 13,831 | 17,178 | 16,396 | 13,655 | 9,694 | 7,755 | 7,505 | 129,510 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 1,739 | 1,227 | 805 | 139 | 0 | 0 | 0 | 0 | 0 | 112 | 709 | 1,029 | 5,760 |
| Monthly Total ($): | 9,444 | 8,610 | 8,691 | 8,216 | 12,443 | 13,831 | 17,178 | 16,396 | 13,655 | 9,806 | 8,464 | 8,534 | 135,270 |

Building Area = 128,800 ft²
Utility Cost Per Area = 1.05 $/ft²

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ------- Monthly Utility Costs ------- | | | | | | | | |
| **Alternative 3** | | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 2,724 | 2,464 | 2,966 | 2,608 | 3,228 | 3,303 | 3,242 | 3,576 | 2,970 | 2,904 | 2,711 | 2,581 | 35,277 |
| Off-Pk Cons. ($) | 261 | 225 | 210 | 218 | 778 | 1,296 | 2,249 | 2,177 | 1,131 | 499 | 210 | 245 | 9,498 |
| On-Pk Demand ($) | 4,917 | 4,886 | 4,983 | 5,166 | 6,693 | 6,796 | 7,877 | 7,165 | 6,935 | 5,348 | 5,023 | 4,876 | 70,666 |
| Off-Pk Demand ($) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 540 |
| Total ($): | 7,947 | 7,620 | 8,203 | 8,037 | 10,744 | 11,440 | 13,413 | 12,964 | 11,081 | 8,796 | 7,989 | 7,748 | 115,981 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 1,767 | 1,273 | 860 | 156 | 0 | 0 | 0 | 0 | 0 | 128 | 747 | 1,076 | 6,009 |
| Monthly Total ($): | 9,714 | 8,893 | 9,063 | 8,193 | 10,745 | 11,440 | 13,413 | 12,964 | 11,081 | 8,925 | 8,736 | 8,824 | 121,991 |

Building Area = 128,800 ft²
Utility Cost Per Area = 0.95 $/ft²

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ------- Monthly Utility Costs ------- | | | | | | | | |
| **Alternative 4** | | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 2,668 | 2,414 | 2,904 | 2,544 | 3,103 | 3,149 | 3,033 | 3,361 | 2,843 | 2,817 | 2,659 | 2,527 | 34,022 |
| Off-Pk Cons. ($) | 260 | 225 | 206 | 249 | 623 | 936 | 1,567 | 1,458 | 852 | 443 | 219 | 245 | 7,283 |
| On-Pk Demand ($) | 4,732 | 4,701 | 4,731 | 4,879 | 6,221 | 6,312 | 7,231 | 6,565 | 6,382 | 5,002 | 4,806 | 4,688 | 66,248 |
| Off-Pk Demand ($) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 540 |
| Total ($): | 7,705 | 7,384 | 7,886 | 7,717 | 9,992 | 10,441 | 11,876 | 11,429 | 10,122 | 8,307 | 7,729 | 7,505 | 108,093 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. ($) | 1,739 | 1,227 | 805 | 139 | 0 | 0 | 0 | 0 | 0 | 112 | 709 | 1,029 | 5,760 |
| Monthly Total ($): | 9,444 | 8,610 | 8,691 | 7,856 | 9,992 | 10,441 | 11,876 | 11,429 | 10,122 | 8,419 | 8,438 | 8,534 | 113,853 |

Building Area = 128,800 ft²
Utility Cost Per Area = 0.88 $/ft²

## Economic Parameters

| | |
|---|---|
| **Project Name:** | Thanksgiving Park |
| **Location:** | Salt Lake City UT |
| **Building Owner:** | |
| **Program User:** | Philip Coleman |
| **Company:** | Trane |
| **Comments:** | |

| | | | |
|---|---|---|---|
| Study Life: | 20 Yrs | Income Tax Rate: | 40.0 % |
| Mortgage Life: | 20 Yrs | Cost of Capital: | 10.0 % |
| Depreciation Life: | 20 Yrs | Property tax rate: | 0.0 % |
| Mortgage Interest Rate: | 10.0 % | Insurance Expense rate: | 0.0 % |
| Percent Financed: | 0.0 % | | |
| Depreciation Method: | Declining balance | Annual Inflation Rate Of | |
| Declining Balance Taxes: | 100.0 % | Maintenance Expense | 3.0 % |
| | | Replacement Expense | 3.0 % |
| | | Property Taxes | 3.0 % |
| | | Insurance Expense | 3.0 % |

| Alt # | First Cost ($/ton) | First Cost ($/ft²) | Additional First Cost | Total First Cost | Maintenance Cost ($/ton) | Maintenance Cost ($/ft²) | Total Maint. Cost | Total Alt. Cost |
|---|---|---|---|---|---|---|---|---|
| 4 | 6,240.55 | 11.97 | 0.00 | 1,542,140.00 | 20.23 | 0.04 | 5,000.00 | 1,547,140.00 |
| 3 | 6,716.33 | 13.02 | 0.00 | 1,677,480.00 | 20.02 | 0.04 | 5,000.00 | 1,682,480.00 |
| 2 | 5,245.06 | 10.06 | 0.00 | 1,296,140.00 | 8.09 | 0.02 | 2,000.00 | 1,298,140.00 |
| 1 | 6,005.73 | 11.65 | 0.00 | 1,500,000.00 | 12.01 | 0.02 | 3,000.00 | 1,503,000.00 |

# Economic Summary

## Economic Summary

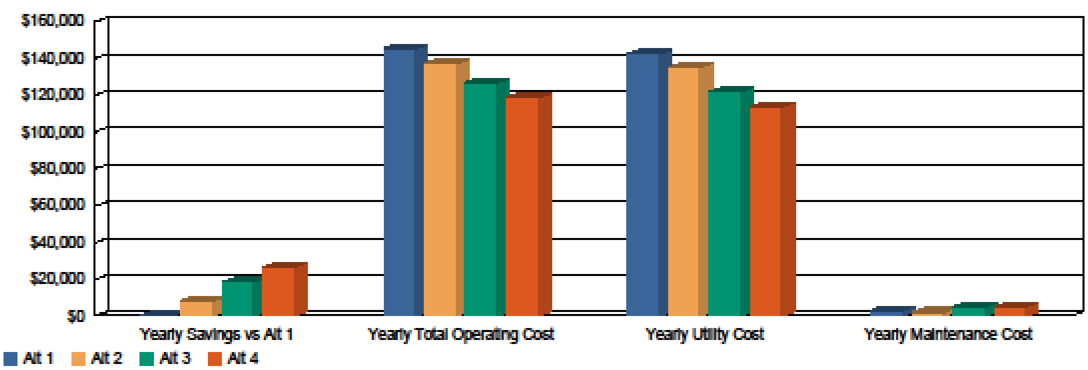
### Project Information

| | | | |
|---|---|---|---|
| Location | Salt Lake City UT | Study Life: | 20 years |
| Project Name | Thanksgiving Park | Cost of Capital: | 10 % |
| User | Philip Coleman | Alternative 1: | Baseline |
| Company | Trane | Alternative 2: | Low Temp Low Flow |
| Comments | | Alternative 3: | Thermal Storage |
| | | Alternative 4: | EarthWise with Storage |

### Economic Comparison of Alternatives

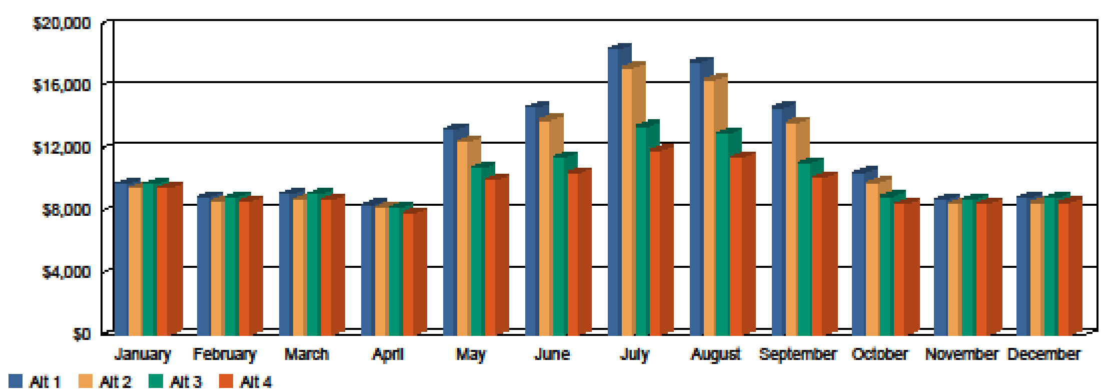
| | Yearly Savings ($) | First Cost Difference ($) | Cumulative Cash Flow Difference ($) | Simple Payback (yrs.) | Net Present Value ($) | Life Cycle Payback (yrs.) | Internal Rate of Return (%) |
|---|---|---|---|---|---|---|---|
| Alt 2 vs Alt 1 | 8,186 | -203,860 | 280,995 | 0.0 | 232,271 | No Payback | 1,000.0 |
| Alt 3 vs Alt 1 | 18,465 | 177,480 | 267,285 | 9.6 | -15,110 | No Payback | 8.9 |
| Alt 4 vs Alt 1 | 26,603 | 42,140 | 509,935 | 1.6 | 159,399 | 2.9 | 44.5 |
| Alt 3 vs Alt 2 | 18,465 | 381,340 | -13,710 | 37.1 | -247,381 | No Payback | Does Not Payback |
| Alt 4 vs Alt 2 | 26,603 | 246,000 | 228,939 | 13.4 | -72,872 | No Payback | 6.0 |
| Alt 3 vs Alt 4 | 18,465 | 135,340 | -242,650 | -1.0 | -174,509 | No Payback | Does Not Payback |

### Annual Operating Costs




| | Yearly Savings vs Alt 1 | Yearly Total Operating Cost ($) | Yearly Utility Cost ($) | Yearly Maintenance Cost ($) |
|---|---|---|---|---|
| Alt 1 | 0 | 145,456 | 142,456 | 3,000 |
| Alt 2 | 8,186 | 137,270 | 135,270 | 2,000 |
| Alt 3 | 18,465 | 126,991 | 121,991 | 5,000 |
| Alt 4 | 26,603 | 118,853 | 113,853 | 5,000 |

### Monthly Utility Costs




Project Name: Thanksgiving Park
Dataset Name: TG PARK STD 62.TRC

TRACE 700 6.2.5
calculated at 08:52 AM on 09/09/2010

# Energy Consumption Summaries

| | Elect Cons. (kWh) | Gas Cons. (kBtu) | % of Total Building Energy | Total Building Energy (kBtu/yr) | Total Source Energy* (kBtu/yr) |
|---|---|---|---|---|---|
| **Alternative 1** | | | | | |
| **Primary heating** | | | | | |
| Primary heating | | 1,013,080 | 17.4 % | 1,013,080 | 1,066,400 |
| Other Htg Accessories | 15,808 | | 0.9 % | 53,951 | 161,869 |
| **Heating Subtotal** | **15,808** | **1,013,080** | **18.4 %** | **1,067,031** | **1,228,270** |
| **Primary cooling** | | | | | |
| Cooling Compressor | 151,096 | | 8.9 % | 515,690 | 1,547,224 |
| Tower/Cond Fans | 18,211 | | 1.1 % | 62,156 | 186,486 |
| Condenser Pump | | | 0.0 % | 0 | 0 |
| Other Clg Accessories | 6,576 | | 0.4 % | 22,445 | 67,340 |
| **Cooling Subtotal....** | **175,883** | | **10.3 %** | **600,290** | **1,801,050** |
| **Auxiliary** | | | | | |
| Supply Fans | 130,369 | | 7.7 % | 444,951 | 1,334,986 |
| Pumps | 6,298 | | 0.4 % | 21,496 | 64,496 |
| Stand-alone Base Utilities | | | 0.0 % | 0 | 0 |
| Aux Subtotal.... | 136,668 | | 8.0 % | 466,447 | 1,399,481 |
| **Lighting** | | | | | |
| Lighting | 445,391 | | 26.2 % | 1,520,119 | 4,560,814 |
| **Receptacle** | | | | | |
| Receptacles | 632,074 | | 37.1 % | 2,157,267 | 6,472,448 |
| **Cogeneration** | | | | | |
| Cogeneration | | | 0.0 % | 0 | 0 |
| **Totals** | | | | | |
| **Totals**** | **1,405,823** | **1,013,080** | **100.0 %** | **5,811,155** | **15,462,062** |

| | Elect Cons. (kWh) | Gas Cons. (kBtu) | % of Total Building Energy | Total Building Energy (kBtu/yr) | Total Source Energy* (kBtu/yr) |
|---|---|---|---|---|---|
| **Alternative 2** | | | | | |
| **Primary heating** | | | | | |
| Primary heating | | 970,474 | 17.2 % | 970,474 | 1,021,552 |
| Other Htg Accessories | 16,049 | | 1.0 % | 54,777 | 164,347 |
| **Heating Subtotal** | **16,049** | **970,474** | **18.2 %** | **1,025,251** | **1,185,899** |
| **Primary cooling** | | | | | |
| Cooling Compressor | 151,096 | | 9.2 % | 515,689 | 1,547,223 |
| Tower/Cond Fans | 18,430 | | 1.1 % | 62,901 | 188,721 |
| Condenser Pump | | | 0.0 % | 0 | 0 |
| Other Clg Accessories | 7,638 | | 0.5 % | 26,069 | 78,216 |
| **Cooling Subtotal....** | **177,164** | | **10.7 %** | **604,660** | **1,814,160** |
| **Auxiliary** | | | | | |
| Supply Fans | 87,460 | | 5.3 % | 298,503 | 895,598 |
| Pumps | 7,300 | | 0.4 % | 24,916 | 74,756 |
| Stand-alone Base Utilities | | | 0.0 % | 0 | 0 |
| Aux Subtotal.... | 94,761 | | 5.7 % | 323,419 | 970,353 |
| **Lighting** | | | | | |
| Lighting | 445,391 | | 27.0 % | 1,520,119 | 4,560,814 |
| **Receptacle** | | | | | |
| Receptacles | 632,074 | | 38.3 % | 2,157,267 | 6,472,448 |
| **Cogeneration** | | | | | |
| Cogeneration | | | 0.0 % | 0 | 0 |
| **Totals** | | | | | |
| **Totals**** | **1,365,438** | **970,474** | **100.0 %** | **5,630,715** | **15,003,673** |

| | Elect Cons. (kWh) | Gas Cons. (kBtu) | % of Total Building Energy | Total Building Energy (kBtu/yr) | Total Source Energy* (kBtu/yr) |
|---|---|---|---|---|---|
| **Alternative 3** | | | | | |
| **Primary heating** | | | | | |
| Primary heating | | 1,013,080 | 16.9 % | 1,013,080 | 1,066,400 |
| Other Htg Accessories | 15,808 | | 0.9 % | 53,951 | 161,869 |
| **Heating Subtotal** | **15,808** | **1,013,080** | **17.8 %** | **1,067,031** | **1,228,270** |
| **Primary cooling** | | | | | |
| Cooling Compressor | 197,717 | | 11.3 % | 674,810 | 2,024,631 |
| Tower/Cond Fans | 22,240 | | 1.3 % | 75,904 | 227,735 |
| Condenser Pump | | | 0.0 % | 0 | 0 |
| Other Clg Accessories | 7,656 | | 0.4 % | 26,129 | 78,394 |
| **Cooling Subtotal....** | **227,613** | | **13.0 %** | **776,842** | **2,330,760** |
| **Auxiliary** | | | | | |
| Supply Fans | 130,369 | | 7.4 % | 444,951 | 1,334,986 |
| Pumps | 7,332 | | 0.4 % | 25,025 | 75,082 |
| Stand-alone Base Utilities | | | 0.0 % | 0 | 0 |
| Aux Subtotal.... | 137,702 | | 7.8 % | 469,976 | 1,410,068 |
| **Lighting** | | | | | |
| Lighting | 445,391 | | 25.4 % | 1,520,119 | 4,560,814 |
| **Receptacle** | | | | | |
| Receptacles | 632,074 | | 36.0 % | 2,157,267 | 6,472,448 |
| **Cogeneration** | | | | | |
| Cogeneration | | | 0.0 % | 0 | 0 |
| **Totals** | | | | | |
| **Totals**** | **1,458,586** | **1,013,080** | **100.0 %** | **5,991,235** | **16,002,358** |

| | Elect Cons. (kWh) | Gas Cons. (kBtu) | % of Total Building Energy | Total Building Energy (kBtu/yr) | Total Source Energy* (kBtu/yr) |
|---|---|---|---|---|---|
| **Alternative 4** | | | | | |
| **Primary heating** | | | | | |
| Primary heating | | 970,474 | 17.4 % | 970,474 | 1,021,552 |
| Other Htg Accessories | 16,049 | | 1.0 % | 54,777 | 164,347 |
| **Heating Subtotal** | **16,049** | **970,474** | **18.4 %** | **1,025,251** | **1,185,899** |
| **Primary cooling** | | | | | |
| Cooling Compressor | 130,917 | | 8.0 % | 446,819 | 1,340,592 |
| Tower/Cond Fans | 20,560 | | 1.3 % | 70,171 | 210,534 |
| Condenser Pump | | | 0.0 % | 0 | 0 |
| Other Clg Accessories | 8,271 | | 0.5 % | 28,230 | 84,697 |
| **Cooling Subtotal....** | **159,748** | | **9.8 %** | **545,220** | **1,635,823** |
| **Auxiliary** | | | | | |
| Supply Fans | 87,460 | | 5.4 % | 298,503 | 895,598 |
| Pumps | 7,905 | | 0.5 % | 26,981 | 80,951 |
| Stand-alone Base Utilities | | | 0.0 % | 0 | 0 |
| Aux Subtotal.... | 95,366 | | 5.8 % | 325,483 | 976,548 |
| **Lighting** | | | | | |
| Lighting | 445,391 | | 27.3 % | 1,520,119 | 4,560,814 |
| **Receptacle** | | | | | |
| Receptacles | 632,074 | | 38.7 % | 2,157,267 | 6,472,448 |
| **Cogeneration** | | | | | |
| Cogeneration | | | 0.0 % | 0 | 0 |
| **Totals** | | | | | |
| **Totals**** | **1,348,628** | **970,474** | **100.0 %** | **5,573,340** | **14,831,531** |

# Monthly Energy Consumptions

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 1** | **Baseline** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 92,606 | 83,780 | 100,816 | 89,141 | 113,603 | 125,714 | 153,230 | 156,723 | 113,083 | 107,007 | 92,158 | 87,749 | 1,315,610 |
| Off-Pk Cons. (kWh) | 8,869 | 7,643 | 7,129 | 5,957 | 5,188 | 5,586 | 14,065 | 8,550 | 6,084 | 5,684 | 7,130 | 8,329 | 90,213 |
| On-Pk Demand (kW) | 400 | 398 | 406 | 439 | 618 | 682 | 854 | 804 | 707 | 569 | 409 | 397 | 854 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 41 | 46 | 48 | 235 | 142 | 48 | 41 | 41 | 46 | 235 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,977 | 2,132 | 1,438 | 293 | 1 | 0 | 0 | 0 | 0 | 240 | 1,250 | 1,800 | 10,131 |
| On-Pk Demand (therms/hr) | 16 | 16 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 15 | 15 | 16 |

| Energy Consumption | | |
|---|---|---|
| Building | 45,118 | Btu/(ft2-year) |
| Source | 120,047 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| CO2 | 3,611,040 lbm/year |
| SO2 | 3,267 gm/year |
| NOX | 6,513 gm/year |

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 2** | **Low Temp Low Flow** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 90,684 | 82,048 | 98,737 | 87,735 | 109,745 | 121,962 | 144,562 | 149,333 | 109,484 | 103,650 | 90,492 | 85,912 | 1,274,345 |
| Off-Pk Cons. (kWh) | 8,854 | 7,635 | 7,004 | 5,834 | 5,372 | 5,899 | 14,297 | 8,822 | 6,178 | 5,762 | 7,109 | 8,328 | 91,093 |
| On-Pk Demand (kW) | 385 | 383 | 385 | 430 | 573 | 637 | 793 | 743 | 651 | 525 | 394 | 381 | 793 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 41 | 46 | 49 | 214 | 146 | 47 | 45 | 41 | 46 | 214 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,930 | 2,052 | 1,345 | 261 | 1 | 0 | 0 | 0 | 0 | 210 | 1,185 | 1,721 | 9,705 |
| On-Pk Demand (therms/hr) | 15 | 15 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 14 | 15 | 15 |

| Energy Consumption | | |
|---|---|---|
| Building | 43,717 | Btu/(ft2-year) |
| Source | 116,488 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| CO2 | 3,498,916 lbm/year |
| SO2 | 3,166 gm/year |
| NOX | 6,310 gm/year |

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 3** | **Thermal Storage** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 92,606 | 83,780 | 100,816 | 88,658 | 101,173 | 103,526 | 101,605 | 112,089 | 93,073 | 98,708 | 92,158 | 87,749 | 1,155,940 |
| Off-Pk Cons. (kWh) | 8,869 | 7,643 | 7,129 | 7,402 | 24,388 | 40,606 | 70,474 | 68,237 | 35,459 | 16,979 | 7,130 | 8,329 | 302,646 |
| On-Pk Demand (kW) | 400 | 398 | 406 | 421 | 439 | 445 | 517 | 470 | 455 | 436 | 409 | 397 | 517 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 188 | 316 | 377 | 461 | 438 | 376 | 271 | 41 | 46 | 461 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,977 | 2,132 | 1,438 | 293 | 1 | 0 | 0 | 0 | 0 | 240 | 1,250 | 1,800 | 10,131 |
| On-Pk Demand (therms/hr) | 16 | 16 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 15 | 15 | 16 |

| Energy Consumption | | |
|---|---|---|
| Building | 46,516 | Btu/(ft2-year) |
| Source | 124,242 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| CO2 | 3,722,942 lbm/year |
| SO2 | 3,369 gm/year |
| NOX | 6,715 gm/year |

| Utility | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative: 4** | **EarthWise with Storage** | | | | | | | | | | | | |
| Electric | | | | | | | | | | | | | |
| On-Pk Cons. (kWh) | 90,684 | 82,048 | 98,737 | 86,489 | 97,258 | 98,677 | 95,070 | 105,333 | 89,092 | 95,763 | 90,410 | 85,912 | 1,115,475 |
| Off-Pk Cons. (kWh) | 8,854 | 7,635 | 7,004 | 8,470 | 19,528 | 29,324 | 49,109 | 45,699 | 26,694 | 15,052 | 7,456 | 8,328 | 233,152 |
| On-Pk Demand (kW) | 385 | 383 | 385 | 397 | 407 | 413 | 474 | 430 | 418 | 407 | 391 | 381 | 474 |
| Off-Pk Demand (kW) | 47 | 47 | 41 | 207 | 218 | 248 | 306 | 285 | 246 | 207 | 80 | 46 | 306 |
| Gas | | | | | | | | | | | | | |
| On-Pk Cons. (therms) | 2,930 | 2,052 | 1,345 | 261 | 1 | 0 | 0 | 0 | 0 | 210 | 1,185 | 1,721 | 9,705 |
| On-Pk Demand (therms/hr) | 15 | 15 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 7 | 14 | 15 | 15 |

| Energy Consumption | | |
|---|---|---|
| Building | 43,271 | Btu/(ft2-year) |
| Source | 115,152 | Btu/(ft2-year) |
| Floor Area | 128,800 | ft2 |

| Environmental Impact Analysis | |
|---|---|
| CO2 | 3,463,263 lbm/year |
| SO2 | 3,134 gm/year |
| NOX | 6,246 gm/year |