HVAC Optimization Study

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14 August 2009- Original
3 September 2009- 1st Revision

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CHAPTER

1. EXECUTIVE SUMMARY

BACKGROUND- Heating, ventilation, and air conditioning (HVAC) can be a very costly effort when applied in industry. So was thought to be the case at the DRS Technologies facility in West Plains, Missouri. Therefore, the Pollution Prevention Program (P2) in cooperation with the DRS Technology internship program—the Cornwell Student Initiative (CSI)—decided to initiate a study focusing on the optimization of the plant's HVAC systems. The systems were thought to have become misapplied and inefficient resulting in additional energy consumption and excess electric and maintenance costs.

The problem-solving approach adhered to throughout the study was the Six Sigma process. Six Sigma's define, measure, analyze, improve and control (DMAIC) outline provided the effective structure to conduct the study. As the study progressed, training sessions were implemented to emphasize all the benefits and applications of the Six Sigma tools. To define the situation, a complete HVAC survey was conducted at the eight-plant facility. Data was then recorded in a field notebook detailing the hardware specifics (date of manufacture, efficiency ratings, and model), the system's application (servicing areas), and the user control (type of thermostat and programmability) of each HVAC system. It should be noted that all assumptions made in the calculations were considered conservative. Additionally, all data collected over this time period represent a relatively mild Missouri summer.

In the Analyze phase, the inventory was compared to benchmarks based on current industry standards. Potential upgrade options were then analyzed for feasibility and costs. This resulted in a prioritization of the alternatives to optimize the recommendations.

KEY PEOPLE INVOLVED IN STUDY

MEMBER NAME	***PROJECT TITLE***
Marcus Rivas	Pollution Prevention Project Manager
Marie Steinwachs	University of Missouri-Director MoEAC
Robert Reed	University of Missouri- Faculty Advisor
Eddie Kimes	DRS-Vice President of Operations
Jeff Ziegler	DRS-Financial Advisor
Pat Holmes	DRS-Quality Assurance Director
Ryan Cundall	DRS-Facilities Manager
Dan Sewell	Pollution Prevention/CSI Intern
Tyler McKee	Pollution Prevention/CSI Intern

SCOPE- This study concentrated on the heating and air conditioning systems in the office and administrative areas in each of the eight buildings of the West Plains manufacturing facility. The study did not include recommendations for improving efficiencies in the actual manufacturing areas.

CONSTRAINTS- The study's scope was confined to options that did not require altering the current plant layouts. Because the study was conducted over a two month period, data was only collected during the cooling season, and assumptions had to be made pertaining to system operations during the heating season. Although, there is equipment with higher efficiency ratings available on the market, upgrade estimates were provided through one of the local contractors which came highly recommended from DRS.

INCENTIVES FOR CHANGE- In addition to identifying cost savings through energy efficiency, the study was designed to aid DRS in meeting goals and objectives of its "green initiative." It was determined the plant could upgrade current HVAC systems using the ozone-depleting R-22 to environmentally-friendly systems that utilize a safer R-410A refrigerant. This equipment is also more energy efficient so will further decrease costs, energy usage, indirect emissions, and the company's overall carbon footprint. Finally, through the American Resource and Recovery Act, there are now new potential tax deductions and other incentives for the company to cut energy use (ARRA, 2009).

RECOMMENDATIONS- It was determined that with an investment of under $2,000 an estimated annual savings of $9,500 could be obtained by user controls throughout the plant. This recommendation would produce energy reductions of 211,111 kWh, resulting in the removal of 118 metric tons of Carbon Dioxide (CO_2) indirect emissions per year. This recommendation included a control metric for instituting and enforcing a "Climate Control Policy" to maximize energy savings.

Hardware recommendations included the optimization of existing central HVAC systems by adding ducting to areas that are currently served by inefficient window air conditioning units. From the results, estimated savings include an annual cost savings potential of $26,037, energy savings of 549,362 kWh and the reduction of about 301 metric tons of CO_2 emissions. The total investment for hardware was estimated at $107,396 with a simple payback of 4.1 years.

2. *BACKGROUND INFORMATION*

DESCRIPTION OF STUDIED PROCESSES - The study was initiated to assess the current state of all HVAC systems and diagnose what events led to their conditions. Intuitively, all systems degrade over time but other processes contribute to the current HVAC system status as well. DRS is a contract-based manufacturer of military support equipment. Therefore, as contracts for new equipment replace old product lines, the facility uses and the plant layout change to accommodate this. Historically, the establishment of new office areas included installation of new HVAC systems. Over time, this resulted in a patchwork of numerous systems of varying age, efficiency, and application.

The Six Sigma process analysis was applied throughout the study. It's define, measure, analyze, improve, and control (DMAIC) process, provided the structure for the project. DRS provided the necessary training to help understand all the tools the Six Sigma process has available.

Once the situation was defined, target goals were established to structure the remainder of the study. In this case, the primary goal was to optimize the HVAC systems to reduce operation costs by 10% for the West Plains facility. The related goals included energy usage reduction, a smaller carbon footprint, and less HVAC maintenance.

A tool known as the SIPOC, for "Supply, Input, Process, Output, and Customer" (Appendix A, pg 23) guided a step-by-step walk-through of the HVAC life-cycle. In this study, the customers were identified as each individual office employee and the management. After identifying the customer, a tool called the Voice of Customer/Critical-To-Quality tree (Appendix B, pg 24) was utilized to verify relevance of the measurable data back to the customer. The SIPOC and VOC/CTQ Tree, along with the goal and situation statements, proved essential tools to reference throughout the project, and especially when overwhelmed by data collection.

HVAC ENERGY CONSUMPTION- In Six Sigma, the measure phase of the project details all aspects of the data collection process, while the analyze phase begins to break down the data into its implications. All the data were obtained in regard to the approved data collection plan (Appendix C, pg 25).

Electricity provided to the plant through the City of West Plains utilities is at a rate of 4.5 cents/kilowatt hour. The total energy bill from the 2008 fiscal year was the first information obtained, resulting in almost $694,000. Of the total energy bill, the energy usage cost was $472,000. It was estimated that $56,000 of the usage charge was attributed to HVAC operations in the office and administrative areas (Appendix F: Equation 3, pg. 31).

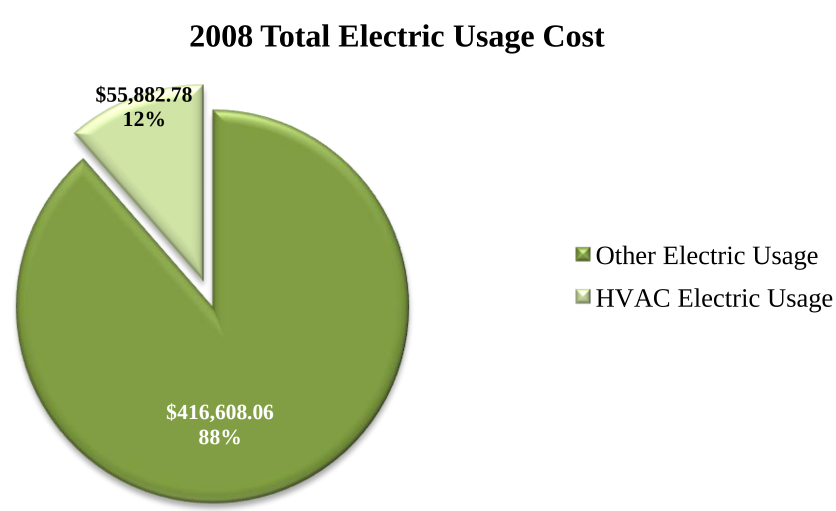


Figure 1-West Plains Total Electric Usage Cost

The City of West Plains Utilities receives approximately one-third of their electricity from hydroelectric and wind power and two-thirds from coal power. Therefore of the more than 1,240,000 kilowatt hours used by the HVAC systems in 2008, about two thirds of it -- or 830,000 kilowatt hours -- was generated by coal power. This resulted in the following indirect emissions from HVAC operation for 2008 (Table 1).

Table 1- 2008 HVAC Indirect Emissions

Energy Used (kWh)	***Carbon Dioxide (Metric Tons)***	***Nitrous Oxide (lbs)***	***Methane (lbs)***
830,000	*700*	*24*	*18*
**Note- Values from EPA's emission calculator (EPA Climate Leaders Simplified GHG Emissions Calculator (SGEC), 2008)*			

PRIMARY (MEASURABLE) DATA- All data were grouped into three main categories: Hardware, Application, and User Control. Hardware data included that unique to each particular system (age, size, seasonal energy efficiency rating (SEER), and refrigerant volume). Initially, the energy consumption and efficiency were going to be measured for each air conditioner compressor using a HOBO U12-006 data logger measuring an ammeter; however, due to time constraints and lack of familiarity with this particular piece of equipment, the data collection plan had to be altered. For application data, dimensions of all climate-controlled areas were measured to address any system sizing issues. Finally, a survey, using a template provided by the University of Missouri Industrial Assessment Center (Appendix D, pg 27), was conducted to focus recommendations to appease the consumer.

HARDWARE: The largest part of the study was attributed to the hardware data collection and itemization. An original asset list was provided that allegedly detailed all HVAC systems inside and outside of the office and administrative areas. However, the asset list was found to be outdated, and many of the listed systems had been replaced or relocated. Consequently, as hardware data were collected, a new system database was devised to update the asset list.

The study identified 35 central HVAC systems that serviced almost 36,500 square feet of office and administrative space. Thirty-one were split systems, in which the compressor unit is split from the air handler. Four were packaged HVAC units in which the compressor unit is packaged with an air-handler. Packaged units are usually more common in commercial application; however they generally have a smaller efficiency rating.

Benchmarks were based upon current industry standards. The U.S. Department of Energy states that manufacturers cannot produce units with less than a 13 SEER efficiency rating (DOE EERE, 2009). Additionally, the Energy Star program approximates life spans for heat pumps and air conditioners to be 12 years and 14 years respectively (EnergyStar, 2009). Using these standards against which to compare, it was found that 17 of the 35 systems were older than ten years of age and 28 of the systems were operating under a 13 SEER efficiency rating (Figure 2).

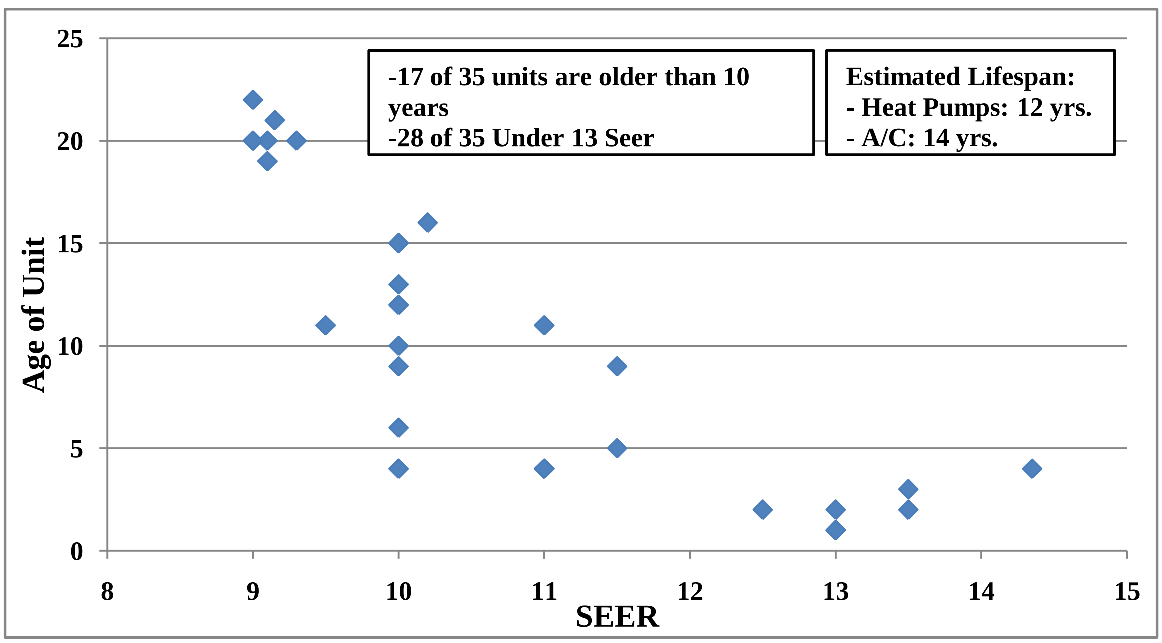


Figure 2- HVAC Efficiency Rating vs. Age of Equipment

In addition to the central HVAC systems, 26 window air conditioners serviced areas around the facility, in some instances sharing air volume with central systems. This relates back to the situation where the plants and processes evolved to meet changing operations. In need of climate-control for offices, a window air-conditioner would be installed, often transferring the energy right back into the plant. For this reason, whenever feasible it was recommended that window air-conditioners be removed.

Refrigerant was also a focus of the study since the refrigerant (R-22) is being phased out for new units as of 2010 and will be phased out completely by 2020 (EPA, 2009). Thus, the refrigerant types and volumes were measured for each system. In all, there were 291.8 pounds of ozone-depleting R-22 and 8.1 pounds of the new environmentally-friendly R-410A. The manufacturing of the stated R-22 amount would produce about 240 metric tons of CO_2 emissions (EPA GHG Conversion Tool, 2009).

APPLICATION: After the system itemization was completed, an estimated BTU/hr loading for each system's service area was calculated based on occupancy, lighting, service area, and mechanical and electrical operations (see formula in Appendix F: Equation 4, pg 31). Comparing this estimation with the actual size of the system provided an idea of how many systems were improperly sized. However, observing the information in a histogram (Figure 3), data indicates that 75% of the systems fall within a range of 25% oversized or undersized.

The 25% range was determined acceptable by DRS to because it represented any variation in the loading estimates and variation existing upon installation. However, there were three oversized systems that deserved a detailed look. Upon further investigation, however, it was found that these three systems were oversized because they had much larger BTU/hr loading requirements. This implicates that even with the outliers, the overall system sizing was not an outstanding issue.

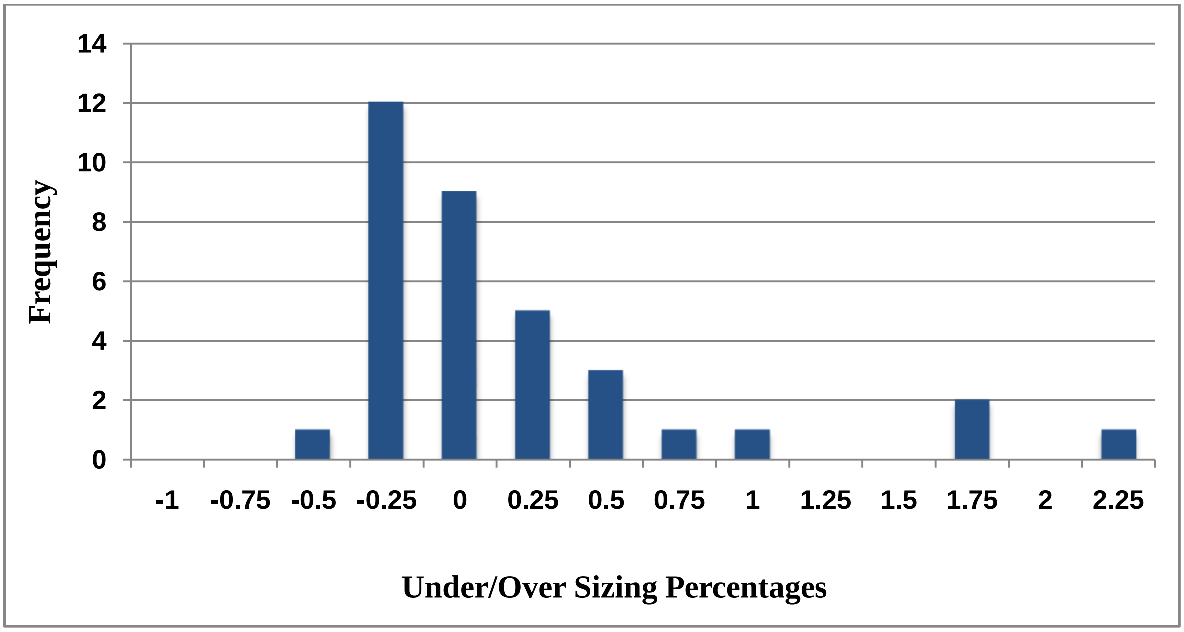
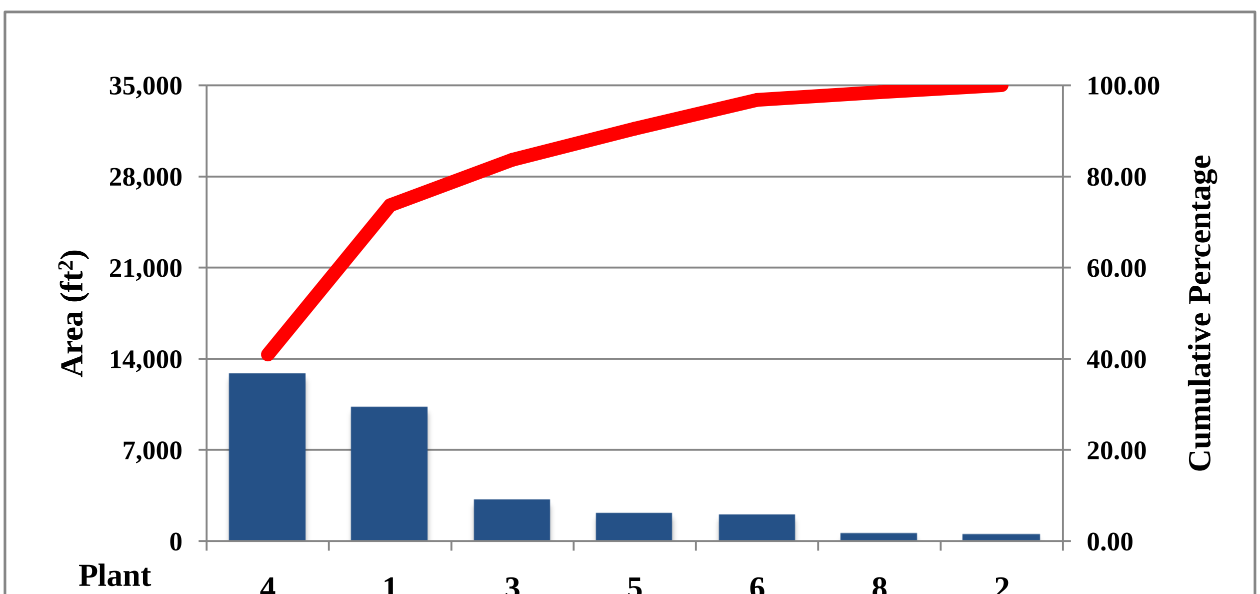


Figure 3- Central HVAC Applications

The next step was to prioritize the plants' HVAC systems based on opportunity for most improvement. Utilizing a Pareto Chart, it was determined that Plants 1 and 4 accounted for a majority of the climate-controlled areas and would therefore provide the greatest opportunities when making recommendations (Figure 4).



Plant	4	1	3	5	6	8	2
Count	12,793.4	10,241.5	3,108.8	2,121.6	1,985.3	519.0	483.0
Percent	40.9	32.8	10	6.8	6.4	1.7	1.6
Cum. %	40.9	73.7	83.7	9.4	96.8	98.5	100.0

Figure 4- HVAC Service Area per Plant

USER CONTROL: Of the 35 central HVAC systems, 24 were found to have programmable thermostats; however, only 3 of them were actually programmed. To emphasize the significance of this finding, two experiments measuring hours of operation of a single compressor unit were conducted.

The purpose of the experiments was to exemplify the hours of operation (run-time) of a single compressor unit in the Plant 4 facility on a summer day. Plant 4 was selected, because relative to all the plants, it best exemplified an office area in terms of occupancy levels, lighting and office equipment loads. The first experiment used a HOBO U12-006 data logger and an Onset Current Transformer to measure the amperage draw of this particular 20 year old air-conditioner compressor every minute for 24 hours.

The first test (Figure 5) was conducted on a non-programmed thermostat that had been set at 74°F and measured 14.5 hours of operation over the 24 hour monitoring period. In the second test (Figure 6), the thermostat was programmed to operate at 74°F during the workday and 78°F after hours resulting in 11.3 hours of operation. Employees were made aware of the tests and asked not to tamper with the thermostat as it would affect the test results, but to point out if the temperature setting was not acceptable in providing optimal comfort. This experiment measured a reduction in operation by 3.2 hours of the 24 hour period; In other words, 13% savings and no complaints of discomfort.

Table 2- User Control Experiments

	Time Span	***Non-Programmed Temp***	***Programmed Temp***	***Reduction in Operation***	***Percent Saved***
Experiment 1	24 hrs	74°F	74-78°F	3.2 hrs	13%
Experiment 2	48 hrs	65°F	85°F	19.5 hrs	40%

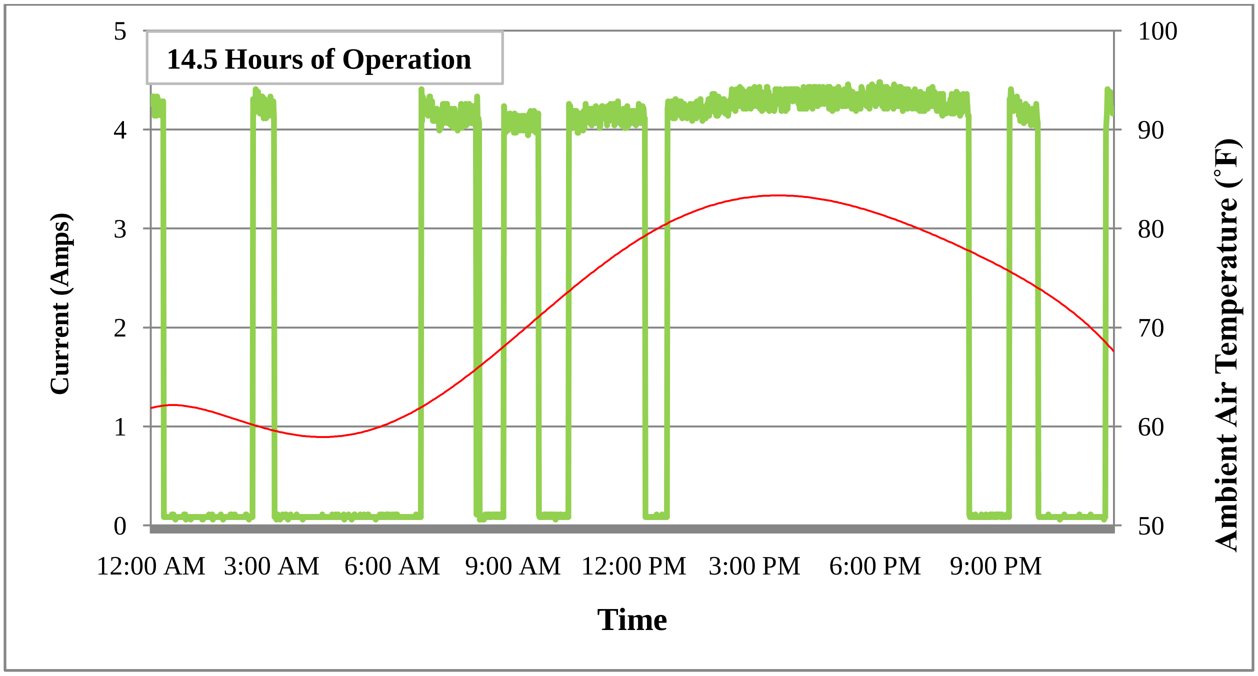


Figure 5- Weekday Non-Programmed A/C Operation

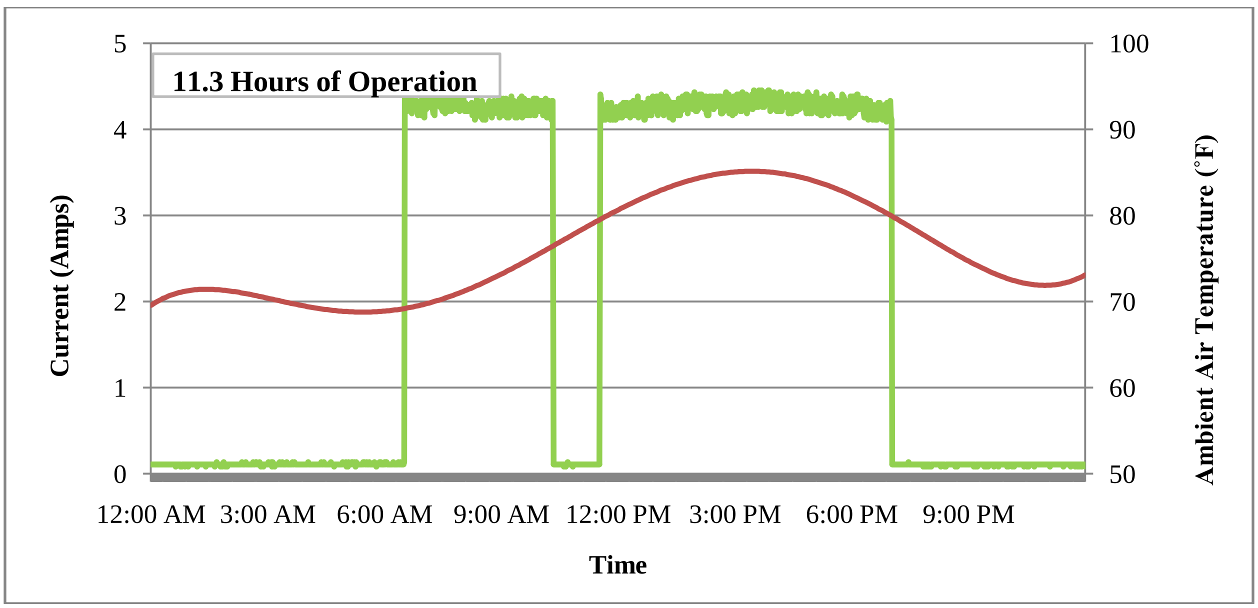


Figure 6- Programmed Weekday A/C Operation

The second experiment was identical to the first; however it was measured over the course of a 48 hour weekend. Prior to the first test (Figure 7), the thermostat was found set at 65°F and not programmed. It was left at this temperature for the remainder of the test. The results indicated that the compressor had operated 32.4 hours of the 48 hour period. For the second test (Figure 8), the thermostat was once again programmed at a constant temperature of 85°F, providing just enough circulation to remove the humidity. The conclusions of this test indicated that the compressor operated only 12.9 hours of the 48 hour period, resulting in savings of almost 40% for weekends of relative outdoor ambient air temperature.

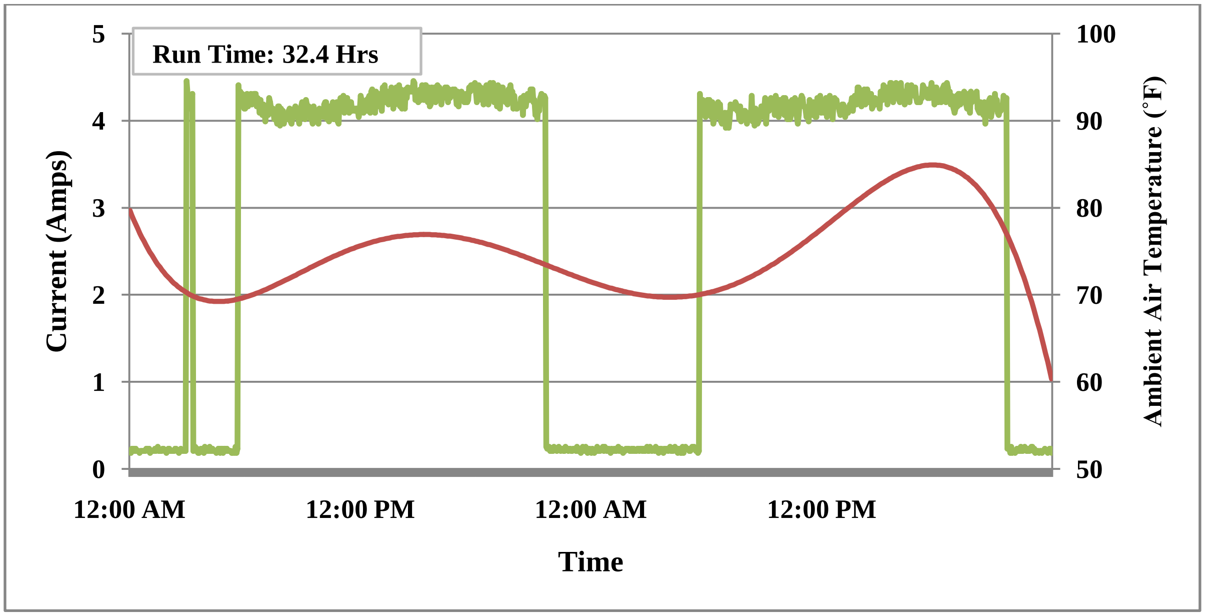


Figure 7- Non-Programmed Weekend A/C Operation

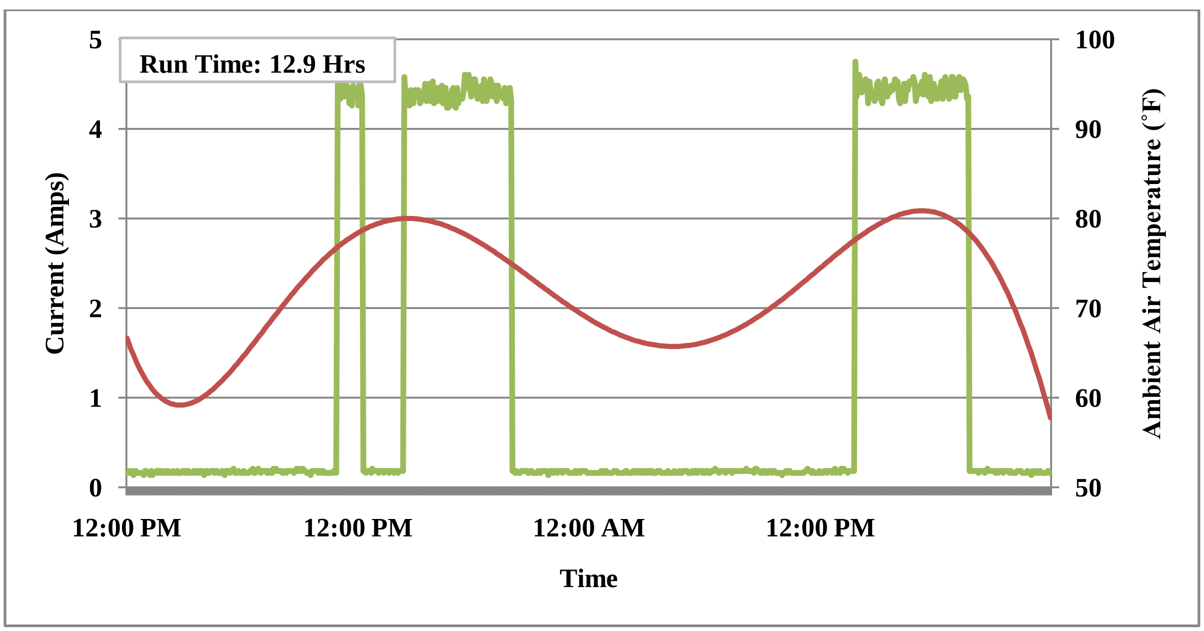


Figure 8- Programmed Weekend A/C Operation

Additional testing would have been ideal to ensure data accuracy and reproducibility. However, due to the strict time constraints, these tests were all that time allowed for. From these tests, data indicate the potential for quick returns on investments in user controls. Adopting a policy that will program and periodically monitor the thermostats can reduce the duty cycle of the equipment and, in turn, reduce costs and greenhouse gas emissions.

SECONDARY (NON-MEASURABLE) DATA- In addition to the utility bills that were used to determine HVAC energy consumption, all the invoices received by a local HVAC contractor for the 2008 year were used to calculate the HVAC operational costs. Data from 2008 was used as the baseline because it was identified by DRS to be a very typical year in terms of HVAC expenditures. From the data, it was found that DRS was charged $9,389 for new installations and replacement units; $8,398 for HVAC associated labor, and $3,530 for refrigerant charging and parts. This brings the total HVAC cost, including energy usage, for the 2008 fiscal year up to more than $77,000 (Figure 9).

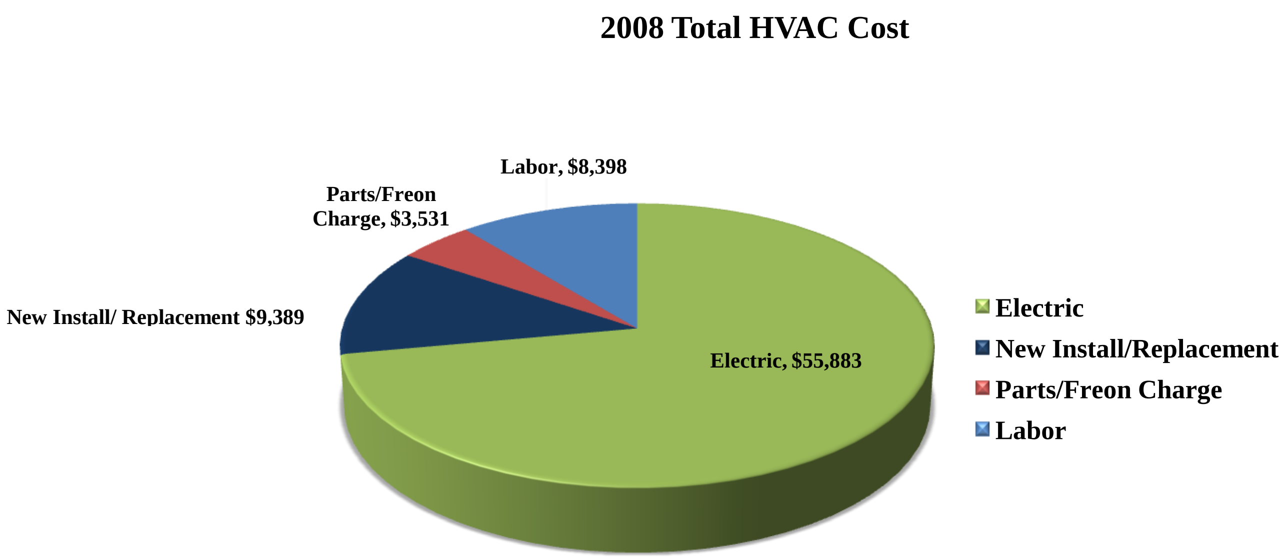


Figure 9- West Plains 2008 Total HVAC Cost

ALTERNATIVES EXPLORED DURING STUDY

Several equipment hardware alternatives were explored and each went through a preliminary evaluation based on several variables: the ability to address the problems with the current situation, the economic feasibility, and the hardware efficiency standards, as well as addressing the issue of sustainability. These options were selected because they have the most advanced technology and are most applicable to DRS' present situation.

Air-Source Heat Pump (ASHP) - In general, the most common alternative to a typical residential air conditioning unit is the air-source heat pump. With the addition of a reversing valve, which reverses the flow of refrigerant to provide heating in the winter in addition to cooling in the summer, the heat pump can extract energy from its environment (in this case, the air) to heat a given, thereby reducing the need for heating and cooling from other sources. In the heating season, ASHP's can be operated only above an outdoor ambient air temperature of 40˚F. For this reason, supplementary heat, such as electric heat or gas heating, may be necessary for regions with temporal regions or extreme winters. However, recent technological advances have provided ASHP's with a much higher and lower ambient temperature tolerance (U.S. Department of Energy, 2009).

Ground-Source Heat Pump (geothermal)- A ground source, or geothermal, heat pump operates in a similar manner to the ASHP with the addition of a reversing valve. However, the exception is that it utilizes stored energy from the earth. This provides a higher efficiency than an equivalent ASHP because, even just a few feet down, the earth's more constant temperature can be tapped to help decrease the temperature differential. However, a geothermal system is usually more expensive to install because of the required excavation. And though a geothermal system generally requires less maintenance, when maintenance is necessary it tends to be expensive because it is buried beneath the ground.

Air Conditioners with Gas Heating- A gas heated air-conditioner works much like a heat pump except that it manufactures heat from a fuel source. It also does not have a reversing valve, so while heat pumps can both heat and cool, gas heated air conditioners only provide cooling. Because natural gas is currently relatively inexpensive at the West Plains facility, natural gas air conditioning was considered a viable option. However, some of the negative aspects of gas include the volatility of market prices. It is dependent on a non-renewable resource which diminishes from the long-term sustainability of the recommendation. Finally, the use of natural gas produces indirect greenhouse gas emissions.

Commercial Chiller and/or Furnace- The installation of chiller/furnace equipment was another considered option. This type of systems tends to be more prevalent in large industrial facilities. However, because of the plant layout of DRS Technologies in West Plains, a large scale retrofit would have been necessary to upgrade to this type of unit. Additionally, these larger scale systems operate at lower efficiencies than smaller scale units.

Keep Existing Systems in Operation- Currently all HVAC systems are still operable and, therefore, maintaining the same systems is still an option. However, this option would not result in the potential savings, increases in efficiencies, and government and utility incentives.

3. *RECOMMENDATIONS*

Recommendations were based on those that would provide the best opportunity for energy and cut reductions, be the easiest to implement, give the greatest return on investment, and provide sustainability and efficiency for future operation.

User Control:

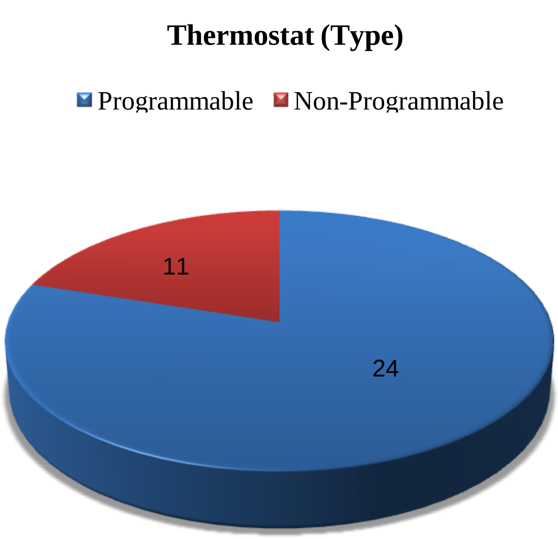


Figure 10- Thermostats (Type)

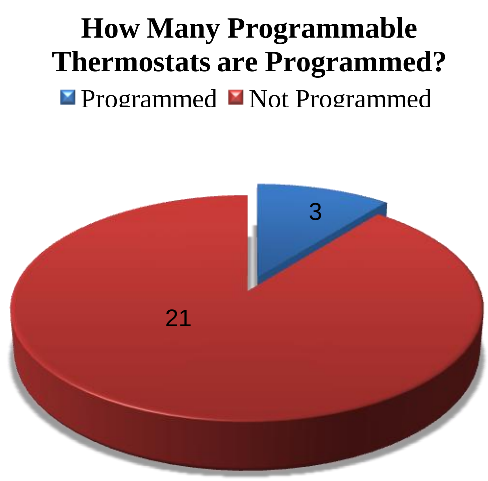


Figure 11- Programmed Thermostats

Of the 35 central HVAC systems located throughout the office/administrative areas, only three of the thermostats were programmed to provide thermal comfort throughout the workday and to reduce run time in the evenings and weekends. According to the EPA, programmable thermostats can save, on average, as much as 17% on energy usage per year (EPA, 2009). With an investment of $1,958 for installing new programmable thermostats where needed and locking covers to reduce tampering, DRS can save $9,500 annually, while saving 211,111 kWh (Appendix F, Equation 3, pg 31) of energy and reducing indirect emissions of CO_2 by 118 metric tons.

In order to predict the potential savings, all systems equipped with non-programmable thermostats were isolated from the database. Using the same usage cost calculations and assumptions utilized to determine the HVAC usage cost for 2008 plus EPA's estimate of 17% savings with programmed thermostats, the operating costs for those isolated systems were summed. West Plains Utilities rate of 4.5 cents per kilowatt hour was used to estimate the kilowatt hours savings. Recalling that the City of West Plains receives two thirds of their electricity from coal power generation and another third from renewable energies, the annual energy saved was scaled down by a factor of two thirds and translated using EPA's GHG Emissions Calculator (EPA Climate Leaders Simplified GHG Emissions Calculator (SGEC), 2008). This savings opportunity was substantiated by the experiments to determine run-time differences during programmed and non-programmed settings.

Table 3- User Control Recommendations

Initial Cost	*Annual Savings*	*Payback Period*	*Annual Energy Saved*	*GHG Reductions (CO_2)*
$1,958.00	*$9,500*	*2.5 Month*	*211,111 kWh*	*118 Metric Tons*

Additionally, in order to ensure these savings continue from year to year, the recommendation includes instituting a "Climate Control Policy" throughout the business in which standards are established and enforced. This policy would include the removal of all personal space heating devices saving about $1,800 annually (Appendix F, Equation 6, pg. 31). Although there are no official standards in place for thermal comfort settings in the workplace, OSHA recommends a temperature range between 68 to 76 degrees (OSHA, 2009). Based on the employee survey conducted following the IAC survey template (Appendix D, pg 26), it was recommended for the cooling season that a base temperature of 74 degrees be used during a typical 40 hour work week and an off-schedule temperature of 85 degrees is maintained in order to remove excess moisture from the air.

HVAC Equipment: After assessing the equipment based on age, efficiency and application, it was determined which equipment should be replaced. The considered alternatives included air-source heat pump, geothermal system, air conditioner with gas heat, commercial chiller and furnace, or keep current system in place. To aid in the decision making process, a prioritization matrix was developed to quantify the replacement decisions (Table 4).

Initially, the geothermal (ground-source heat pump) heating and cooling systems had promise. DRS management contacted geothermal experts at the University of Missouri to explore a partnership for government funding for a geothermal demonstration project. However, after further discussions the management determined that the DRS facilities could not support a project on the scale of what the government grant was funding. Additionally, the analysis of the situation determined that geothermal was not a feasible option due to the very high initial cost, current infrastructure in place, low electric rates in the West Plains area, and relatively small amount of areas required to be heated and cooled.

Table 4- Prioritization Matrix

	Criteria for Evaluation							
	Address Root Cause	*CTQ Impact*	*Feasibility*	*Initial Cost*	*ROI*	*Efficiency*	*Sustainability*	***Sum***
Weight	12	10	13	17	17	16	15	**100.00**
Solutions								
A	4	5	4	4	4	3.5	4	**4.02**
B	5	5	2	1	2	5	5	**3.42**
C	4	5	3	3	3	4	3	**3.48**
D	5	5	2.5	2	3	3	4	**3.36**
E	1	1	5	5	0	1	1	**2.03**

	Scale
1	Weak
2	Semi-Moderate
3	Moderate
4	Semi-Strong
5	Strong

A: Air-source Heat Pump **B:** Geothermal **C:** Air Conditioner w/ Gas Heat **D:** Commercial Chiller/Boiler **E:** Leave as is

Additionally, with geothermal technology—in general—the greatest potential savings with this type of technology is during the heating season. However, the demand for cooling is much higher at the DRS facility than the demand for heating. This is due to the region of the country as well as the building heat load generated from the manufacturing processes. Therefore, air-source heat pumps (ASHP) were selected as the preferred technology due to the fact that current systems on the market are very efficient, they have the ability to use refrigerant (in a reverse cycle) during the heating season versus using electric or gas heat, and can be easily retrofitted into the ductwork currently in place.

Table 5- Breakdown/Cost Analysis

Criteria for Replacements: • *Age > 10 years* • *Efficiency < 13 SEER* • *Poor Current/Future Application* *Mismatched Equipment*	***Replace 21 Units:*** • *18 ASHP Systems with SEER ≥14* • *Economizer Cycles* • *2 Air Handler Units* • *1 Heat Pump* • *R-410A Refrigerant* • *Re-Duct 3 Locations to Eliminate 7 Window A/Cs*

Table 6- HVAC Recommendations Summary

Plant	***HVAC Equipment Cost***	***Annual Savings***	***Payback Period***	***Energy Saved per Yr***	***GHG Reductions (CO2 tons)***
4	*$50,116*	*$11,390*	*4.4 yrs*	*254,393 kWh*	*143*
1	*$28,074*	*$7,845*	*3.6 yrs*	*131,711 kWh*	*74*
6	*$15,870*	*$3,717*	*4.3 yrs*	*85,424 kWh*	*46*
3	*$11,378*	*$3,085*	*3.7 yrs*	*77,834 kWh*	*38*

Using the hardware requisites previously established (Table 5), 21 units were selected to be recommended for replacement. These recommendations, in all, upgraded 19 air-source heat pumps and two air handler units. All of the new units utilized the new environmentally friendly R410-A refrigerant and, in three instances, re-ducted the applications to eliminate seven window air conditioners.

With a total investment of a little over $100,000, the company can save nearly half of its HVAC usage cost; this would save 549,300 kWh equating to a reduction of 301 metric tons of CO_2 (Table 6). These estimates do not include tax incentives, equipment discounts available to DRS, and other potential savings.

CONCLUSION: The comprehensive study identified two opportunities in energy savings. Overall, the study succeeded in reaching the stated goals. However, the estimation fell just short of the savings sought. Beginning assumptions estimated that HVAC costs were 40% of a company's total energy costs. It was found in this instance that HVAC contributed 12-15% of the electric costs. That being said, the recommendations provide for nearly a 50% reduction in annual HVAC costs—much larger than the stated goal of reducing HVAC energy cost by 10%.

4. Alternative Opportunities of Improvement

Plant 2: Another project proposed by DRS, separate from the HVAC optimization study, was to research and recommend the best solution to heat and cool a facility that has not been in use for a couple of years. Plant 2 operations will start within the next year to accommodate a new product where the entire facility (1,714.15 m^2) will need to be climate controlled in order to ensure the integrity on the manufacturing process. Using a study published by the Washington State University Energy Program that makes cost assumptions based on cost-per-square meters ($/$m^2$), the following estimates could be determined for initial and lifecycle cost.

Table 7- Initial Annual Cost

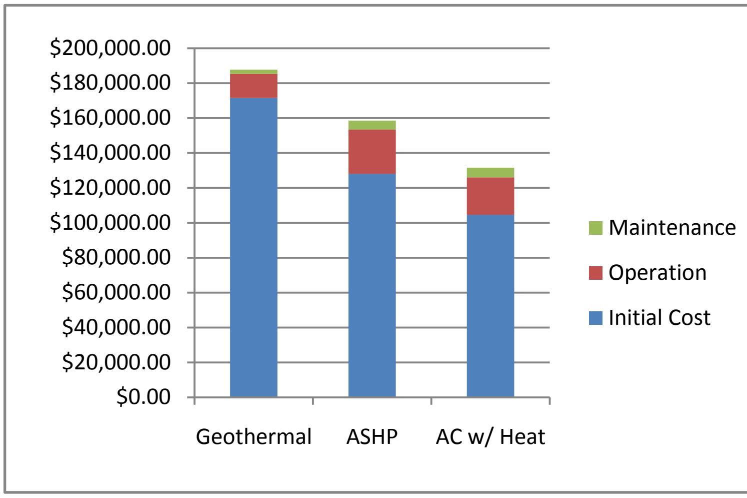
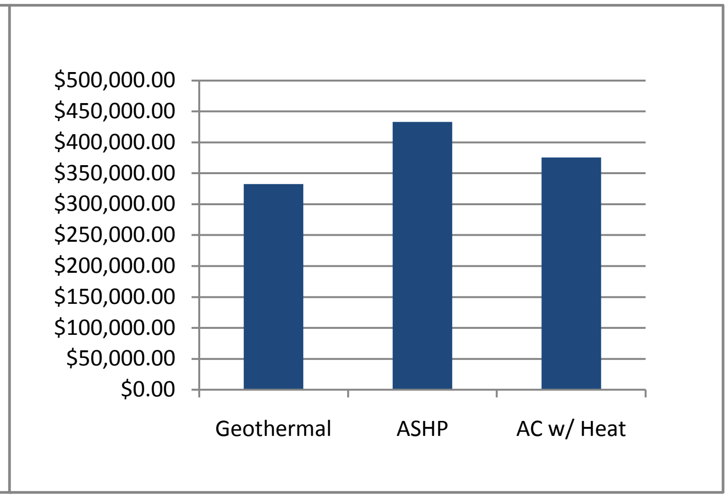


Table 8- Ten-Year Lifecycle Cost



In general, this analysis shows that even with the large initial cost that geothermal technology requires, looking at the total potential life cycle of standard equipment versus this technology shows a substantial savings potential. Additionally, the equipment associated with geothermal lasts nearly twice as long than conventional HVAC system equipment. However, the other variables not included in the analysis (electric rate, annual heat/cool hours, manufacturing contract lifespan, and required return-on-investment) currently make this technology unfeasible at this plant.

Demand Charge: The segregation of electricity costs into the usage charge and demand charge implicated an opportunity to minimize the demand costs. For the year 2008, DRS was charged $221,500 for their peak demand costs. Prior to 2008, the demand charge has been steadily increasing (Appendix E, pg 30). Though some of the increase is attributed to a raise in rates, there was also an increase in usage during peak hours. Due to the time allotted for this study, the topic was not addressed in detail; however, it would be beneficial to DRS to examine the root causes of this increase.

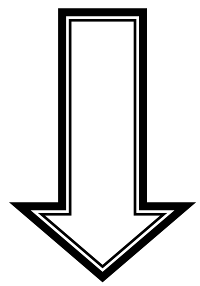
5. *PARTNERS AND PEOPLE INVOLVED*

DRS SUSTAINMENT SYSTEMS, INC.	
Eddie Kimes	*Vice President of Operations*
Jeff Ziegler	*Financial Advisor*
Pat Holmes	*Quality Assurance Director*
Ryan Cundall	*Facilities Manager*
Dan Sewell	*Cornwell Student Initiative Intern*
Tyler McKee	*Cornwell Student Initiative Intern*
US EPA REGION 7	
Marcus Rivas	*Pollution Prevention Project Investigator*
UNIVERSITY OF MISSOURI	
Robert Reed	*Faculty Advisor*
Marie Steinwachs	*Director MEAC*
Dan Sewell	*Pollution Prevention Intern*
Tyler McKee	*Pollution Prevention Intern*

6. *APPENDICES*

APPENDIX A: SIPOC

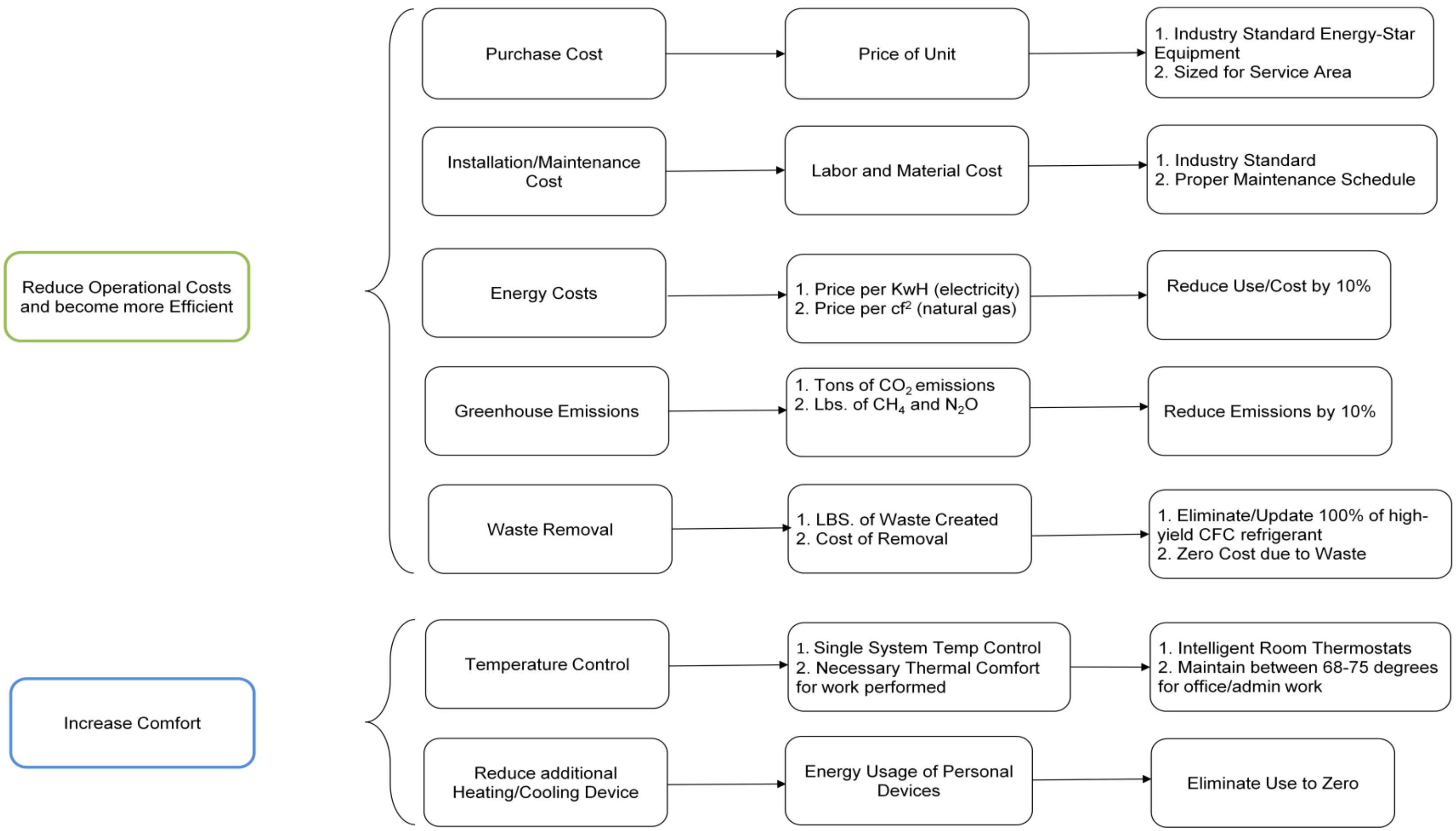
Suppliers	Inputs	Process Steps	Outputs	Customers
Users	Climate Requirements		Climate Control (comfort/need)	User
Utility Companies	Energy Source		Operating Cost/Budget	Management/DRS
Unit Suppliers	Hardware/Machinery			
Plant Engineers	Facility Limits/Requirements			



Process Steps

Start				End
Identify Need for HVAC	Identify Requirements for Purchasing Equipment	Install and Operate New Equipment	Maintain and Service Equipment	Retire and Replace Equipment at End of Service Life

APPENDIX B: VOC/CTQ Tree



APPENDIX C: Data Collection Plan

Needed Data	Stratification	Sample Size	CTQ Link
Inventoried Equipment (HVAC)	Location Type Size Age Manuf. Data Rated Efficiency Service Area	100%	Operating Cost/Budget
Energy Consumption	Meters/Facility Individual Unit (measured)	100% S/S	Operating Cost/Budget
Maintenance Cost	Type Age Location	5 Yrs.	Operating Cost/Budget
Repair Cost	Type Age Location	5 Yrs.	Operating Cost/Budget
Failures	Type Qty	5 Yrs.	Operating Cost/Budget
Greenhouse Emissions	Types Qty	100%	Operating Cost/Budget
Hazardous Waste	Type Qty (Toxic Release Inv.?)	Undetermined	Operating Cost/Budget
Customer Satisfaction	Qty of extra fans/heaters Number of Complaints	100% Survey	Customer Satisfaction

APPENDIX D: Industrial Assessment Center Survey

AIR CONDITIONING EQUIPMENT CHECKLIST (HVAC 1.1)

Yes No

What type of air-conditioning system is used in the building? (Check appropriate one)

- ☐ Reverse cycle
- ☐ Refrigerative wall unit
- ☐ Refrigerative central system (split or packaged system)
- ☐ Chiller central system
- ☐ Evaporate system
- ☐ None

What does AC have controls for?

- ☐ Temperature (thermostat)
- ☐ Time of use
- ☐ Zones of use
- ☐ Air flow speeds of fan (high, medium, low)
- ☐ Air vent direction
- ☐ Other

Are AC controls easily accessible to relevant personnel?
Are the AC controls clearly labeled with their appropriate functions?
What temperature is the thermostat set to on the AC when cooling or heating the building?

When is the AC system turned off? Check appropriate boxes.

- ☐ End of the day
- ☐ Weekends
- ☐ Public Holidays
- ☐ When the room or area is unoccupied
- ☐ Never

Does the air conditioner have an economy cycle (order models might label it as "fan")?

HVAC DISTRIBUTION CHECKLIST (HVAC 1.2)

Yes No

Is the building adequately insulated to enhance cooling and reduce the need for air-conditioning? (Especially the ceiling)

Is low air-flow a problem anywhere, especially at the intake vents?

Do vents have dampers to allow closing off of unneeded vents?

Are the vents blowing air to the proper locations? Into walls? Into unoccupied areas?

Do the vents and ducts seem to be sealed well?

COOLED AREAS CHECKLIST (HVAC 1.3)

Yes No

Are only occupied areas being air-conditioned?

Are any external windows or doors left open in air-conditioned rooms? (Should only be left open if an evaporative AC is used or a refrigerative AC runs on the economy cycle.)

Is lighting and office equipment switched off when not used, where possible, to minimize room heating? Can this equipment be used in naturally cooler areas?

Are ceiling fans installed in the building to enhance cooling and reduce the need for air-conditioning? Where and how many?

Is shading employed?

- ☐ Trees
- ☐ Indoor curtains and shades
- ☐ Outdoor awnings
- ☐ Other

HVAC MAINTENANCE CHECKLIST (HVAC 1.4)

Yes No

Is the air-conditioning system more than 10 years old?

Is the system maintained according to the manufacturer's instructions?

Describe the maintenance plan for all areas of the system (compressors, fans, and ducts).

Is service performed by maintenance in-house, or by service people?

HEATING AND FURNACES CHECKLIST (HVAC 1.5)

Yes	No	
		What is the fuel source? Electricity Natural Gas Propane Other
		Does it have a stack damper?
		Is indoors or outdoors air used for combustion?
		What is the surface temperature and surface area of the apparatus? Is the oven furnace flue gas used or just exhausted? (Check one) ☐ flue ☐ exhausted
		Do any other systems provide heat recovery to the heating system?

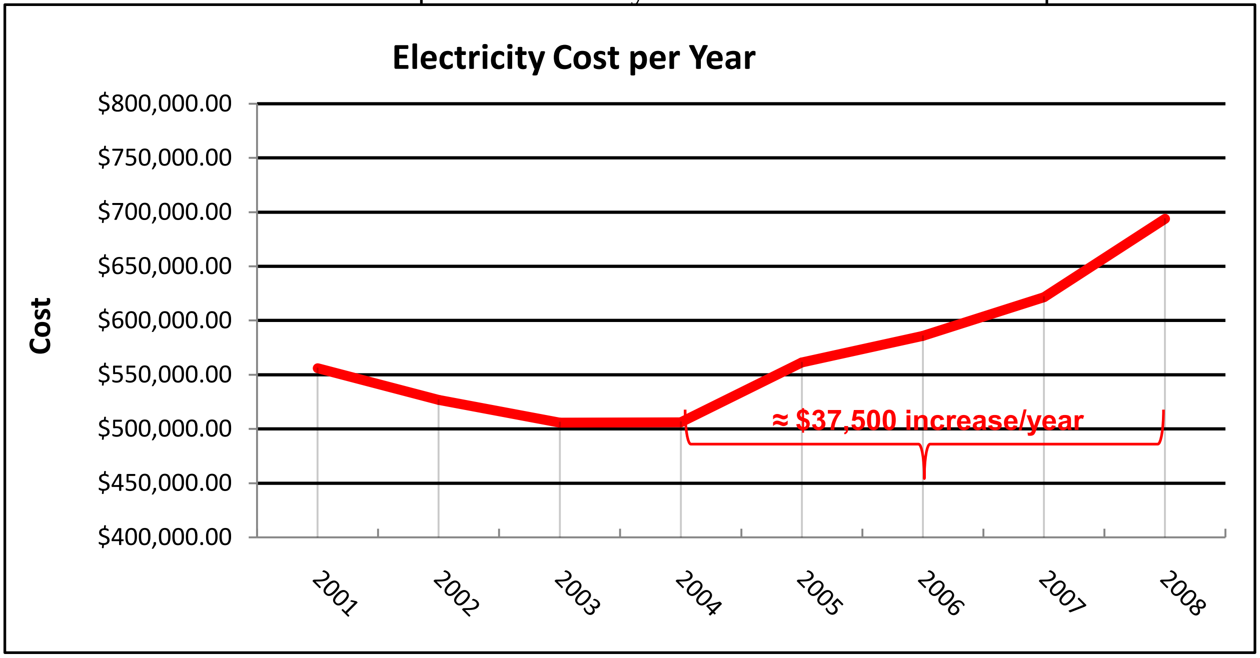
APPENDIX E: *DATA*

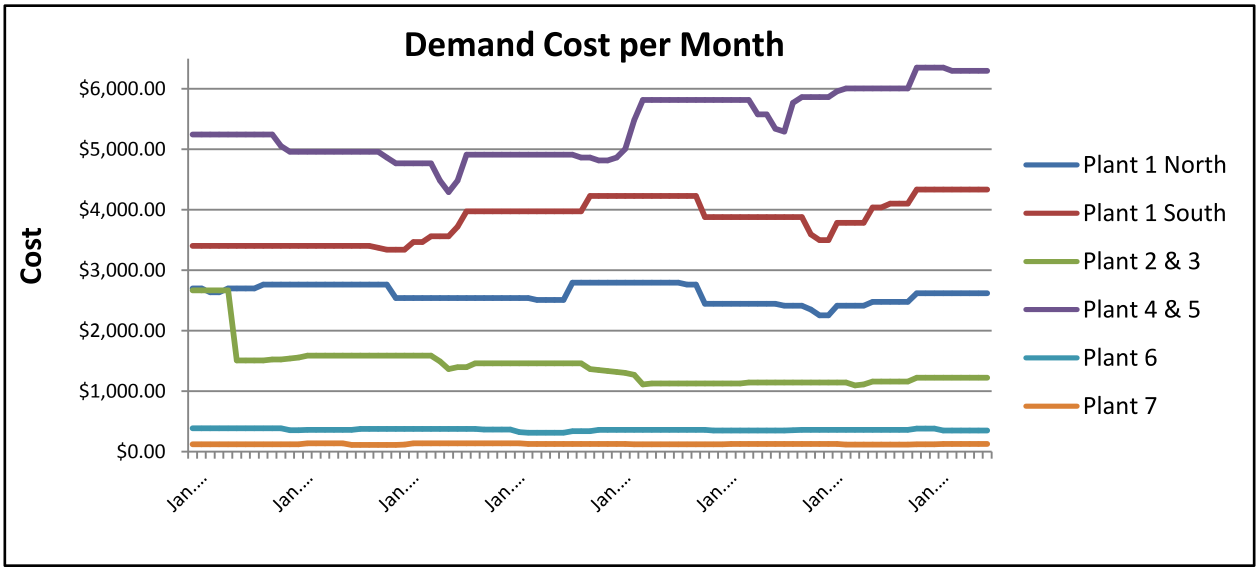
Plant 2 Analysis:

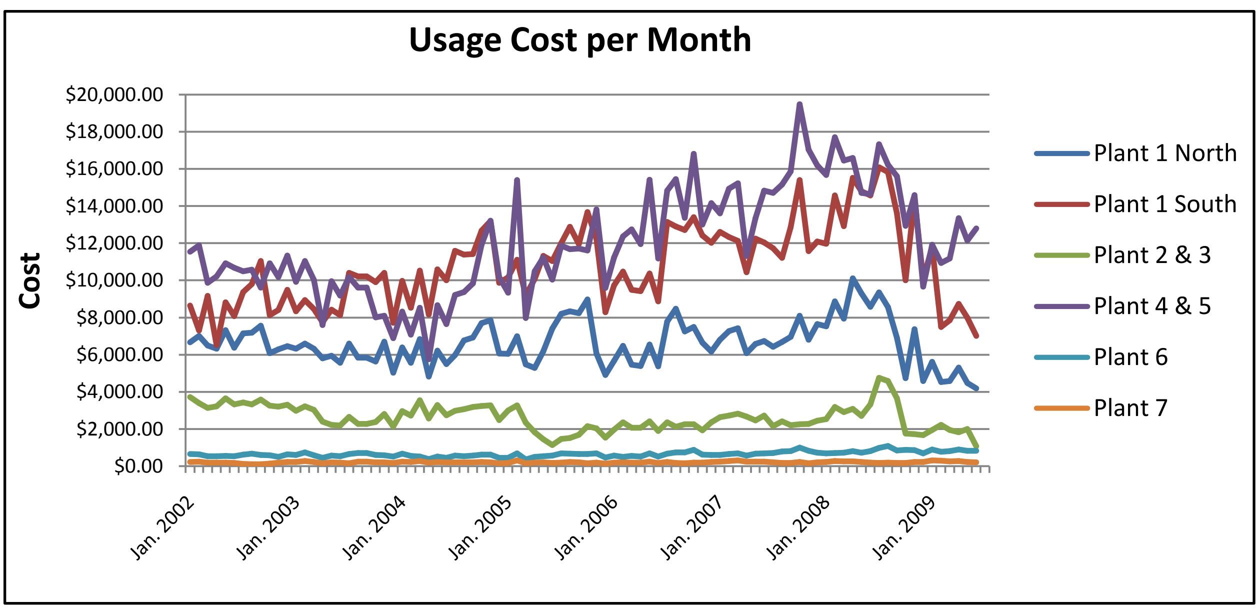
Plant 2 Options		
Option 1	***Geothermal***	
Initial Cost	$85,793.21	
Maintenance Cost	$2,399.81	
Operating Cost	$13,713.20	
Total Cost	$101,906.22	$246,923.31
	Year 1	Year 10
Option 2	***ASHP***	
Initial Cost	$64,023.50	
Maintenance Cost	$5,142.45	
Operating Cost	$25,369.42	
Total Cost	$94,535.37	$369,142.20
	Year 1	Year 10
Option 3	***AC w/ Gas Heat***	
Initial Cost	$52,281.58	
Maintenance Cost	$5,656.70	
Operating Cost	$21,426.88	
Total Cost	$79,365.15	$323,117.28
	Year 1	Year 10

Electric Usage Rates—DRS Technologies locations around U.S.:

	West Plains, MO	**San Diego, CA**	**Dallas, TX**	**Palm Beach, FL**	**Parsippany, NJ**
2005	$0.033	$0.095	$ 0.071	$ 0.065	$0.098
2006	$0.034	$0.085	$0.078	$ 0.074	$0.106
2007	$0.043	$0.092	$ 0.077	$ 0.077	$0.089
2008	$0.043	$0.095	$0.083	$ 0.078	$0.125
2009	$0.045	$0.090	$0.076	$ 0.096	$0.095
Note: (1) Electricity rate values as quoted from *West Plains, City Utility Dept.* (2) All other rates are state averages from the *U.S. Energy Information Agency* (http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html)					


Electricity Cost per Year
Cost
$800,000.00
$750,000.00
$700,000.00
$650,000.00
$600,000.00
$550,000.00
$500,000.00
$450,000.00
$400,000.00
≈ $37,500 increase/year
2001
2002
2003
2004
2005
2006
2007
2008


Demand Cost per Month
Cost
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$0.00
Jan....
Plant 1 North
Plant 1 South
Plant 2 & 3
Plant 4 & 5
Plant 6
Plant 7


Usage Cost per Month
Cost
$20,000.00
$18,000.00
$16,000.00
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$0.00
Jan. 2002
Jan. 2003
Jan. 2004
Jan. 2005
Jan. 2006
Jan. 2007
Jan. 2008
Jan. 2009
Plant 1 North
Plant 1 South
Plant 2 & 3
Plant 4 & 5
Plant 6
Plant 7

APPENDIX F: CALCULATIONS/ASSUMPTIONS

1. **GHG Emissions:** Approximately 1/3 of electricity is supplied via renewable energy; therefore only 2/3 of total kWh usage was used to calculate GHG indirect emissions. Indirect emissions calculated by taking annual kWh and then using EPA's Pollution Prevention GHG Calculator.

2. **ASHP Annual Cost:** To figure out annual cost of recommended replacement HVAC central systems (Air-Source Heat Pumps), the EPA ASHP excel calculator was used based on 1402 Cooling hours and 2942 Heating Degree Days (HDD).

3. **Annual Energy Use/Cost:** The following was used to calculate the cost and energy use of the current HVAC systems:
   - $\text{SEER} = \frac{\text{BTU}}{\text{kWh}} \text{ x } 2668 \text{ Cooling Hrs. x } .045\ \$/\text{kWh} = \text{Annual Cooling Cost}$
     - (1402 Cooling hrs. estimate from EPA) x (1.8 coefficient) =2668 Cooling Hrs.
     - 1.8 industrial operations coefficient determined by current run-time estimate and high cooling demand for facility layout
   - Annual Heating Cost based on 2942 HDD for Region (HVACOPCOST, 2009)
   - Because HVAC equipment does not keep its efficiency due to "wear and tear" and other factors, a three-percent degradation in efficiency per year of use was used to calculate additional cost of current systems.

4. **BTU Load Requirement:** To determine how a current central HVAC system was sized for its current application, a calculation was derived that would compare the estimated BTU/hr load requirement for a specific area and then compare it to the system in place. From there, it could be determined if the current system was over or undersized in its current state.

$$BTU\frac{Load}{hr} = \left[Area(ft2) \times \left(\frac{\frac{12000\ BTU}{hr}}{500\ ft2}\right)\right] + \left[\left(\frac{Area(ft2)}{130\ ft2}\right) \times \left(\frac{400\ BTU}{hr}\right)\right] \times \left[150\ watts \times \left(3.4\frac{BTU}{watt \cdot hr}\right)\right] + \left[Area(ft2) \times \left(7\frac{watts}{ft2}\right) \times \left(3.4\frac{BTU}{watt \cdot hr}\right)\right]$$

Area times estimated average BTU per square feet

Occupancy per square foot times BTU output per person

Average office equipment BTU output per occupant

Average output per light fixture times square feet

- -130 sq./ft. based on estimated occupancy per person (Engineer's Cookbook)
- -400 Btu/hr estimated heat load of person performing moderate office work (Engineer's Cookbook)
- -150 Watts estimated power consumed for general office equipment (computers, printers, etc.)
- -7 Watts estimate of power from lighting per square feet (Engineer's Cookbook)

5. **Heat Transfer:** To estimate the heat loss through a PVC strip door in one of the HVAC applications at DRS, a heat transfer equation was used assuming the strip door acts as a thermal resistor. The purpose was to justify closing it off and re-ducting a system to allow for the removal of one window air conditioner at no extra operational cost.

$$\dot{Q} = \frac{T_i - T_o}{\frac{1}{h_i A} + \frac{1}{h_o A} + \frac{L_1}{k_1 A}}$$

Data Collected	**Assumptions**
• @2:00 PM on the 30 July, 2009 • Exterior Temperature of PVC Door (Door/EXT) = 301.2 K • Interior Temperature of PVC Door (Door/INT) = 299.5 K • Temperature of Interior Wall (Wall/INT) = 297.4 K • Area of Door = 1.907 m2 • Width of PVC = 0.003 m	• Conducting Coefficient of PVC (k1) = 0.19 w/mK • Range of Convection Coefficient for air (hi, ho) = 10 to 100 w/m2K • Operates only during the cooling season with regional operation hours * 1.8 Operational Hours Coefficient

Results- The solution was in a range from between 7,755 BTU/hr to 13,681 BTU/hr because of the conductive coefficient ranges for air. However, it is safe to say that approximately 12,000 BTU/hr is lost due to the strip door because it is not sealed around the edges and the calculation assumes that it is.

6. **Space Heater Cost:** This cost is based on an average annual work schedule of 260 day per year.

- 260 days x 8 hrs/day x 1.5 kW/heater x 13 heaters issued x $.045/kWh = $1825.20

REFERENCES

Bloomquist, R. Gordon. (2003). *The Economics of Geothermal Heat Pump Systems for Commercial and Institutional Buildings.* <www.repartners.org/tools/doc/GHPEcoAtlanta.doc> (July 22, 2009)

Engineer's Cookbook, A handbook for the mechanical designer (2nd edition), Springfield, MO: 1999.

Industrial Assessment Center. (2008). "Industrial Energy Efficiency." <http://iac.missouri.edu/webtool/index.html> (July 3, 2009).

North Carolina State University. (2009). "Business Energy Investment Tax Credit" <http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&State=federal&currentpageid=1&ee=1&re=1> (July 1, 2009)

The Engineering Toolbox. (2005). "Thermal Conductivity of Some Common Materials." <http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html> (July 29, 2009).

US Air Conditioning Distributers. *(2009).* "HVACOPCOST" <http://www.hvacopcost.com/> (July 7, 2009).

U.S. Department of Energy. (2009). "Air-Source Heat Pumps." <http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12620> (July 21, 2009).

U.S. Department of Energy. (2009). "Heating and Cooling." <http://www1.eere.energy.gov/consumer/tips/heating_cooling.html> (July 21, 2009).

U.S. Department of Energy and U.S. Environmental Protection Agency. (2009). "Central Air Conditioners." <http://www.energystar.gov/index.cfm?c=cac.pr_central_ac> (July 1, 2009)

U.S. Department of Labor. (2003). "Reiteration of Existing OSHA Policy on Indoor Air Quality: Office Temperature/ Humidity and Environmental Tobacco Smoke." <http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=24602> (July 3, 2009).

U.S. Environmental Protection Agency. (2009). "EPA Climate Leaders Simplified GHG Emissions Calculator (SGEC)." <http://www.epa.gov/stateply/resources/lowemitters.html> (July 7, 2009).
U.S. Environmental Protection Agency. (2009). "GHG Conversion Tool_May 2009." <peakstoprairies.org/webinars/20090519_p2-calculators/GHG-Conversion-Tool_May-2009.xls> (July 7, 2009).

Wikipedia. (2009). "Heat Transfer." <http://en.wikipedia.org/wiki/Heat_transfer> (July 29, 2009).