CALVIN COLLEGE ENGINEERING

West Wing Geothermal Design Project

ENGR 333

2012

Introduction

Calvin College is considering an addition to the West Wing of the Spoelhof Center to provide additional space for the art and business programs. The construction of this new addition provides the opportunity to investigate the feasibility of installing new, sustainable technology. This semester the students of Engineering 333 were presented with the following challenge: "*What it will take for Calvin College to install a geothermal HVAC system for the West Wing?*" A geothermal HVAC (heating, ventilation, and air conditioning) system utilizes the relatively constant temperature of the earth to provide heating during winter and cooling during summer. Geothermal HVAC systems require a below ground network of pipes, called a bore field, a heat pump, and a distribution system within the building.

Several considerations had to be taken into account for a geothermal HVAC feasibility analysis, such as increased initial cost, ongoing costs, LEED rating contribution, and increased sustainability. In order to analyze all of the different considerations associated with a geothermal HVAC system the class was broken down into five groups: LEED/Energy Modeling, Infrastructure, Below Ground, Above Ground, and Financial.

Procedure

To determine if a geothermal HVAC system is a viable choice to install in the Spoelhof Center West Wing, it was important to determine the overall cost of components and installation, as well as the ongoing costs to operate a geothermal system. Each group was responsible for various tasks associated with accomplishing this common goal. The Energy Modeling group determined the cooling and heating loads necessary to keep the building warm during winter months and cool during summer months. Other groups were then able to use these loads to gauge component sizes and estimate energy required to operate the system. The main responsibility of the Infrastructure group was to research and decide on a bore field loop type and a bore field location on Calvin College's campus. From these decisions, the Below Ground group could then investigate the specifics of the bore field design. This group was tasked with determining the cost of installing a bore field, and what it would look like (area, depth, number of bore holes, etc.). In order to transfer the energy from bore loops in the ground to the building, a heat pump is required. The main responsibility of the Above Ground group was to select a heat pump that is both cost effective and cooperates with Calvin College's current infrastructure. Finally, the Financial group was concerned with the financial analysis of the geothermal HVAC system. This team examined the estimated initial and ongoing costs of the system to determine if installing a geothermal system makes financial sense.

Results

The Energy Modeling group used rules of thumb followed by an advanced heat gain and loss model to calculate the heating and cooling loads for the new addition. Figure B-1 shows the results of their analysis. Necessary ventilation requirements per room, calculated by the Above Ground group using Michigan Mechanical Codes and ASHRAE requirements, can be found in Table E-3. The Energy Modeling group's calculations and a full description of work done can be found in Appendix B. Similarly, Appendix E provides an in depth report of the work accomplished by the Above Ground Group. The Infrastructure group determined that Calvin should pursue a vertical loop bore field design, which helped the Below Ground group create a final bore field design, complete with system design parameters and cost estimates. More detailed analyses by the Infrastructure group and the Below Ground group can be found in Appendix C and Appendix D, respectively. The Above Ground group considered the tradeoffs between and centralized and distributed geothermal system, and used these tradeoffs to recommend a custom water-to-air heat pump from Trane to meet the heating, cooling, and ventilation requirements of the new addition. The complete calculations, cost estimates, and reasoning behind the recommendation can be found in Appendix D. Using the recommendations from the four aforementioned groups, the Financial group analyzed the financial costs of the proposed system, comparing the costs with those of conventional HVAC, which Calvin currently uses. Figure 1 shows the cumulative costs of the two solutions. Appendix F contains an extensive summary of the Financial group's calculations and considerations.

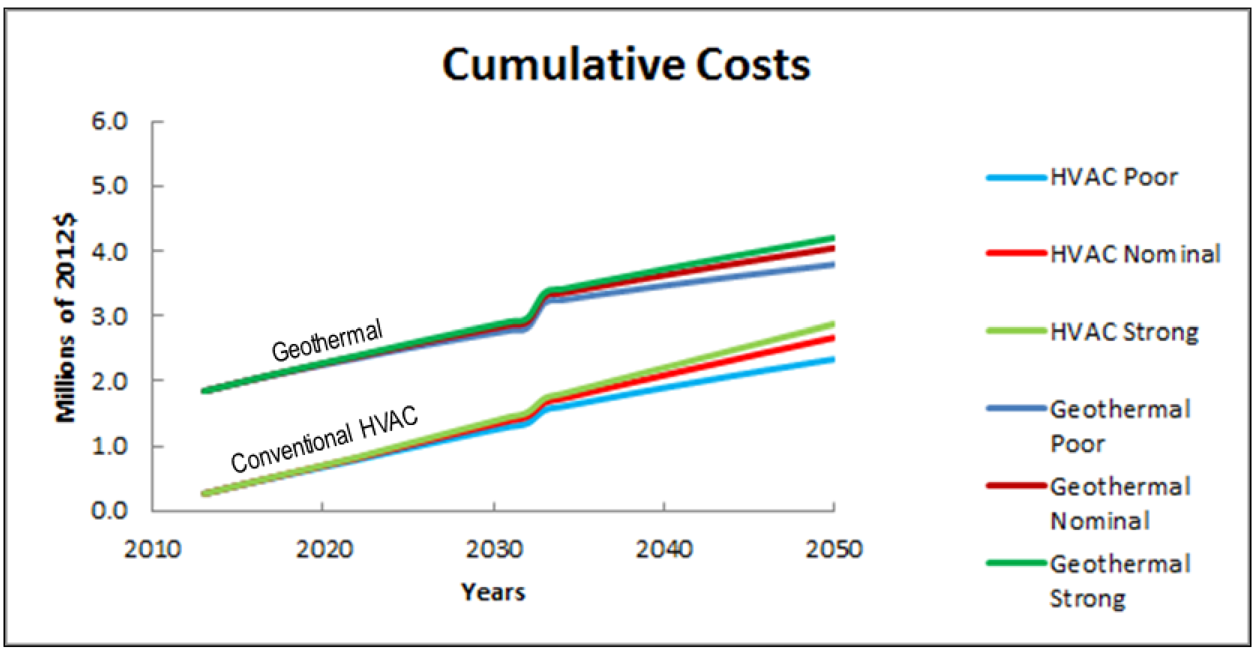

Figure 1: Cumulative Costs

Conclusion

There are many advantages to using a geothermal system. A geothermal system would use less energy than a conventional HVAC system, which helps Calvin achieve one of its goals of promoting and practicing stewardship and sustainability. A geothermal system would also contribute to LEED certification, require less maintenance than a conventional HVAC system, and enhance the college’s image by demonstrating the pursuit and implementation of alternative energy solutions. However, the class’s final recommendation is that Calvin should install a conventional HVAC system in the new addition, rather than a geothermal system. Although the geothermal system has many benefits, there is no foreseeable economic payback, particularly when natural gas prices are so low and the cost of utilizing Calvin’s existing infrastructure is significantly less than installing a new geothermal system. Issues of stewardship and sustainability apply not only energy issues, but also to financial matters, which is why the class recommends installing a conventional HVAC system in the West Wing.

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Appendix A: LEED

Introduction

LEED (Leadership in Energy and Environmental Design) is an independent organization which serves to verify and acknowledge energy efficient projects. The goal of LEED is to promote sustainable design for new and existing buildings. LEED standards were used as baselines throughout the geothermal project this semester. The program was developed by the U.S. Green Building Council to commend project designers for not only cost efficient constructions, but also for reducing the carbon footprint. The six LEED point categories are shown in Figure A-1.

Feasibility Process

For the geothermal project, our goal as the energy modeling group was to achieve a Silver level certification from LEED. In the 2009 LEED rating system a silver level certification can be attained from 50-59 points out of a maximum 110 points. Energy and Atmosphere points were the primary focus in this project, as they were the most relevant to our design responsibilities. Possible points associated with Energy and Atmosphere is shown in Figure A-2.

Results

According to the US Energy Information Administration, heating and cooling accounts for approximately 34% of a building energy usage, shown in Figure 3. Using a geothermal HVAC system provides 75% of the heating and cooling using energy from the ground, a renewable source, and 25% from electricity. Taking into account both of these percentages, calculations showed geothermal HVAC systems can provide 26% of the building's total energy from renewable sources. After looking at the possible points for renewable energy, in order to achieve the maximum amount of points of seven, the geothermal system would have to contribute 13% to renewable energy, seen in the LEED renewable energy points table in Figure 4. Since our system contributes 34% renewable energy, the geothermal will be more than sufficient to achieve all seven points. A geothermal system could contribute to the other points under the energy and atmosphere category, but these points cannot be estimated directly because design factors such as materials used in walls, window types, and light fixtures influence these points as well.

Recommendations

A geothermal system would contribute to the goal of silver certification but the majority of other points must come from building design specifications such as water efficiency, building materials, and building location.

Appendix A-1: Tables and Figures

Figure A-1: LEED Point Categories

Energy and Atmosphere		**35 Possible Points**
☑ Prerequisite 1	Fundamental Commissioning of Building Energy Systems	Required
☑ Prerequisite 2	Minimum Energy Performance	Required
☑ Prerequisite 3	Fundamental Refrigerant Management	Required
☐ Credit 1	Optimize Energy Performance	1–19
☐ Credit 2	On-site Renewable Energy	1–7
☐ Credit 3	Enhanced Commissioning	2
☐ Credit 4	Enhanced Refrigerant Management	2
☐ Credit 5	Measurement and Verification	3
☐ Credit 6	Green Power	2

Figure A-2: Possible LEED Points for Energy and Atmosphere

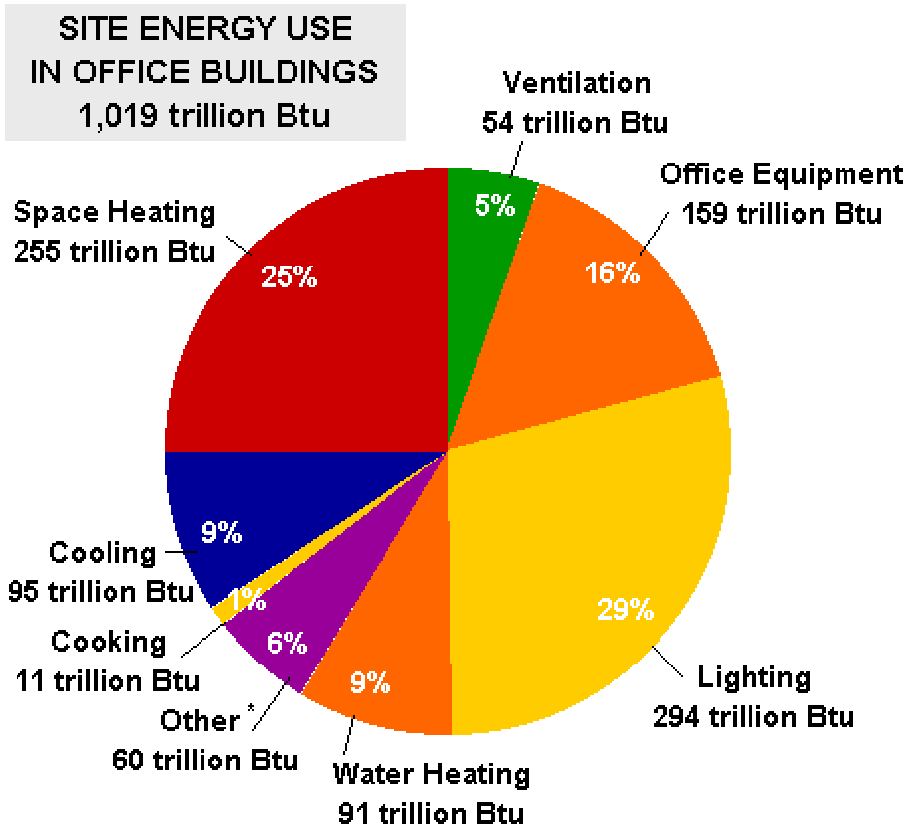

Figure A-3: Building Energy Usage Breakdown

Percentage Renewable Energy	Points
1%	1
3%	2
5%	3
7%	4
9%	5
11%	6
13%	7

Figure A-4: LEED Renewable Energy Available Points

Appendix B: Energy Modeling

Purpose and Background

To correctly size the HVAC system for a building, it is critical to have an accurate estimate of the heat transfer. In the winter, buildings lose heat primarily through convection to outside air, radiation to the sky and ventilation; and an academic building gains heat from occupants, lighting and heat dissipation from equipment.

Convection happens on both ends of heat conduction within the wall. Depending on the heat resistance of the wall, the total heat loss due to convection to outside air will vary significantly. To evaluate the heat transfer, a thermal circuit could be constructed based on estimates on factors like window area and wall material.

Radiation is another major part of heat loss. Particularly, it has the most effect on the roof, which directly faces the sky. Considering that warm air tends to rise to the top in the building and the effect of radiation, roof heat loss is likely to be a major part of building heat loss.

Though heat conduction to the foundation and soil is more significant than minor factors such as opening and closing doors, it is relatively small compared with convection and radiation. Therefore, in this simplified calculation, it will not be accounted for.

Ventilation is another important heat loss source. When the building exchanges air with outside, the heat carried by the warm air will be not recovered completely. Therefore, the heat loss associated with the rate of air exchange must also be accounted for.

Besides heat loss, building also gains heat from occupants. Human body maintains average temperature warmer than the surrounding. So, the heat gain from occupants is directly proportional to the number of estimated occupants inside the building. Equipment like computer, lights, prints and projectors all generate heat when working. These heat gains were fairly easy to estimate based on the rated power of these equipment. In the winter, these heat gains serve as a positive heat source, because it reduces the required heating for the building. But for summer, it will exacerbate the amount of cooling required for the building.

Method

The effective thermal resistance of the building was calculated. This value was used in a spreadsheet to calculate heating/cooling loads for each day of the year.

To calculate the effective thermal resistance, a past Senior Design project was used as a starting point. In the 2007-2008 year, Jordan Wanner, Dan VandenAkker, and Christina Overbeck modeled heat transfer in a dorm room (citations shown in EES code). The code was modified to add a more complex heat transfer calculation method, more building components (e.g. a basement and roof), internal heat gains, and ventilation. (EES code shown in Appendix B-1). The effective resistance was found to be 1.1 ft^2-hr-F/Btu.

A Heating Degree Days table was found at www.degreedays.net for the Gerald R. Ford International Airport. Using a base temperature of 63°F and the effective R-value, heating loads for each day of the year were calculated. The heating and cooling loads are presented graphically in Figure B-1.

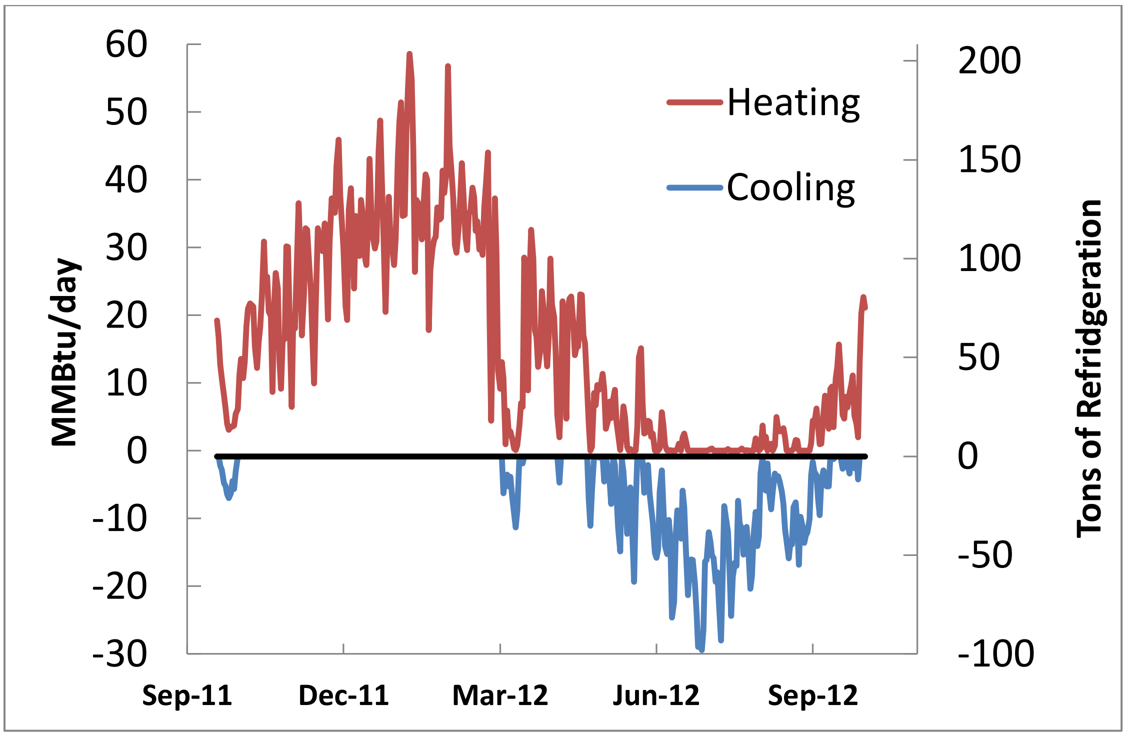

Figure B-1: Yearly Heating and Cooling Loads

For a 98th percentile HVAC system, the 6th coldest and 6th warmest days of the year were used for the final load answers. These were 174 tons for heating and 84 tons for cooling.

APPENDIX B-1: Calculations

```
"!ENGR333 West Wing Project  - building heat transfer resistance caclulation"
//by Jacob VandeHaar and Nate Konyndyk of the Energy Modeling Group
//Revised from a past project *7

"!__R_total__" "this value will be used in Excel for HDD/CDD"
Q_dot_net=A_effective*(T_o-T_i)*convert(BTU/hr,tons)/R_total

"!__NOTATION__"
// Heat into building is positive
Q$[1..16]=["1"'cond_wall', 'cond_window', 'cond_roof', "4"'conv_wall', 'conv_window', 'conv_roof',
"7"'rad_wall', 'rad_window', 'rad_roof', "10"'total_wall', 'total_window', 'total_roof', "13"'outsideair',
"14"'people', 'computers', 'lights']

"!__ENVIRONMENT__"
T_i = converttemp(F,R,72[F]) "inside room temperature"
T_o = converttemp(F,R,21) "outside ambient temperature for 6th coldest day in Grand Rapids *6"
T_surr = T_o-20[R] "temperature at 'infinity' for radiation heat transfer"
P_o = 1 [atm]

"!__HEAT LOSS THROUGH EXTERIOR WALL__"
// Ignore heat loss through basement (recommended by *5)
// Model walls (for example) as: Series(conduction_wall + Parallel(convection_wall + radiation_wall))

"!Areas"
h_wall=20[ft]; h_basement=10[ft]
L_west=230[ft]; L_north=100[ft]; L_south=62[ft]
A_floor=L_west*L_north
A_wallframe = ((L_west+L_north+L_south)*h_wall) "doesn't include basement *5"
A_wall = A_wallframe - A_window
A_window = (0.5{length fraction of window} * 0.7{height fraction of window} * A_wallframe)
A_roof=L_north*L_west
A_effective=53000[ft^2] "*6"

"!Thermal resistances of walls, roof" "*2"
R_facebrick = 0.43[ft^2-hr-F/BTU] "exterier face brick"
R_foam = 10[ft^2-hr-F/BTU] "2 inch rigid foam insulation"
R_CMUbrick = 1.11[ft^2-hr-F/BTU] "8 inch C.M.U. brick"
R_window = 0.9[ft^2-hr-F/BTU] "double pained with .75in air gap"
R_roof = 0.5[ft^2-hr-F/BTU] "estimation for OSB, tar, and pebbles"
R_o_air = 0.17[ft^2-hr-F/BTU] "outside air"
R_i_air = 0.35[ft^2-hr-F/BTU] "inside air"
R_wall_conduction = R_i_air+R_CMUbrick+R_foam+R_facebrick
R_window_conduction = R_i_air+R_window
R_roof_conduction = R_foam+R_roof+R_o_air

"!Conductive heat transfer"
"total heat transfer in through wall"
    q_dot_spec[1] = (T_wall-T_i)/R_wall_conduction
    Q_dot[1] = A_wall*q_dot_spec[1]*convert(BTU/hr,tons)
"total heat transfer in through window"
    q_dot_spec[2] = (T_window-T_i)/R_window_conduction
    Q_dot[2] = A_window*q_dot_spec[2]*convert(BTU/hr,tons)
"total heat transfer in through roof"
    q_dot_spec[3] = (T_roof-T_i)/R_roof_conduction
```

```
    Q_dot[3] = A_roof*q_dot_spec[3]*convert(BTU/hr,tons)

"!Convective heat transfer"
"convective part of heat transfer to outside of wall"
    q_dot_spec[4] = (T_o-T_wall)/R_o_air
    Q_dot[4] = A_wall*q_dot_spec[4]*convert(BTU/hr,tons)
"convective part of heat transfer to outside of window"
    q_dot_spec[5] = (T_o-T_window)/R_o_air
    Q_dot[5] = A_window*q_dot_spec[5]*convert(BTU/hr,tons)
"convective part of heat transfer to outside of roof"
    q_dot_spec[6] = (T_o-T_roof)/R_o_air
    Q_dot[6] = A_roof*q_dot_spec[6]*convert(BTU/hr,tons)

"!Radiation heat transfer"
F = 1 "view factor to sky"
sigma = (5.67*10^(-8))[W/m^2-K^4]*convert(W/m^2-K^4,BTU/hr-ft^2-R^4) "Stephon-Boltzman constant"
epsilon_facebrick = 0.75 "emissivity of exterior face brick"
epsilon_window = 0.94 "emissivity of window"
epsilon_roof = 0.80 "guess for emissivity of roof"
"radiative part of heat transfer to outside of wall"
    q_dot_spec[7] = epsilon_facebrick * F * sigma * (T_surr^4-T_wall^4)
    Q_dot[7] = q_dot_spec[7] * A_wall*convert(BTU/hr,tons)
"radiative part of heat transfer to outside of window"
    q_dot_spec[8] = epsilon_window * F * sigma * (T_surr^4-T_window^4)
    Q_dot[8] = q_dot_spec[8] * A_window*convert(BTU/hr,tons)
"radiative part of heat transfer to outside of roof"
    q_dot_spec[9] = epsilon_roof * F * sigma * (T_surr^4-T_roof^4)
    Q_dot[9] = q_dot_spec[9] * A_roof*convert(BTU/hr,tons)

"!Total heat transfer" "*4"
duplicate i=1,3; Q_dot[i]=Q_dot[i+3]+Q_dot[i+6]; end "conduction=convection + radiation"
duplicate i=1,3; Q_dot[i+9]=Q_dot[i+3]+Q_dot[i+6]; end "same heat flux as conduction"
Q_dot_heatloss = SUM(Q_dot[i],i=10,12) "total heat transfer from exterior walls & windows"
Q_dot_heatloss = (A_floor+A_wallframe)*(T_o-T_i)/R_bldg*convert(BTU/hr,tons) "finds R_bldg"

"!__VENTILATION/INFILTRATION LOADS__"
V_bldg = A_floor*(h_wall+h_basement) "volume of building"
"ACH values online are anywhere between 0.05 and 10--lets assume 3.3"
    ACH = 3.3[1/hr]
V_dot = ACH*V_bldg*convert(min,hr) "to assure enough flow"
c_p_air = specheat(air,T=T_o)
rho_air = density(air,T=T_o,P=P_o)
Q_dot[13] = V_dot*rho_air*c_p_air*(T_o-T_i)*convert(hr,min)*convert(BTU/hr,tons) "total heat transfer
from outside air loads"

"!__OCCUPANT LOADS__"
Q_dot_person = 150[W]*convert(W,tons)
occupancy = 100{people}*((6[hr])/(24[hr])) "average occupancy"
Q_dot[14] = Q_dot_person*occupancy "total heat generation from suite occupants"

"!__COMPUTER LOADS__"
Q_dot_computer = 500[W]
computer_use = 20{computers}*((11[hr])/(24[hr])) "average computer heating power"
Q_dot[15] = Q_dot_computer*computer_use*convert(W,tons) "total heat generation from computers"

"!__LIGHTING LOADS__"
Q_dot_bulb = 0.25{estimate of heat given off}*40[W]*convert(W,tons)
```

```
lighting = 3{bulbs/fixture}*15{fixtures/room}*40{rooms}*((14[hr])/(24[hr])) "average computer heating power"
Q_dot[16] = Q_dot_bulb*lighting "total heat generation from lights"

"!__TOTAL HEATING LOAD__"
Q_dot_losses=(SUM(Q_dot[i],i=10,13))
Q_dot_gains=(SUM(Q_dot[i],i=14,16))
Q_dot_net = Q_dot_gains+Q_dot_losses

"!__NOTES__"
"*1 - heating load considerations found at
http://www.canren.gc.ca/prod_serv/index.asp?CaId=169&PgId=1024"
"*2 - Thermal resistances were found at www."
"*3 - Emissivities were found at http://www.electro-optical.com/bb_rad/emissivity/matlemisivty.htm#Misc"
"*4 - possitive heat transfer is entering the building"
"*5 - http://www.pdhengineer.com/courses/hv/M-5009.pdf"
"*6 - the other team members--Lake, Ryan, and Santi"
"*7 - Senior Design 2007-8 Team 4: Cooling Calvin Cleanly. Jordan Wanner, Dan VandenAkker, Christina
Overbeck. http://www.calvin.edu/academic/engineering/senior-design/SeniorDesign07-08/Team04/"
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Appendix C: Infrastructure

Objective

The ENGR 333 class project posed the question,

- *"What will it take for Calvin College to install a geothermal HVAC system for the West Wing?"*

The Infrastructure Team was specifically tasked with answering these more specific questions, also found in the project handout:

- *"How does the existing campus infrastructure constrain your selection of geothermal design options?"*
- *"What design options should be considered for the geothermal systems?"*

By finding answers to these questions, the Infrastructure Team was able to define a context for how the project fit with Calvin College's current and future operations, and also make preliminary design decisions about the geothermal systems that other teams would study more specifically.

Understanding Calvin's Current HVAC Systems

In looking to provide a framework in which the geothermal system would be operating, the team investigated Calvin's existing HVAC systems. Paul Pennock, a mechanical contractor at the Calvin Physical Plant, met with the team and gave a thorough tour of the campus infrastructure. Calvin operates three HVAC power plants that supply hot and cold water to the entire campus through a large network of pipes and tunnels. The power plants, each consisting of a natural gas boiler and chiller, are located in Knollcrest Dinning Hall, Commons Dinning Hall, and the Engineering Mechanical Building (See Appendix C-1). These power plants operate significantly under capacity. In fact, in the summer of 2012, one single chiller provided sufficient cooling to the entire campus while the other two were undergoing maintenance.

Integration or Stand-Alone

To specify the geothermal system design, it was necessary to decide if and how to integrate with the existing HVAC infrastructure. This decision could be based on the ease in which integration could be realized, the cost associated with integration, and the preference of the customer, Vice President of Finance Henry DeVries. During the HVAC tour, it was noted that hot and cold supply water mains dead end into the basement of the Spoelhof Center. These mains could be extended to the West Wing with relatively low cost and construction. However, Henry DeVries stated that the project should be considered as a stand-alone geothermal system. This would narrow the scope of the project and allow him to more easily identify the merits of a geothermal system.

Ground-Coupled Heat Exchanger Design

There are three main designs for geothermal bore fields, or ground-coupled heat exchangers. A *horizontal loop* consists of series of pipes buried in shallow, underground trenches[1], typically three to six feet deep[2]. A *pond loop* is essentially a horizontal loop submerged in a body of water, rather than in soil[3]. A *vertical loop* (Figure 1) has the least surface footprint by running pipes into deep bores, up to 400 feet deep[4]. The Infrastructure Team decided that the vertical loop was the best option for the West Wing because of its smaller footprint, and the opportunity for future construction atop the bore field. A side-by-side comparison of the bore fields can be found in Appendix C-2.

Bore Field Location

In choosing a location for the vertical bore field, consideration was given to the cost of piping from the field to the West Wing, the impact of construction, and the overall fit with the college's future plans. Pipe material and booster pump costs increase significantly with the distance from the West Wing. An analysis of this can be found in Appendix C-3. By locating the bore field under Parking Lot 3 (Figure C-2), the piping costs are minimized. The repaving costs could be shared with an existing plan to reroute the campus ring road, but these projects would have to be timed in coordination.

Figure C-1: Vertical bore fields can be up to 400 feet deep.\

[1] http://www.geothermalgenius.org/how-it-works/geothermal-ground-loop-fields/
[2] http://www.fhp-mfg.com/?p=geothermal_technology
[3] http://geothermal-house.com/geothermal-pond-loops.html
[4] http://www.michigan. gov/documents/deq/dnre-wb-dwehs-wcu-bestpracticesgeothermal_311868_7.pdf

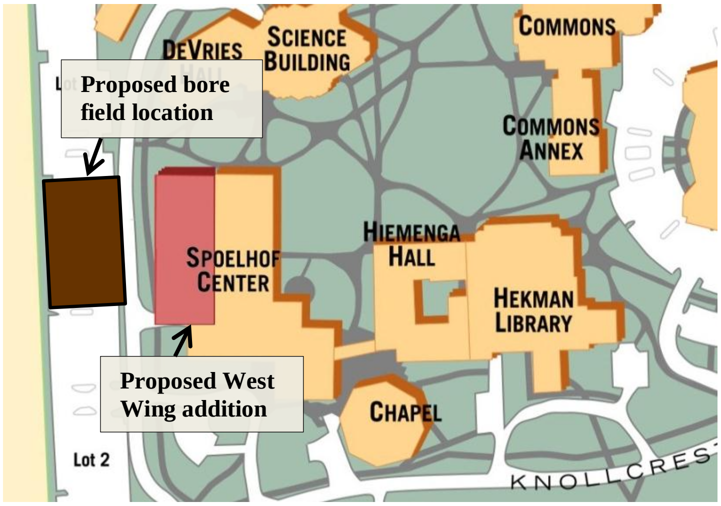

Figure C-2: Locating the bore field in Lot 3 minimizes transport costs and reduces construction impact.

Conclusions

By understanding Calvin's current HVAC infrastructure, working with the customer, and researching various ground-coupled heat exchanger designs, the Infrastructure team was able to supply the rest of the teams with a baseline context for the geothermal system design. The system should be mechanically separate from the rest of the campus' HVAC system, supplied by a vertical loop bore field located in the parking lot adjacent to the West Wing.

Appendix C-1: Location of Exsisting HVAC Power Plants

Figure C-3: Location of exsisting HVAC power plants on the campus of Calvin College, Grand Rapids, MI. These power plants have more than enough capacity to supply the entire campus and the addition of a West Wing on the Spoelhof Center.

Appendix C-2: Comparison of Ground-Coupled Heat Exchangers

Table C-1: Pros and Cons of Various Geothermal Loop Designs

Loop	Horizontal	Vertical	Pond
			
Pros	• Shallow Excavation • Less Expensive	• Small footprint • High efficiency • No property value loss	• No digging • Easy installation • Small environmental impact
Cons	• Large Footprint • Decrease property value from loss of building potential	• High construction cost	• Access to a body of water • Inefficient

Appendix C-3: Costs Estimation for Transport Piping

Introduction

When choosing the location for bore field construction, the cost of transporting the working fluid to and from the terminal user (heat pump) is largely a function the relative distance between the bore field and the heat pump. To estimate this, the cost of piping, booster pumps, and instillation must be accounted for. An EES worksheet was developed to generate these costs.

Costing Methods

Pipe

The team obtained the unit cost of underground pipe from several catalogues and local suppliers. Calvin mechanical contractor Paul Pennock indicated that the correct pipe type is known as welded black steel. It was noted that the greater the quantity purchased, the more the relative unit cost decreased. In addition, the team spoke with several local contractors to obtain estimates of installation costs. There was usually a minimum up-front cost and then a per unit installation cost. The diameter of the pipe also greatly affected the cost, with larger diameters cost proportionally far more than smaller diameters. Weighing each of these factors, Equation C-1 was developed (in the style of Bejan's Appendix B), where C_1=3[$], C_2=0.75[$/inch], C_3=1.5[feet$^{-2/3}$], and C_4=30[$/feet].

$$PipeCost = C_1 e^{(C_2 D_{nominal})}\left(1 + C_3 L_{pipe}^{\frac{-3}{2}}\right) + C_4 L_{pipe} \qquad \text{[Eq. C-1]}$$

Booster Pump

To overcome the frictional losses in the pipe, a booster pump is a necessary part of the transport system. The cost of a pump is a function of the required flow rate and the required pressure. The flow rate was specified by the Below Ground team, so all pump costs were estimated with that nominal flow rate. The frictional losses, or head loss, is a fuction of the internal diameter of the pipe, the pipe material, the viscosity of the working fluid, the velocity of the working fluid, the length of the pipe, the Reynolds number, and the gravitational acceleration. By calling local suppliers and consulting online catalogues, Equation C-2 was developed to estimate the cost of the booster pump based on the previously mentioned factors. C_5=1.2[$], C_6=8.4[$/feet], and C_7=2324[$].

$$BoosterPumpCost = C_5\left(C_6 h_{L,feet} + C_7\right) \qquad \text{[Eq. C-2]}$$

The total transport cost, which includes installation, is the sum of the booster pump cost and the pipe costs (Equation 3).

$$TransportCost = BoosterPumpCost + PipeCost \qquad \text{[Eq. 3]}$$

For a given pipe length, the total cost will vary based on the pipe diameter (which contributes to the head loss). Therefore, for each length, a diameter was chosen to minimize the cost. Table C-2 shows the total transport cost for several proposed bore field locations.

Table C-2: Transport cost estimations based on the distance from the West Wing project.

Bore Field Location	Distance from West Wing [m]	Distance from West Wing [ft]	Nominal Pipe Diameter [in]	Pipe Cost [$]	Booster Pump Cost [$]	Total [$]
Parking Lot 3	50	164	6	$5,192	$2,925	**$8,116**
Commons Lawn	170	560	6	$17,002	$3,248	**$20,251**
Sem Pond	370	1214	7	$36,989	$3,253	**$40,242**
Huizenga T&T Parking Lot	580	1900	7	$57,658	$3,516	**$61,175**
Lower Athletic Fields	690	2264	7	$68,485	$3,654	**$72,139**

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"ENGR 333, Fall 2012
Class Geothermal Project
Infrastructure Team
Jon Hofman"

"Pipe and Booster Pump Cost Estimations"


T=283[K]                                    "average temp of working fluid in pipes"
P=101[kPa]

rho=density(H2O, T=T, P=P)                  "water glycol mix estimated as pure water"
V_dot=0.03407[m^3/s]                        "flow rate from Below Ground Team"
velo_dot=V_dot/A
mu=viscosity(H2O, T=T)
Re=(rho*D*velo_dot)/(mu)                    "Reynold' number based on diameter"

L=690[m]                                    "the distance from the West Wing to the bore field"

D=D_inches*convert(in,m)
A=((D/2)^2)*pi#

weldedsteel=0.045                           "Paul Pennock specified material, this roughness is from the ENGR 319 textbook"
f=MoodyChart(Re, weldedsteel)

g=9.81[m/s^2]
h_L=f*(L/D)*(velo_dot^2/(2*g))
h_L_feet=h_L*convert(m,ft)

"D_inches=3[in]"
L_feet=L*convert(m,ft)

Cost_pipe=((3*exp(.75*D_inches))*(1+(3/(2*(sqrt(L_feet)*L_feet))))+(30*L_feet))
Cost_pump=1.2*((8.4*h_L_feet)+2325)
Cost_total=Cost_pipe+Cost_pump
```

Figure C-4: EES Sheet

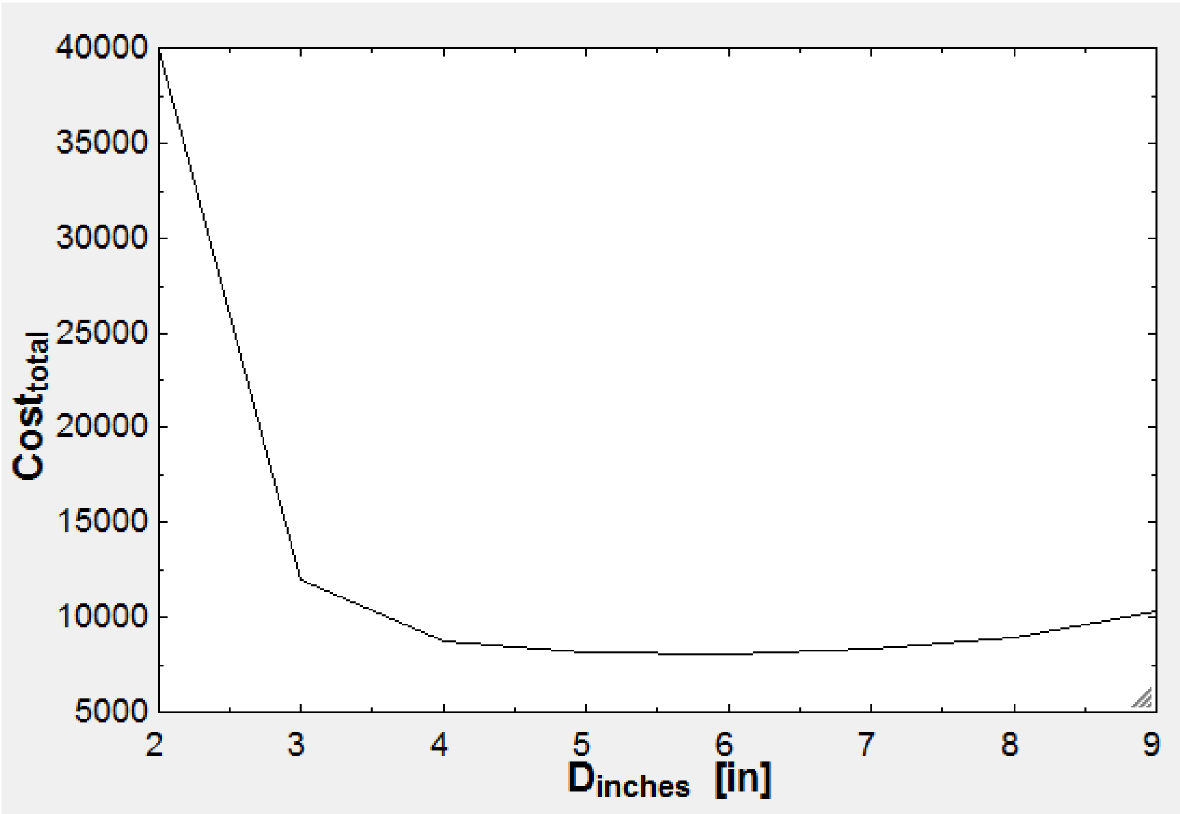

Figure C-5: Total transport cost for a bore field located 690 meters away from the West Wing. The total cost is dependant on the diameter of the pipe; minimum cost is for 7 inch pipe.

Appendix D: Below Ground

Geothermal System Design

The article Vertical Geothermal Bore fields: Sizing Calculation Spreadsheet[5] gives a method by which depth of bore fields can be calculated. This article was helpful in the beginning stages of our calculations; however, it was not used in our end calculations as we did not have adequate resources to complete the calculations using this method.

Based on the work of a previous Senior Design team that investigated geothermal heating in the KHvR dormitory,[6] an EES (Engineering Equation Solver) worksheet was developed to model the bore field – specifically, a set of base-case calculations of the depth and number of bore holes required to meet the heating and cooling load requirements. This code can be seen in Figure D-1 of Appendix D-1. We looked into doing some refinement of the model by looking for ways to model thermodynamic qualities of the ground more accurately. Doing this we looked mainly into temperature gradients as a function of depth and local soil composition. In terms of the temperature gradient, we initially used an equation received from Oklahoma State Soil Physics. This equation accounted for the sinusoidal behavior of soil temperature throughout the year and can be seen at the top of the next page along with definitions of used variables. However, as we found through research the deeper the soil, the more constant the temperature becomes. This behavior can be seen in Figure D-2 in Appendix D-1.

$$T(z,t) = T_a + Ae^{\frac{-z}{d}} \sin[\frac{2\pi(t-t_0)}{365} - \frac{z}{d} - \frac{\pi}{2}] \qquad \text{[Eq. D-1]}$$

T_a = average soil temp (°C)
A = annual amplitude of surface soil temp (°C)
z = soil depth (m)
t = time (days)
d = $\frac{2D_h}{\omega}^{.5}$
$\omega = \frac{2\pi}{365}$ (day^{-1})
D_h = thermal diffusivity

When looking at the impact soil composition would have on the installation of our geothermal site we found that drilling would not be a concern, however, by investigating stratigraphic data for western Michigan we saw that the biggest factor of the soil that would affect the bore field design would be the thermal conductivity. While we knew this was important, we only found recommended values but sought to find a way to accurately calculate this for our bore field. For these reasons, we sought further refinement of the bore field model from Midwest Geothermal (MWGT), the same company that assisted the Senior Design team in 2008.

[5] Phillippe, Mikael, Michel Bernier, and Dominique Marchio. Vertical Geothermal Bore fields: Sizing Calculation Spreadsheet. N.p.: ASHRAE Journal, 2010. Web. 11 Oct. 2012.
[6] Overbeck, Christina, Daniel VandenAkker, and Jordan Wanner. Calvin College. "Cleanly Cooling Calvin" Senior Design Team 2008. Design Report

Bore Field Refinement

With the help of Scott Skoog, President of MWGT, we were able to more accurately model what it would take to install a geothermal system adequate for Byker Hall. One of the first things he recommended was to do a couple tests to gain information about our digging site, thus pointing us towards an optimized design. The first test is a thermal conductivity test that helps determines the rate of heat transfer through the soil. This information is crucial to the spacing of the bores. As the thermal conductivity increases, bores can be spread out more. Contrarily, as the thermal conductivity decreases, bores must be moved closer to achieve the same amount of heat transfer to accommodate the loads of the building. For our model, Scott Skoog advised us to use a thermal conductivity of 1.35 $^{BTU}/_{hr\text{-}ft\text{-}°F}$, a value commonly used in the Grand Rapids area. The second test recommended to us was a test bore. This test collects more accurate data about how heat flows through the soil at various depths at the site in question, therefore, determining an optimal depth for the bores. We found that these tests can be done in sync with each other and for our project would cost $9,500, of which $5,000 could be recouped by using the test bore site as one of the bores for the final implementation.

Given heating and cooling loads, provided by the LEED/Energy Modeling Group, and industrial assumptions made by Scott Skoog, we developed a refined model of our initial calculations. We found that if we dug a single bore, we would require 28,446 feet; however, due to inefficiencies within the first 30 feet of each bore, we found that we would actually need an adjusted depth of 33,180 feet. We also opted to use an operating fluid instead on only water in our geothermal loop. This allowed us to operate our heat pumps over a temperature range below 32°F due the decrease of the fluid's freezing point with the addition of propylene glycol, a refrigerant already purchased in large volumes by the Calvin College Physical Plant. For our design we chose an operating temperature range of 30°F to 90°F. Figure D-3 in Appendix D-1 shows that a fluid composed of 10% propylene glycol by weight would allow for our minimal operating temperature. An effect of increasing our temperature range also allows us to use less bores than would be needed for a model using only water as the operating fluid, therefore, reducing installation costs. With all of these design options taken into consideration we reached a final design for the Byker Hall bore field. Table D-1, also found in Appendix D-1, outlines all design features of our final proposal, including a total cost of installation and materials of $478,720.

Table D-1: Final Proposal

Number of Bores	88
Bore Depth, L_B (ft)	400
Bore Diameter, D_B (in)	5
Pipe Material	HDPE
Pipe Diameter (in)	1.25
Center-to-Center, S_B (ft)	20
Total Cost	$478,720
Economic Life	50
Physical Life	50+

Appendix D-1: Tables and Figures

```
"Known Parameters"
T_ground=10[C]
Q_dot_max=48[ton]*convert(ton,W)                    "Max load ever needed"
D_pipe=1.25[in]*convert(in,m)                       "Diameter of Pipe"
epsilon=0.00001[m]                                  "ID Roughness of ground loop"
eta_pump=0.8                                        "Pump efficiency"
x_water=0                                           "Quality of the water, always 0"
rho_water=density(water,t=t_ground,x=x_water)       "Density of water in loop"
mu=Viscosity(Water,T=T_ground,x=x_water)            "Viscosity of water in loop"
g=9.81[m/s^2]                                       "Gravity"
k_L=.4+1.2                                          "Minor Losses, see Table 14-4 Bejan"
P_1=101325[Pa]                                      "Arbitrary"
P_1=P_2
Z_1=0[m]
Z_2=h

"Design Variables"
V_dot=12[gpm]*convert(gpm,m^3/s)                    "Volumetric flow rate of ground loop"
T_water=16[C]                                       "Water entering ground loop"
//DELTAT=6[C]                                       "Temperature differential at max load"
h=400[ft]*convert(ft,m)                             "Depth of Gound Well"
h=(L-10[m])/2                                       "Finds overall length of pipe in ground loop"
{//L=500[ft]*convert(ft,m)}                         "Overall length of pipe in ground loop"

"Calculated Parameters"
A_x_pipe=PI*(D_pipe^2)/4                            "Cross sectional area of pipe"
m_dot=V_dot*rho_water                               "Mass flow rate"
V=V_dot/A_x_pipe                                    "Velocity of flow"
V=V_1;V=V_2                                         "for Bernulli equation"
Re=(rho_water*V*D_pipe)/mu
B=(epsilon/D_pipe)/3.7+2.51/(Re*f^.5)               "Greater than 4000"
1/(f^.5)=-2.0*log10(B)                              "Colebrook Equation, finds f"

"Head Loss and Pump Power"
h_L=(f*(L/D_pipe)*(V^2/(2*g)))+(k_L*(V^2/(2*g)))    "Major and Minor losses"
h_L=(E_dot_mech_loss)/(m_dot*g)                     "Finds mech loss"
m_dot*(P_1/rho_water+V_1^2/2+g*Z_1)+W_dot_pump=m_dot*(P_2/rho_water+V_2^2/2+g*Z_2)+E_dot_mech_loss
W_act=W_dot_pump*eta_pump
W_dot_pump_actual=W_act*convert(W,hp)               "Finds W_act"

{"Effective Thermal Resistance of the ground"
Q_dot_max=((2*h*(T_water-T_ground))/R)*convert(w,kW)   "Based on Water out Temp"
Q_dot_max=((2*h*(DELTAT))/R)*convert(w,kW)             "Temperature Differential"
R_english=R*convert(m-K/W,hr-ft-F/Btu)                 "Thermal Resistance"
//R=.01[m-K/W]
//R_english=.008[hr-ft-F/Btu]                          "Thermal Resistance english 0.008?"
//Conductivity=1/R_english                             "Conductivity"
//Conductivity=2.0[Btu/hr-ft-F]}                       "Conductivity"
```

Unit Settings: SI C kPa kJ mass deg

$A_{x,pipe}$ = 0.0007917 [m^2]	B = 0.0007593	D_{pipe} = 0.03175 [m]	ε = 0.00001 [m]
η_{pump} = 0.8	$\dot{E}_{mech,loss}$ = 71.62 [W]	f = 0.02569	g = 9.81 [m/s^2]
h = 121.9 [m]	h_L = 9.646 [m]	k_L = 1.6	L = 253.8 [m]
μ = 0.001307 [kg/m*s]	$\dot{m}$ = 0.7569 [kg/s]	P_1 = 101325 [Pa]	P_2 = 101325 [Pa]
$\dot{Q}_{max}$ = 168809 [W]	Re = 23229	ρ_{water} = 999.7 [kg/m^3]	T_{ground} = 10 [C]
T_{water} = 16 [C]	V = 0.9562 [m/s]	V_1 = 0.9562 [m/s]	V_2 = 0.9562 [m/s]
$\dot{V}$ = 0.0007571 [m^3/s]	W_{act} = 781.5 [W]	$\dot{W}_{pump}$ = 976.8 [W]	$\dot{W}_{pump,actual}$ = 1.048 [hp]
x_{water} = 0	Z_1 = 0 [m]	Z_2 = 121.9 [m]	

No unit problems were detected.

Calculation time = .0 sec.

Figure D-1: Engineering Equation Solver (EES) Code for Initial Thermal Modeling

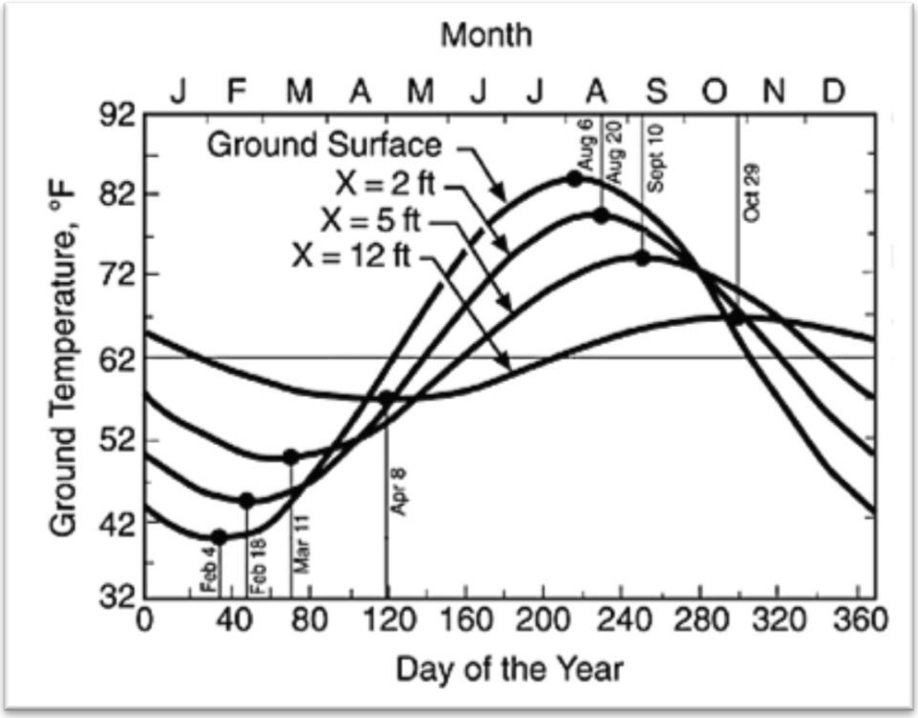

Figure D-2: Sinusoidal Temperature Gradient at Various Depths

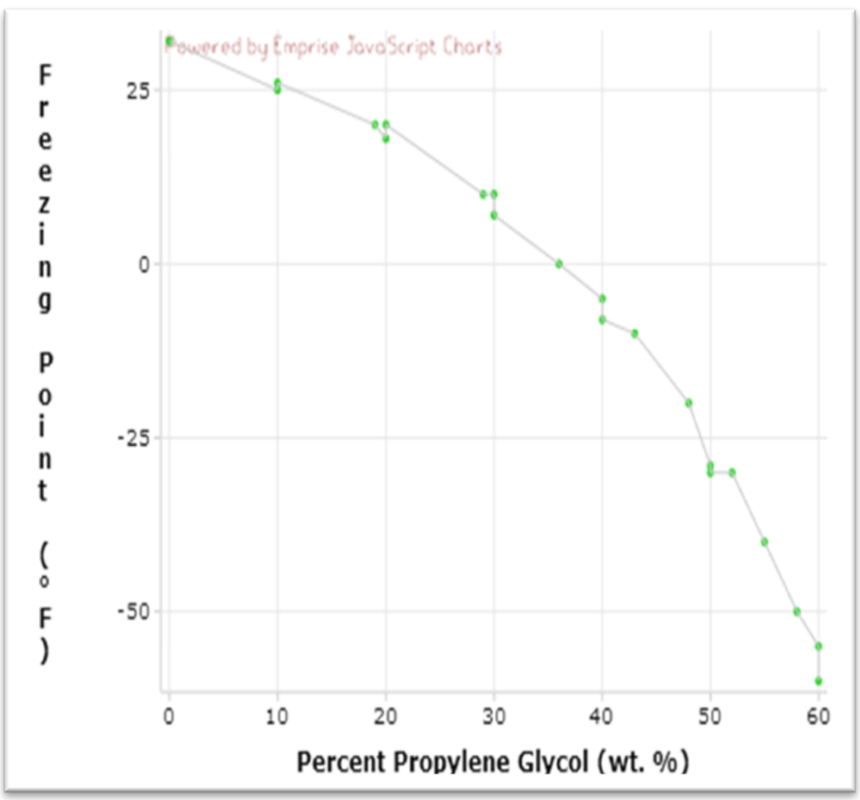

Figure D-3: Geothermal Loop Fluid Freezing Point as Weight Percent of Propylene Glycol Increases

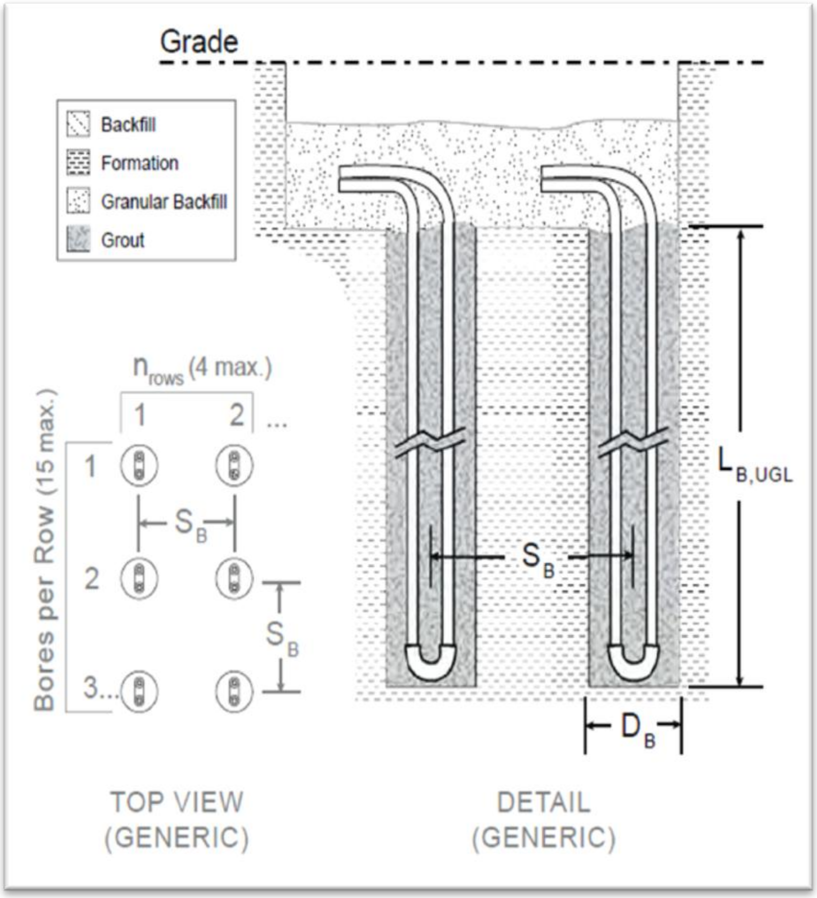

Figure D-4: Cross-Sectional View of Bore

Table D-1: Final Proposal

Number of Bores	88
Bore Depth, L_B (ft)	400
Bore Diameter, D_B (in)	5
Pipe Material	HDPE
Pipe Diameter (in)	1.25
Center-to-Center, S_B (ft)	20
Total Cost	$478,720[7]
Economic Life	50
Physical Life	50+

[7] Cost calculated via MWGT modeling software, using $13.60/bore foot and average installation costs

Appendix E: Above Ground

Objective

This semester, the above ground group was tasked with three main questions. Will we transfer the heat throughout the building via a water loop or an air loop? Will we pursue a centralized heat pump or a distributed set of heat pumps? What is the value of adding a heat recovery ventilation system? This report will discuss the design options involved with each of these.

Analysis

Water to Water vs. Water to Air Heat Pump

In the winter, a water to water heat pump works by transferring heat from the ground water loop to the building water loop. In the summer, the heat is transferred from the building to the ground loop. This system is generally regarded in industry as outdated and requiring more maintenance than a water to air system. Additionally, no building can function purely on a water to water heat pump, as some sort of ventilation is required. This necessitates the need for two systems, one water to water and water to air. This hybrid system is what we see in the majority of Calvin buildings. It is essential that the two systems be sized properly as the air system must be able to keep up with dehumidification so that condensation does not build up on the radiators throughout the building. Calvin solves this issue by using the radiators only for heating in the winter. All cooling of the building is done with a purely air system.

Most modern geothermal systems use water to air heat pumps. A water to air system works by cooling the air with the ground water in summer and heating the air with the ground water in winter. This system is advantageous because it is simpler to maintain. There is only an air loop running throughout ductwork in the building opposed to an air loop and a water loop. It is because of the simpler maintenance that we recommend a water to air system.

Central Load vs. Distributed Load

Distributed systems use a series of smaller heat pumps sized according to room-specific heating and cooling zones. For the West Wing addition, approximately thirty 5-10 ton heat pumps would be selected to meet the heating and cooling demands, with each heat pump sized to service a single room or space, or a single zone of rooms. These heat pumps would be placed in mechanical closets or above hung ceilings. The system would cost approximately 1.2 million dollars to purchase and install, based on a square footage rule of thumb provided by Dean Anderson, a geothermal HVAC specialist from Carrier.

Centralized geothermal systems use a single, centralized heat pump to handle all of the heating and cooling loads of the building. Extensive flow distribution systems are needed for this kind of system, such as ductwork and flow control systems for water-to-air heat pumps. A benefit of this system is that the noise produced by the heat pump can be localized to a single area, which is attractive in an academic setting. The largest commercial unit available is the new, 70 ton, V-Cube Slim from Mammoth Inc. For this reason, a custom unit from Trane was pursued. Dan Pabst, a geothermal HVAC engineer from Trane, gave a price of $840,000 for a custom, 175 ton, water-source heat pump that would be installed on the roof of the new addition.

Calvin currently operates under what can best be classified as a centralized system: one large boiler and chiller form the basis for a conventional HVAC system that services an entire building, or set of buildings, by sending chilled and heated water to the buildings, which is then distributed to a system of air handlers and radiators that heats and cools the rooms as necessary. The similarity of the geothermal system to Calvin's existing infrastructure was also factored into the final recommendation.

Table E-1 displays the decision matrix used to justify the selection of a centralized system.

Table E-1: Centralized and distributed load decision matrix

		Design Alternatives	
Design Factors	Weights	Centralized	Distributed
Equipment and Installation Cost	5	4	3
Maintenance Cost	4	5	3
Noise Localization	3	5	4
Simplicity	4	4	3
Similarity to Existing Infrastructure	3	4	3
Size/Space Requirement	2	3	5
		89	70

Ventilation

Ventilation requirements were calculated using standards required by law in the Michigan Mechanical Codes (2006), and the ASHRAE standard 62-2001[1]. The Michigan Mechanical codes plainly stated that the ventilation systems should be designed to comply with ASHRAE standards at a minimum. In accordance with the Michigan Mechanical Codes (Table E-2 in appendix E-1), the ASHRAE codes specified different rates of airflow according to the room type. Hence, calculations were done for each type of building space (offices, reception areas, classrooms, etc.). Floor space was based upon the preliminary West Wing floor plans provided by our industrial liaison, Trent DeBoer. The total airflow requirement for the West Wing addition was calculated to be 47697 cubic feet per minute (Table E-3).

Table E-3: Air Flow Requirements by Room Type

Room Type	Total Air Flow Requirement (cfm)
Classrooms	35606
Conference Rooms	1502
Reception Areas	6120
Rest Rooms	4176
Offices	293
Combined	**47697**

Energy Recovery Ventilation (ERV)

Energy Recovery Ventilation is the process by which the energy in exhaust air from a building is exchanged and used to treat incoming air. In this light, during winter settings, this component of the HVAC system will serve as the air preheater; the warmer exhaust air will heat and humidify the cool incoming air. Conversely, during the summer settings, this component will serve as the air pre-cooler; the cooler exhaust air will cool and dehumidify the warm incoming air. The efficiency/effectiveness of the ERV component, which comes in the form of an air-to-air heat exchanger, is built on the fact that the more extreme the weather conditions, the greater the coefficient of performance of the system.

The ERV component is highly recommended, not only because it reduces both the heating and cooling load, but also because it contributes to improving the indoor air quality. The ERV component further ensures ASHRAE ventilation and energy standards are met.

Though this component comes at an extra expense ($200,000), this form of renewable energy is cost effective.

Air Ducts

The air ducts are an important part of any HVAC system, as they are responsible for directing the conditioned air around the building. They also provide ventilation to bring fresh air into the building. There is, however, a cost that goes into purchasing and installing the system, which will be analyzed in this section.

At the beginning of the project, the class obtained preliminary building plans from the architect. These plans were then used for a multitude of calculations, including the air duct length requirement. The procedure for figuring out the air duct lengths was very basic. The drawings were imported into AutoCAD software, and lines were drawn accordingly across the plan to where ductwork seemed reasonable.

The first floor accounted for the majority of the ductwork usage, as the square footage of the section was very much larger than the second and third floors. The floor plan and ductwork estimate for the first floor are shown in figure E-1. Note that the ductwork does not cover the auditorium in the bottom left, as that is part of the current Spoelhof building.

As was previously stated, the second and third floors did not have as large of a footprint as the first floor. The ductwork estimate plans for the second and third floors are shown in figures E-2 and E-3, respectively.

The costing for the ductwork came from an RS Means textbook that provided many different prices for air ducts. The duct cross sectional area ranged from 4" x 8" all the way up to 30" x 36". The varying prices for purchase and installation are presented in table E-4.

Table E-4: Air duct pricing based on sizing

Height (in)	Width (in)	Cross Sectional Area (in^2)	Cost (per ft)
4	8	32	$ 2.16
6	8	48	$ 2.62
10	12	120	$ 3.46
12	14	168	$ 5.10
16	18	288	$ 5.10
18	24	432	$ 6.45
30	36	1080	$ 7.70

As the required flow through the building was very high, the final decision was to go with the 30" by 36" ducts. An assumption was made that some areas would require smaller ducts, but others would need larger ones, so the pricing would balance itself out. To handle the changes in air flow, we would need to purchase variable air volume (VAV) units that distribute the flow accordingly between rooms. The VAV is controlled by a thermostat, which tells the unit whether to open or close based on the room conditions. For this project, the team did not look into these options as that was beyond our scope.

Using the AutoCAD drawings as well as the pricing information, a final length and cost were calculated. To account for any errors in the system, the duct lengths were increased by 30%, and the total cost was increased by 20%. This was a "cushion factor," as the analysis was fairly rough and could have some big flaws in it. The results of the ductwork analysis are presented in table E-5.

Table E-5: Ductwork lengths and total purchase and installation costs

Floor	Length of Ducts Required (ft)	Cost
First	3684.2	$34,042.01
Second	1671.8	$12,872.86
Third	952.9	$ 7,337.33
Total	6308.9	$54,252.20

Conclusion

In the end, there were three specific recommendations to deliver to the customer. These revolve around the following three questions:

1. Will we transfer the heat throughout the building via a water loop or an air loop?
2. Will we pursue a centralized heat pump or a distributed set of heat pumps?
3. Will we pursue an energy recovery ventilation system along with the existing ventilation?

In the event that the college decides to pursue a West Wing expansion with a geothermal HVAC system it is our recommendation that a centralized, water to air heat pump with an energy recovery unit be chosen. We believe this system to best fit the building and to be the simplest to maintain. We have contacted Trane and obtained an estimate of $1,240,000 for centralized water to air 174 ton heat pump with an energy recovery system. This estimate includes both component and installation costs.

Appendix E-1: Tables and Figures

Table E-2: Michigan Mechanical Codes Airflow requirements[8]

REQUIRED OUTDOOR VENTILATION AIR

OCCUPANCY CLASSIFICATION	ESTIMATED MAXIMUM OCCUPANT LOAD, PERSONS PER 1,000 SQUARE FEET[a]	OUTDOOR AIR [Cubic feet per minute (cfm) per person] UNLESS NOTED[e]
Correctional facilities		
Cells		
without plumbing fixtures	20	20
with plumbing fixtures[g, h]	20	20
Dining halls	100	15
Guard stations	40	15
Dry cleaners, laundries		
Coin-operated dry cleaner	20	15
Coin-operated laundries	20	15
Commercial dry cleaner	30	30
Commercial laundry	10	25
Storage, pick up	30	35
Education		
Auditoriums	150	15
Classrooms	50	15
Corridors	—	0.10 cfm/ft^2
Laboratories	30	20
Libraries	20	15
Locker rooms[h]	—	0.50 cfm/ft^2
Music rooms	50	15
Smoking lounges[b, g]	70	60
Training shops	30	20
Food and beverage service		
Bars, cocktail lounges	100	30
Cafeteria, fast food	100	20
Dining rooms	70	20
Kitchens (cooking)[f, g]	20	15
Hospitals, nursing and convalescent homes		
Autopsy rooms[b]	—	0.50 cf m/ft^2
Medical procedure rooms	20	15
Operating rooms	20	30
Patient rooms	10	25
Physical therapy	20	15
Recovery and ICU	20	15
Hotels, motels, resorts and dormitories		
Assembly rooms	120	15
Bathrooms[g, h]	—	35
Bedrooms	—	30 cfm per room
Conference rooms	50	20
Dormitory sleeping areas	20	15
Gambling casinos	120	30
Living rooms	—	30 cfm per room
Lobbies	30	15
Offices		
Conference rooms	50	20
Office spaces	7	20
Reception areas	60	15
Telecommunication centers and data entry	60	20

REQUIRED OUTDOOR VENTILATION AIR

OCCUPANCY CLASSIFICATION	ESTIMATED MAXIMUM OCCUPANT LOAD, PERSONS PER 1,000 SQUARE FEET[a]	OUTDOOR AIR (Cubic feet per minute (cfm) per person) UNLESS NOTED[e]
Private dwellings, single and multiple		
Garages, common for multiple units[b]	—	1.5 cfm/ft^2
Garages, separate for each dwelling	—	100 cfm per car
Kitchens[g]	—	100 cfm intermittent or 25 cfm continuous
Living areas[c]	Based upon number of bedrooms. first bedroom: 2; each additional bedroom: 1	0.35 air changes per hour[d] or 15 cfm per person, whichever is greater
Toilet rooms and bathrooms[g, h]	—	Mechanical exhaust capacity of 50 cfm intermittent or 20 cfm continuous
Public spaces		
Corridors and utilities	—	0.05 cfm/ft^2
Elevator car[g]	—	1.00 cfm/ft^2
Locker rooms[h]		0.5 cfm/ft^2
Shower rooms (per shower head)[g,h]		50 cfm intermittent or 20 cfm continuous
Smoking lounges[b,h]	70	60
Toilet rooms[g,h]		75 cfm per water closet or urinal

[8]Indoor Air Quality: A Guide to Understanding ASHRAE Standard 62-2001, http://www.trane.com/commercial/Uploads/PDF/520/ISS-APG001-EN.pdf

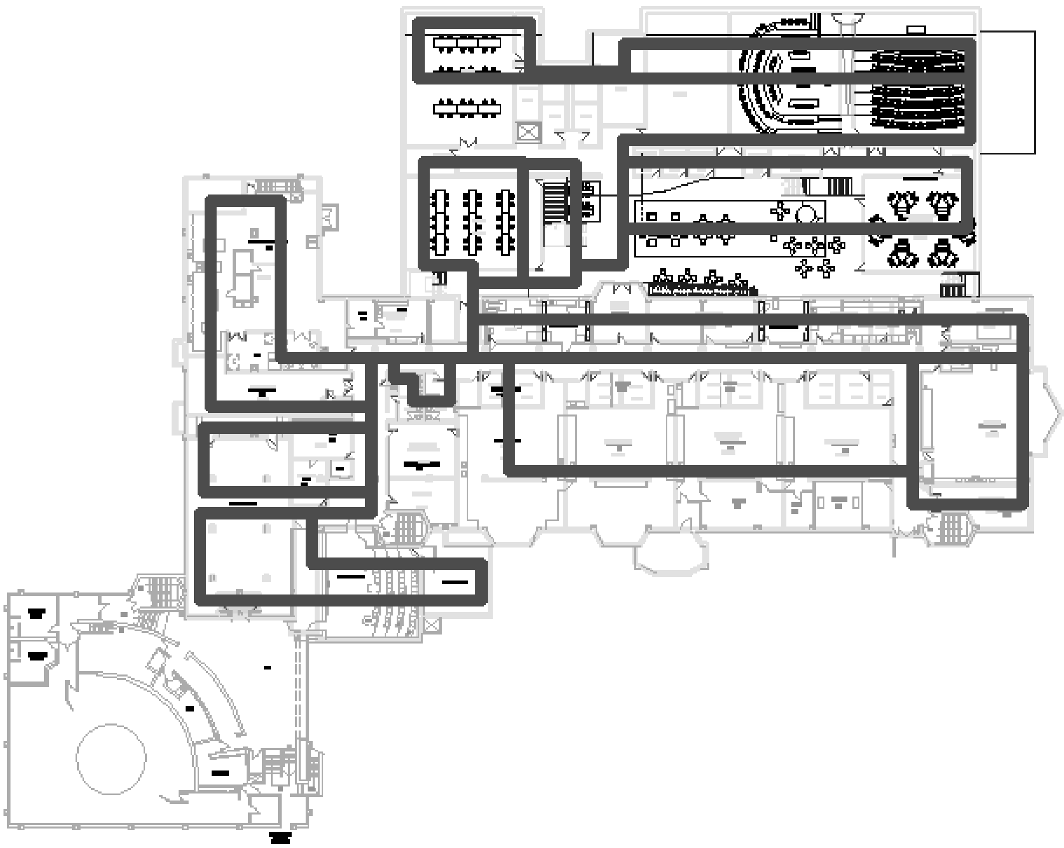

Figure E-1: First floor plan and ductwork design

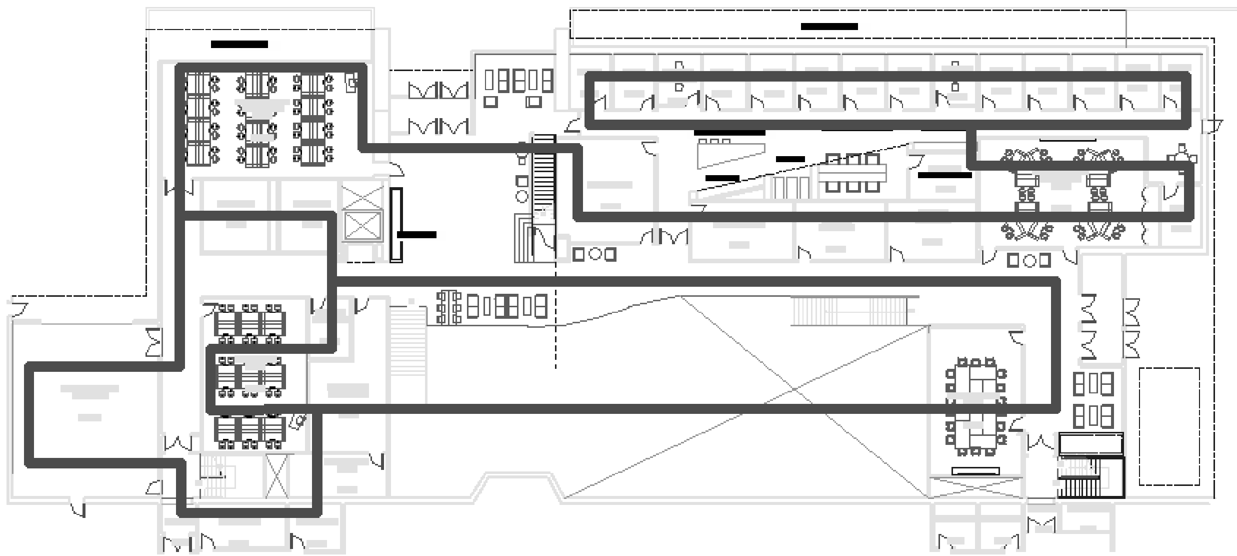

Figure E-2: Second floor plan and ductwork diagram

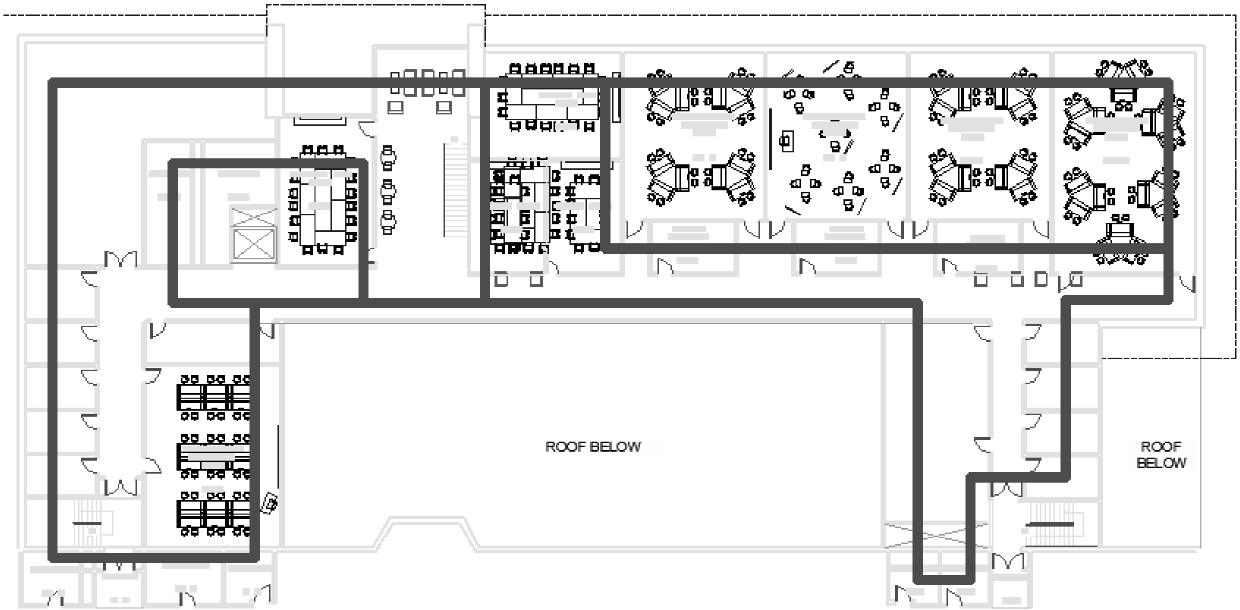

Figure E-3: Third floor plan and ductwork diagram

Figure E-4: EES Sheet

```
"Maximum Occupancy Calculations"
"References:
http://www.automatedbuildings.com/news/jan03/articles/ebtron/ebt.htm

http://www.trane.com/commercial/Uploads/PDF/520/ISS-APG001-EN.pdf"

"Estimated maximum occupancy"
Occupancy_office = 0.007
Occupancy_receptionarea = 0.060
Occupancy_computerlabs = 0.060
Occupancy_conferencerooms = 0.020
Occupancy_restrooms = 0.060
Occupancy_smokinglounge = 0.060
Occupancy_classrooms = 0.100

"Square footage"
"1st Floor"
Footage_classrooms1 = 9587
Footage_restrooms1 = 521
Footage_office1 = 165
Footage_receptionarea1 = 4000

MaxOc_office1 = Footage_office1*Occupancy_office
MaxOc_classrooms1 = Footage_classrooms1*Occupancy_classrooms
MaxOc_restrooms1 = Footage_restrooms1*Occupancy_restrooms
MaxOc_receptionarea1 = Footage_receptionarea1*Occupancy_receptionarea

"2nd Floor"
Footage_classrooms2 = 3388
Footage_restrooms2 = 419
Footage_office2 = 1930
Footage_receptionarea2 = 2200
Footage_conferencerooms2 = 1518

MaxOc_office2 = Footage_office2*Occupancy_office
MaxOc_classrooms2 = Footage_classrooms2*Occupancy_classrooms
MaxOc_restrooms2 = Footage_restrooms2*Occupancy_restrooms
MaxOc_receptionarea2 = Footage_receptionarea2*Occupancy_receptionarea
MaxOc_conferencerooms2 = Footage_conferencerooms2*Occupancy_conferencerooms

"3rd Floor"
Footage_classrooms3 = 4828
Footage_restrooms3 = 452
Footage_receptionarea3 = 600
Footage_conferencerooms3 = 2236

MaxOc_classrooms3 = Footage_classrooms3*Occupancy_classrooms
MaxOc_restrooms3 = Footage_restrooms3*Occupancy_restrooms
MaxOc_receptionarea3 = Footage_receptionarea3*Occupancy_receptionarea
MaxOc_conferencerooms3 = Footage_conferencerooms3*Occupancy_conferencerooms

"Total Maximum Occupancy"
MaxOc_office = MaxOc_office1 + MaxOc_office2
MaxOc_classrooms = MaxOc_classrooms1 + MaxOc_classrooms2 + MaxOc_classrooms3
```

MaxOc_restrooms = MaxOc_restrooms1 + MaxOc_restrooms2 + MaxOc_restrooms3
MaxOc_receptionarea = MaxOc_receptionarea1 + MaxOc_receptionarea2 + MaxOc_receptionarea3
MaxOc_conferencerooms = MaxOc_conferencerooms2 + MaxOc_conferencerooms3

"Minimum Air Flow Requirements"
Flowregulation_office = 20
Flowregulation_classrooms = 20
Flowregulation_restrooms = 50
Flowregulation_receptionarea = 15
Flowregulation_conferencerooms = 20

AirFlow_office = Flowregulation_office*MaxOc_office
AirFlow_classrooms = Flowregulation_classrooms*MaxOc_classrooms
AirFlow_restrooms = Flowregulation_restrooms*MaxOc_restrooms
AirFlow_receptionarea = Flowregulation_receptionarea*MaxOc_receptionarea
AirFlow_conferencerooms = Flowregulation_conferencerooms*MaxOc_conferencerooms

Unit Settings: SI C kPa kJ mass deg

$AirFlow_{classrooms}$ = 35606 [ft^3/min]	$AirFlow_{conferencerooms}$ = 1502 [ft^3/min]
$AirFlow_{office}$ = 293.3 [ft^3/min]	$AirFlow_{receptionarea}$ = 6120 [ft^3/min]
$AirFlow_{restrooms}$ = 4176 [ft^3/min]	$Flowregulation_{classrooms}$ = 20 [ft^3/min-person]
$Flowregulation_{conferencerooms}$ = 20 [ft^3/min-person]	$Flowregulation_{office}$ = 20 [ft^3/min-person]
$Flowregulation_{receptionarea}$ = 15 [ft^3/min-person]	$Flowregulation_{restrooms}$ = 50 [ft^3/min-person]
$Footage_{classrooms1}$ = 9587 [ft^2]	$Footage_{classrooms2}$ = 3388 [ft^2]
$Footage_{classrooms3}$ = 4828 [ft^2]	$Footage_{conferencerooms2}$ = 1518 [ft^2]
$Footage_{conferencerooms3}$ = 2236 [ft^2]	$Footage_{office1}$ = 165 [ft^2]
$Footage_{office2}$ = 1930 [ft^2]	$Footage_{receptionarea1}$ = 4000 [ft^2]
$Footage_{receptionarea2}$ = 2200 [ft^2]	$Footage_{receptionarea3}$ = 600 [ft^2]
$Footage_{restrooms1}$ = 521 [ft^2]	$Footage_{restrooms2}$ = 419 [ft^2]
$Footage_{restrooms3}$ = 452 [ft^2]	$MaxOc_{classrooms}$ = 1780
$MaxOc_{classrooms1}$ = 958.7 [people]	$MaxOc_{classrooms2}$ = 338.8 [people]
$MaxOc_{classrooms3}$ = 482.8 [people]	$MaxOc_{conferencerooms}$ = 75.08 [people]
$MaxOc_{conferencerooms2}$ = 30.36 [people]	$MaxOc_{conferencerooms3}$ = 44.72 [people]
$MaxOc_{office}$ = 14.67 [people]	$MaxOc_{office1}$ = 1.155 [people]
$MaxOc_{office2}$ = 13.51 [people]	$MaxOc_{receptionarea}$ = 408 [people]
$MaxOc_{receptionarea1}$ = 240 [people]	$MaxOc_{receptionarea2}$ = 132 [people]
$MaxOc_{receptionarea3}$ = 36 [people]	$MaxOc_{restrooms}$ = 83.52 [people]
$MaxOc_{restrooms1}$ = 31.26 [people]	$MaxOc_{restrooms2}$ = 25.14 [people]
$MaxOc_{restrooms3}$ = 27.12 [people]	$Occupancy_{classrooms}$ = 0.1 [people/ft^2]
$Occupancy_{computerlabs}$ = 0.06 [people/ft^2]	$Occupancy_{conferencerooms}$ = 0.02 [people/ft^2]
$Occupancy_{office}$ = 0.007 [people/ft^2]	$Occupancy_{receptionarea}$ = 0.06 [people/ft^2]
$Occupancy_{restrooms}$ = 0.06 [people/ft^2]	$Occupancy_{smokinglounge}$ = 0.06 [people/ft^2]

No unit problems were detected.

Calculation time = .0 sec.

Appendix F: Financial

Introduction

The financial team researched and analyzed the initial and lifetime costs for both a geothermal system and a conventional HVAC system to be implemented in the proposed West Wing expansion of the Spoelhof Center. Present and Future Natural Gas and Electricity costs, equipment costs, installation costs, heating and cooling loads, and various economic scenarios were used to determine the initial and ongoing costs of both systems as well as the potential payback period for implementing a geothermal system. The financial team also looked into the use of CERF funds, as well as other external funding opportunities.

Approach

The first costs to be considered were the initial costs for purchasing and installing components of a geothermal and conventional HVAC system. A geothermal system requires the construction of a bore field, piping and pumps, and a heat pump. These costs were found by the work of other groups. The costs that the teams found included both equipment purchase and installation of all components. For a conventional HVAC system, the initial costs are ductwork and air handler costs. Ductwork costs were given by the above ground group, and air handler cost was based upon an estimate for a system with a similar capacity and included the prices for installation and piping.

The first step in finding lifetime energy costs for both systems was to find the future prices for natural gas and electricity, shown in Figures F-1 and F-2, respectively. These prices came from the United States Department of Energy, and extended until the year 2035. In order to make energy cost predictions from the years 2035-2050, best-fit models were used to understand the trends and extrapolate data until the year 2050. As both figures show, due to new energy extraction techniques, natural gas and electricity prices are projected to remain fairly steady over the course of the near future. The next step in finding energy costs is to know energy loads and system efficiencies. For a geothermal system, energy costs are based on the heating and cooling loads and pump usage, and energy is provided completely by electricity. Conventional HVAC also depends on heating and cooling loads, but for conventional systems, natural gas provides for the heating load, while electricity provides for the cooling load. Research was conducted to determine the coefficient of performances (COP) and energy efficiency ratios (EER) of each system.

The next ongoing costs are maintenance costs. This included annual maintenance for the first 10 years of system operation, whereupon maintenance costs increased by 50%. This cost addition, known as later maintenance, models the increased breakdown of HVAC systems as they age and deteriorate. Geothermal maintenance costs were based on several sources, including the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). In addition to general maintenance, a geothermal system would require the replacement of heat pumps after 20 years, at a cost of $336,000. For a conventional HVAC system, the method for determining maintenance costs were based upon a scaling of ASHRAE sources, as well as the costs of hiring a maintenance technician for the entire HVAC system on campus, and estimating what portion of time would be spent on the West Wing based upon square footage. In addition, an air handler would need to be replaced after 20 years on a conventional system, at a cost of $150,000. Finally, in order to model possible economic conditions, which would change future costs, three economic scenarios were modeled representing strong, nominal, and weak economies. The different interest and inflation rates for these scenarios are shown in Table 1.

Additional team goals were to research the feasibility of offsetting costs with the use of either the Calvin Energy Recovery Fund (CERF) or external funding. CERF currently has a budget of about $60,000 available for this project; however, it was decided not to utilize CERF, as the scope of this project lies in the millions of dollars, so the amount available from CERF would have done little to reduce the total cost. Another source researched to offset the project cost was government tax incentives given to organizations working to develop renewable energy systems on their facilities. This resource was also not used because Calvin College is a tax-exempt institution. However, an architect/engineering firm can apply for a tax deduction for designing or building an energy saving building for a non-profit or government agency. This way the firm saves money on building Calvin's geothermal system and these savings can be partially passed on to Calvin College.

Results

Initial costs for both the geothermal and conventional HVAC systems are included in Table 2. This table highlights the high initial cost for geothermal. The next results were energy loads for each system, shown in Table F-3. As the table shows, geothermal is more efficient on an annual energy basis, and this is shown in Figure F-3, which shows cumulative energy costs under strong economic conditions. As the graph shows, although conventional HVAC requires more energy, the low cost of natural gas keeps the prices relatively close for about 20 years, before conventional HVAC becomes more expensive in terms of energy costs due to the projected decrease in electricity costs. Table F-4 shows maintenance costs for both systems. With all costs accounted for, a cumulative costs graph can compare both geothermal and conventional HVAC, shown in Figure F-4. As the graph shows, economic payback does not occur in the near future, indicating that a geothermal system is not a financially viable option. This is due to the relatively low natural gas prices, which deflate the energy costs for the conventional HVAC system. Compare this to Figure F-5, where natural gas prices start at $14/MMBtu, which is the all-time high price. In this case, payback occurs in approximately 20 years for a geothermal system. Tables F-5 through F-13 in the appendix outline annual energy and maintenance costs for each system at the different economic and natural gas conditions.

Conclusion

As Christians, we have a calling to be stewards of God's creation and money. In light of this, since there is no foreseeable financial payback for a geothermal system, the financial team recommends that a geothermal system not be constructed, and the existing campus HVAC infrastructure be expanded for the West Wing. In order for a geothermal system to be constructed, several scenarios must occur that would make a geothermal system more financially viable. The first of these scenarios would be that natural gas prices radically rise and stay at this very high price, thus creating a financially feasible situation for this geothermal construction. The second scenario where geothermal could be financially successful would be if a geothermal system for the entire campus is considered. Previous studies have shown that a campus wide system has a stronger economic performance than smaller systems intended for single buildings. Therefore, the financial team recommends that a geothermal not be constructed for the West Wing, until such time that either of the previously mentioned scenarios occur.

Appendix F-1: Tables and Figures

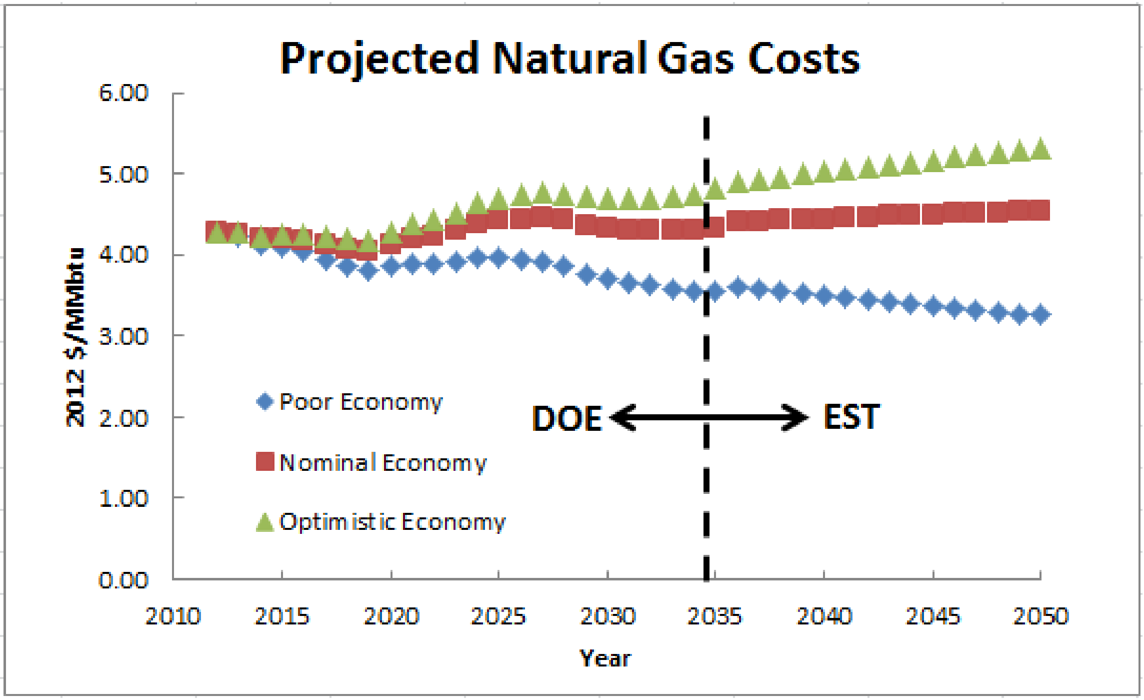

Figure F-1: Projected prices for natural gas until 2050. Data from US Department of Energy

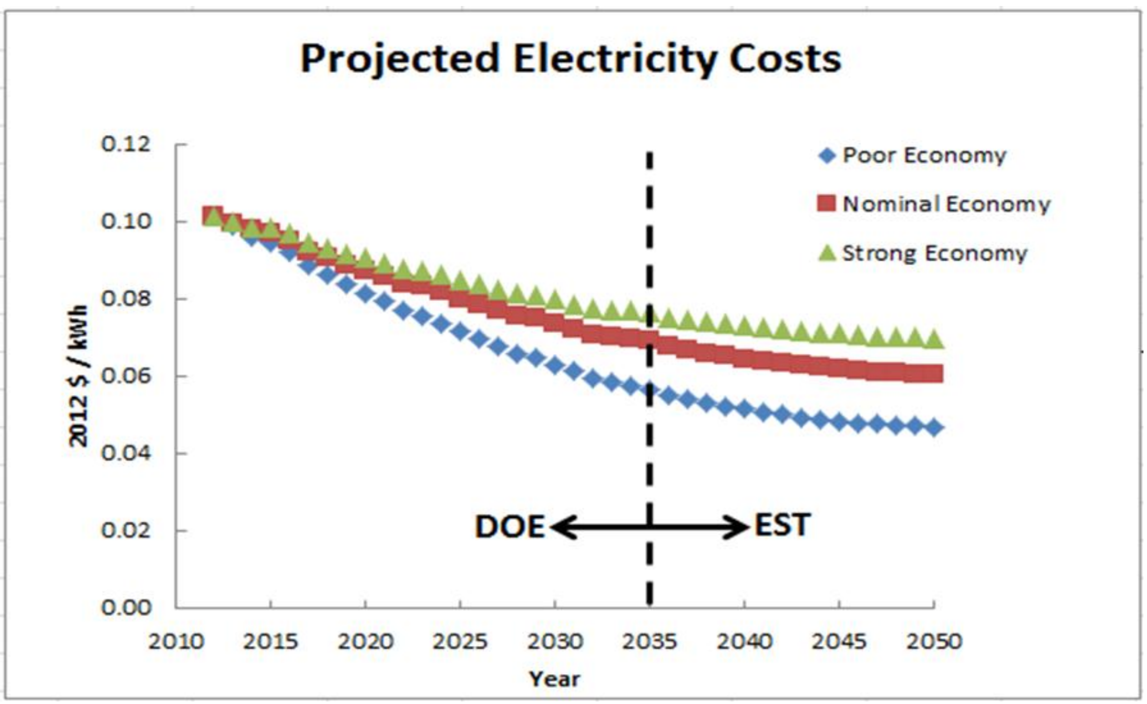

Figure F-2: Projected prices for electricity until 2050. Data from US Department of Energy

Table F-2: Inflation and interest rates for different economic conditions

Economy	Inflation (%)	Interest (%)
Strong	2.5	4.0
Nominal	4.0	6.0
Poor	7.0	10.0

Table F-3: Initial costs for conventional HVAC and geothermal systems

Conventional HVAC System	
Initial Costs	
Ductwork Cost	$ 53,806
Air Handler Cost	$ 150,000
Total Cost	$ 203,806
Geothermal System	
Initial Costs	
Building Size (ft^2)	56,150
Bore Field Cost	$ 478,720.00
Piping/Pumps Cost	$ 10,000.00
Heat Pump Cost	$ 1,240,000.00
Total Cost	$ 1,784,870.00

Table F-4: Energy loads and efficiencies for conventional HVAC and geothermal

Conventional HVAC Heating Eff.	80%
Conventional HVAC Cooling EER	10
Heating Load (MMBtu/yr)	7,316
Cooling Load (kWh/yr)	143,808
Energy per year (kWh/yr)	2,288,350
Geothermal Heating COP	3.68
Geothermal Cooling EER	21.39
Energy per year (kWh/yr)	562,040

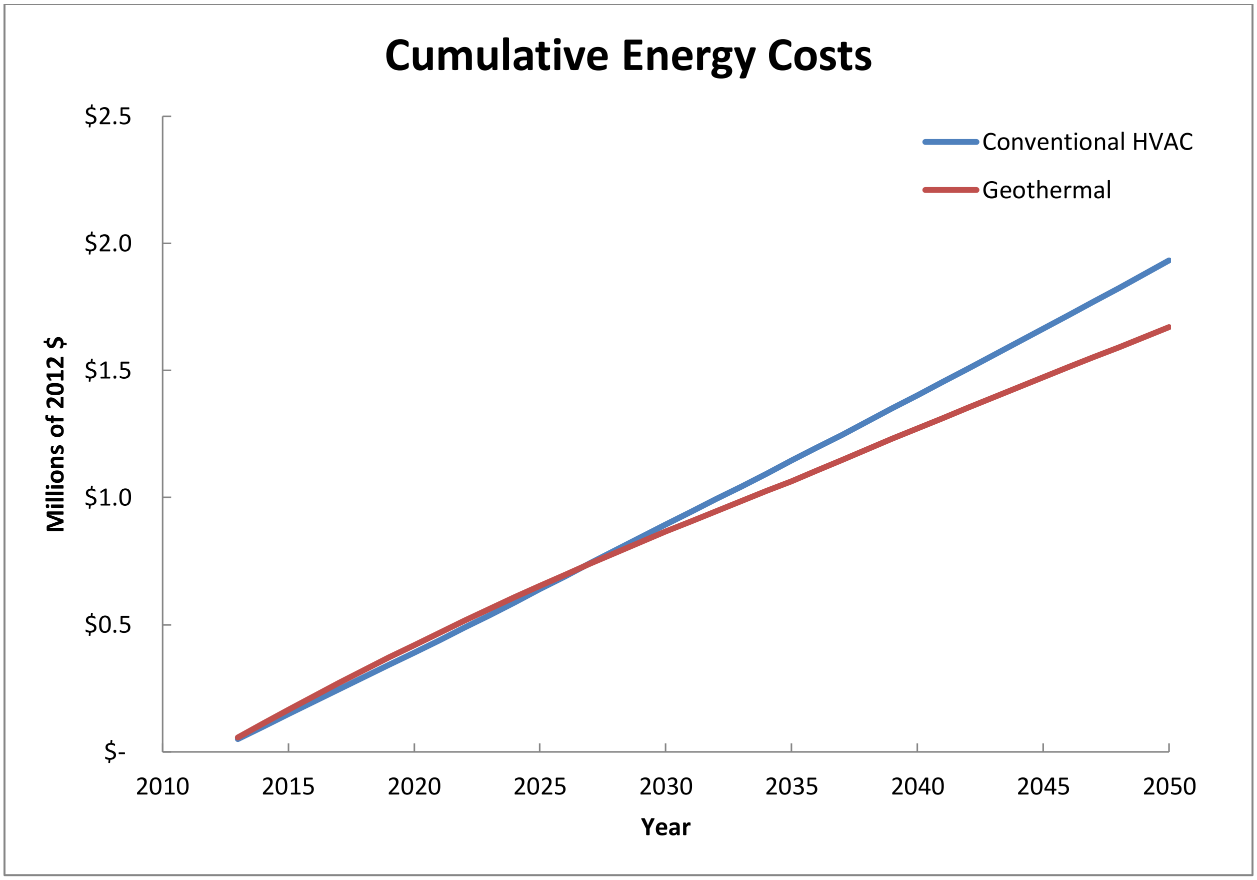

Figure F-3: Cumulative energy costs for conventional HVAC and geothermal system

Table F-5: Maintenance costs for conventional HVAC and geothermal

Conventional HVAC	
Annual Maintenance ($/yr)	15,000
Later Maintenance ($/yr)	22,500
Air Handler Replacement Cost ($)	150,000
Geothermal	
Annual Maintenance ($/yr)	9,000
Later Maintenance ($/yr)	13,500
Heat Pump Replacement Cost ($)	336,000

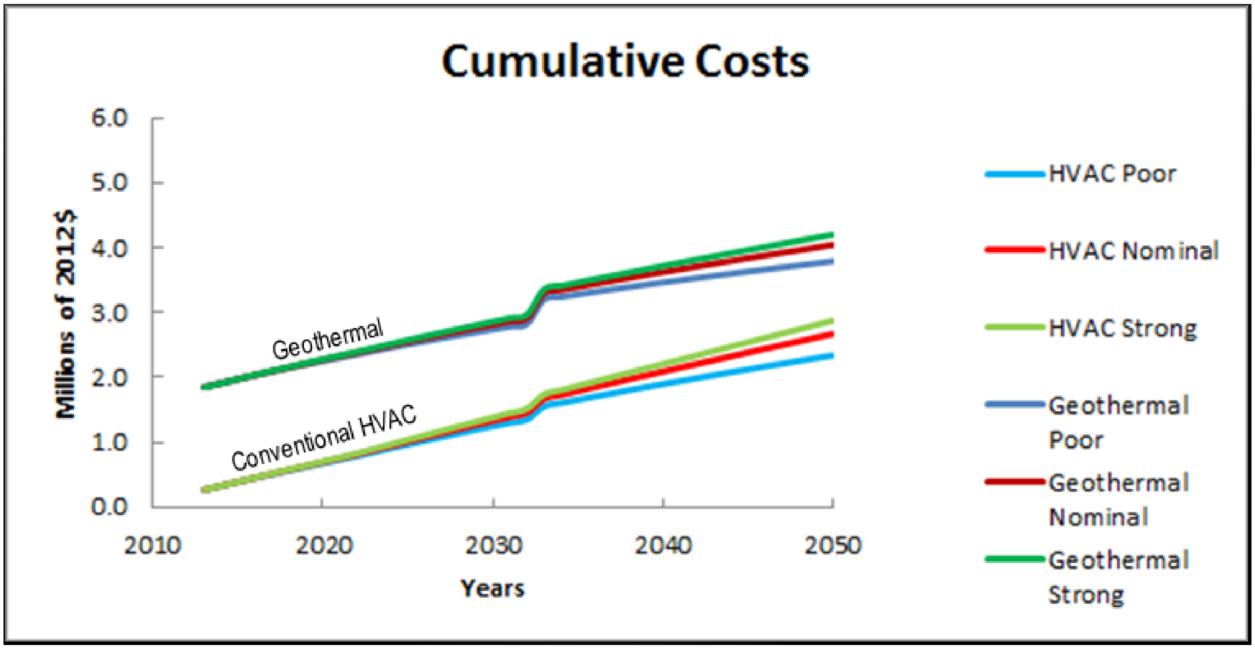

Figure F-4: Cumulative costs for both the conventional HVAC and geothermal systems

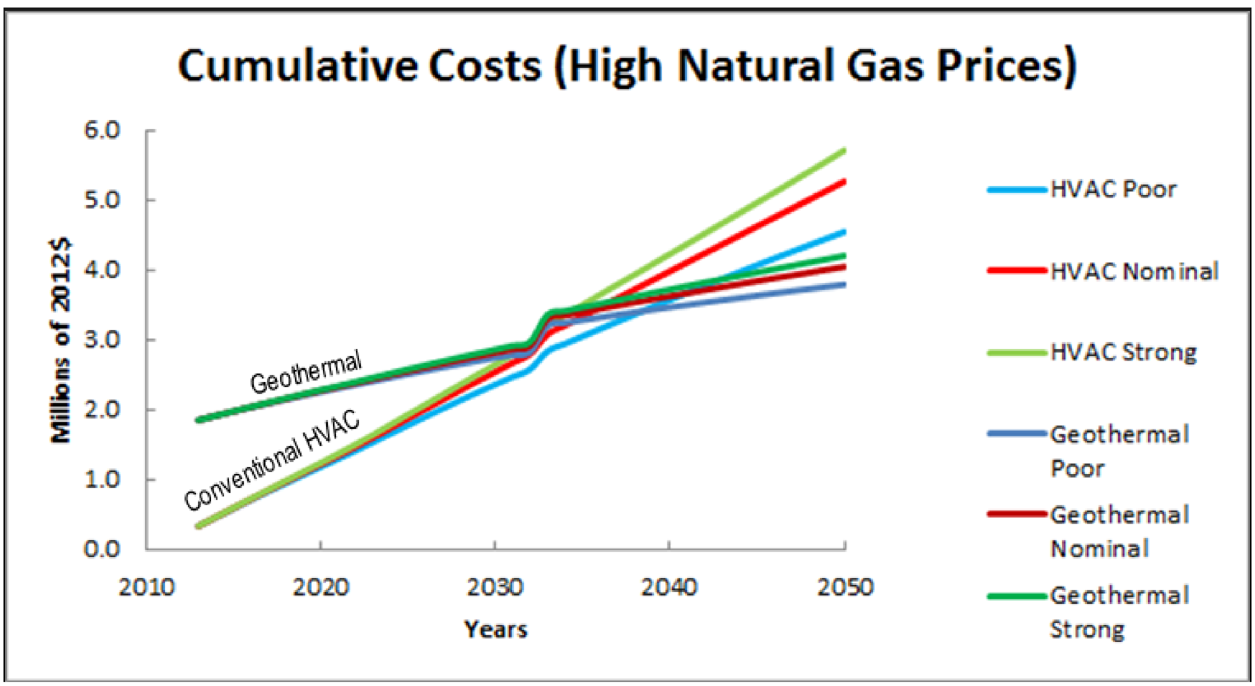

Figure F-5: Cumulative costs with high natural gas prices

Table F-6: Geothermal Operational and Maintenance costs under optimistic economy

Geothermal Present Value Costs - Optimistic Case				
Year	Electricity	Maintenance	Annual	Cumulative
2013	$ 56,209	$ 9,000	$ 65,209	$ 1,850,079
2014	$ 55,398	$ 8,870	$ 64,268	$ 1,914,347
2015	$ 55,168	$ 8,742	$ 63,910	$ 1,978,257
2016	$ 54,372	$ 8,616	$ 62,988	$ 2,041,245
2017	$ 53,035	$ 8,492	$ 61,527	$ 2,102,773
2018	$ 52,270	$ 8,369	$ 60,640	$ 2,163,412
2019	$ 51,517	$ 8,249	$ 59,765	$ 2,223,178
2020	$ 50,774	$ 8,130	$ 58,903	$ 2,282,081
2021	$ 50,041	$ 8,012	$ 58,054	$ 2,340,135
2022	$ 49,319	$ 7,897	$ 57,216	$ 2,397,351
2023	$ 49,114	$ 11,675	$ 60,789	$ 2,458,140
2024	$ 48,406	$ 11,506	$ 59,912	$ 2,518,052
2025	$ 47,708	$ 11,340	$ 59,048	$ 2,577,100
2026	$ 47,020	$ 11,177	$ 58,196	$ 2,635,297
2027	$ 46,342	$ 11,015	$ 57,357	$ 2,692,654
2028	$ 45,673	$ 10,857	$ 56,530	$ 2,749,184
2029	$ 45,479	$ 10,700	$ 56,179	$ 2,805,362
2030	$ 44,823	$ 10,546	$ 55,368	$ 2,860,731
2031	$ 44,176	$ 10,394	$ 54,570	$ 2,915,300
2032	$ 43,539	$ 10,244	$ 53,783	$ 2,969,083
2033	$ 43,349	$ 10,096	$ 389,445	$ 3,358,528
2034	$ 43,155	$ 9,950	$ 53,106	$ 3,411,633
2035	$ 42,958	$ 9,807	$ 52,765	$ 3,464,398
2036	$ 42,253	$ 9,665	$ 51,918	$ 3,516,316
2037	$ 41,896	$ 9,526	$ 51,422	$ 3,567,738
2038	$ 41,561	$ 9,389	$ 50,950	$ 3,618,688
2039	$ 41,248	$ 9,253	$ 50,501	$ 3,669,189
2040	$ 40,956	$ 9,120	$ 50,076	$ 3,719,265
2041	$ 40,686	$ 8,988	$ 49,674	$ 3,768,939
2042	$ 40,437	$ 8,858	$ 49,295	$ 3,818,234
2043	$ 40,210	$ 8,731	$ 48,940	$ 3,867,174
2044	$ 40,004	$ 8,605	$ 48,609	$ 3,915,783
2045	$ 39,819	$ 8,481	$ 48,300	$ 3,964,083
2046	$ 39,657	$ 8,358	$ 48,015	$ 4,012,098
2047	$ 39,515	$ 8,238	$ 47,753	$ 4,059,851
2048	$ 39,396	$ 8,119	$ 47,515	$ 4,107,366
2049	$ 39,297	$ 8,002	$ 47,299	$ 4,154,666
2050	$ 39,221	$ 7,886	$ 47,107	$ 4,201,773

Table F-7: Geothermal Operational and Maintenance Costs for nominal economy

Geothermal Present Value Costs - Nominal Case				
Year	Electricity	Maintenance	Annual	Cumulative
2013	$ 55,955	$ 9,000	$ 64,955	$ 1,849,825
2014	$ 54,899	$ 8,830	$ 63,730	$ 1,913,555
2015	$ 54,425	$ 8,664	$ 63,088	$ 1,976,643
2016	$ 53,398	$ 8,500	$ 61,898	$ 2,038,541
2017	$ 51,850	$ 8,340	$ 60,190	$ 2,098,731
2018	$ 50,872	$ 8,182	$ 59,054	$ 2,157,785
2019	$ 49,912	$ 8,028	$ 57,940	$ 2,215,726
2020	$ 48,970	$ 7,877	$ 56,847	$ 2,272,572
2021	$ 48,046	$ 7,728	$ 55,774	$ 2,328,347
2022	$ 47,140	$ 7,582	$ 54,722	$ 2,383,069
2023	$ 46,732	$ 11,159	$ 57,891	$ 2,440,959
2024	$ 45,850	$ 10,948	$ 56,798	$ 2,497,758
2025	$ 44,985	$ 10,741	$ 55,727	$ 2,553,485
2026	$ 44,137	$ 10,539	$ 54,675	$ 2,608,160
2027	$ 43,304	$ 10,340	$ 53,644	$ 2,661,804
2028	$ 42,487	$ 10,145	$ 52,632	$ 2,714,435
2029	$ 42,115	$ 9,953	$ 52,068	$ 2,766,504
2030	$ 41,320	$ 9,766	$ 51,086	$ 2,817,589
2031	$ 40,541	$ 9,581	$ 50,122	$ 2,867,711
2032	$ 39,776	$ 9,401	$ 49,176	$ 2,916,888
2033	$ 39,423	$ 9,223	$384,647	$ 3,301,534
2034	$ 39,070	$ 9,049	$ 48,119	$ 3,349,654
2035	$ 38,716	$ 8,878	$ 47,595	$ 3,397,249
2036	$ 37,950	$ 8,711	$ 46,661	$ 3,443,910
2037	$ 37,481	$ 8,547	$ 46,028	$ 3,489,938
2038	$ 37,039	$ 8,385	$ 45,425	$ 3,535,363
2039	$ 36,624	$ 8,227	$ 44,851	$ 3,580,214
2040	$ 36,235	$ 8,072	$ 44,307	$ 3,624,521
2041	$ 35,874	$ 7,920	$ 43,793	$ 3,668,314
2042	$ 35,539	$ 7,770	$ 43,309	$ 3,711,623
2043	$ 35,230	$ 7,624	$ 42,854	$ 3,754,477
2044	$ 34,949	$ 7,480	$ 42,428	$ 3,796,905
2045	$ 34,694	$ 7,339	$ 42,033	$ 3,838,938
2046	$ 34,466	$ 7,200	$ 41,666	$ 3,880,604
2047	$ 34,265	$ 7,064	$ 41,329	$ 3,921,933
2048	$ 34,090	$ 6,931	$ 41,021	$ 3,962,954
2049	$ 33,942	$ 6,800	$ 40,743	$ 4,003,697
2050	$ 33,821	$ 6,672	$ 40,493	$ 4,044,190

Table F-8: Geothermal Operational and Maintenance Costs for Poor Economy

Geothermal Present Value Costs - Pessimistic Case				
Year	Electricity	Maintenance	Annual	Cumulative
2013	$ 55,476	$ 9,000	$ 64,476	$ 1,849,346
2014	$ 53,963	$ 8,755	$ 62,717	$ 1,912,063
2015	$ 53,038	$ 8,516	$ 61,554	$ 1,973,617
2016	$ 51,592	$ 8,284	$ 59,875	$ 2,033,492
2017	$ 49,667	$ 8,058	$ 57,725	$ 2,091,217
2018	$ 48,313	$ 7,838	$ 56,150	$ 2,147,367
2019	$ 46,995	$ 7,624	$ 54,619	$ 2,201,986
2020	$ 45,713	$ 7,416	$ 53,129	$ 2,255,116
2021	$ 44,467	$ 7,214	$ 51,680	$ 2,306,796
2022	$ 43,254	$ 7,017	$ 50,271	$ 2,357,067
2023	$ 42,512	$ 10,239	$ 52,751	$ 2,409,818
2024	$ 41,353	$ 9,959	$ 51,312	$ 2,461,131
2025	$ 40,225	$ 9,688	$ 49,913	$ 2,511,044
2026	$ 39,128	$ 9,424	$ 48,552	$ 2,559,596
2027	$ 38,061	$ 9,167	$ 47,228	$ 2,606,823
2028	$ 37,023	$ 8,917	$ 45,940	$ 2,652,763
2029	$ 36,385	$ 8,673	$ 45,058	$ 2,697,821
2030	$ 35,392	$ 8,437	$ 43,829	$ 2,741,650
2031	$ 34,427	$ 8,207	$ 42,634	$ 2,784,284
2032	$ 33,488	$ 7,983	$ 41,471	$ 2,825,755
2033	$ 32,907	$ 7,765	$376,672	$ 3,202,427
2034	$ 32,333	$ 7,553	$ 39,886	$ 3,242,313
2035	$ 31,766	$ 7,347	$ 39,113	$ 3,281,427
2036	$ 30,973	$ 7,147	$ 38,120	$ 3,319,547
2037	$ 30,383	$ 6,952	$ 37,335	$ 3,356,882
2038	$ 29,833	$ 6,763	$ 36,596	$ 3,393,478
2039	$ 29,324	$ 6,578	$ 35,902	$ 3,429,380
2040	$ 28,854	$ 6,399	$ 35,253	$ 3,464,632
2041	$ 28,424	$ 6,224	$ 34,649	$ 3,499,281
2042	$ 28,035	$ 6,054	$ 34,089	$ 3,533,370
2043	$ 27,685	$ 5,889	$ 33,574	$ 3,566,945
2044	$ 27,376	$ 5,729	$ 33,104	$ 3,600,049
2045	$ 27,106	$ 5,572	$ 32,679	$ 3,632,728
2046	$ 26,877	$ 5,421	$ 32,297	$ 3,665,025
2047	$ 26,687	$ 5,273	$ 31,960	$ 3,696,985
2048	$ 26,538	$ 5,129	$ 31,667	$ 3,728,652
2049	$ 26,429	$ 4,989	$ 31,418	$ 3,760,070
2050	$ 26,360	$ 4,853	$ 31,213	$ 3,791,282

Table F-9: Conventional HVAC costs for optimistic economy

Conventional HVAC Present Value Costs - Optimistic Case					
Year	Gas	Electricity	Maintenance	Annual	Cumulative
2013	$ 35,333	$ 14,382	$ 15,000	$ 64,715	$ 268,521
2014	$ 34,903	$ 14,175	$ 14,784	$ 63,861	$ 332,382
2015	$ 35,088	$ 14,116	$ 14,570	$ 63,774	$ 396,156
2016	$ 35,126	$ 13,912	$ 14,360	$ 63,398	$ 459,554
2017	$ 34,813	$ 13,570	$ 14,153	$ 62,536	$ 522,091
2018	$ 34,631	$ 13,374	$ 13,949	$ 61,954	$ 584,045
2019	$ 34,578	$ 13,181	$ 13,748	$ 61,507	$ 645,552
2020	$ 35,338	$ 12,991	$ 13,550	$ 61,879	$ 707,431
2021	$ 36,107	$ 12,804	$ 13,354	$ 62,265	$ 769,696
2022	$ 36,635	$ 12,619	$ 13,162	$ 62,416	$ 832,111
2023	$ 37,344	$ 12,567	$ 19,458	$ 69,368	$ 901,480
2024	$ 38,255	$ 12,386	$ 19,177	$ 69,818	$ 971,298
2025	$ 38,855	$ 12,207	$ 18,900	$ 69,962	$ 1,041,260
2026	$ 39,107	$ 12,031	$ 18,628	$ 69,765	$ 1,111,025
2027	$ 39,419	$ 11,857	$ 18,359	$ 69,635	$ 1,180,660
2028	$ 39,295	$ 11,686	$ 18,094	$ 69,075	$ 1,249,736
2029	$ 38,955	$ 11,637	$ 17,833	$ 68,425	$ 1,318,161
2030	$ 38,706	$ 11,469	$ 17,576	$ 67,751	$ 1,385,912
2031	$ 38,716	$ 11,303	$ 17,323	$ 67,342	$ 1,453,254
2032	$ 38,887	$ 11,140	$ 17,073	$ 67,100	$ 1,520,354
2033	$ 39,016	$ 11,092	$ 16,826	$ 216,935	$ 1,737,289
2034	$ 39,236	$ 11,042	$ 16,584	$ 66,862	$ 1,804,150
2035	$ 39,766	$ 10,992	$ 16,345	$ 67,102	$ 1,871,252
2036	$ 40,406	$ 10,811	$ 16,109	$ 67,326	$ 1,938,578
2037	$ 40,654	$ 10,720	$ 15,877	$ 67,251	$ 2,005,829
2038	$ 40,903	$ 10,634	$ 15,648	$ 67,185	$ 2,073,014
2039	$ 41,152	$ 10,554	$ 15,422	$ 67,128	$ 2,140,142
2040	$ 41,401	$ 10,479	$ 15,199	$ 67,080	$ 2,207,222
2041	$ 41,650	$ 10,410	$ 14,980	$ 67,040	$ 2,274,261
2042	$ 41,898	$ 10,347	$ 14,764	$ 67,009	$ 2,341,270
2043	$ 42,147	$ 10,288	$ 14,551	$ 66,987	$ 2,408,257
2044	$ 42,396	$ 10,236	$ 14,341	$ 66,973	$ 2,475,230
2045	$ 42,645	$ 10,189	$ 14,134	$ 66,968	$ 2,542,197
2046	$ 42,893	$ 10,147	$ 13,931	$ 66,971	$ 2,609,168
2047	$ 43,142	$ 10,111	$ 13,730	$ 66,982	$ 2,676,150
2048	$ 43,391	$ 10,080	$ 13,532	$ 67,003	$ 2,743,153
2049	$ 43,640	$ 10,055	$ 13,336	$ 67,031	$ 2,810,184
2050	$ 43,888	$ 10,035	$ 13,144	$ 67,068	$ 2,877,252

Table F-10: Conventional HVAC costs for nominal economy

Conventional HVAC Present Value Costs - Nominal Case					
Year	Gas	Electricity	Maintenance	Annual	Cumulative
2013	$ 35,174	$ 14,317	$ 15,000	$ 64,491	$ 268,297
2014	$ 34,589	$ 14,047	$ 14,717	$ 63,353	$ 331,650
2015	$ 34,615	$ 13,926	$ 14,439	$ 62,980	$ 394,629
2016	$ 34,497	$ 13,663	$ 14,167	$ 62,326	$ 456,956
2017	$ 34,035	$ 13,267	$ 13,900	$ 61,202	$ 518,157
2018	$ 33,704	$ 13,017	$ 13,637	$ 60,358	$ 578,515
2019	$ 33,501	$ 12,771	$ 13,380	$ 59,652	$ 638,167
2020	$ 34,083	$ 12,530	$ 13,128	$ 59,741	$ 697,908
2021	$ 34,668	$ 12,294	$ 12,880	$ 59,841	$ 757,749
2022	$ 35,016	$ 12,062	$ 12,637	$ 59,714	$ 817,463
2023	$ 35,532	$ 11,957	$ 18,598	$ 66,087	$ 883,550
2024	$ 36,236	$ 11,732	$ 18,247	$ 66,214	$ 949,764
2025	$ 36,637	$ 11,510	$ 17,902	$ 66,050	$ 1,015,814
2026	$ 36,709	$ 11,293	$ 17,565	$ 65,566	$ 1,081,381
2027	$ 36,835	$ 11,080	$ 17,233	$ 65,148	$ 1,146,529
2028	$ 36,553	$ 10,871	$ 16,908	$ 64,332	$ 1,210,862
2029	$ 36,074	$ 10,776	$ 16,589	$ 63,439	$ 1,274,300
2030	$ 35,682	$ 10,573	$ 16,276	$ 62,531	$ 1,336,831
2031	$ 35,530	$ 10,373	$ 15,969	$ 61,872	$ 1,398,703
2032	$ 35,526	$ 10,177	$ 15,668	$ 61,371	$ 1,460,074
2033	$ 35,483	$ 10,087	$ 15,372	$ 210,943	$ 1,671,016
2034	$ 35,522	$ 9,997	$ 15,082	$ 60,601	$ 1,731,617
2035	$ 35,839	$ 9,906	$ 14,797	$ 60,543	$ 1,792,160
2036	$ 36,267	$ 9,710	$ 14,518	$ 60,495	$ 1,852,655
2037	$ 36,343	$ 9,590	$ 14,244	$ 60,178	$ 1,912,834
2038	$ 36,420	$ 9,477	$ 13,976	$ 59,873	$ 1,972,707
2039	$ 36,497	$ 9,371	$ 13,712	$ 59,580	$ 2,032,286
2040	$ 36,574	$ 9,272	$ 13,453	$ 59,299	$ 2,091,585
2041	$ 36,651	$ 9,179	$ 13,199	$ 59,029	$ 2,150,614
2042	$ 36,728	$ 9,093	$ 12,950	$ 58,771	$ 2,209,385
2043	$ 36,804	$ 9,014	$ 12,706	$ 58,525	$ 2,267,910
2044	$ 36,881	$ 8,942	$ 12,466	$ 58,290	$ 2,326,199
2045	$ 36,958	$ 8,877	$ 12,231	$ 58,066	$ 2,384,266
2046	$ 37,035	$ 8,819	$ 12,000	$ 57,854	$ 2,442,119
2047	$ 37,112	$ 8,767	$ 11,774	$ 57,653	$ 2,499,772
2048	$ 37,188	$ 8,723	$ 11,552	$ 57,463	$ 2,557,235
2049	$ 37,265	$ 8,685	$ 11,334	$ 57,284	$ 2,614,519
2050	$ 37,342	$ 8,654	$ 11,120	$ 57,116	$ 2,671,635

Table F-11: Conventional HVAC costs for poor economy

Conventional HVAC Present Value Costs - Pessimistic Case					
Year	Gas	Electricity	Maintenance	Annual	Cumulative
2013	$ 34,872	$ 14,195	$ 15,000	$ 64,067	$ 267,873
2014	$ 33,999	$ 13,807	$ 14,591	$ 62,397	$ 330,270
2015	$ 33,733	$ 13,571	$ 14,193	$ 61,497	$ 391,767
2016	$ 33,330	$ 13,201	$ 13,806	$ 60,336	$ 452,103
2017	$ 32,602	$ 12,708	$ 13,429	$ 58,740	$ 510,843
2018	$ 32,008	$ 12,362	$ 13,063	$ 57,433	$ 568,276
2019	$ 31,543	$ 12,025	$ 12,707	$ 56,274	$ 624,550
2020	$ 31,816	$ 11,697	$ 12,360	$ 55,873	$ 680,423
2021	$ 32,085	$ 11,378	$ 12,023	$ 55,485	$ 735,908
2022	$ 32,129	$ 11,067	$ 11,695	$ 54,892	$ 790,800
2023	$ 32,324	$ 10,878	$ 17,064	$ 60,266	$ 851,066
2024	$ 32,681	$ 10,581	$ 16,599	$ 59,861	$ 910,928
2025	$ 32,761	$ 10,292	$ 16,146	$ 59,199	$ 970,127
2026	$ 32,543	$ 10,012	$ 15,706	$ 58,261	$ 1,028,388
2027	$ 32,375	$ 9,739	$ 15,278	$ 57,392	$ 1,085,779
2028	$ 31,853	$ 9,473	$ 14,861	$ 56,187	$ 1,141,966
2029	$ 31,165	$ 9,310	$ 14,456	$ 54,931	$ 1,196,897
2030	$ 30,563	$ 9,056	$ 14,061	$ 53,680	$ 1,250,577
2031	$ 30,172	$ 8,809	$ 13,678	$ 52,659	$ 1,303,236
2032	$ 29,910	$ 8,569	$ 13,305	$ 51,784	$ 1,355,019
2033	$ 29,618	$ 8,420	$ 12,942	$ 200,980	$ 1,555,999
2034	$ 29,397	$ 8,273	$ 12,589	$ 50,259	$ 1,606,258
2035	$ 29,405	$ 8,128	$ 12,246	$ 49,779	$ 1,656,037
2036	$ 29,916	$ 7,925	$ 11,912	$ 49,753	$ 1,705,790
2037	$ 29,711	$ 7,774	$ 11,587	$ 49,072	$ 1,754,862
2038	$ 29,506	$ 7,633	$ 11,271	$ 48,411	$ 1,803,273
2039	$ 29,302	$ 7,503	$ 10,964	$ 47,768	$ 1,851,041
2040	$ 29,097	$ 7,383	$ 10,665	$ 47,144	$ 1,898,185
2041	$ 28,892	$ 7,273	$ 10,374	$ 46,538	$ 1,944,724
2042	$ 28,687	$ 7,173	$ 10,091	$ 45,951	$ 1,990,675
2043	$ 28,482	$ 7,084	$ 9,816	$ 45,381	$ 2,036,056
2044	$ 28,277	$ 7,005	$ 9,548	$ 44,830	$ 2,080,886
2045	$ 28,072	$ 6,936	$ 9,287	$ 44,296	$ 2,125,181
2046	$ 27,868	$ 6,877	$ 9,034	$ 43,779	$ 2,168,960
2047	$ 27,663	$ 6,828	$ 8,788	$ 43,279	$ 2,212,239
2048	$ 27,458	$ 6,790	$ 8,548	$ 42,796	$ 2,255,035
2049	$ 27,253	$ 6,762	$ 8,315	$ 42,330	$ 2,297,366
2050	$ 27,048	$ 6,745	$ 8,088	$ 41,881	$ 2,339,247

Table F-12: Conventional HVAC costs with high natural gas prices

Conventional HVAC Present Value Costs (High Nat. Gas)- Optimistic Case					
Year	Gas	Electricity	Maintenance	Annual	Cumulative
2013	$ 102,465	$ 14,382	$ 15,000	$ 131,847	$ 335,653
2014	$ 101,219	$ 14,175	$ 14,784	$ 130,177	$ 465,830
2015	$ 101,754	$ 14,116	$ 14,570	$ 130,440	$ 596,270
2016	$ 101,866	$ 13,912	$ 14,360	$ 130,138	$ 726,408
2017	$ 100,958	$ 13,570	$ 14,153	$ 128,681	$ 855,089
2018	$ 100,429	$ 13,374	$ 13,949	$ 127,752	$ 982,842
2019	$ 100,276	$ 13,181	$ 13,748	$ 127,205	$ 1,110,047
2020	$ 102,480	$ 12,991	$ 13,550	$ 129,021	$ 1,239,068
2021	$ 104,710	$ 12,804	$ 13,354	$ 130,868	$ 1,369,936
2022	$ 106,241	$ 12,619	$ 13,162	$ 132,022	$ 1,501,958
2023	$ 108,297	$ 12,567	$ 19,458	$ 140,321	$ 1,642,280
2024	$ 110,941	$ 12,386	$ 19,177	$ 142,503	$ 1,784,783
2025	$ 112,679	$ 12,207	$ 18,900	$ 143,786	$ 1,928,569
2026	$ 113,409	$ 12,031	$ 18,628	$ 144,068	$ 2,072,637
2027	$ 114,315	$ 11,857	$ 18,359	$ 144,532	$ 2,217,169
2028	$ 113,955	$ 11,686	$ 18,094	$ 143,736	$ 2,360,904
2029	$ 112,969	$ 11,637	$ 17,833	$ 142,439	$ 2,503,344
2030	$ 112,249	$ 11,469	$ 17,576	$ 141,293	$ 2,644,637
2031	$ 112,277	$ 11,303	$ 17,323	$ 140,903	$ 2,785,540
2032	$ 112,773	$ 11,140	$ 17,073	$ 140,986	$ 2,926,526
2033	$ 113,148	$ 11,092	$ 16,826	$ 291,066	$ 3,217,592
2034	$ 113,784	$ 11,042	$ 16,584	$ 141,410	$ 3,359,002
2035	$ 115,321	$ 10,992	$ 16,345	$ 142,657	$ 3,501,659
2036	$ 117,177	$ 10,811	$ 16,109	$ 144,097	$ 3,645,756
2037	$ 117,898	$ 10,720	$ 15,877	$ 144,494	$ 3,790,250
2038	$ 118,619	$ 10,634	$ 15,648	$ 144,901	$ 3,935,151
2039	$ 119,341	$ 10,554	$ 15,422	$ 145,317	$ 4,080,468
2040	$ 120,062	$ 10,479	$ 15,199	$ 145,741	$ 4,226,209
2041	$ 120,784	$ 10,410	$ 14,980	$ 146,174	$ 4,372,383
2042	$ 121,505	$ 10,347	$ 14,764	$ 146,616	$ 4,518,998
2043	$ 122,226	$ 10,288	$ 14,551	$ 147,066	$ 4,666,064
2044	$ 122,948	$ 10,236	$ 14,341	$ 147,525	$ 4,813,589
2045	$ 123,669	$ 10,189	$ 14,134	$ 147,992	$ 4,961,581
2046	$ 124,390	$ 10,147	$ 13,931	$ 148,468	$ 5,110,049
2047	$ 125,112	$ 10,111	$ 13,730	$ 148,952	$ 5,259,001
2048	$ 125,833	$ 10,080	$ 13,532	$ 149,445	$ 5,408,447
2049	$ 126,555	$ 10,055	$ 13,336	$ 149,946	$ 5,558,393
2050	$ 127,276	$ 10,035	$ 13,144	$ 150,456	$ 5,708,848

Table F-13: Conventional HVAC costs with high natural gas prices

Conventional HVAC Present Value Costs (High Nat. Gas)- Nominal Case					
Year	Gas	Electricity	Maintenance	Annual	Cumulative
2013	$ 102,003	$ 14,317	$ 15,000	$ 131,320	$ 335,126
2014	$ 100,308	$ 14,047	$ 14,717	$ 129,072	$ 464,198
2015	$ 100,383	$ 13,926	$ 14,439	$ 128,748	$ 592,946
2016	$ 100,040	$ 13,663	$ 14,167	$ 127,870	$ 720,816
2017	$ 98,702	$ 13,267	$ 13,900	$ 125,868	$ 846,685
2018	$ 97,742	$ 13,017	$ 13,637	$ 124,396	$ 971,080
2019	$ 97,153	$ 12,771	$ 13,380	$ 123,304	$ 1,094,384
2020	$ 98,841	$ 12,530	$ 13,128	$ 124,498	$ 1,218,882
2021	$ 100,536	$ 12,294	$ 12,880	$ 125,709	$ 1,344,592
2022	$ 101,546	$ 12,062	$ 12,637	$ 126,244	$ 1,470,836
2023	$ 103,044	$ 11,957	$ 18,598	$ 133,599	$ 1,604,435
2024	$ 105,084	$ 11,732	$ 18,247	$ 135,062	$ 1,739,497
2025	$ 106,249	$ 11,510	$ 17,902	$ 135,661	$ 1,875,158
2026	$ 106,455	$ 11,293	$ 17,565	$ 135,313	$ 2,010,471
2027	$ 106,821	$ 11,080	$ 17,233	$ 135,135	$ 2,145,606
2028	$ 106,004	$ 10,871	$ 16,908	$ 133,784	$ 2,279,389
2029	$ 104,614	$ 10,776	$ 16,589	$ 131,979	$ 2,411,368
2030	$ 103,478	$ 10,573	$ 16,276	$ 130,326	$ 2,541,694
2031	$ 103,037	$ 10,373	$ 15,969	$ 129,379	$ 2,671,073
2032	$ 103,025	$ 10,177	$ 15,668	$ 128,870	$ 2,799,944
2033	$ 102,902	$ 10,087	$ 15,372	$ 278,361	$ 3,078,305
2034	$ 103,014	$ 9,997	$ 15,082	$ 128,093	$ 3,206,397
2035	$ 103,934	$ 9,906	$ 14,797	$ 128,638	$ 3,335,035
2036	$ 105,173	$ 9,710	$ 14,518	$ 129,402	$ 3,464,437
2037	$ 117,898	$ 9,590	$ 14,244	$ 141,733	$ 3,606,169
2038	$ 118,619	$ 9,477	$ 13,976	$ 142,072	$ 3,748,241
2039	$ 119,341	$ 9,371	$ 13,712	$ 142,424	$ 3,890,665
2040	$ 120,062	$ 9,272	$ 13,453	$ 142,787	$ 4,033,452
2041	$ 120,784	$ 9,179	$ 13,199	$ 143,162	$ 4,176,614
2042	$ 121,505	$ 9,093	$ 12,950	$ 143,548	$ 4,320,162
2043	$ 122,226	$ 9,014	$ 12,706	$ 143,947	$ 4,464,109
2044	$ 122,948	$ 8,942	$ 12,466	$ 144,356	$ 4,608,465
2045	$ 123,669	$ 8,877	$ 12,231	$ 144,777	$ 4,753,242
2046	$ 124,390	$ 8,819	$ 12,000	$ 145,209	$ 4,898,452
2047	$ 125,112	$ 8,767	$ 11,774	$ 145,653	$ 5,044,105
2048	$ 125,833	$ 8,723	$ 11,552	$ 146,107	$ 5,190,212
2049	$ 126,555	$ 8,685	$ 11,334	$ 146,573	$ 5,336,785
2050	$ 127,276	$ 8,654	$ 11,120	$ 147,050	$ 5,483,835

Table F-14: Conventional HVAC costs with high natural gas prices

Conventional HVAC Present Value Costs (High Nat. Gas)- Pessimistic Case					
Year	Gas	Electricity	Maintenance	Annual	Cumulative
2013	$ 101,129	$ 14,195	$ 15,000	$ 130,324	$ 334,130
2014	$ 98,597	$ 13,807	$ 14,591	$ 126,995	$ 461,125
2015	$ 97,826	$ 13,571	$ 14,193	$ 125,589	$ 586,714
2016	$ 96,656	$ 13,201	$ 13,806	$ 123,663	$ 710,377
2017	$ 94,546	$ 12,708	$ 13,429	$ 120,684	$ 831,061
2018	$ 92,824	$ 12,362	$ 13,063	$ 118,249	$ 949,310
2019	$ 91,475	$ 12,025	$ 12,707	$ 116,206	$ 1,065,515
2020	$ 92,267	$ 11,697	$ 12,360	$ 116,324	$ 1,181,839
2021	$ 93,045	$ 11,378	$ 12,023	$ 116,446	$ 1,298,285
2022	$ 93,175	$ 11,067	$ 11,695	$ 115,937	$ 1,414,222
2023	$ 93,740	$ 10,878	$ 17,064	$ 121,682	$ 1,535,904
2024	$ 94,776	$ 10,581	$ 16,599	$ 121,956	$ 1,657,860
2025	$ 95,006	$ 10,292	$ 16,146	$ 121,445	$ 1,779,305
2026	$ 94,375	$ 10,012	$ 15,706	$ 120,093	$ 1,899,397
2027	$ 93,889	$ 9,739	$ 15,278	$ 118,905	$ 2,018,302
2028	$ 92,372	$ 9,473	$ 14,861	$ 116,706	$ 2,135,009
2029	$ 90,380	$ 9,310	$ 14,456	$ 114,145	$ 2,249,154
2030	$ 88,632	$ 9,056	$ 14,061	$ 111,749	$ 2,360,903
2031	$ 87,499	$ 8,809	$ 13,678	$ 109,986	$ 2,470,889
2032	$ 86,739	$ 8,569	$ 13,305	$ 108,613	$ 2,579,501
2033	$ 85,893	$ 8,420	$ 12,942	$ 257,255	$ 2,836,757
2034	$ 85,250	$ 8,273	$ 12,589	$ 106,112	$ 2,942,869
2035	$ 85,275	$ 8,128	$ 12,246	$ 105,648	$ 3,048,517
2036	$ 86,757	$ 7,925	$ 11,912	$ 106,594	$ 3,155,111
2037	$ 86,163	$ 7,774	$ 11,587	$ 105,524	$ 3,260,634
2038	$ 85,569	$ 7,633	$ 11,271	$ 104,473	$ 3,365,108
2039	$ 84,975	$ 7,503	$ 10,964	$ 103,441	$ 3,468,549
2040	$ 84,381	$ 7,383	$ 10,665	$ 102,428	$ 3,570,976
2041	$ 83,786	$ 7,273	$ 10,374	$ 101,433	$ 3,672,409
2042	$ 83,192	$ 7,173	$ 10,091	$ 100,456	$ 3,772,866
2043	$ 82,598	$ 7,084	$ 9,816	$ 99,498	$ 3,872,363
2044	$ 82,004	$ 7,005	$ 9,548	$ 98,557	$ 3,970,920
2045	$ 81,410	$ 6,936	$ 9,287	$ 97,633	$ 4,068,553
2046	$ 80,816	$ 6,877	$ 9,034	$ 96,727	$ 4,165,280
2047	$ 80,222	$ 6,828	$ 8,788	$ 95,838	$ 4,261,119
2048	$ 79,628	$ 6,790	$ 8,548	$ 94,966	$ 4,356,085
2049	$ 79,034	$ 6,762	$ 8,315	$ 94,111	$ 4,450,196
2050	$ 78,440	$ 6,745	$ 8,088	$ 93,273	$ 4,543,468