Final Report

Mechanical Project Final Report

04/04/2012

New Castle Center for Delaware Hospice, Inc.

Image By: Skanska

New Castle, DE

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Architectural Engineering

Advisor: Professor Bahnfleth

Mechanical Option

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DE Hospice

New Castle, DE

Project information:

Size:	65,000 SF
Stories:	2
Delivery Method:	GMP, CM at risk

Project Team:

Owner:	Delaware Hospice
Architecture:	Reese, Lower, Patrick & Scoot
Construction Manager:	Skanska
MEP Engineering:	Reese Engineeering
Civil Engineering:	Landmark Engineering
Landscape Architect:	Rummler Associates

Structural:

- CMU and concrete footers
- concrete basement walls
- floors 1&2 metal studs
- Hollow structural section columns, I beams

-Slab on grade and metal deck with concrete

- Wood Truss Roof

Architecture:

-aluminum curtain wall systems with manufactured stone for the lower part of the exterior wall for the first floor and manufactured stone for some exterior walls. The manufactured stone is also used chimney on the East side . The building is topped with gable roof and cupolas. Windows are clad wood windows with louvers for shading.

Mechanical Systems:

-180 MBH water to water geothermal heat pump

- Two energy recovery units, one at 1,555 CFM supply air and the other one at 1825 CFM

-Three water to air geothermal ventilation heat pumps at 1,250, 2,140, and 2,265 CFM

-Many water to air geothermal heat pumps inline water to water geothermal heat pump and either energy recovery unit, ventilation heat pump, or straight outside air

Electrical/Lighting

-2,000 A, 480/277V, 3-Phase, 4-wire Mmain distribution center, rated for 65, AIC

- 500KW, 480/277V, 3 phase, 4 wire, 30 hr diesel generator

-Many dry-type transformer from 3KVA to 500KVA, 480V, 208V, 15A to 750A 3 phase

- Mostly fluorescent lamps automatic in ceiling

Zachary Klixbull

Mechanical Option

CPEP SITE: http://www.engr.psu.edu/ae/thesis/portfolios/2012/zpk104/index.html

Building Overview and Existing Condition

Background

New Castle Center for Delaware Hospice is a two story building at 65,000 SF. DE Hospice is a medical building with long term patients and administration building for the hospice's support and services to the patient and the patient's family. (Throughout the report New Castle Center for Delaware Hospice may show as DE Hospice to shorten the name). The DE Hospice is divided into two buildings connected by a Lobby area. Building A is a one story building with the main entrance and patient area facilities for the DE Hospice. The support services and administration are in the two story building B. Building A has patient rooms open to an outside patio and a courtyard for the inner patient rooms. DE Hospice has aluminum curtain wall systems with manufactured stone for the lower part of the exterior wall for the first floor and manufactured stone for some exterior walls. The manufactured stone is also used chimney on the East side of building B. The building is topped with asphalt shingles on the gable roof and cupolas. Windows are cladwood windows with louvers for shading.

Existing Mechanical System

The DE Hospice has a geothermal based mechanical cooling and heating system. The geothermal wells are under the east parking lot and in to the mechanical room in the basement. Then it is piped up to the attic where heat pumps and energy recovery units are. The water to water geothermal heat pump exchanges the energy from 20% glycol source to the R410A refrigerant in the heat pumps that are supplied by the water to water geothermal heat pump. The refrigerant goes to heat pump units throughout the attic and the three ventilation heat pumps. The mechanical system does use two energy recover units that are located in the attic with the heat pumps. There are eight mechanical rooms in the attic. One mechanical room in the attic is not in line with an energy recovery unit or ventilation heat pump unit, it receives outside air directly to a regular heat pump. (see ASHRAE Standard 62.1-2007 section 6 and appendix for more information on the mechanical ventilation)

Overall Mechanical System

The building types are split into hospice and low-rise office buildings with geothermal design for heating and cooling loads. The geothermal system has saved a lot of energy on the heating load. It has all so has saved energy on the cooling load. With the geothermal systems can be must commonly compare to a boiler and cooling tower. The geothermal saves on space compared to the boiler and cooling tower. Supply fans and lighting has most of the energy consumed at about 60% of the annual total. This would be the area to look into finding improvement in energy consumption. The building is in good shape to receive LEED accreditation based on "Energy and Atmosphere", "Indoor Environmental Quality" and working with the Delaware Hospice building the past three technical reports.

ASHRAE Standard 90.1 Energy Design

The DE Hospice does well for ASHREA Standards 90.1 until the supply air fans HP is overall to low for section 6 of analysis (table 4), it doesn't comply. DE Hospice does comply with all other sections of ASHREA Standards 90.1.

Building and Plant Energy

The building types are split into hospice and low-rise office buildings. After review of report this report and results of Trane Trace 700 modeling program, the data since to be skew to a cooling load profile and less of a heating load profile, which is typical in North America. My setting in Trane Trace 700 is off, farther view and reading is need to find the mistake in the trace modeling programs setting.

Mechanical Redesign Overview

The redesign of DE Hospice mechanical system will look at changing a full ground source heat pump system to a hybrid ground source heat pump system. By changing the mechanical system to a hybrid system the system will become more cost effective. In the HyGSHP (hybrid ground source heat pump system) will include cooling tower, boiler, reducing the size of ground heat exchanger, reducing size of pumps, finding an optimal control over new system and solar shingles to keep Leed rating. Hybrid system does not sacrifice environmental benefits because the boiler and cooling tower operates a part-load.

Site

Table 1 shows Geotechnical data collected showed for a 400 feet loop length bore at De, Hospice's site. In Image 1 is the location of De, Hospice.

Results of ground for geothermal wells	
Thermal Conductivity	2.14 Btu/(h*ft*F)
Estimated Thermal Diffusivity	1.38 ft^2 per day
Average Heat Flux	14.8 Watts/foot
Calculation Interval	0.0-40.0 Hours
Assumed Rock Specific Heat-Dry	0.22 Btu/(F*lbm)
Assumed Rock Density Dry (pcf)	160.0
Moisture (0-100%)	5.00%

Table1: Geotechnical data collection

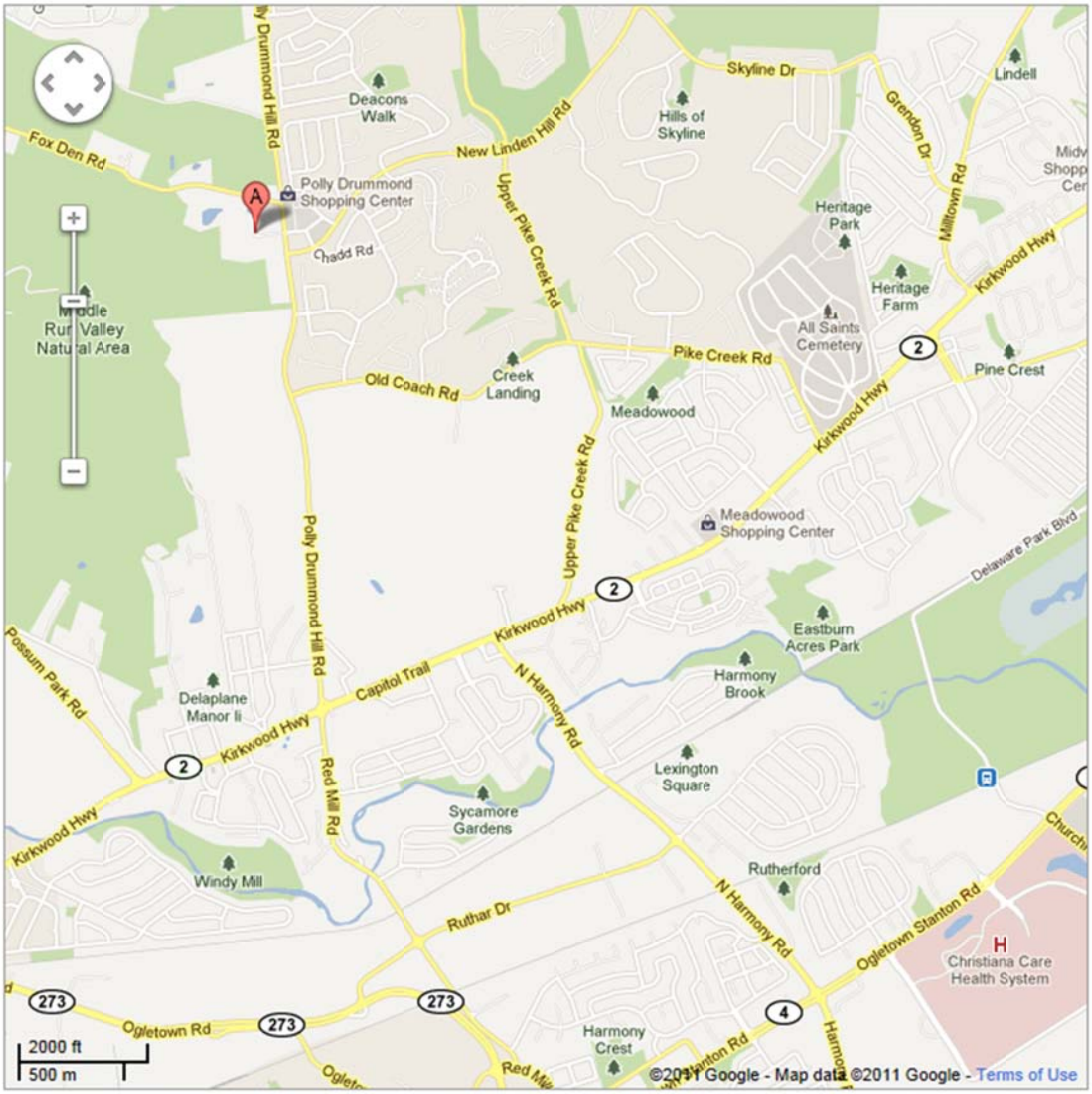

Image 1: A is the location of site, Image by maps.google.com

Calculations

Calculating for number and length of bore I used Ground-Source Heat Pumps: Design of Geothermal System for Commercial and Institutional Buildings by StephenP. Kavanaugh and Kevin Rafferty .Also used Chapter 32 of the 2007 ASHRAE Handbook-HVAC Applications. Equation is located in Appendix A.

In Figure 1 and 2, below, are my Geothermal Vertical Ground Loop Design spreadsheets. Figure 1 is the calculation for the building for cooling load. Figure 2 is calculation for the building for heating. The whole building was used for this calculation. The parameter put in to the spreadsheet was from DE Hospice drawings, and specifications (Geotechnical report was in the specifications). I used the load calculations from last year’s Trane Trace model.

Geothermal Vertical Ground Loop Design

INPUT DATA		
Short-circuit heat loss factor	1.02	
Building design Cooling block load	1060800	BTU
	88.4	Ton
Building design heating block load	-266785.3	BTU
Thermal Resistance of bore	0.4672897	BTU/(F*lbm)
Undisturbed ground temperature	57.2	F
Temperature penalty for interfernce of adjacent bore	0.7694444	
Liquid temperature at heat pump inlet (cooling)	85	F
Liquid temperature at heat pump outlet (cooling)	95	F
Liquid temperature at heat pump inlet (Heating)	54	F
Liquid temperature at heat pump outlet (Heating)	44	F
power input at design cooling load	14412.096	W
power input at design heating load	-1461.0934	W
Heat pump correction factors		
Thermal diffusivity	1.38	FT^2/Day
Diameter of bore	0.5	ft
Time	3681	hr

G-factor	0.9	
bore separation distance	20	ft

Calculation

required bore length for cooling	-30489.454	ft
required bores @450 ft for cooling	-67.754342	
required bore length for heating	7836.7895	ft
required bores @ 450 ft for heating	17.415088	
Fo	81276.48	
effective thermal resistance of the ground, annual pulse	0.25	h*ft*F/Btu
effective thermal resistance of the ground, daily pulse	0.19	h*ft*F/Btu
effective thermal resistance of the ground, monthly pulse	0.31	h*ft*F/Btu
Part-load Factor during design month (cooling)	0.3207827	
Part-load Factor during design month (heating)	0.20996	
Net annual average heat transfer to the ground	362.30682	Btu/h
Ground Loop Heat Exchanger Length	-344.90332	ft/Ton
EER	14.07	
COP	4	
SEER	14.7735	

Figure 1: calculation for the building for cooling load

INPUT DATA

Short-circuit heat loss factor	1.02	
Building design Cooling block load	1060800	BTU
	88.4	Ton
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Thermal Resistance of bore	0.4672897	BTU/(F*lbm)
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Heat pump correction factors		
Thermal diffusivity	1.38	FT^2/Day
Diameter of bore	0.5	ft
Time	3681	hr
G-factor	0.9	
bore separation distance	20	ft

Calculation

required bore length for cooling	9057.9775	ft
required bores @450 ft for cooling	20.128839	
required bore length for heating	7836.7895	ft
required bores @ 450 ft for heating	17.415088	
Fo	81276.48	
effective thermal resistance of the ground, annual pulse	0.25	h*ft*F/Btu
effective thermal resistance of the ground, daily pulse	0.19	h*ft*F/Btu
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Part-load Factor during design month (cooling)	0.3207827	
Part-load Factor during design month (heating)	0.20996	
Net annual average heat transfer to the ground	362.30682	Btu/h
Ground Loop Heat Exchanger Length	102.46581	ft/Ton

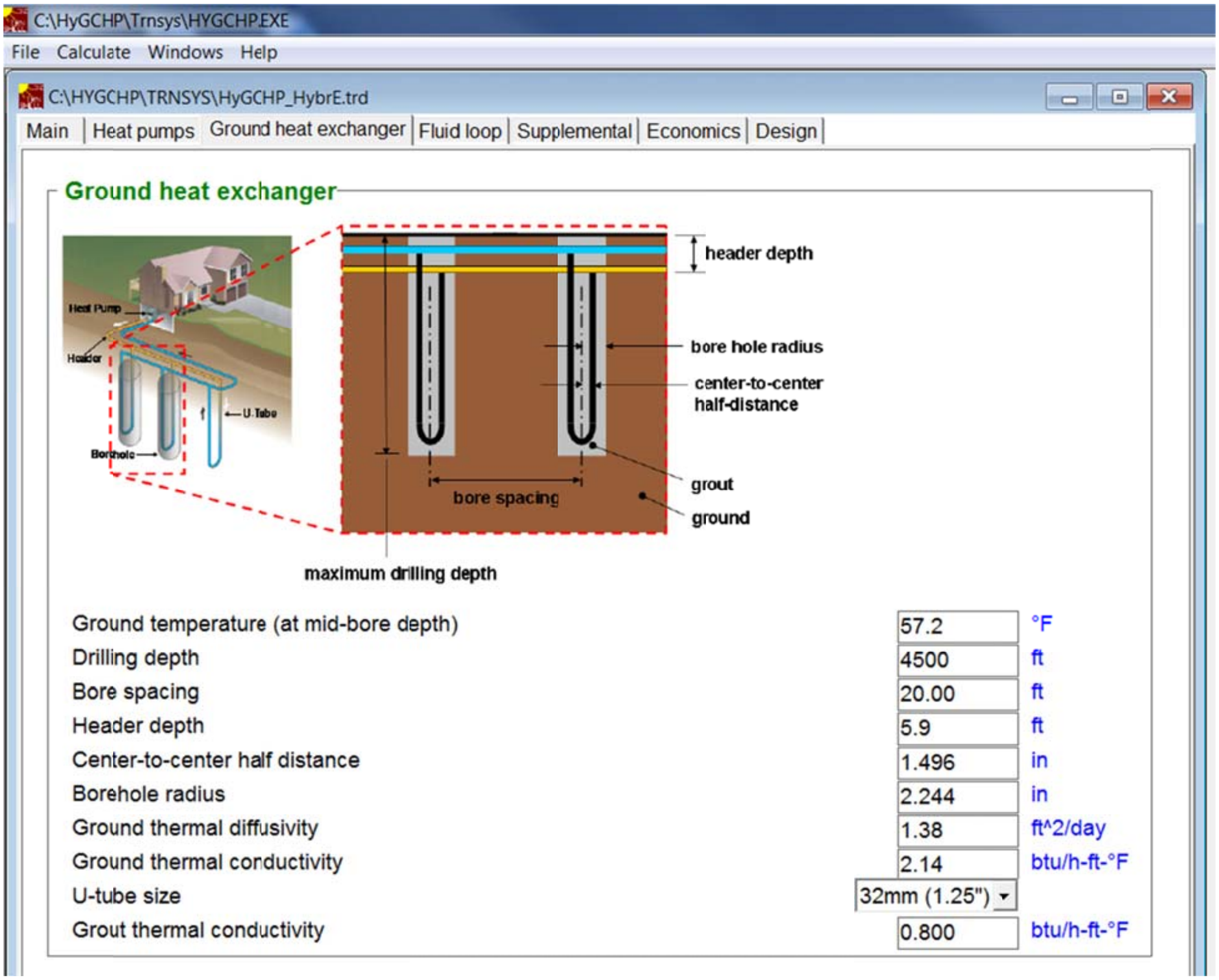
EER	14.07
COP	4
SEER	14.7735

Figure 2: calculation for the building for heating

I used HyGCHP software from Energy Center of Wisconsin for life cycle cost, equipment cost, operation cost, energy consumed and other data. I used data from Trace 700, and my Geothermal Vertical Ground Loop Design spreadsheets. In figure 3, below, I show my ground heat exchanger properties, which is used with all systems considered. Figure 4, following, are my economics data and parameters, which is used with all systems considered. I ran simulation for the orginal design (Ground Heat Exchanger only) frist. Figure 5 shows parameters and diagram. Figure 6 show the temperture of ground heat exchanger (blue) and entering water temperture to the heat pump (red) for a year. Figure 7 are the results for cycle cost, equipment cost, operation cost, energy consumed and other data.

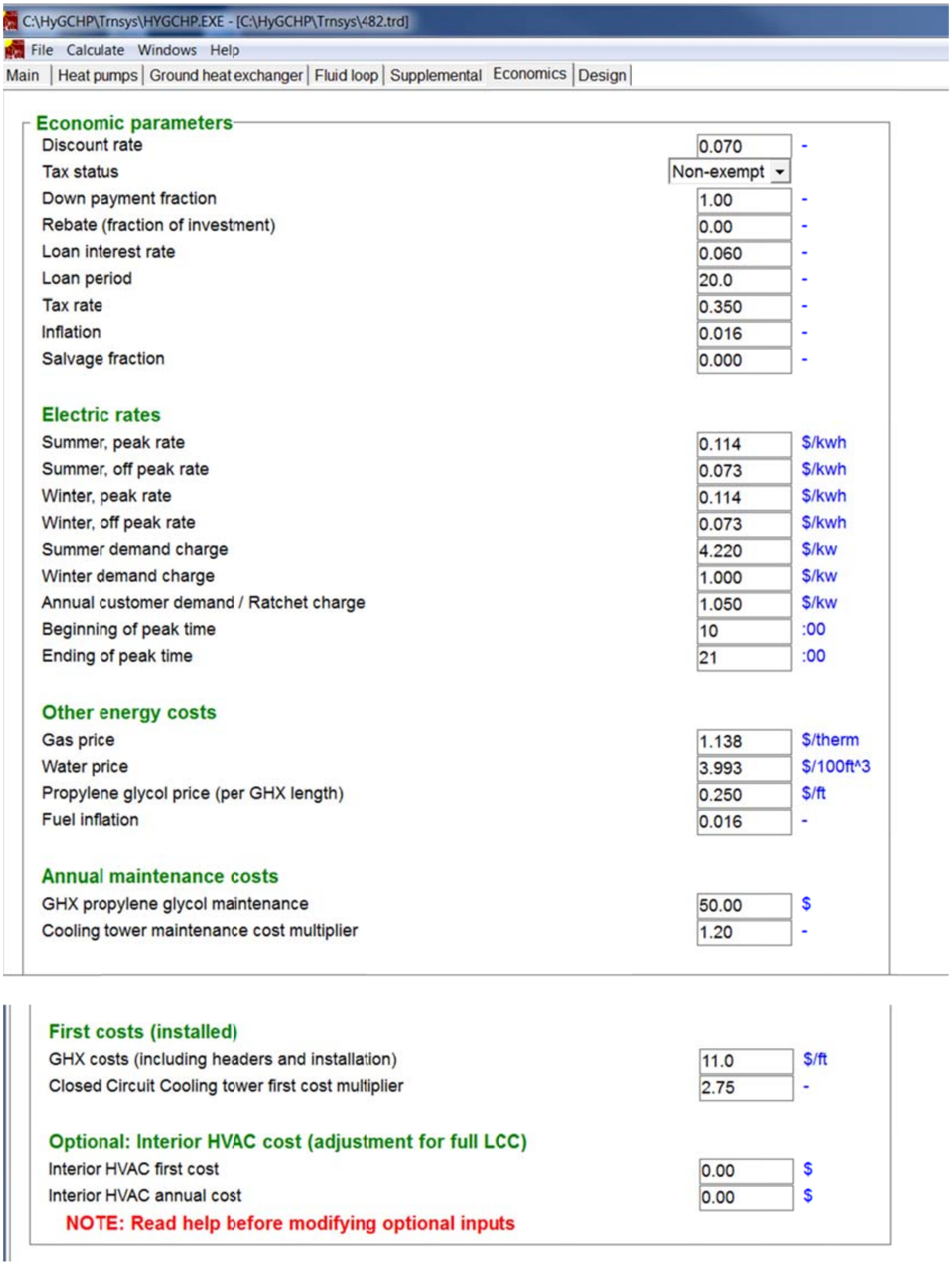
I then ran a optimal calculation with HyGCHP software and put the results in to tha simulation . Figure 8 shows parameters and diagram of Hybrid geothermal system. Figure 9 show the temperture of ground heat exchanger (blue), cooling tower (purple) and entering water temperture to the heat pump (red) for a year. Figure 10 are the results for cycle cost, equipment cost, operation cost, energy consumed and other data.

Last I ran an optimal calculation for cooling tower and boiler and put the data into the simulation Figure 11 show the tempertures of cooling tower (purple) and entering water temperture to the heat pump (red) for a year. Figure 1123 are the results for cycle cost, equipment cost, operation cost, energy consumed and other data.



Ground temperature (at mid-bore depth)	57.2	°F
Drilling depth	4500	ft
Bore spacing	20.00	ft
Header depth	5.9	ft
Center-to-center half distance	1.496	in
Borehole radius	2.244	in
Ground thermal diffusivity	1.38	ft^2/day
Ground thermal conductivity	2.14	btu/h-ft-°F
U-tube size	32mm (1.25")	
Grout thermal conductivity	0.800	btu/h-ft-°F

Figure 3: ground heat exchanger properties



Economic parameters

Discount rate	0.070	-
Tax status	Non-exempt	
Down payment fraction	1.00	-
Rebate (fraction of investment)	0.00	-
Loan interest rate	0.060	-
Loan period	20.0	-
Tax rate	0.350	-
Inflation	0.016	-
Salvage fraction	0.000	-

Electric rates

Summer, peak rate	0.114	$/kwh
Summer, off peak rate	0.073	$/kwh
Winter, peak rate	0.114	$/kwh
Winter, off peak rate	0.073	$/kwh
Summer demand charge	4.220	$/kw
Winter demand charge	1.000	$/kw
Annual customer demand / Ratchet charge	1.050	$/kw
Beginning of peak time	10	:00
Ending of peak time	21	:00

Other energy costs

Gas price	1.138	$/therm
Water price	3.993	$/100ft^3
Propylene glycol price (per GHX length)	0.250	$/ft
Fuel inflation	0.016	-

Annual maintenance costs

GHX propylene glycol maintenance	50.00	$
Cooling tower maintenance cost multiplier	1.20	-

First costs (installed)

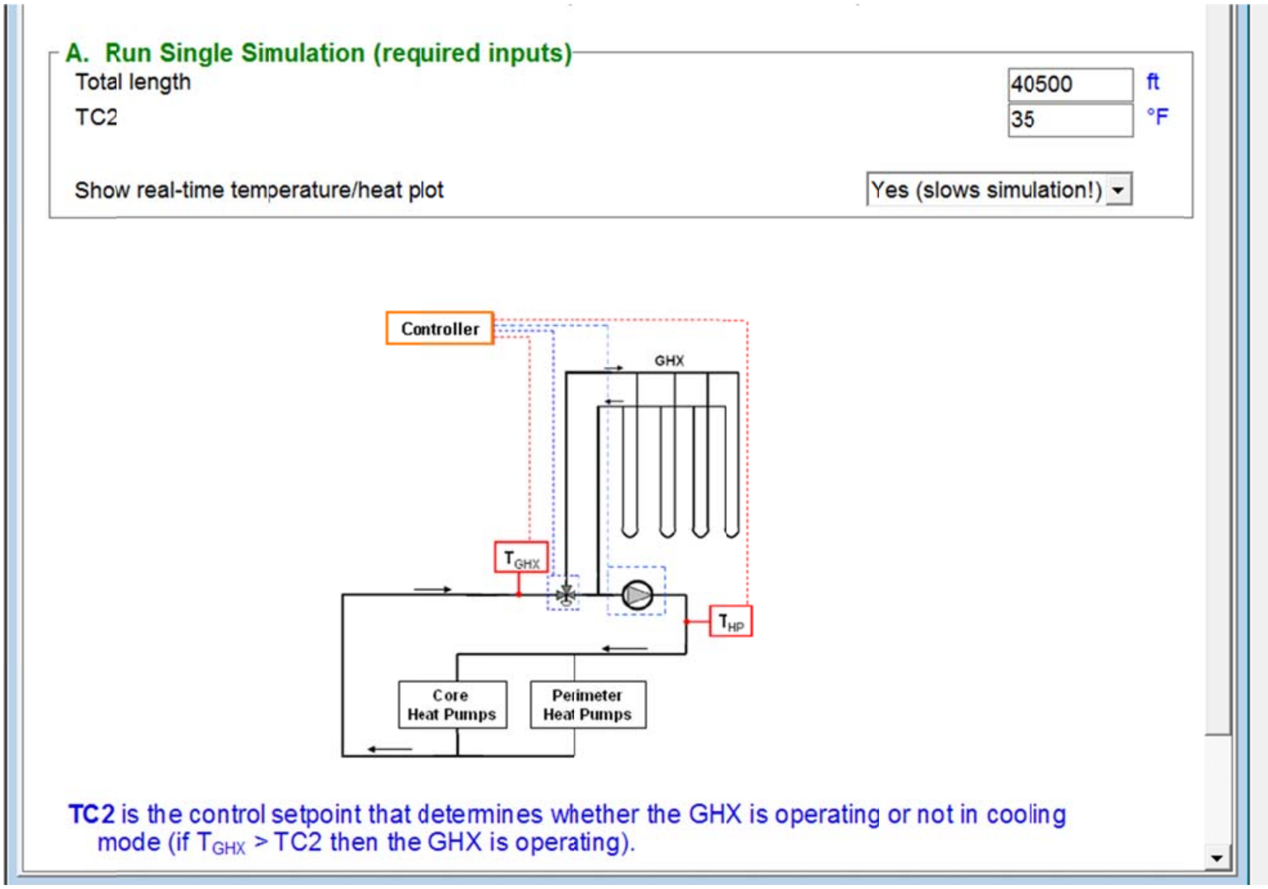
GHX costs (including headers and installation)	11.0	$/ft
Closed Circuit Cooling tower first cost multiplier	2.75	-

Optional: Interior HVAC cost (adjustment for full LCC)

Interior HVAC first cost	0.00	$
Interior HVAC annual cost	0.00	$

NOTE: Read help before modifying optional inputs

Figure 4: economics data and parameters



A. Run Single Simulation (required inputs)

Total length	40500	ft
TC2	35	°F
Show real-time temperature/heat plot	Yes (slows simulation!)	

TC2 is the control setpoint that determines whether the GHX is operating or not in cooling mode (if T_{GHX} > TC2 then the GHX is operating).

Figure5: Ground Heat Exchanger

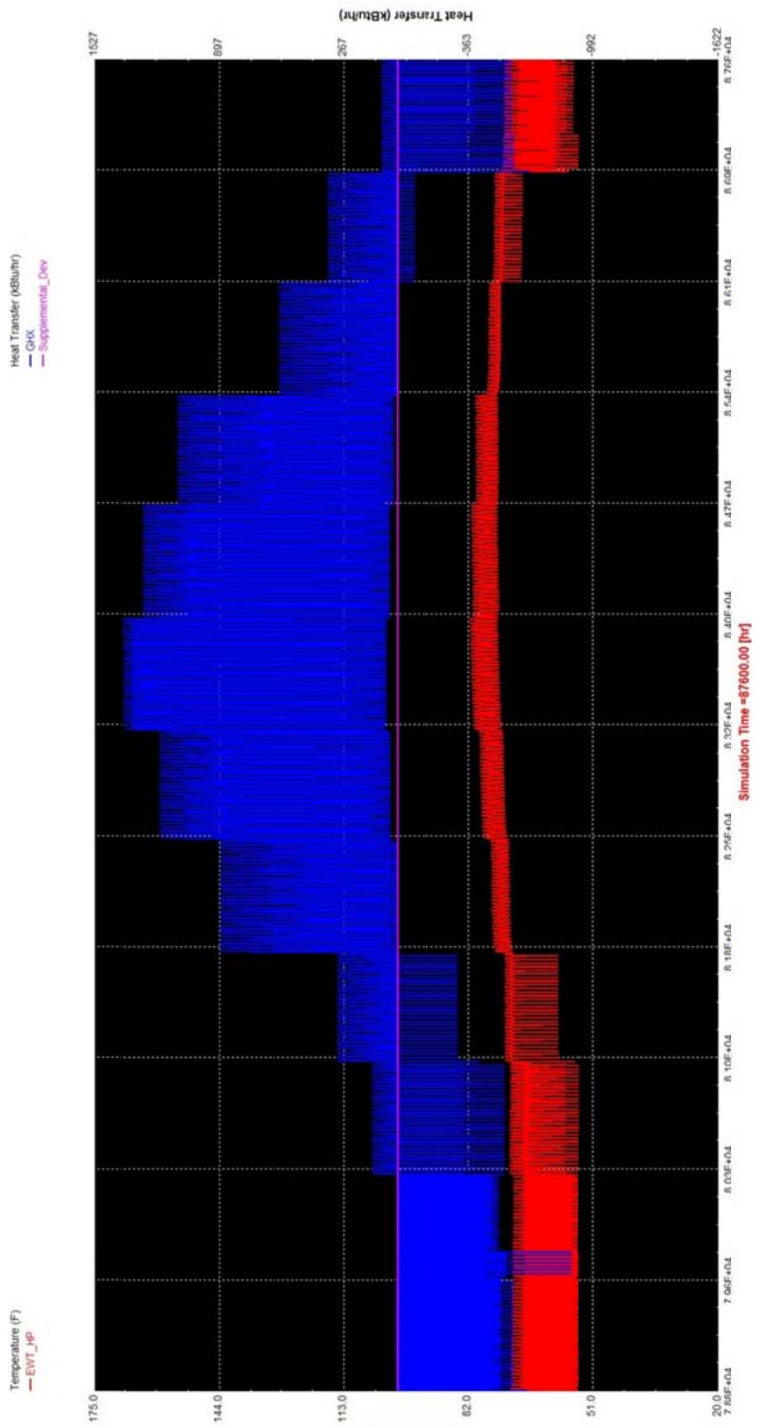
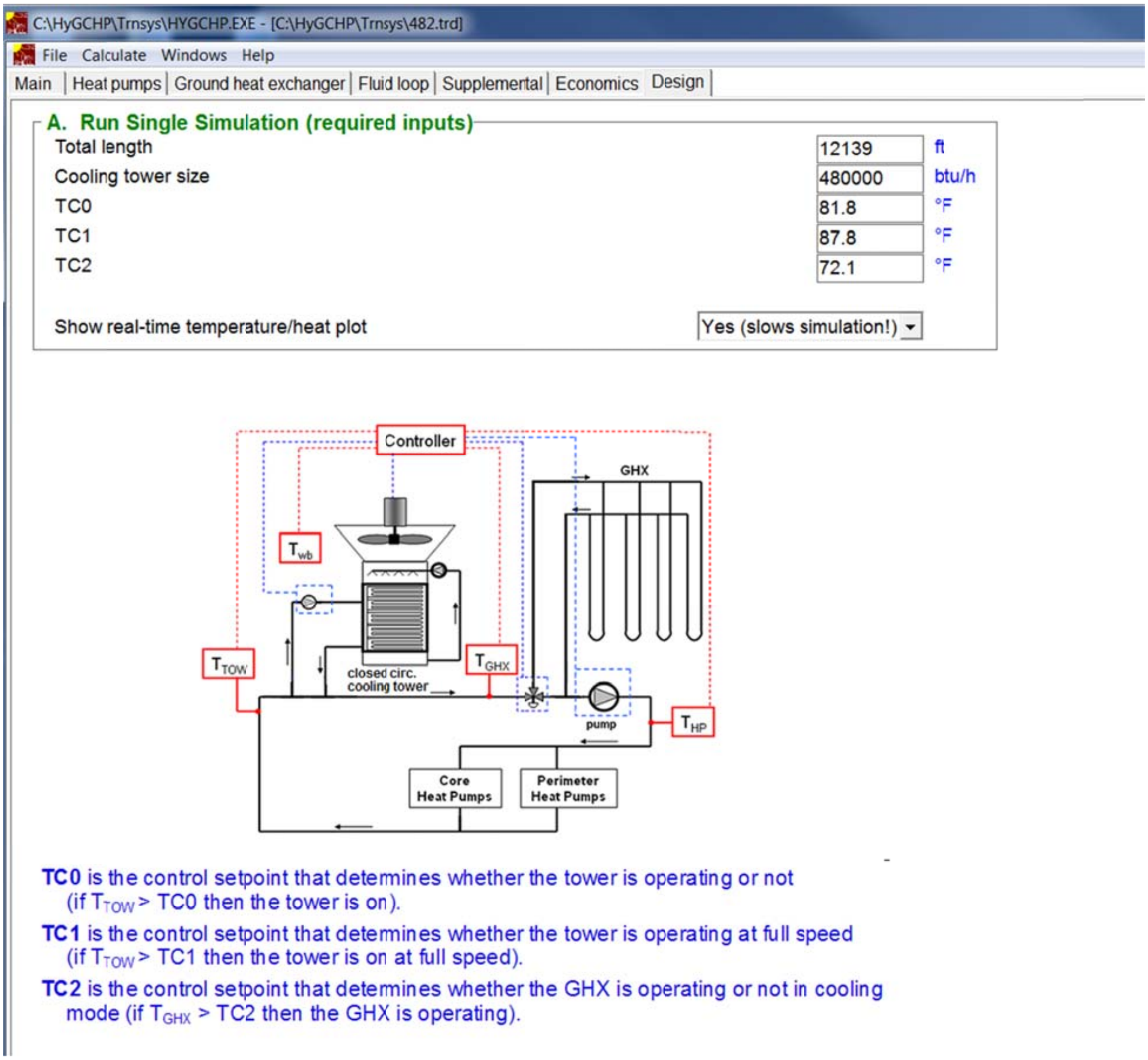


Figure 6: Ground Heat Exchanger graph

Specific Case Results - GSHP Only		
20-yr Life Cycle Cost* (real $)	601.4	k$
Equipment Cost (nominal $)		
Total	455.74	k$
GHX cost	455.62	k$
Operating Costs (nominal $)		
Electricity - consumption	195.47	k$
Electricity - demand	14.5	k$
Maintenance cost	10.74	k$
Water cost	0	k$
Gas cost	0	k$
Energy Consumption		
Total	1885316.8	kWh
Heat pumps	1716697.5	kWh
Pumping	168619.3	kWh
Cooling tower, fan	0	kWh
Cooling tower, spray pump	0	kWh
Boiler	0	kWh
Other Data		
Min. heat pump Tin	53.9	°F
Max. heat pump Tin	81.7	°F
Avg. annual ground temp change	1.3	D°F
GHX max. flow	271.4	gpm
Temperature violations	0	hours
Design Parameters		
GHX length	40500	ft
GHX cooling setpoint (TC2)	35	°F
GHX heating setpoint (TH2)	59	°F
Tower setpoint	N/A	
Tower high speed	N/A	

Cooling tower size	N/A
Boiler size	N/A

Figure 7: Ground Heat Exchanger Results



A. Run Single Simulation (required inputs)

Total length 12139 ft

Cooling tower size 480000 btu/h

TC0 81.8 °F

TC1 87.8 °F

TC2 72.1 °F

Show real-time temperature/heat plot Yes (slows simulation!)

TC0 is the control setpoint that determines whether the tower is operating or not (if T_{TOW} > TC0 then the tower is on).

TC1 is the control setpoint that determines whether the tower is operating at full speed (if T_{TOW} > TC1 then the tower is on at full speed).

TC2 is the control setpoint that determines whether the GHX is operating or not in cooling mode (if T_{GHX} > TC2 then the GHX is operating).

Figure 8: Hybrid system

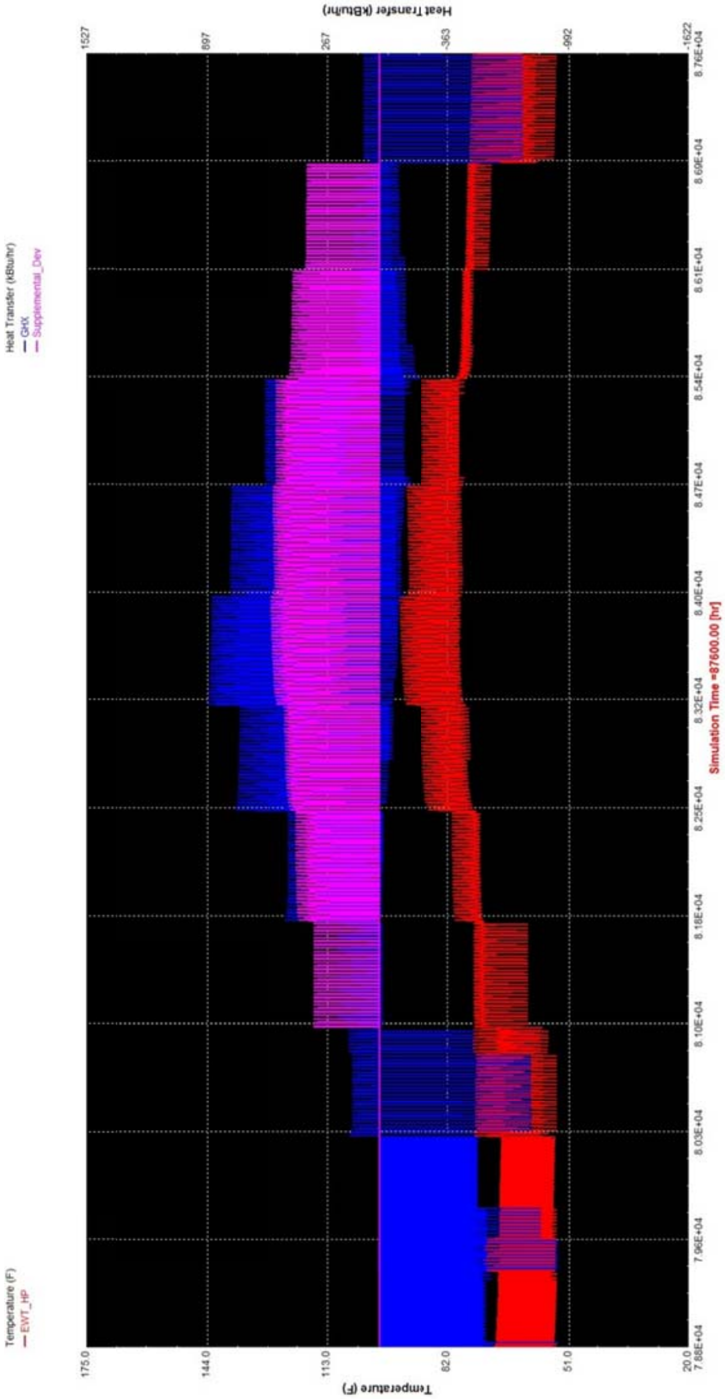


Figure 9: Hybrid system graph

20-yr. Life Cycle Cost* (real $)	378.77	k$
Equipment Cost (nominal $)		
Total	164.21	k$
GHX cost	136.56	k$
Operating Costs (nominal $)		
Electricity - consumption	240.31	k$
Electricity - demand	19.16	k$
Maintenance cost	8.11	k$
Water cost	11.26	k$
Gas cost	0	k$
Energy Consumption		
Total	2303608.5	kWh
Heat pumps	1922459.8	kWh
Pumping	175677.5	kWh
Cooling tower, fan	180159.6	kWh
Cooling tower, spray pump	25311.5	kWh
Boiler	0	kWh
Other Data		
Min. heat pump Tin	50.8	°F
Max. heat pump Tin	94.8	°F
Avg. annual ground temp change	1.5	D°F
GHX max. flow	279.2	gpm
Temperature violations	0	hours
Optimal Design Parameters		
GHX length	12139	ft
GHX cooling setpoint (TC2)	72.1	°F
GHX heating setpoint (TH2)	58.8	°F
Tower setpoint (DT1)	49.8	D°F
Tower high speed (TC1)	87.8	°F
Cooling tower size	40	tons
Boiler size	N/A	

Figure 10: Hybrid results

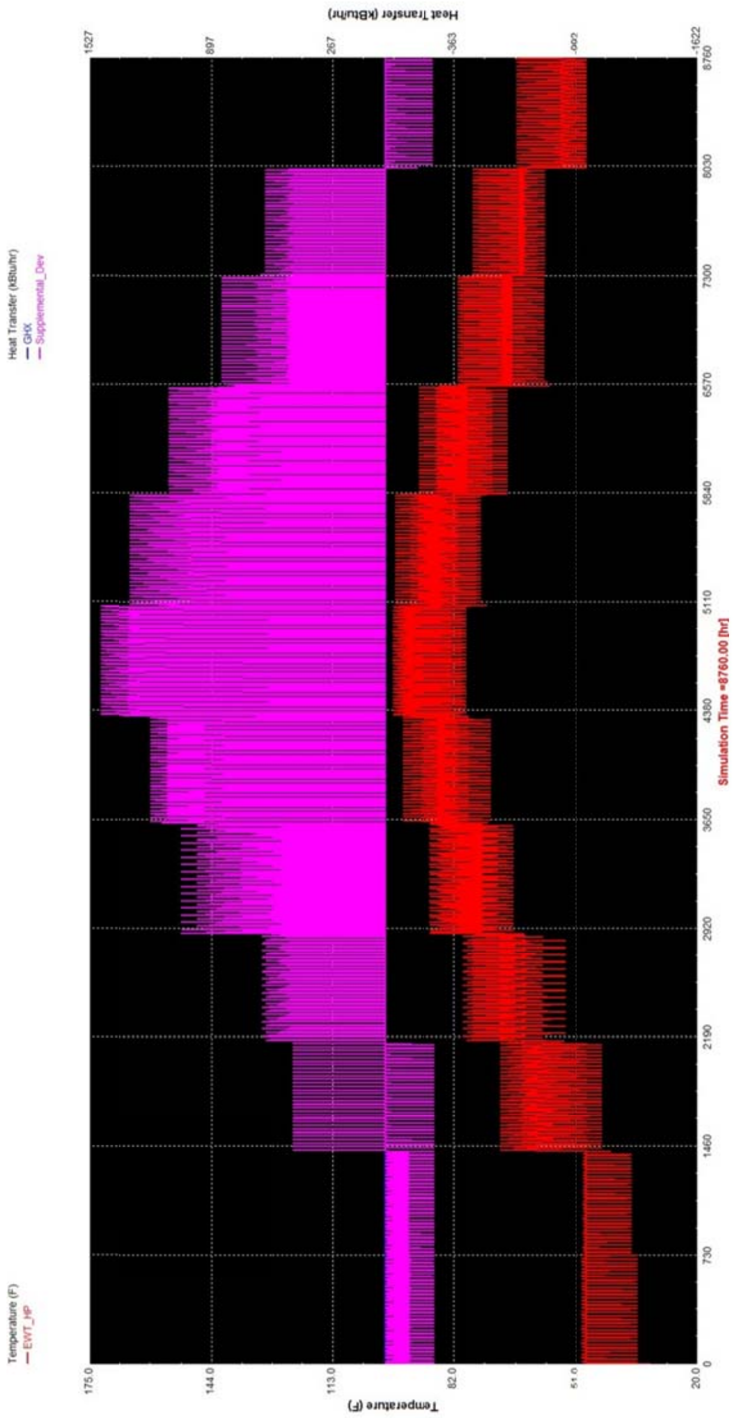


Figure 11: Cooling Tower graph

20-yr. Life Cycle Cost* (real $)	353.3	k$
Equipment Cost (nominal $)	59.2	k$
GHX cost	0	k$
Operating Costs, annual (nom. $)		
Electricity - consumption	28.22	k$
Electricity - demand	2.28	k$
Maintenance cost	1.82	k$
Water cost	2.58	k$
Gas cost	1.8	k$
Energy Consumption		
Total	317210.1	kWh
Heat pumps	201398.5	kWh
Pumping	19665.2	kWh
Cooling tower, fan	43912.6	kWh
Cooling tower, spray pump	5812	kWh
Boiler	46421.9	kWh
Other Data		
Min. heat pump Tin	35.2	°F
Max. heat pump Tin	97.8	°F
Avg. annual ground temp change	N/A	
GHX max. flow	N/A	
Temperature violations	0	Hours
Optimal Design Parameters		
GHX length	N/A	
GHX cooling setpoint	N/A	
Boiler heating setpoint (TH1)	48.2	°F
Tower setpoint (DT1)	28.8	D°F
Tower high speed (TC1)	102.2	°F
Cooling tower size	92	tons
Boiler size	320	MBtu/hr

Figure 12: Boiler and Cooling Tower results

Breadth Topics

Electrical

Object

Changing size of equipment and adding more equipment with solar shingle will change the electrical design. With all the new equipment changes to the building should cause the panel to be changed and add more of them. The electrical new wiring and panels will be design in accords with NEC 2008. Solar Shingle data was not received, so I will substitute Photovoltaics.

Calculations

I used Solar Photovoltaic On-Grid Calculator from Energy Works US. Figure 13, below shows the area on the roof where I plan to place the photovoltaic panels (red). I plan on only using about 1/2 of the south facing roof (3360 sq. ft.) to the panel does not interfere with the architectural parts (blue) of the roof. I choose to design on the best part of roof to check to see if placing more would be worth it. The design loads for the solar panels is 3000 kilowatt-hours per month (2.6% total of the average month) and a 75% effective to max absorption. I use Wilmington, Delaware for site location and a 4.6 average sun-hour based on this location. With 21.2 kilowatts of solar energy from the panels I select 185 Watts per solar panel. As a result of 115 panels for a total of 2175 watts and 1587 sq. ft. of solar panels. Total investment including accessories and installation is about $191,475. Once I apply Federal tax credit and local incentives the total is now $134,028. The annual savings calculation with $0.114 dollars / kw/hr for electricity comes out to be $4,059 annual savings. The payback period for the design is 33.04 years.

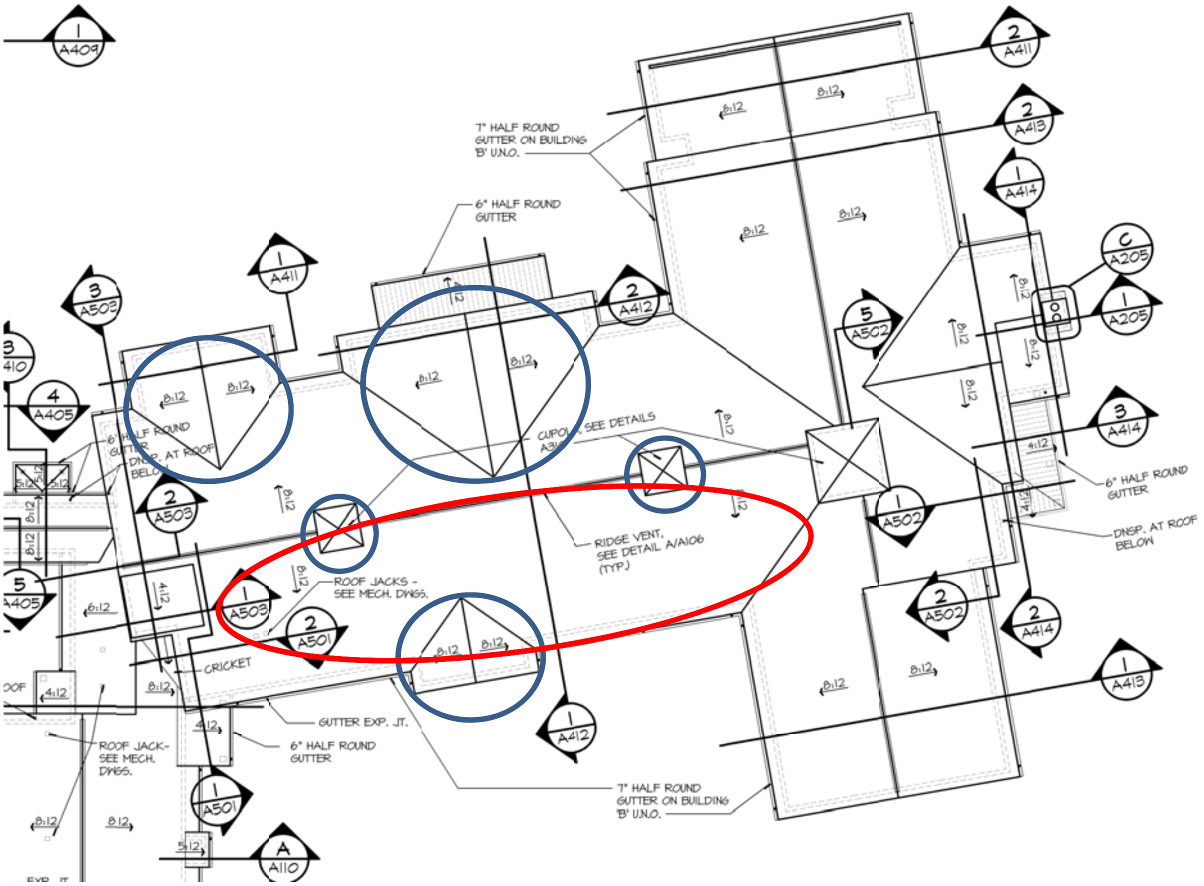


Figure 13: Building B south facing roof Solar panel in red area and roof architectural in blue

Analysis

Based on my finding solar panel would not make as a good choice. The payback period is too long and I would have like to see at less 20 years. The annual saving of $4,000 would mean that all of the roof would need to be cover to see a better annual savings that could make a difference. The total investment would be to high to cover most of the roof.

Structural

Object

The cooling tower will add weight to the roof structure and may require more room for it. The roof may need to be lifted, which will affect the structure of the roof. The current Structural material is wood. The cooling tower will have ducts of outside air to it and exhaust air though a membrane lined chimney. In having the cooling tower in the attic it will hide and chimney will better control indoor air quality. Load on the attic structure will calculated to either change size of matter and/or change the shape or size of the attic.

Calculations

For the calculation I used Table 1, below, for the loads with a tributary area of 1055 SF. The mechanical room is Fir #2 timber at 13.5 ft floor wide with 2x6 spaced at 16 inches on center. The flooring sheathing is ¾ inch T&G plywood. The wooding deck is designed for 100 psf, so this deck is good. The Mechanical room is held up by cold formed structural metal framing of: 600S137-54 16 inches on center. The load acting on the load bearing (10ft high) framed wall is 1120 plf. The building has a lateral load of 24 psf (from drawings). 1120 divided by 720 equals 1.55, which is less than 3.90 (good).The load acting on the frame for the first floor is 1860 plf Plus 1120 plf equals 2980 plf.2980 divided by 720 is 4.13, which is more than 3.90. Changing the GA to 14 and spacing at 24 inches on center will allow the deflection to increase to 5.01, which allow the metal framing to meet the needs of the build's load.

Component for Mech. Room		Component for 2^{ND} Floor	
Roof and Insulation	5 psf	Steel and Joist	4 psf
Ceiling	2 psf	Ceiling	2 psf
Collateral	3 psf	Collateral	2 psf
Wood Trusses	10 psf	Concrete Slab on Deck	47 psf
Heat pumps	5 psf		
Water to Water Heat Pump	.75 psf		
Veritable Heat pump	1 psf		
Cooling Tower	1. 5 psf		
Live Load	65 psf	Live load	100 psf
Total Load	**93.25 psf**		**155 psf**

Table 1: Load on the building plus the new cooling tower

Analysis

Based on my finding on the structural calculation the cold formed structural metal framing needs to increase the 16 GA (600S137-54 16 inches on center) to a 14 GA on 24 inches on center (600S137-64). The increase spacing could decrease the cost of the new stronger metal framing.

Redesign Energy Analysis

Energy

The over energy consumption for hybrid geothermal is 18.1% higher than ground source heat pump only. In figure 14, below, it shows you can see the energy break down on parts for the heating and cooling system. Figure 15 shows a visional graph to compare.

Energy Consumption (kWh)	GSHP Only	Hybrid	Conv. Boiler/Tower
Heat pump	1716698.0	1922460.0	201398.5
Pumping	168619.3	175677.5	19665.2
Cooling Tower, Fan	0.0	180159.6	43912.6
Cooling Tower, spray pump	0.0	25311.5	5812.0
Boiler	0.0	0.0	46421.9
Total	1885317.0	2303609.0	317210.1

Figure 14

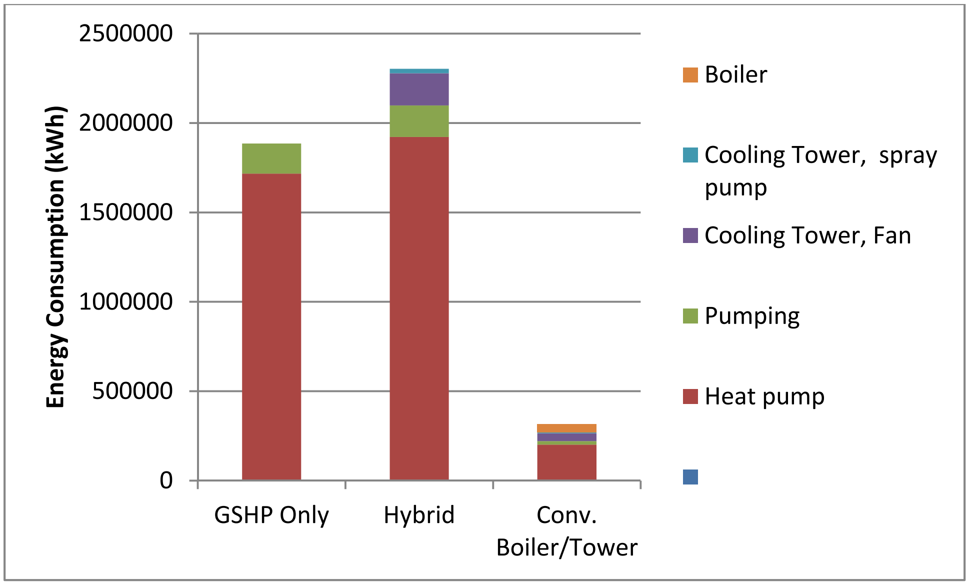


Figure 15

Cost

In figure 16, below, the annual operation cost of hybrid geothermal system is 20.5% more than that of the ground source heat pump system. Figure 17 gives a visual representation. In figure 18 and 19 shows that the first cost of the hybrid system is 70% less than the ground source heat pump.

Operating Cost, annual (k$)	GSHP Only	Hybrid	Conv. Boiler/Tower
Electivity - consumption	195.47	240.31	28.22
Electivity - demand	14.5	19.16	2.28
Maintenance cost	10.74	8.11	1.82
Water cost	0	11.26	2.58
Gas cost	0		1.8
Total	206.21	259.68	34.42

Figure 16

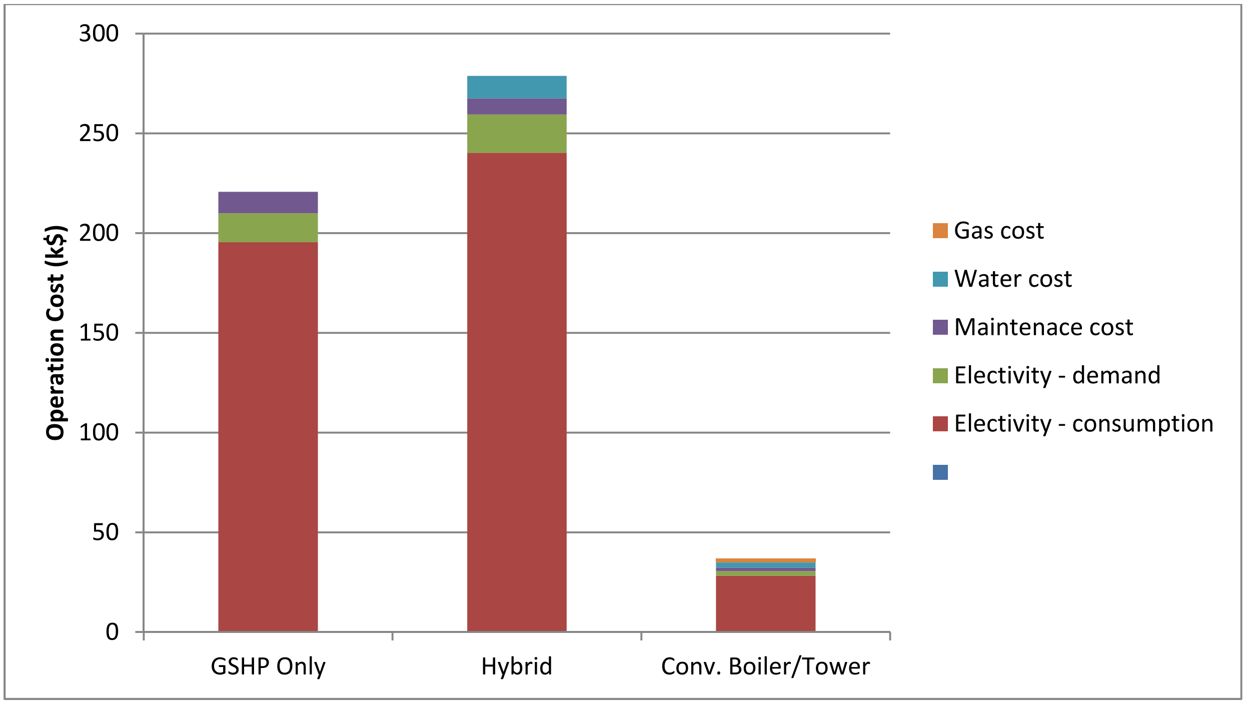


Figure 17

Equipment cost (k$)	GSHP Only	Hybrid	Conv. Boiler/Tower
GHX	455.62	164.21	0
Total	455.74	136.56	59.2

Figure18

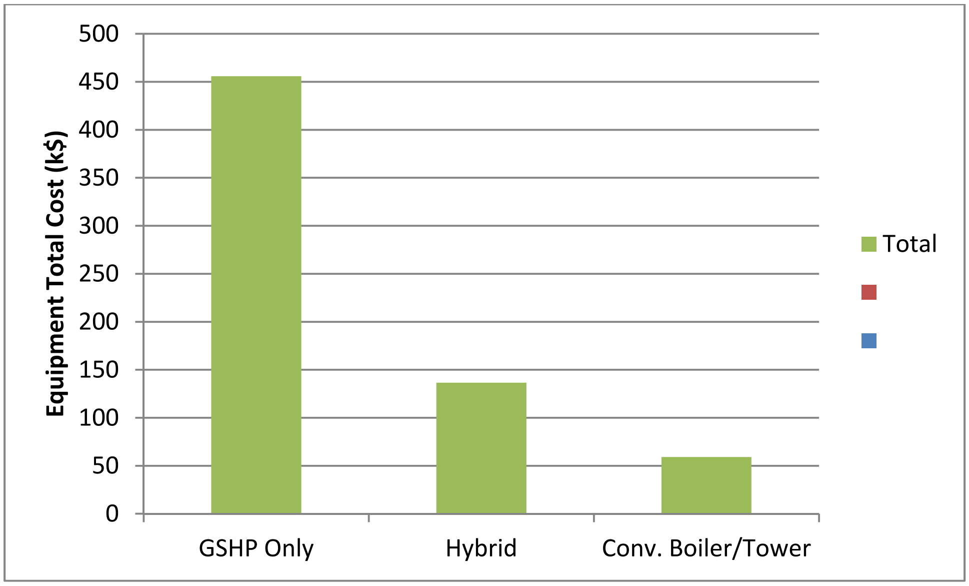


Figure19

Life Cycle

The 20 year life cycle cost for hybrid is $378,770, which is less than ground source heat pump's 20 year life cycle cost of $601,400 as seen in figure 20 and 21.

20-yr. Life Cycle Cost (k$)	GSHP Only	Hybrid	Conv. Boiler/Tower
20-yr. Life Cycle Cost	601.4	378.77	353.3

Figure 20

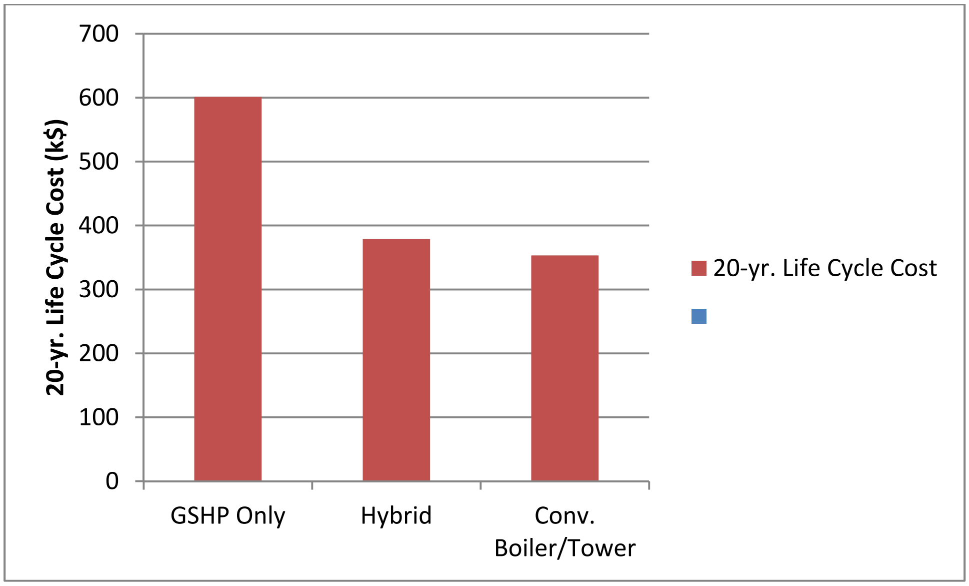


Figure 21

Figure 21 show the deferent parameters of the ground source heat pump for both cases.

Other Data	GSHP Only	Hybrid
Number of boreholes in ground heat exchanger	90 @ 450 ft	27 @ 450
Average annual ground temp. change (F)	1.3	1.5
Max. fluids temperature entering heat pumps (F)	81.7	94.8
Min. fluids temperature entering heat pumps (F)	53.9	50.8
GHX max. flow (gpm)	271.4	279.2

Figure 22

Conclusion

In conclusion on my research of ground source heat pump or hybrid geothermal for DE Hospice, I find that hybrid geothermal is a great choice for a more green design with a lower first cost. If ground source heat pumps can be afforded it would be better to choice them in the long run. With only saving $53,000 a year, it would only take just over six year of annual savings to make up for the $319,180 in equipment cost.

Reference

Scott Hackel. “Hybrid Ground-Source Heat Pump Installations: Experiences, Improvements and Tools.” Energy Center of Wisconsin. June 30, 2011

“2007 ASHRAE Handbook: HVAC Applications.” 2007. American Society of Heating, Refrigeration, and Air-Conditioning Engineers

Carol Marriott. “3 Simple Approaches to Energy Efficiency: Optimal Air, Energy Recovery, Geothermal” ASHRAE Journal July (2006): pp. 44-50

Al Barfield. “Hybrid Geothermal Heat Pump for Beachfront Hotel” ASHRAE Journal Sept. (2006): pp. 49-55

Stephen P. Kavanaugh and Kevin Rafferty. “Ground-Source Heat Pumps: Design of Geothermal System for Commercial and Institutional Buildings” 1997 American Society of Heating, Refrigeration, and Air-Conditioning Engineers

http://www.buildsite.com/detail/product/structural-s-stud

AE 404 class notes taking by Zachary Klixbull, Spring 2011

Appendix

A)

$$L_c = \frac{q_a \cdot R_{ga} + \left[q_{lc} - 3.142 \cdot W_c\right] \cdot \left[R_p + PLF_m \cdot R_{gm} + R_{gd} \cdot F_{sc}\right]}{t_g - \left[\frac{t_{wi} - t_{wo}}{2}\right] - t_p}$$

F_{sc}= *short circuit heat loss factor*
L_c= *required bore length for cooling, ft*
q_a= *net annual average heat transfer to ground, Btu/h*
q_{lc}= *building design cooling block load, Btu/h*
R_{ga}= *effective thermal resistance of ground (annual pulse), h-ft-°F/Btu*
R_{gd}= *effective thermal resistance of ground (daily pulse) , h-ft-°F/Btu*
R_{gm}= *effective thermal resistance of ground (monthly pulse) , h-ft-°F/Btu*
R_p= *thermal resistance of pipe and borehole, h-ft-°F/Btu*
t_g= *undistributed ground temperature, °F*
t_p= *temperature penalty for interference of adjacent bores, °F*
t_{wi}= *liquid temperature at heat pump inlet, °F*
t_{wo}= *liquid temperature at heat pump at outlet, °F*
W_c= *power input at design cooling load, Btu/h*
PLF_m= *part load factor during design month*

$$F_{of} = \frac{4 \cdot \alpha \cdot \tau_f}{d_p^{\,2}} \qquad R_{ga} = \frac{G_f - G_1}{k_g}$$

$$F_{o1} = \frac{4 \cdot \alpha \cdot \left[\tau_f - \tau_1\right]}{d_p^{\,2}} \qquad R_{gm} = \frac{G_1 - G_2}{k_g}$$

$$F_{o2} = \frac{4 \cdot \alpha \cdot \left[\tau_f - \tau_2\right]}{d_p^{\,2}} \qquad R_{gd} = \frac{G_2}{k_g}$$

F_{of} = *Fouriers number for* τ_f

F_{o1} = *Fouriers number for* τ_1

F_{o2} = *Fouriers number for* τ_2

α = *Thermal diffusivity of the ground,* m^2/day

d_p= *Outside diameter of pipe, ft*

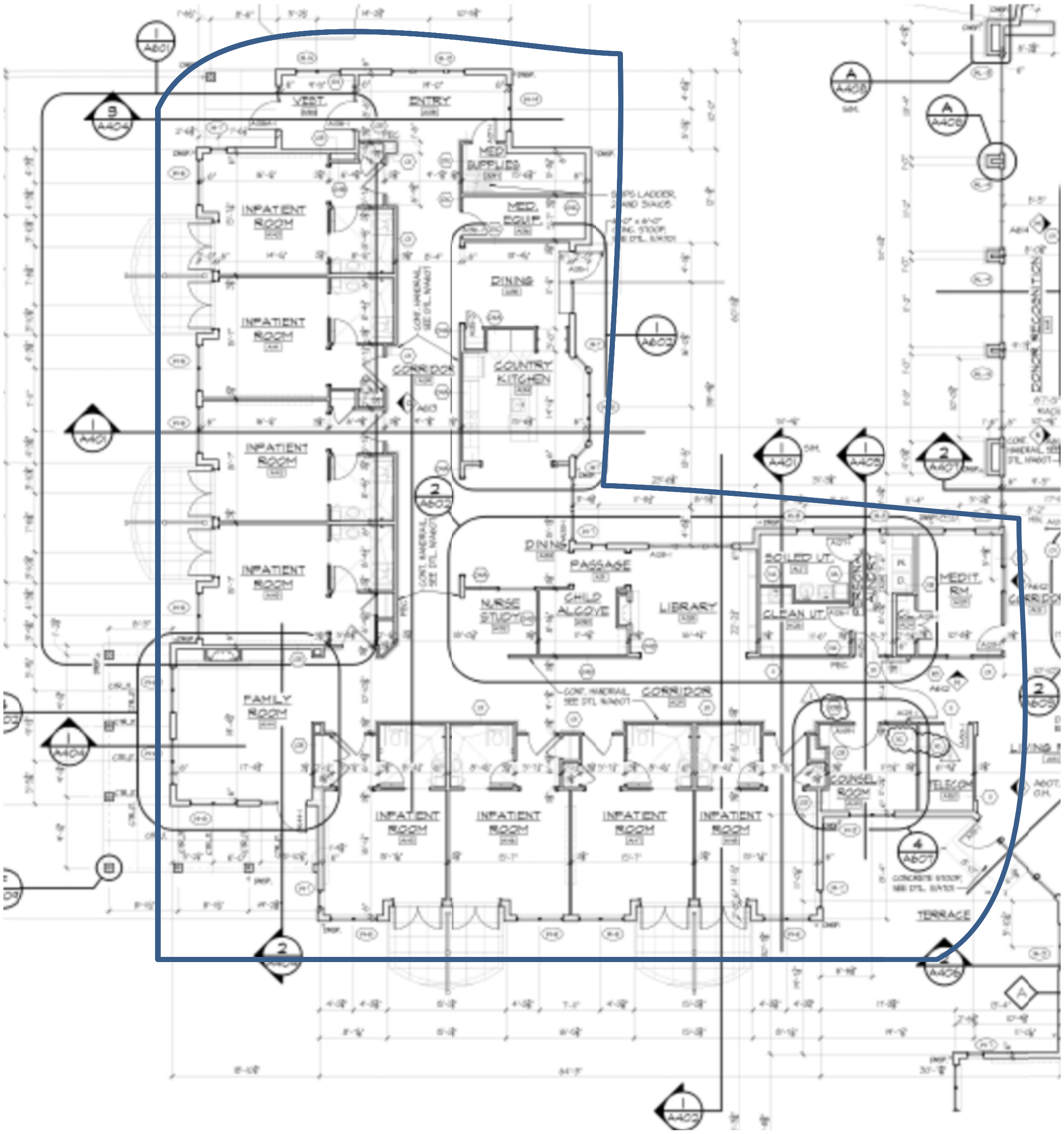
k_g= *Thermal conductivity of the ground, Btu /h-ft-°F*

B)

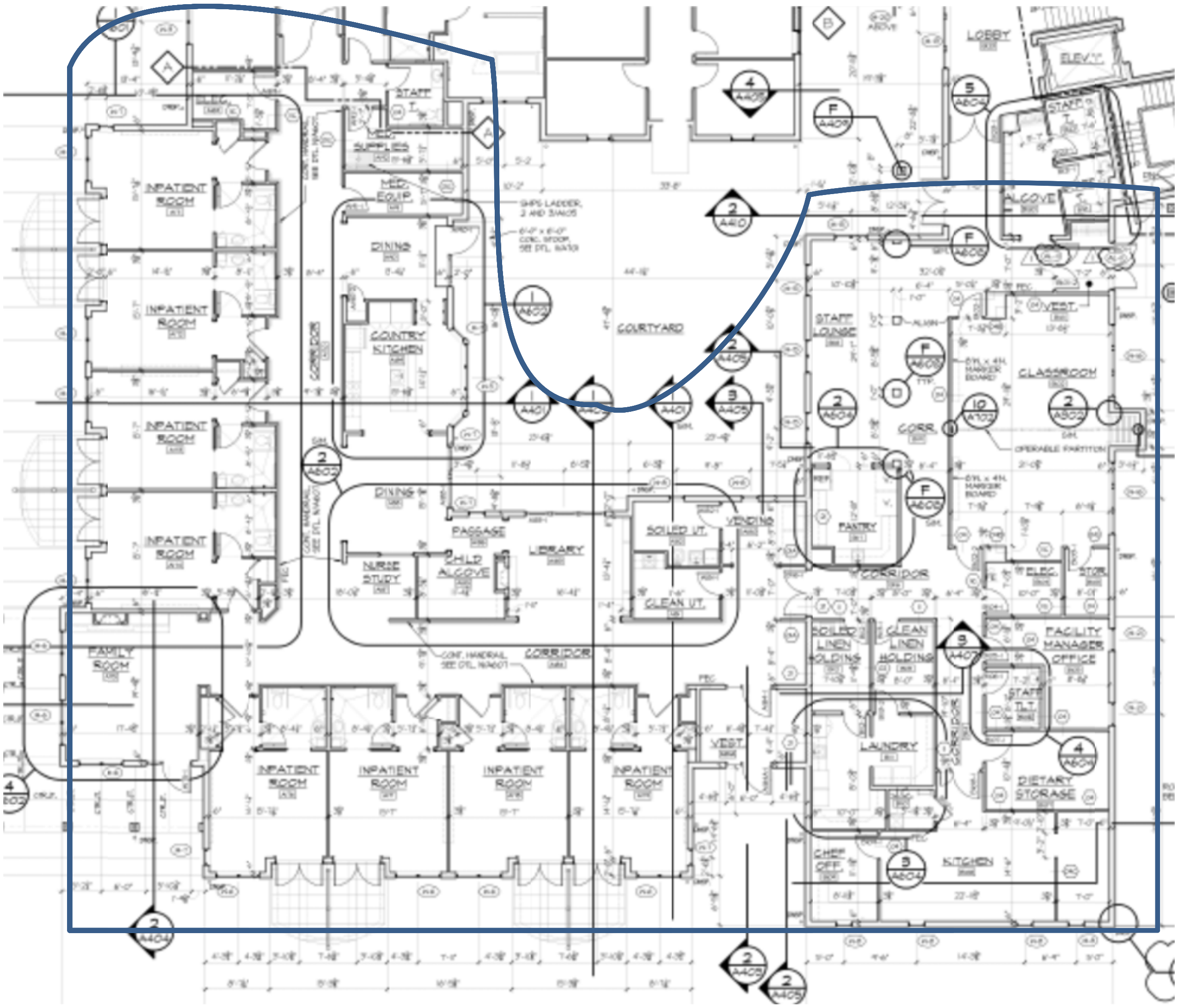
$$LCC = C_{FIRST} = PV(C_{ENERGY}) + PV(C_{Maintenance} + C_{Water} + C_{Replacement} - C_{taxBenefits}\ C_{Salvage})$$

C) Zones

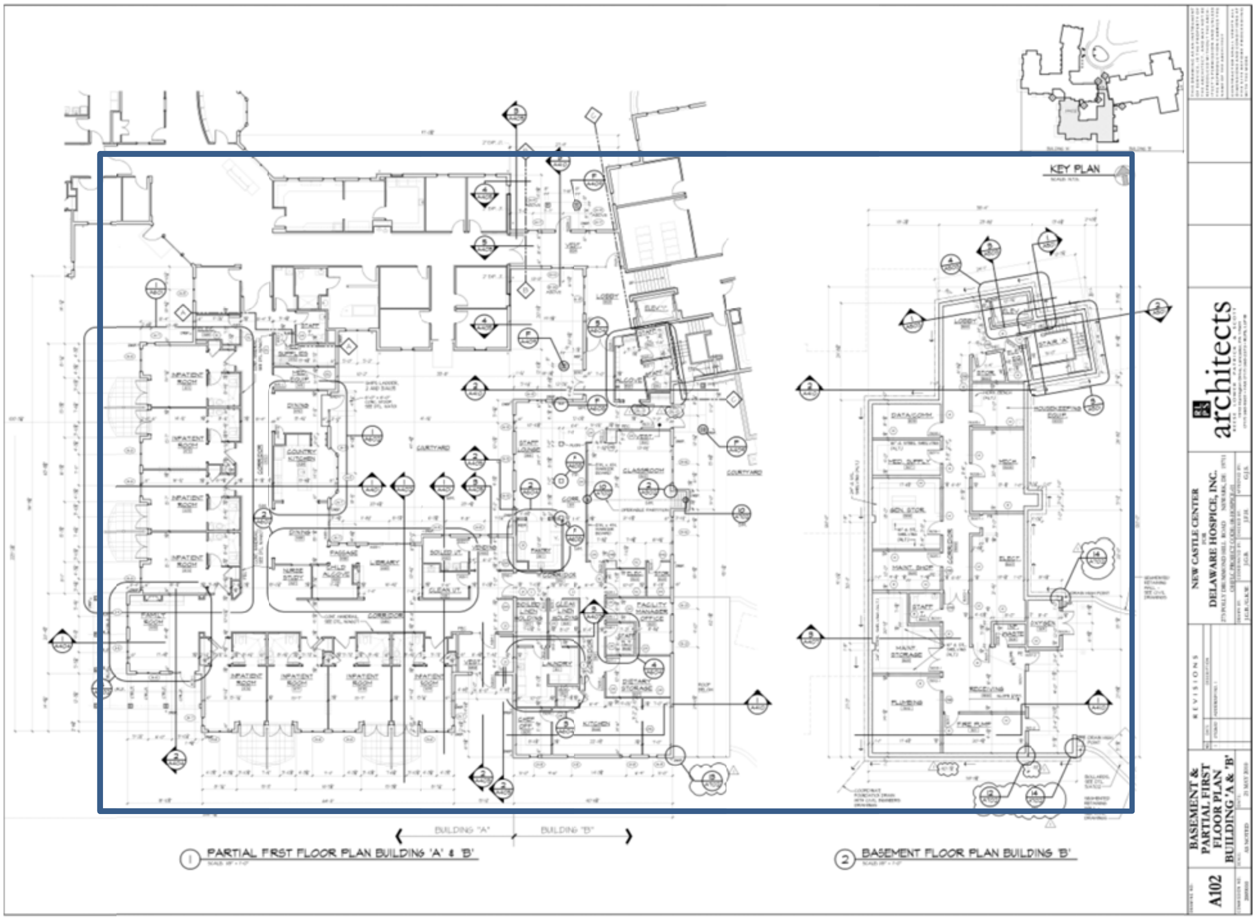
C1:Zone1


VEST.
ENTRY
MED. SUPPLIES
MED. EQUIP.
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
DINING
COUNTRY KITCHEN
CORRIDOR
DINING
PASSAGE
CHILD ALCOVE
NURSE STUDY
LIBRARY
SOILED UT.
CLEAN UT.
MEDIT. RM
FAMILY ROOM
CORRIDOR
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
COUNSEL. ROOM
TELECOM
TERRACE
DONOR RECOGNITION
A601
A404
A401
A602
A602
A403
A405
A407
A406
A402
A607

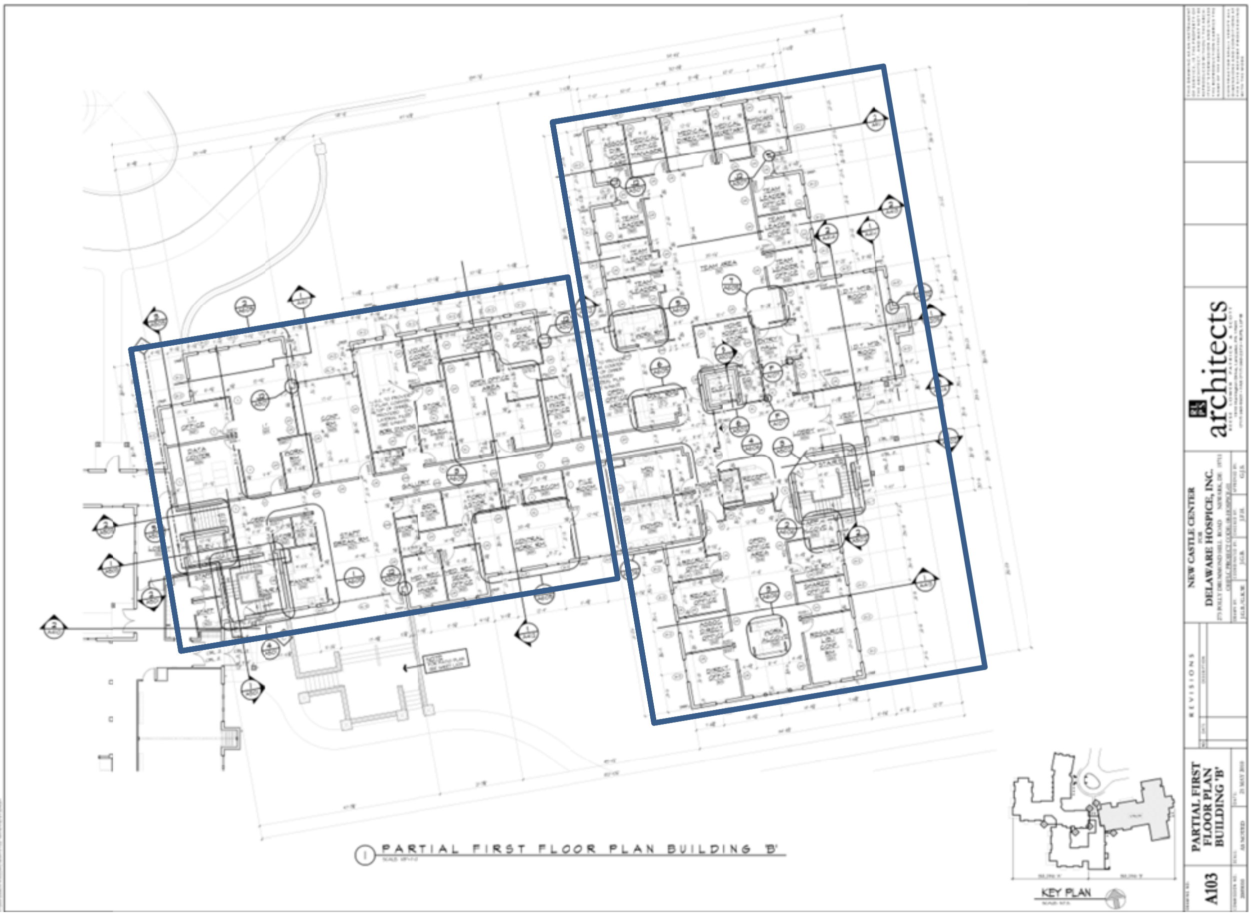
C1: Zone 2


INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
STAFF
MED. SUPPLIES
MED. EQUIP.
DINING
COUNTRY KITCHEN
CORRIDOR
COURTYARD
LOBBY
ELEV.
STAFF
ALCOVE
STAFF LOUNGE
VEST.
CLASSROOM
CORR.
PANTRY
DINING
PASSAGE
NURSE STUDY
CHILD ALCOVE
LIBRARY
SOILED UT.
VENDING
CLEAN UT.
CORRIDOR
ELEC.
STOR.
FAMILY ROOM
CORRIDOR
SOILED LINEN HOLDING
CLEAN LINEN HOLDING
FACILITY MANAGER OFFICE
STAFF TLT.
LAUNDRY
CORRIDOR
DIETARY STORAGE
VEST.
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
INPATIENT ROOM
CHEF OFF.
KITCHEN
SHIPS LADDER, 2 AND 3/A605
COURTYARD

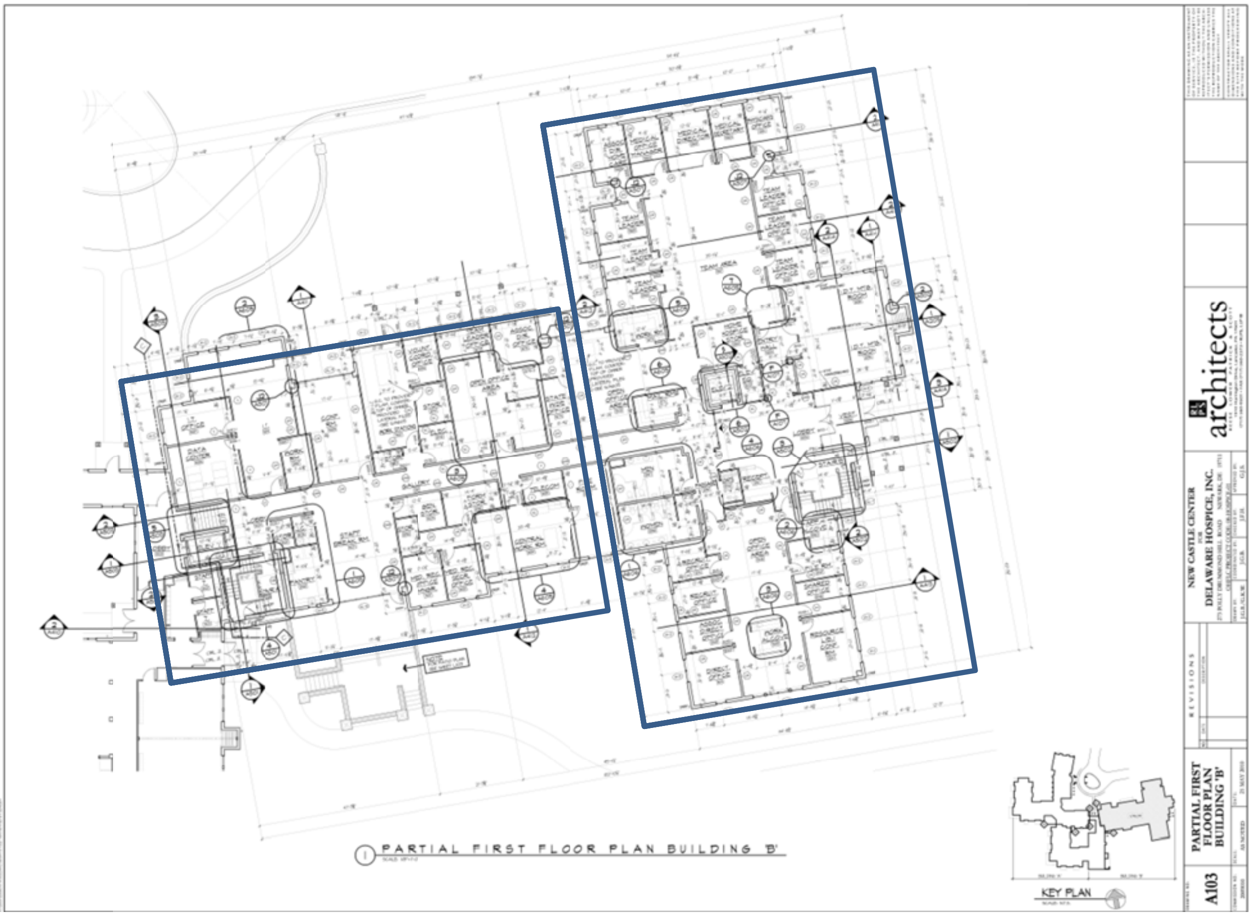
C3: Zone 3


KEY PLAN
PARTIAL FIRST FLOOR PLAN BUILDING 'A' & 'B'
BASEMENT FLOOR PLAN BUILDING 'B'
BUILDING "A"
BUILDING "B"
COURTYARD
architects
NEW CASTLE CENTER
DELAWARE HOSPICE, INC.
BASEMENT & PARTIAL FIRST FLOOR PLAN BUILDING 'A' & 'B'
A102

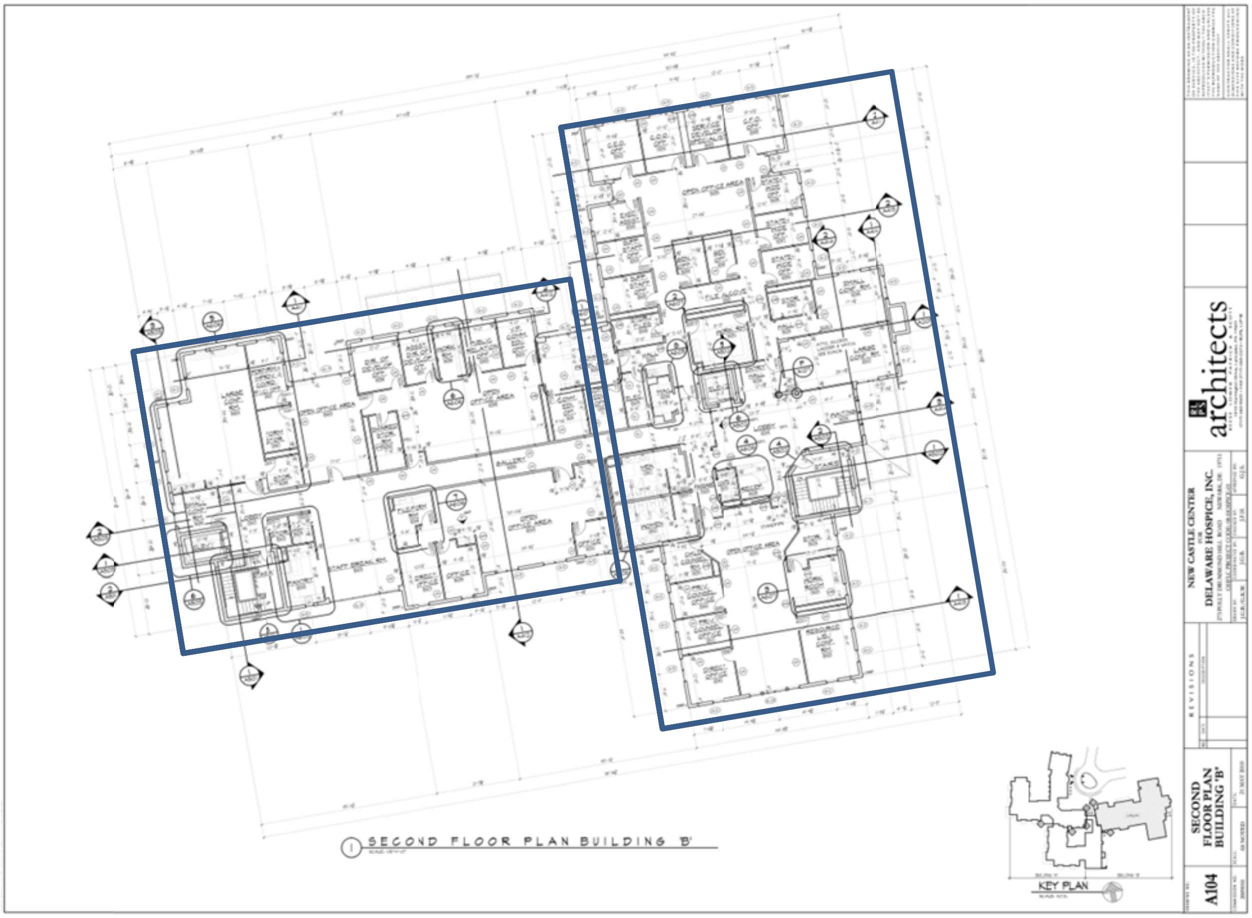
C5: Zone 4



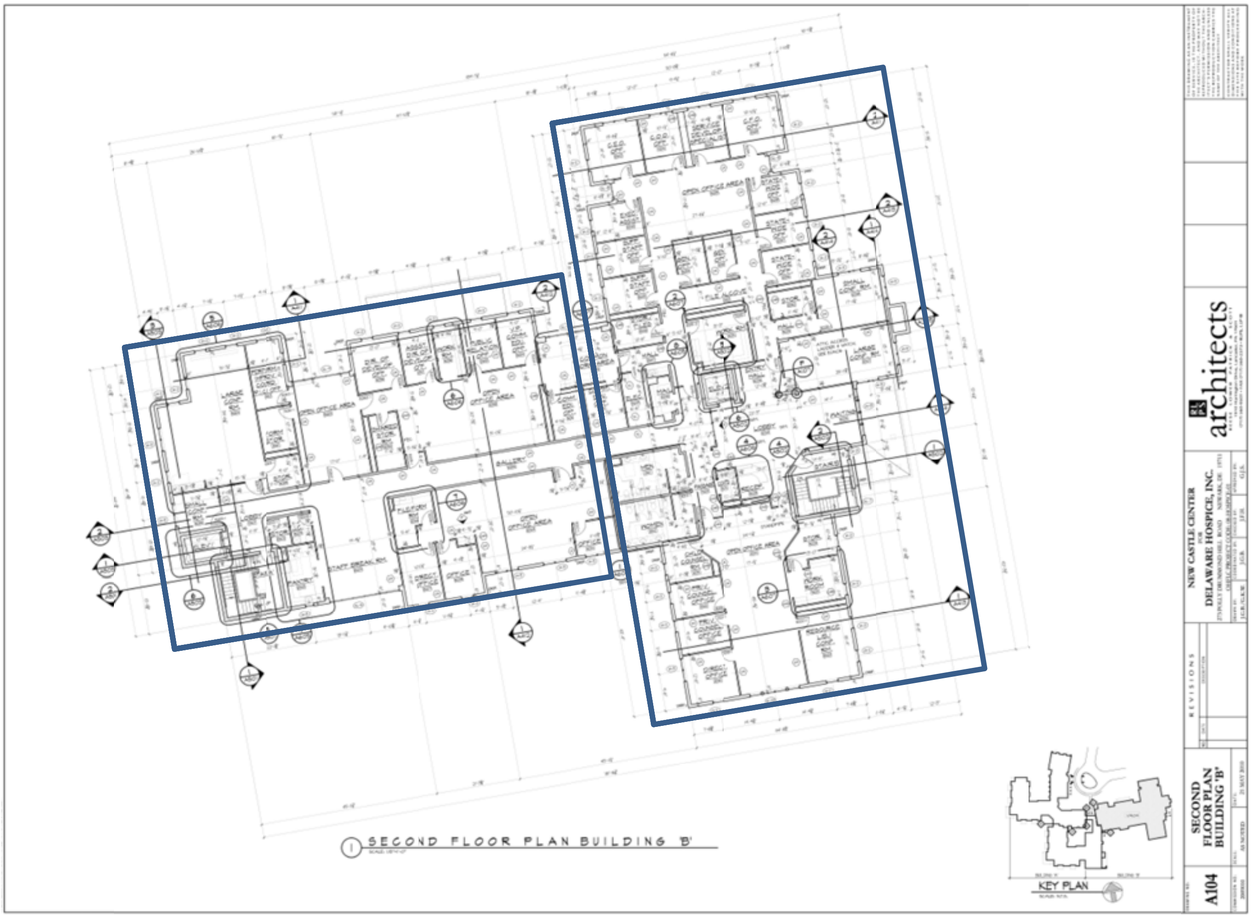
C6: from left to right Zone 5, Zone 6



C7: from left to right Zone 5, Zone 6



C8: from left to right Zone 7, Zone 8



C9: from left to right Zone 7, Zone 8

Load Sources and Scheduling

The building being a hospice and offices, I used a hospital typical scheduling for building A and an office typical scheduling for building B. Building A is zones 2-4 and Building B is zone 1, 5-8.