The American Swedish Institute

Minneapolis, MN

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Advisor – Dr. Stephen Treado
The Pennsylvania State University

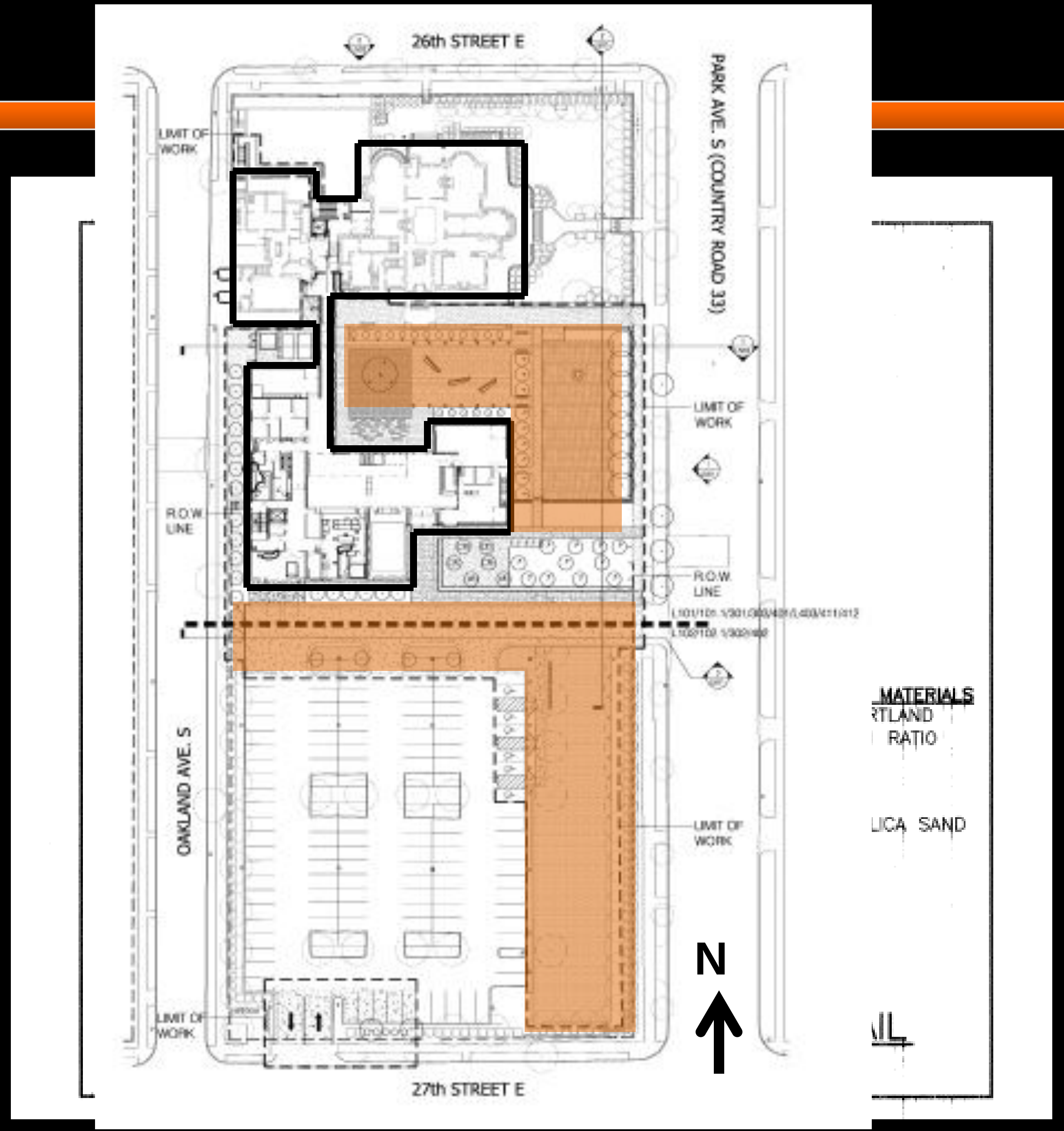
Building Information

- Size: 75,000 square feet
- Occupancy Type: Cultural Center
- Construction Cost: $13.5 million
- Construction Dates: January 2011 – June 2012
- Delivery Method: Design – Bid – Build
- Project Team:
  - Engineers and Architect: HGA
  - Construction Manager: Adolfson & Peterson Construction
  - Owner: The American Swedish Institute

Existing Mechanical System

- **Building Introduction**
  - Building Information
  - **Existing Mechanical System**
- Proposed Solutions and Goals
- Depth 1 – VAV System
- Depth 2 – Chilled Beam System
- Breadth 1 – Structural
- Conclusion
- Questions/Comments

- Geothermal source closed loop heat pump system
- Vertical heat exchanger
- Design Summary
  - Peak design heat loss : 917 MBH
  - Peak design heat gain : 1202 MBH
  - Heat pump COP at 32°F: 3.5
  - Design minimum supply temperature : 32°F
  - Design maximum supply temperature : 88°F
  - 30% propylene glycol in water



Existing Mechanical System

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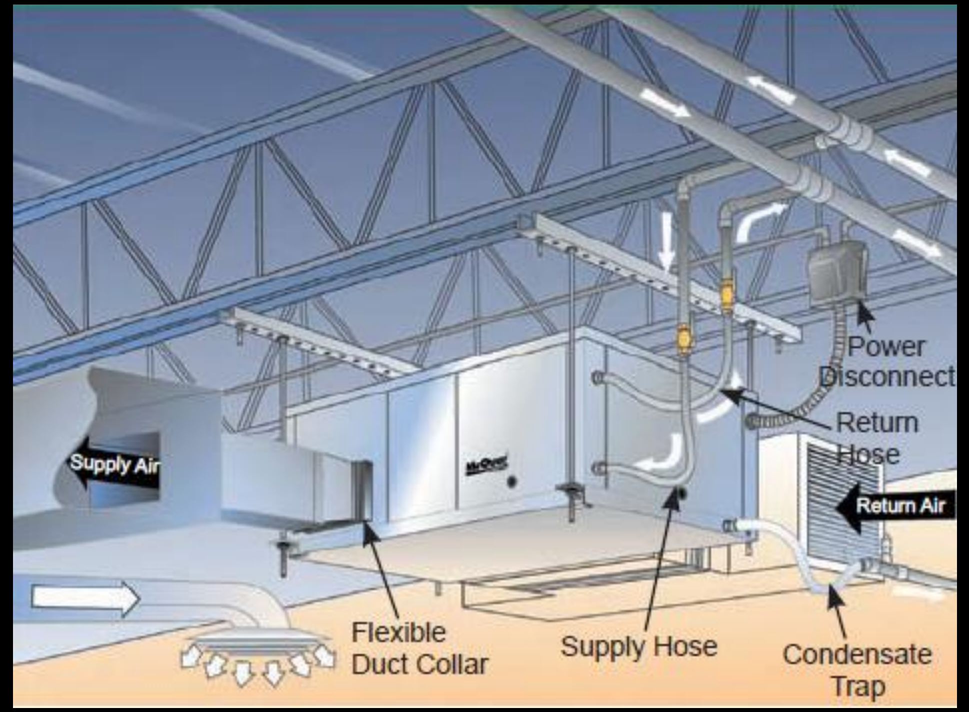
- Makeup Air Unit
  - 8,000 cfm
  - Serves the heat pumps located in the Addition and Mansion
- Water-to-air heat pumps
  - 48 units
  - 300-2,000 cfm range



McQuay Enfinity Horizontal Ceiling Water Source Heat Pump

AAON SA Series Makeup Air Unit

Mechanical System Evaluation

- Areas for improvement:
  - Energy usage
  - Fan energy
  - Cost spent on utilities annually
- Goals:
  - Reduce annual operating costs
  - Decrease fan energy
  - Decrease annual amount of energy usage

Breadth Evaluation

- Breadth 1: Architectural
  - Replace existing roof on walkway
- Breadth 2: Structural
  - Walkway was analyzed for original roof loads
  - Calculate loads for extensive and intensive options
  - Comparison of original to new options

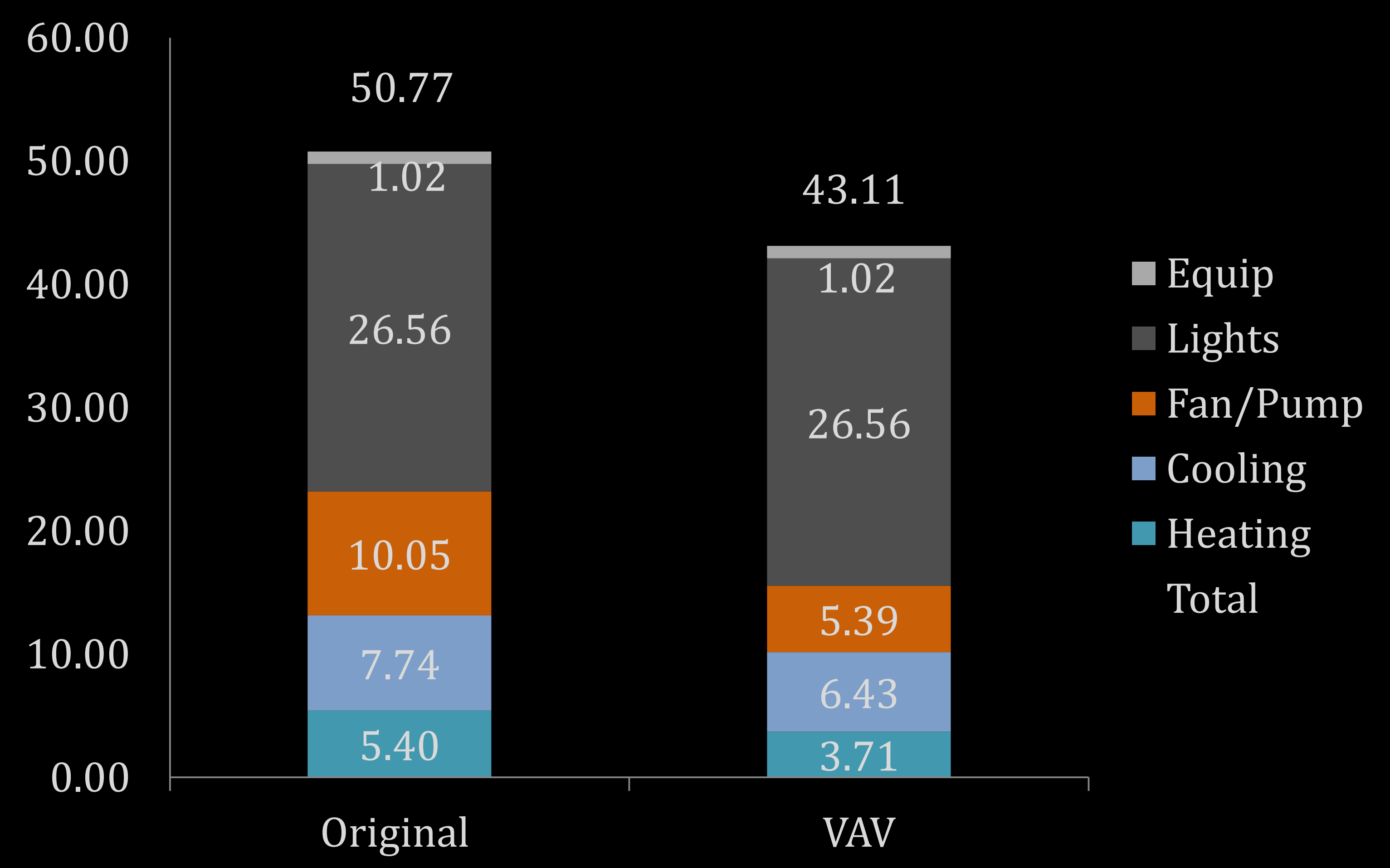
Background Information

- Fan powered VAV boxes shall supply conditioned air to zones
- Water-to-water heat pumps in combination with geothermal system

- Procedure:
  - Schedules and rooms were inputted into Trane TRACE
  - Calculate monthly and annual amounts for energy usage
  - Determine annual costs
  - Size equipment based on results
  - Compare results to original

Energy Analysis

Annual Energy Use for HVAC Options by End Use



- 15.1% decrease in end use
- 46.4% decrease in fan energy

	Electricity (kWh)	Natural Gas (kBtu)	Total (kBtu/yr)
Original	917,790	66,748	3,199,165
VAV	773,055	78,169	2,716,604

- 15.8% decrease in electricity
- 14.6% increase in natural gas

Energy Costs

- Utility Rates taken from Xcel Energy
- Electricity Costs:
  - $11.19/kW from June to Sept.
  - $7.79/kW from Oct. to May
- Natural Gas Costs:
  - $0.59/therm from April to Oct.
  - $0.65/therm from Nov. to March

Annual Utility Breakdown		
Source	**Energy (10^6 Btu/yr)**	**Cost ($/yr)**
Electricity	2,638.4	60,639.45
Gas	78.2	905.68
Total	**2,717**	**61,545.13**

First Cost

- VAV System first cost:
  - $2,459,350.00
  - $54.65 per square foot
- Included:
  - Geothermal wellfield & piping
  - Water -to-water heat pumps
  - Air handling unit
  - Fan-powered VAV boxes
- Original system first cost: $2,031,979
- 17.4% increase

System Components	Component Costs
Geothermal wellfield & piping	$408,000.00
Water-to-water heat pumps	$224,000.00
Air handling unit	$240,000.00
VAV Boxes	$160,000.00
Boiler	$81,600.00
Pumps	$7,500.00
Valving	$50,000.00
Exhaust Fans	$52,100.00
Unit heaters & misc.	$37,500.00
Air Distribution	$686,600.00
Hydronic piping	$249,450.00
Controls	$312,600.00

Life-Cycle Cost

- Building Introduction
- Proposed Solutions and Goals
- **Depth 1 – VAV System**
  - Background Information
  - Energy Analysis
  - Energy Costs
  - First Cost
  - **Life-Cycle Cost**
  - Recommendation
- Depth 2 – Chilled Beam System
- Breadth 1 – Structural
- Conclusion
- Questions/Comments

- 30 year life-cycle cost
- System was analyzed based on:
  - Capital Investment
  - Overhaul
  - Maintenance
  - Annual electric and natural gas costs
  - Escalation Factors

Maintenance ($)	Annual Electricity Costs ($)	Annual Natural Gas Costs ($)	OMB Base Discount Rate (%)
44,285.00	60,639.45	905.68	3.0

- Total net present value: $ 5,184,469.43
- 3.9% increase

	Original	VAV
HVAC System First Cost	$2,031,979.00	$2,459,350.00
Annual Maintenance Cost	$52,100.00	$44,285.00
Replacements Costs: 5	-	-
10	-	-
15	$275,500.00	$89,600.00
20	$372,479.00	$544,100.00
25	$81,600.00	$81,600.00
30	$275,500.00	$489,600.00
Annual Recurring Electric	$73,720.36	$60,639.45
Annual Recurring Natural Gas	$817.27	$905.68
Total Energy Costs	$74,537.63	$61,545.13

Recommendation

- Decrease of energy consumption and usage
  - 15.1% overall
  - 46.4% for fan and pump energy
  - 16.9% for cooling
  - 31.3% for heating
- $13,080.91 less spent on electricity annually
- Total first cost: $2,459,350
- Payback period of 33 years
- Is this a good option?

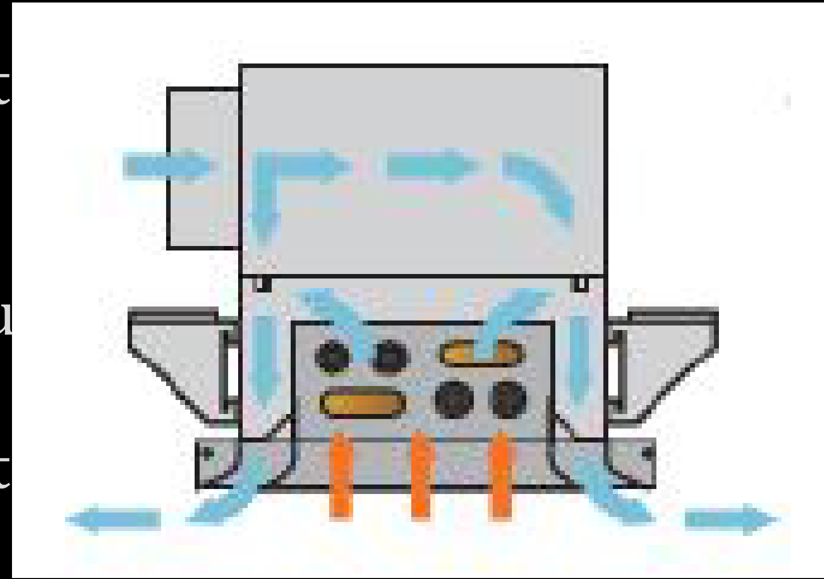
Yes

Background Information

- Building Introduction
- Proposed Solutions and Goals
- Depth 1 – VAV System
- **Depth 2 – Chilled Beam System**
  - **Background Information**
  - Energy Analysis
  - Energy Costs
  - Chilled Beam Calculation
  - First Cost
  - Life-Cycle Cost
  - Recommendation
- Breadth 1 – Structural
- Conclusion
- Questions/Comments

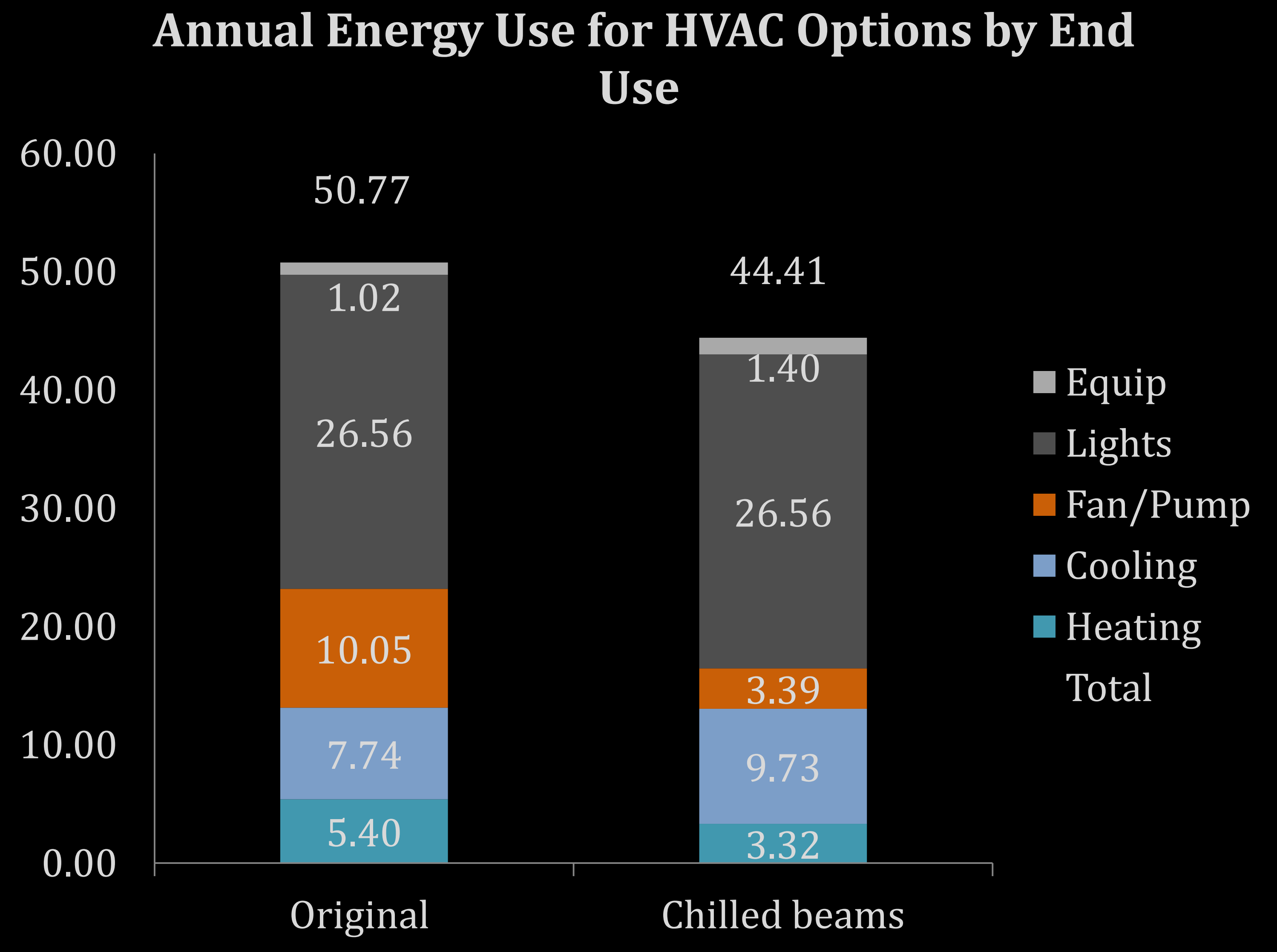
- Active chilled beams shall supply conditioned air to the spaces
- Water-to-water heat pumps combined with geothermal system

- Procedure:
  - Schedules and rooms were inputted into Trane TRACE
  - Calculat s for energy usage
  - Size equ
  - Calculat d size
  - Determine annual costs and first costs
  - Compare results to original



ACBL © Price Industries Limited 2011

Energy Analysis



- 12.4% decrease in end use
- 66.3% decrease in fan energy
- Primary airflow decreases by 65%

	Electricity (kWh)	Natural Gas (kBtu)	Total (kBtu/yr)
Original	917,790	66,748	3,199,165
Chilled Beams	810,230	31,113	2,798,427

- 11.7% decrease in electricity
- 53.4% decrease in natural gas

Energy Costs

- Utility Rates taken from Xcel Energy
- Electricity Costs:
  - $11.19/kW from June to Sept.
  - $7.79/kW from Oct. to May
- Natural Gas Costs:
  - $0.59/therm from April to Oct.
  - $0.65/therm from Nov. to March

Annual Utility Breakdown		
Source	**Energy (10^6 Btu/yr)**	**Cost ($/yr)**
Electricity	2,765.3	64,953.16
Gas	33.1	556.70
Total	**2,798**	**65,509.85**

Chilled Beam Calculation

- Taken from Trace:
  - $Q_{T(sensible)}$ = 6,480 Btu/hr
  - $Q_{T(latent)}$ = 1,000 Btu/hr
- Based on ASHRAE 62.1: V_r = 85 cfm
- Room conditions:
  - T_r = 75°F
  - w_r= 0.0100 lbw/lbda
- Air conditions:
  - T_v = 55°F
  - w_v= 0.0090 lbw/lbda

- Cooling capacity of air:
  - $Q_{(latent)}$ = 411 Btu/hr
  - $Q_{(sensible)}$ = 1,836 Btu/hr
- $Q_{T(latent)} > Q_{(latent)}$ therefore, need to recalculate V(cfm)
  - V=207 cfm
  - $Q_{(sensible)}$ = 4,463 Btu/hr
- Selection made from Price manufacturer:
  - 210 cfm per beam
  - Beam length of 6 ft
  - 7,059 Btu/hr per beam
  - # of beams needed = 210/207=1

- Total of 546 lf of chilled beams needed

First Cost

- Chilled beam first cost:
  - $2,549,100.00
  - $56.65 per square foot
- Included:
  - Geothermal wellfield & piping
  - Water -to-water heat pumps
  - DOAS unit
  - Chilled beams
- Original system first cost: $2,031,979
- 20.3% increase

System Components	Component Costs
Geothermal wellfield & piping	$408,000.00
Water-to-water heat pumps	$224,000.00
DOAS	$58,000.00
Chilled Beams	$177,450.00
Boiler	$81,600.00
Pumps	$7,500.00
Valving	$50,000.00
Exhaust Fans	$52,100.00
Unit heaters & misc.	$37,500.00
Air Distribution	$784,600.00
Hydronic piping	$327,600.00
Controls	$390,750.00

Life-Cycle Cost

- 30 year life-cycle cost
- System was analyzed based on:
  - Capital Investment
  - Overhaul
  - Maintenance
  - Annual electric and natural gas costs
  - Escalation Factors

Maintenance ($)	Annual Electricity Costs ($)	Annual Natural Gas Costs ($)	OMB Base Discount Rate (%)
36,470.00	63,951.48	524.13	3.0

- Total net present value: $ 5,678,296.01
- 12.2% increase

	Original	Chilled Beam
HVAC System First Cost	$2,031,979.00	$2,549,100.00
Annual Maintenance Cost	$52,100.00	$36,470.00
Replacements Costs: 5	-	-
10	-	-
15	$275,500.00	$89,600.00
20	$372,479.00	$622,250.00
25	$81,600.00	$259,050.00
30	$275,500.00	$147,600.00
Annual Recurring Electric	$73,720.36	$63,951.48
Annual Recurring Natural Gas	$817.27	$524.13
Total Energy Costs	$74,537.63	$64,475.61

Recommendation

- Decrease of energy consumption and usage
  - 12.5% overall
  - 66.3% for fan and pump energy
  - 38.5% for heating
  - 65% for primary airflow
- $9,768.88 less spent on electricity annually
- Total first cost: $2,549,100.00
- Payback period of 52 years
- Is this a good option?

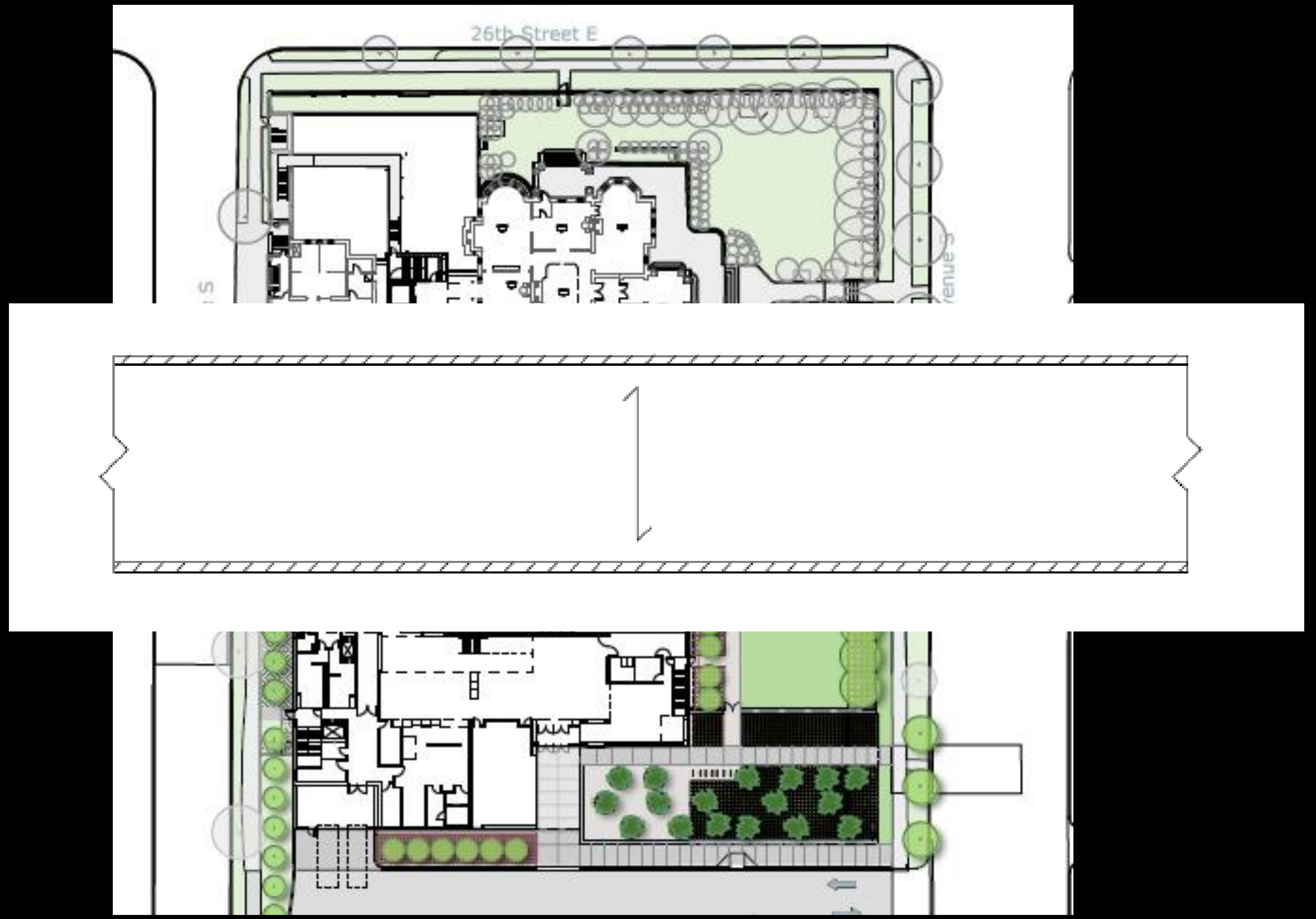
Yes

Structural Overview

- Building Introduction
- Proposed Solutions and Goals
- Depth 1 – VAV System
- Depth 2 – Chilled Beam System
- **Breadth 1 – Structural**
  - **Structural Overview**
  - Original Roof Deck Analysis
  - Extensive Green Roof Analysis
  - Recommendation
- Conclusion
- Questions/Comments

Analysis:

- Calculations were completed for the original roof
- Dead loads
- Flat roof snow load
- Roof live load
- Weights from LiveRoof Hybrid Green Roof System manufacturer
- Total loads based on factored load equation
- Comparison of new loads to original



Original Roof Deck Analysis

- Dead Load: D = 25 psf
  - Metal deck, rigid insulation, built up roofing, misc. dead load
- Snow Load: S =35 psf
- Live Load: L_r = 20 psf
- Calculated Factored Load: R_u = 86 psf

- Decking selection:
  - Use 3N18, 1 span of 8’-4”
- Check:
  - Max. SDI Construction Span = 15’-11” > 8’-4”
  - For 10’-0” Total Load = 91 psf >86 psf

No. of Spans	Deck Type	Max. SDI Const. Span	10–0
1	N22	11'-7	50 / 43
	N20	13'-2	66 / 56
	N19	14'-7	79 / 69
	N18	15'-11	91 / 81
	N16	18'-6	118 / 110

Vulcraft Steel Roof and Floor Deck Catalog 2008

Extensive Green Roof Analysis

- Dead Load: D = 31 psf
  - Metal deck, rigid insulation, fenestration system, green roof (lite) saturated, misc. dead load
- Snow Load: S =35 psf
- Live Load: L_r = 20 psf
- Calculated Factored Load: R_u = 94 psf

- Decking selection:
  - Use 3N16, 1 span of 8'-4"
- Check:
  - Max. SDI Construction Span = 18'-6" > 8'-4"
  - For 10'-0" Total Load = 118psf >94 psf

No. of Spans	Deck Type	Max. SDI Const. Span	10-0
1	N22	11'-7	50 / 43
	N20	13'-2	66 / 56
	N19	14'-7	79 / 69
	N18	15'-11	91 / 81
	N16	18'-6	118 / 110

Vulcraft Steel Roof and Floor Deck Catalog 2008

Recommendation

Roof Type	Deck	Dead Load	Roof Live Load	Snow Load	Factored Load
Original	**3N18**	29	20	35	91
Extensive	**3N16**	34	20	35	97
Intensive (Opt. 1)	**2VLI16**	119	100	35	303
Intensive (Opt. 2)	**3VLI16**	119	100	35	303
Intensive (Opt. 3)	**1.5VLI18**	105	100	35	286

- Increase in loads
  - Extensive: 6.2%
  - Intensive Opt .1 and 2: 70%
  - Intensive Opt. 3: 68%
- Selection: Extensive green roof
  - Smallest increase in loads
  - 8 psf increase in factored loads

Conclusion

- Conclusions for depth :

	VAV (%)	Chilled Beam (%)
End Use	(15.1)	(12.5)
Heating	(31.3)	(38.5)
Cooling	(16.9)	20.5
Fan/Pump	(46.4)	(66.3)
FC	17.4	20.3
LLC	3.9	12.2
SPB	33 years	52 years

- Mechanical system recommendation: VAV

- Conclusion for Structural breadth: Extensive green roof
  - Roof decking 3N16

Acknowledgements

AE Faculty

HGA Architects and Engineers

The American Swedish Institute

Friends and Family

Questions?

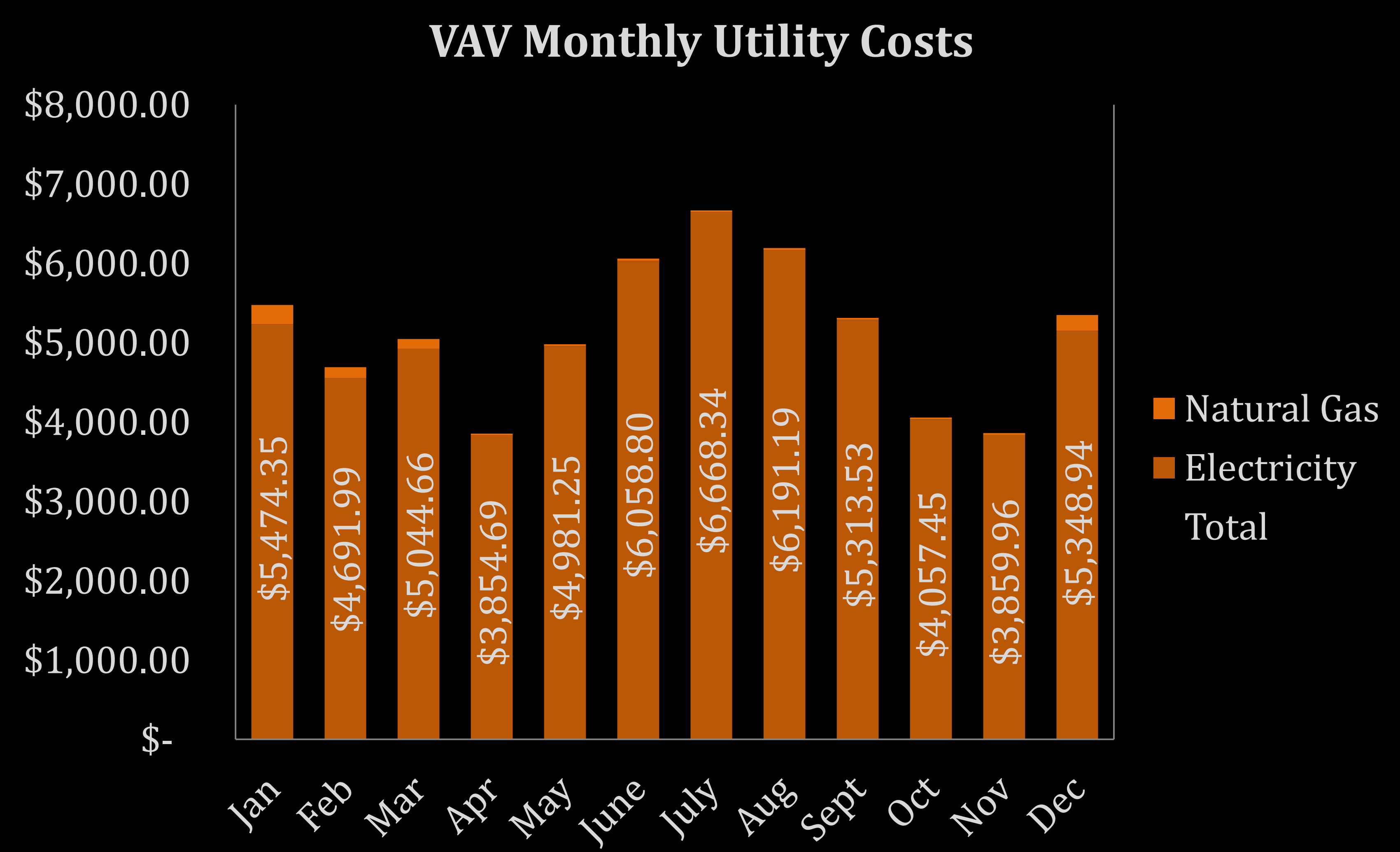
Occupancy Schedule

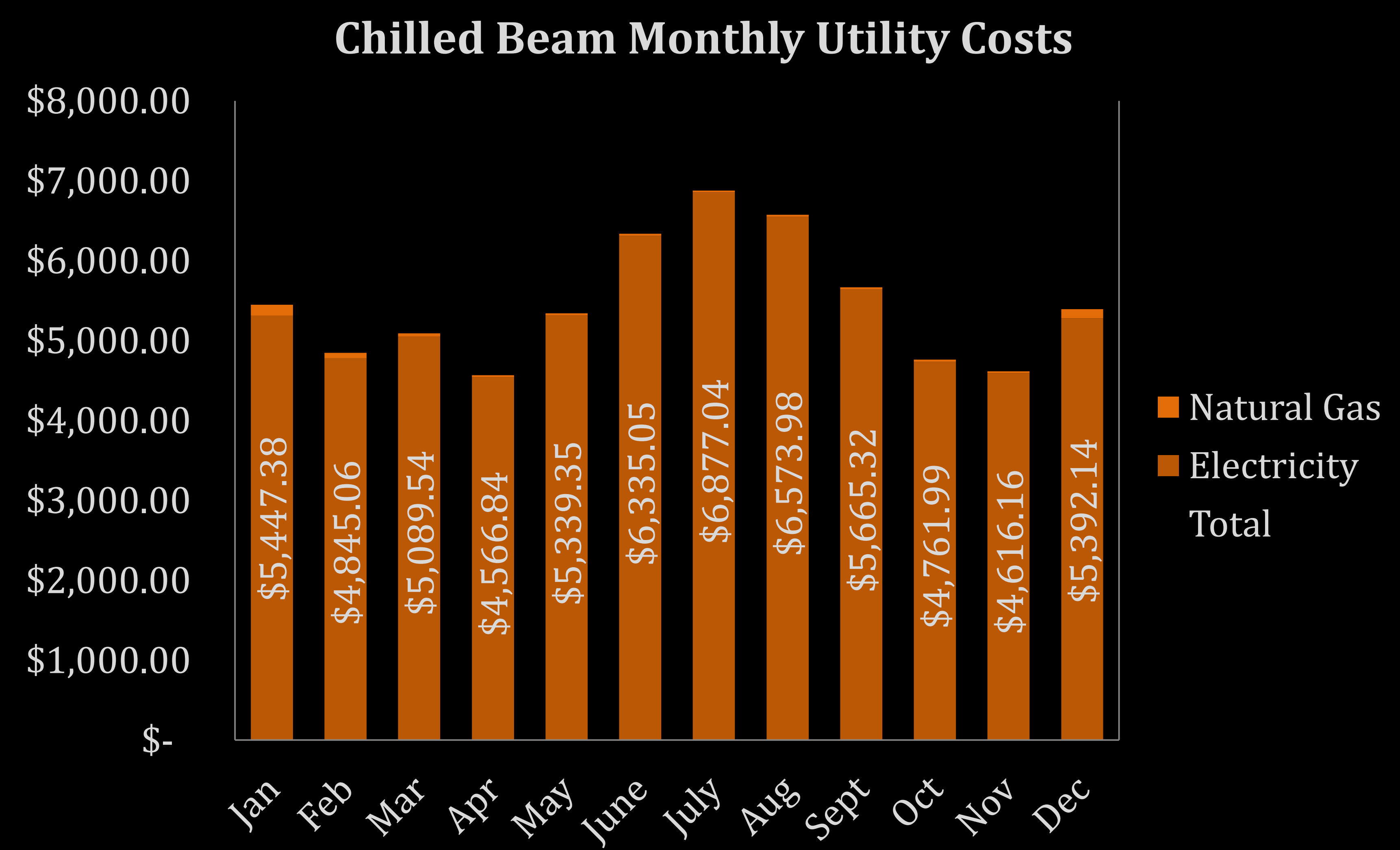
Cooling Design Weekday Schedule		
Start Time	**End Time**	**Percentage**
Midnight	5 a.m.	30
5 a.m.	6 a.m.	60
6 a.m.	7 a.m.	90
7 a.m.	8 p.m.	100
8 p.m.	9 p.m.	90
9 p.m.	10 p.m.	60
10 p.m.	Midnight	30

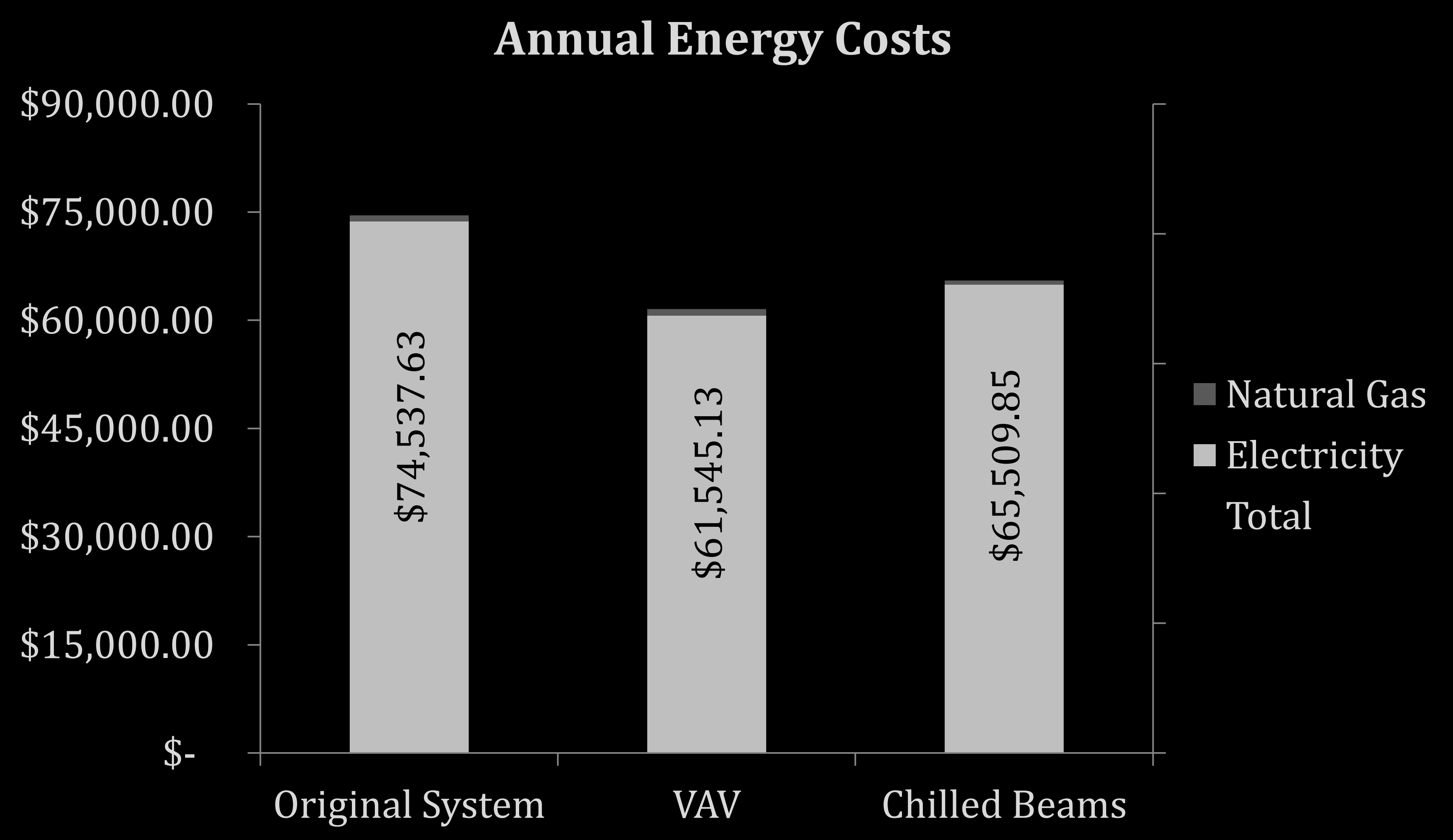
Heating Design Schedule		
Start Time	**End Time**	**Percentage**
Midnight	Midnight	100

Saturday and Sunday Schedule		
Start Time	**End Time**	**Percentage**
Midnight	5 a.m.	30
5 a.m.	7 a.m.	60
7 a.m.	9 a.m.	90
9 a.m.	6 p.m.	100
6 p.m.	8 p.m.	90
8 p.m.	9 p.m.	60
9 p.m.	Midnight	30

Energy Costs







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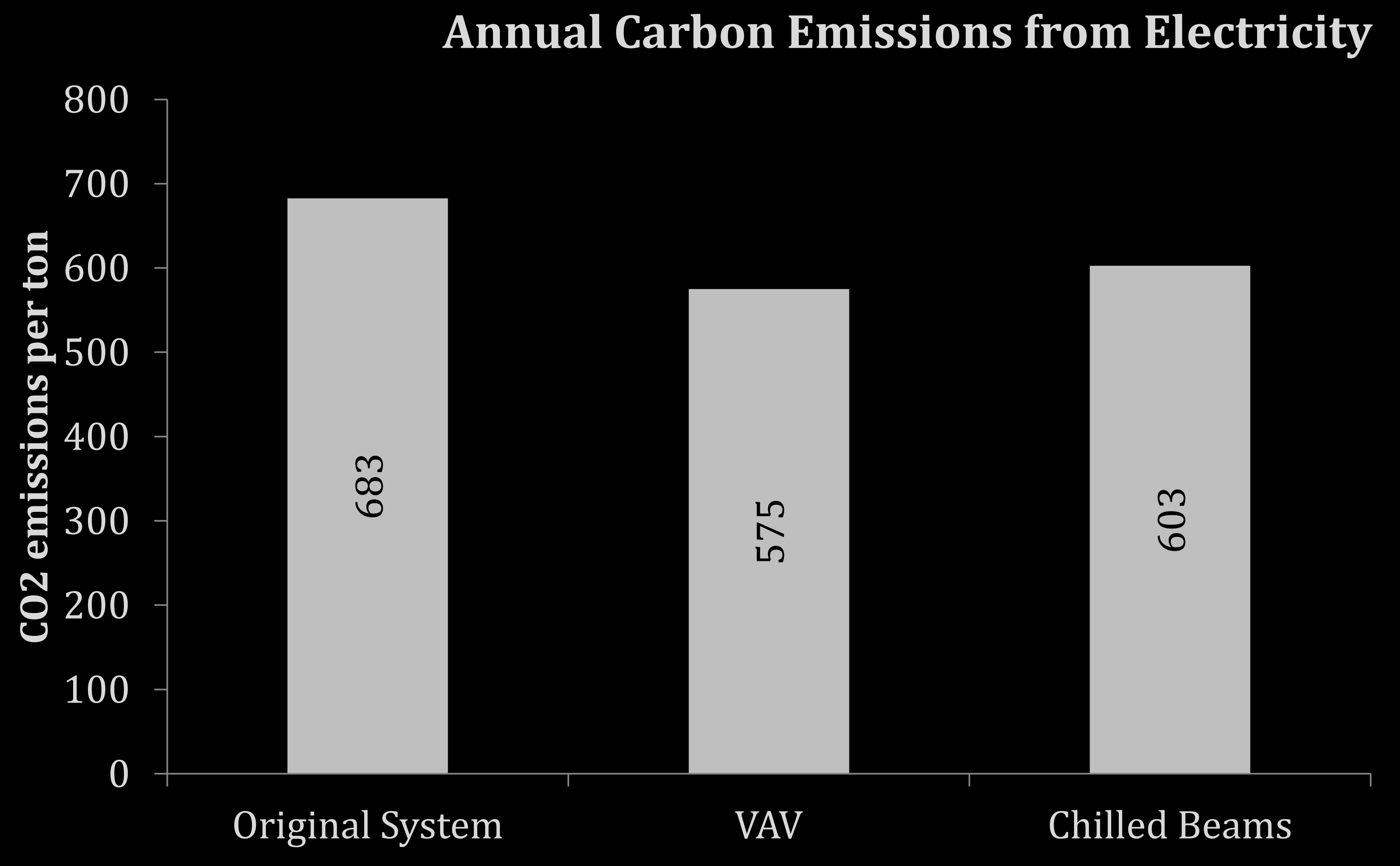
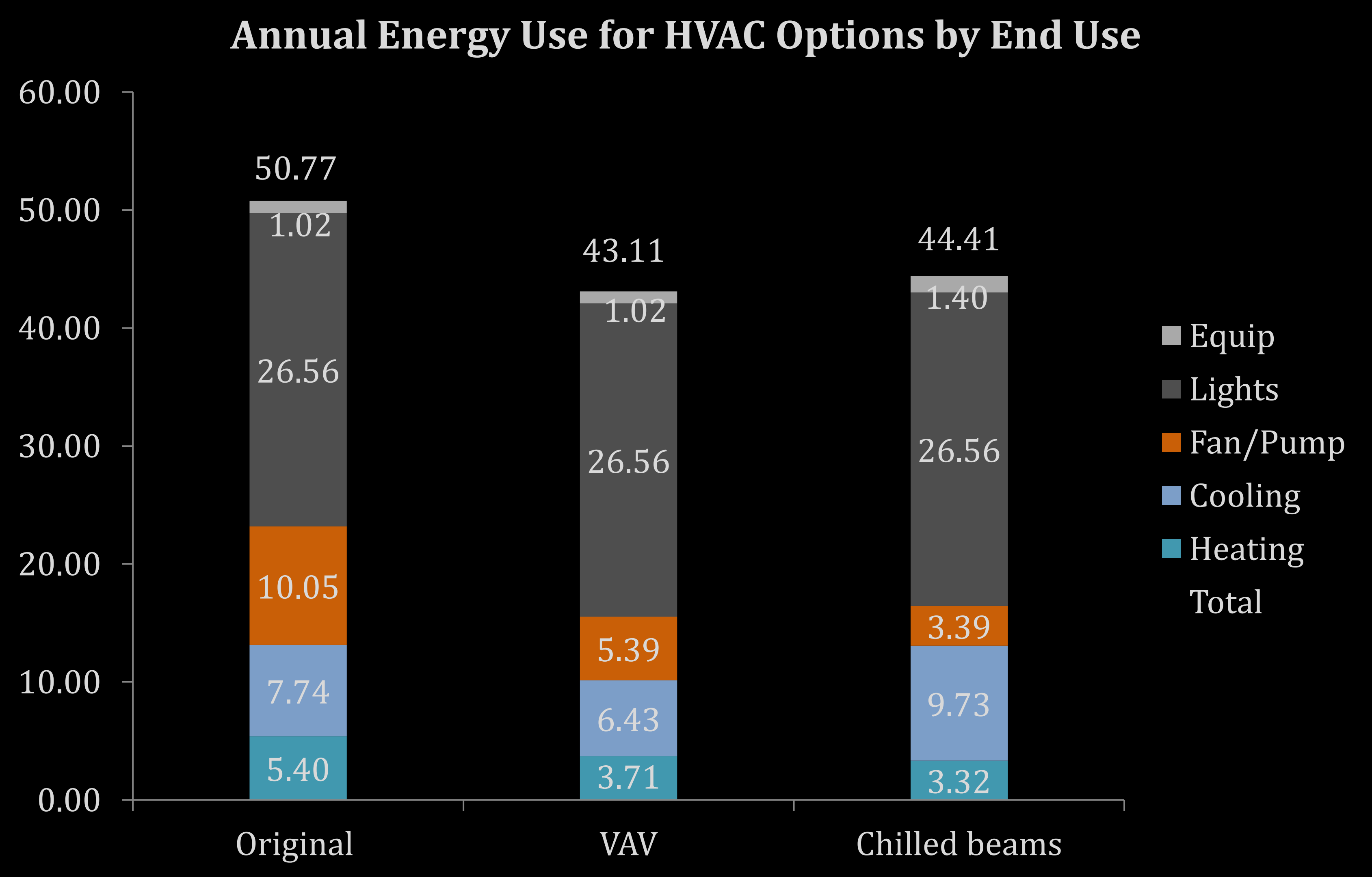
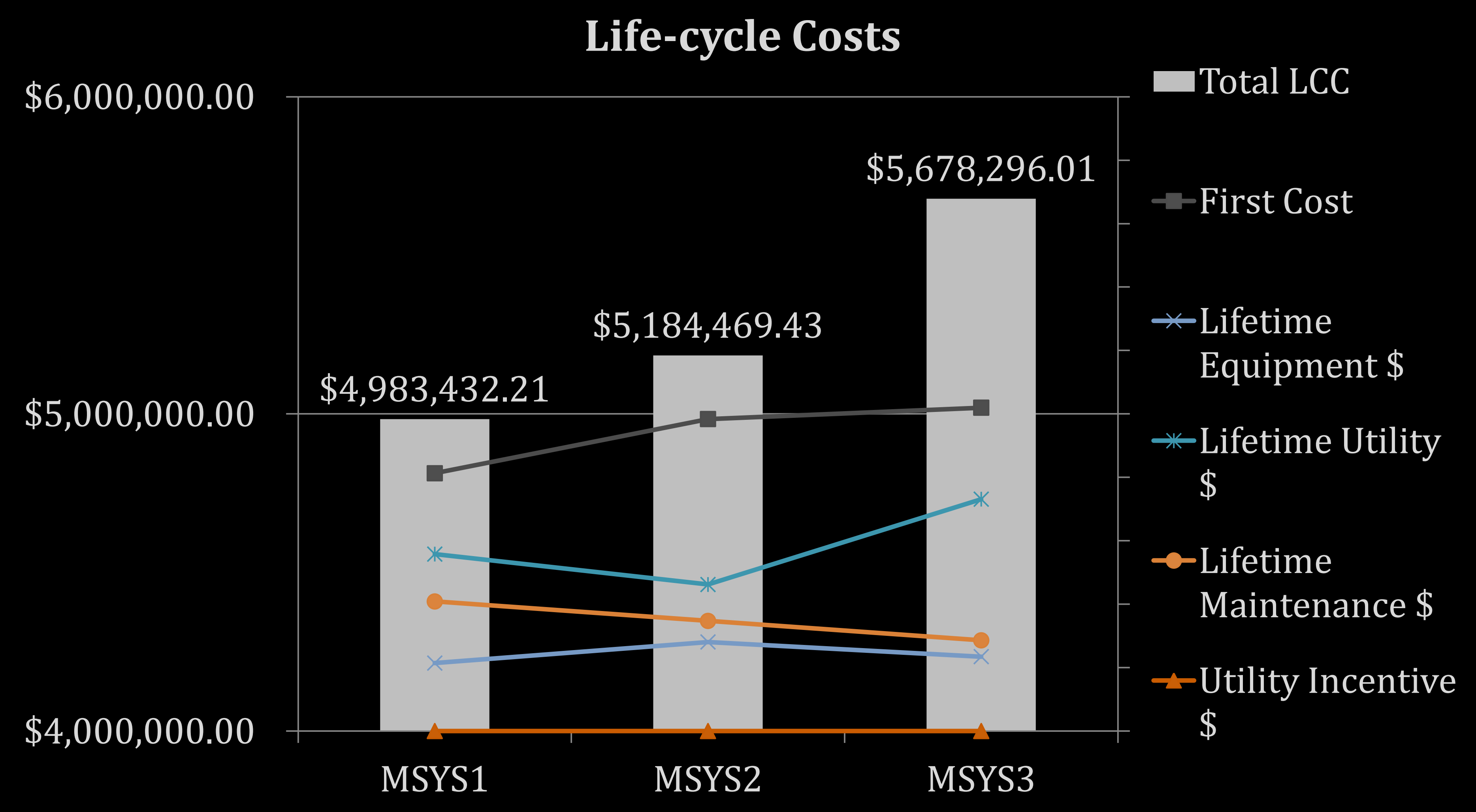
Emissions and Energy Usage

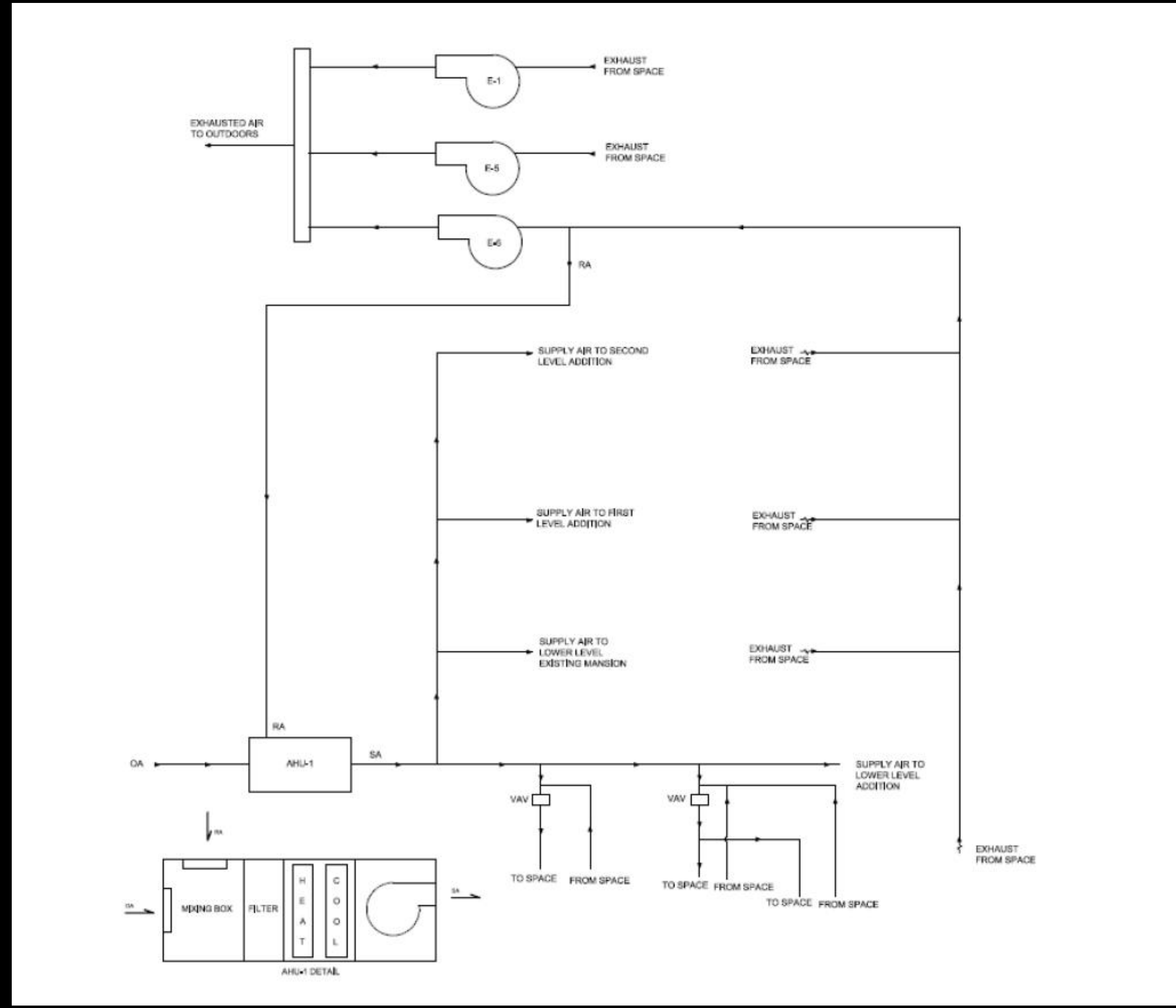




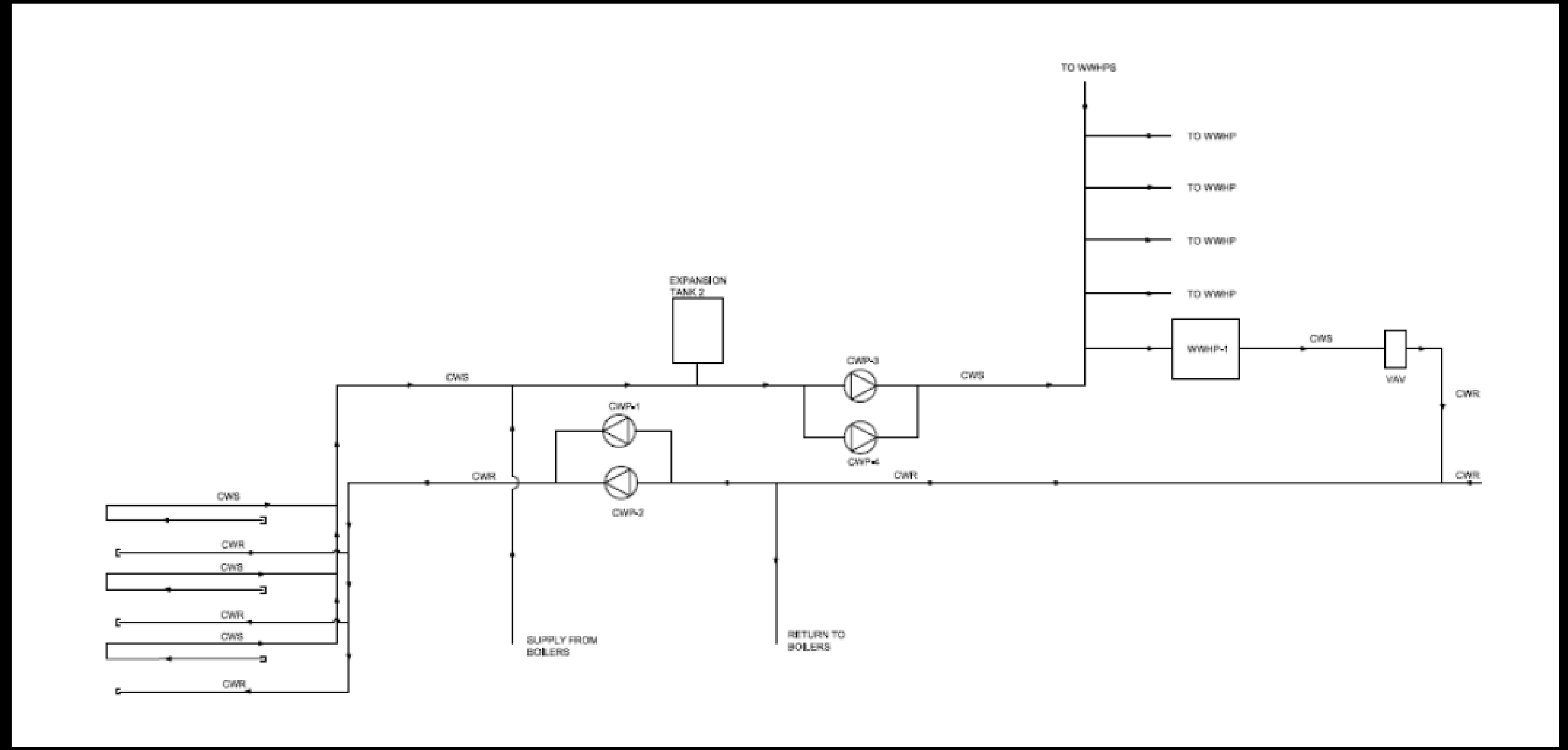
Life-Cycle Cost



VAV Schematic

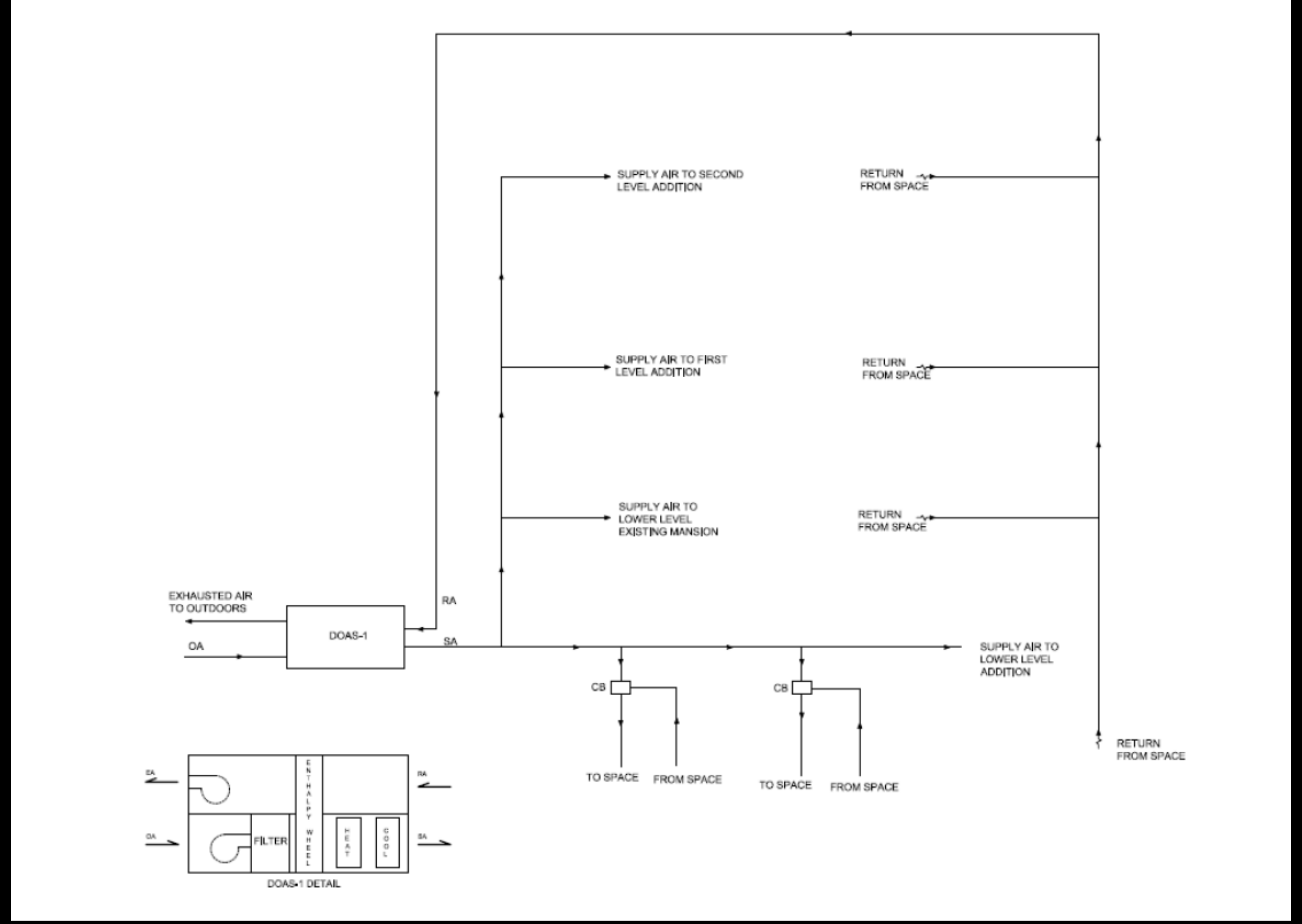


Ventilation Schematic for VAV

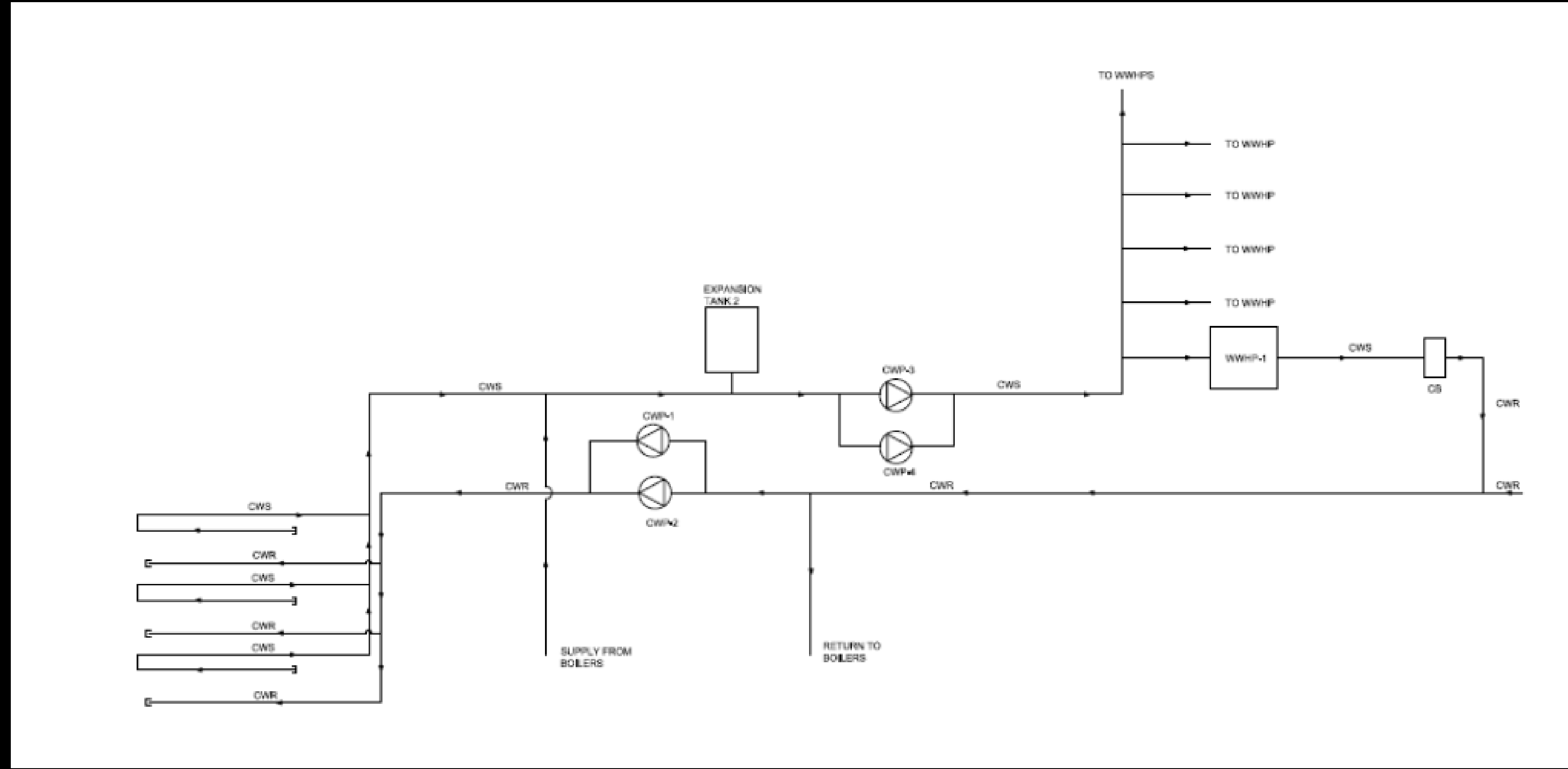


Geothermal Schematic for VAV

Chilled Beam Schematics



Ventilation Schematic for Chilled Beams



Geothermal Schematic for Chilled Beams

Chilled Beam Full Calculation

- Chilled Beam Calculation:
- Taken from Trace:
  - $Q_{T(sensible)}$ = 6,480 Btu/hr
  - $Q_{T(latent)}$ = 1,000 Btu/hr
  - Q_{total} = 7,480 Btu/hr
- Type of room based on ASHRAE Std. 62.1-2007, Table 6.1: Library:
  - Rp = 5 cfm/person
  - Pz = 500(ft^2)*10/1000(# person/ft^2) = 5 person
  - Ra = 0.12 cfm/ft^2
  - Az = 500 ft^2
  - Ez = 1
    - Vr(cfm) = Rp*Pz+Ra*Az = 5*5+0.12*500 = 85 cfm

- Room conditions:
  - T_r = 75°F
  - w_r= 0.0100 lbw/lbda
- V conditions:
  - T_v = 55°F
  - w_v= 0.0090 lbw/lbda
- Calculated values:
  - $Q_{(latent)}$ = 4840*cfm*(w_r - w_v)
  - $Q_{(latent)}$ = 4840*85*(0.01-0.009) = 411 Btu/hr
  - $Q_{(sensible)}$ = 1.08*cfm *(T_r - T_v)
  - $Q_{(sensible)}$ = 1.08*85*(75-55) = 1,836 Btu/hr
- $Q_{T(latent)} > Q_{(latent)}$ therefore, need to recalculate V(cfm)
  - V= [$Q_{T(latent)}$]/[4840* (w_r - w_v)]
  - V= [1000]/[4840* (0.01- 0.009)]= 207 cfm

- $Q_{(sensible)}$ = 1.08*207*(75-55) = 4,463 Btu/hr
- Check:
  - $Q_{(sensible)}$ = 6,480Btu/hr-4,463 Btu/hr = 2,017 Btu/hr
- Selection made from Price manufacturer:
  - 210 cfm per beam
  - Nozzle diameter of 0.300 inches
  - Beam length of 6 ft
  - 7,059 Btu/hr per beam
  - # of beams needed = 210/207=1
  - 4.2 inches of head per beam
  - 6 lf of beams needed
- All chilled beam results can be seen in Appendix G of report