Valerie Miller, BAE

Mechanical Option

Advisor: Dr. Freihaut

All renderings from AECOM bridging drawings – www.aecom.com

NASA Langley Research Center
Administration Office Building One (AOB1)

Hampton, VA

Table of Contents

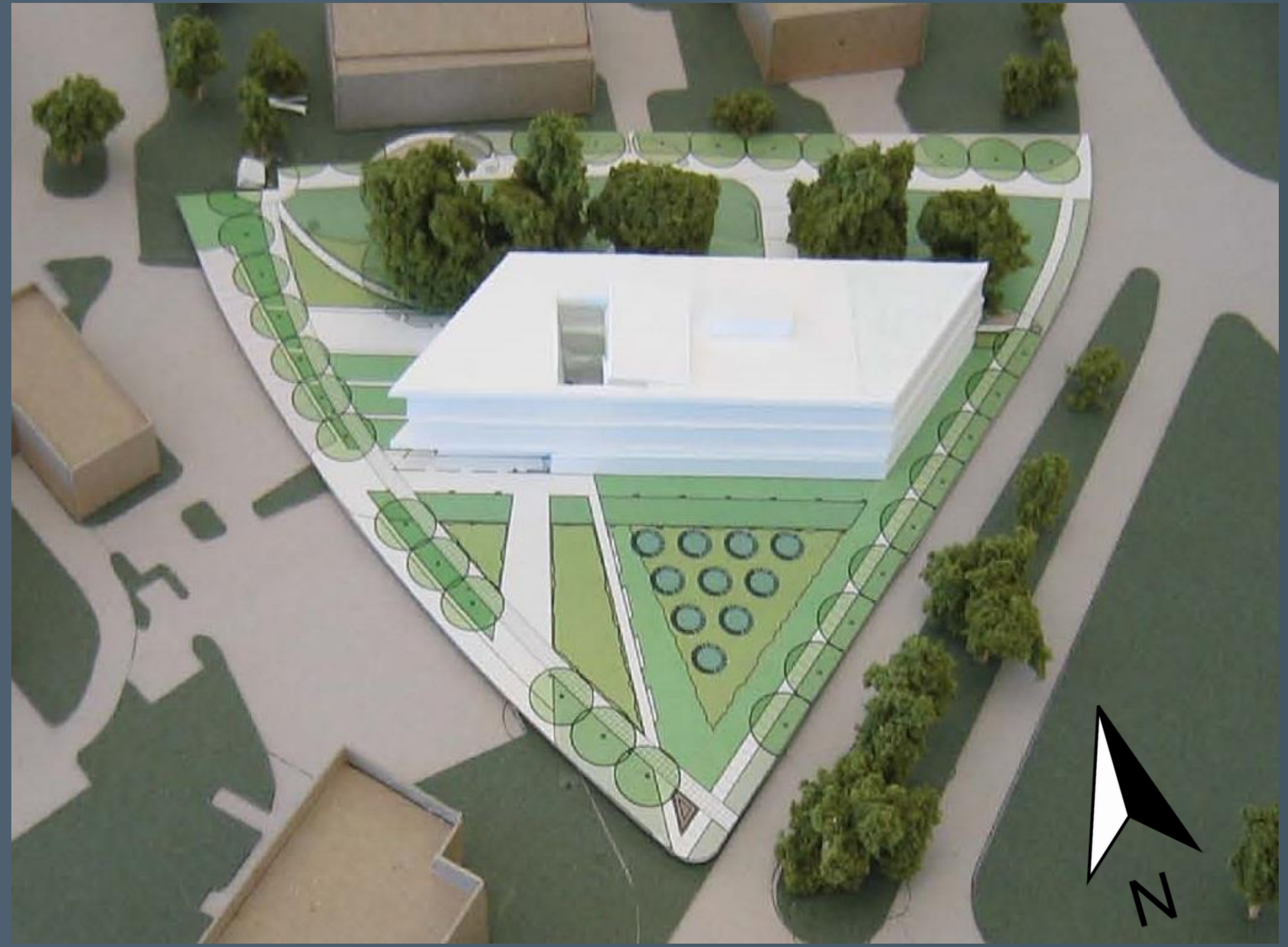
All renderings from AECOM bridging drawings – www.aecom.com

- Owner: NASA & U.S. General Services Administration
- Location: Hampton, VA
- 79,000 ft^2
- 3 stories + penthouse
- LEED Platinum rating
- Cost: $26 million
- Ribbon cutting: June 17, 2011

Table of Contents

All renderings from AECOM bridging drawings – www.aecom.com

- Owner: NASA & U.S. General Services Administration
- Location: Hampton, VA
- 79,000 ft^2
- 3 stories + penthouse
- LEED Platinum rating
- Cost: $26 million
- Ribbon cutting: June 17, 2011



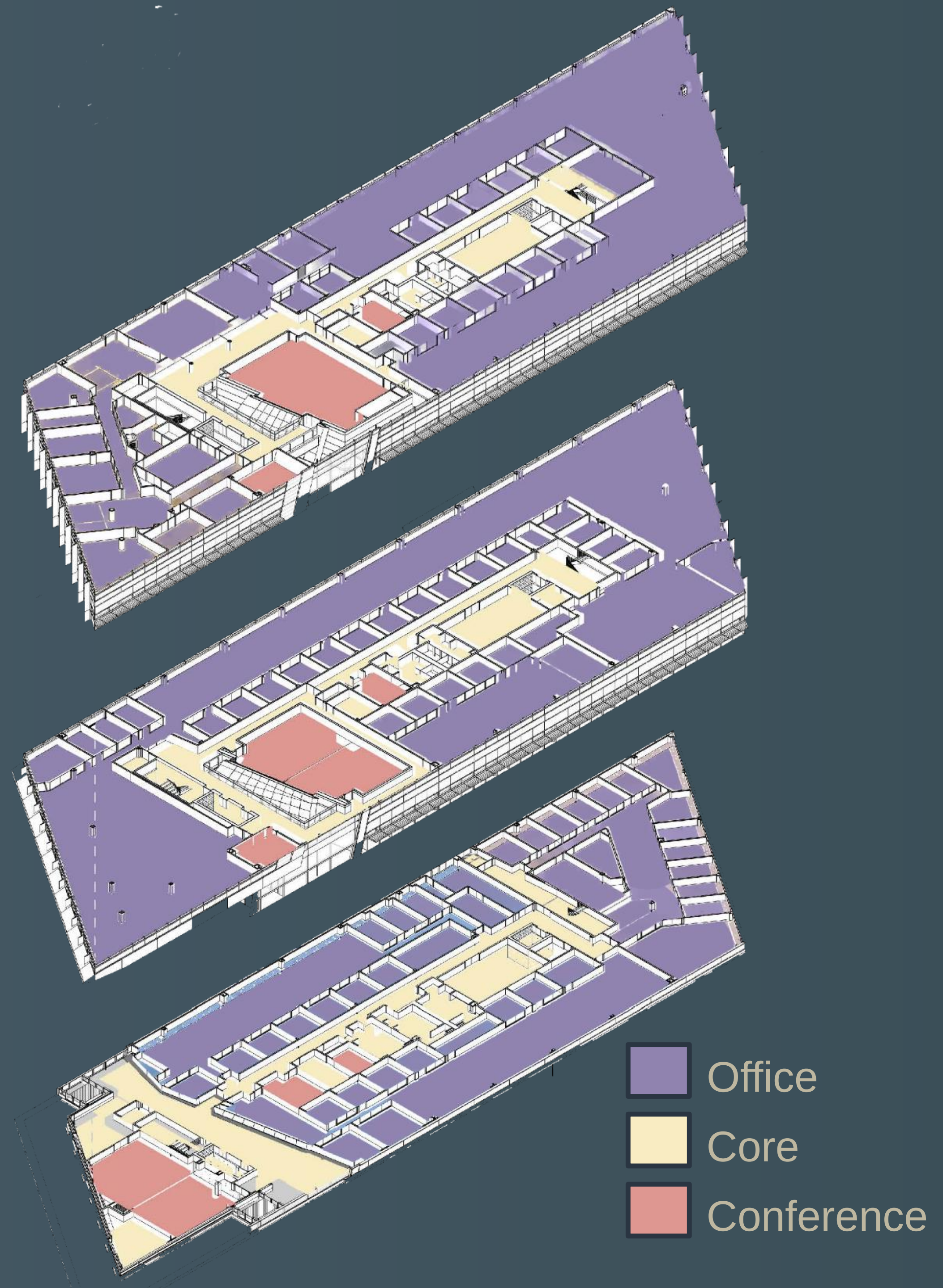
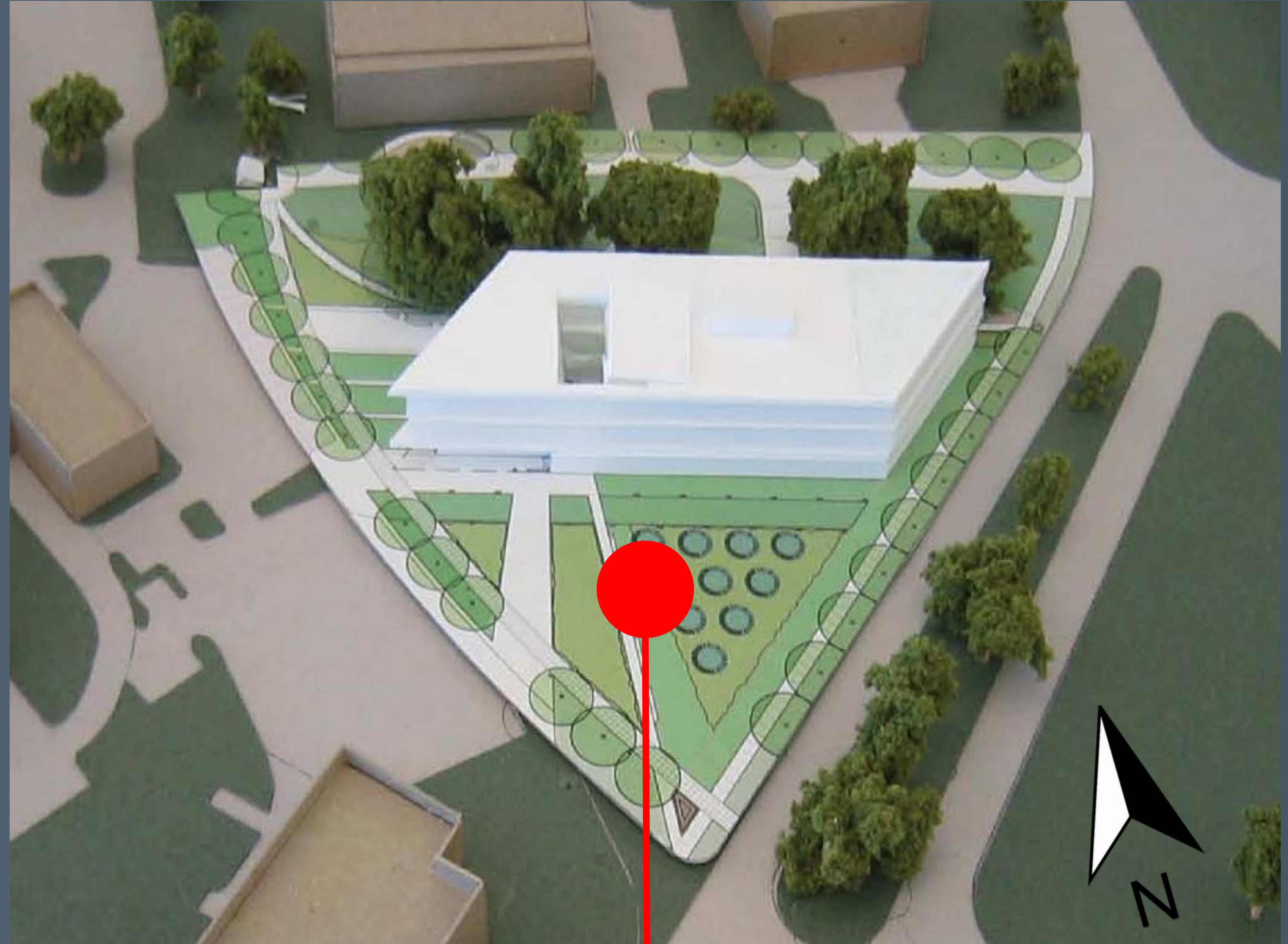


TABLE OF CONTENTS


All renderings from AECOM bridging drawings – www.aecom.com

- Owner: NASA & U.S. General Services Administration
- Location: Hampton, VA
- 79,000 ft^2
- 3 stories + penthouse
- LEED Platinum rating
- Cost: $26 million
- Ribbon cutting: June 17, 2011



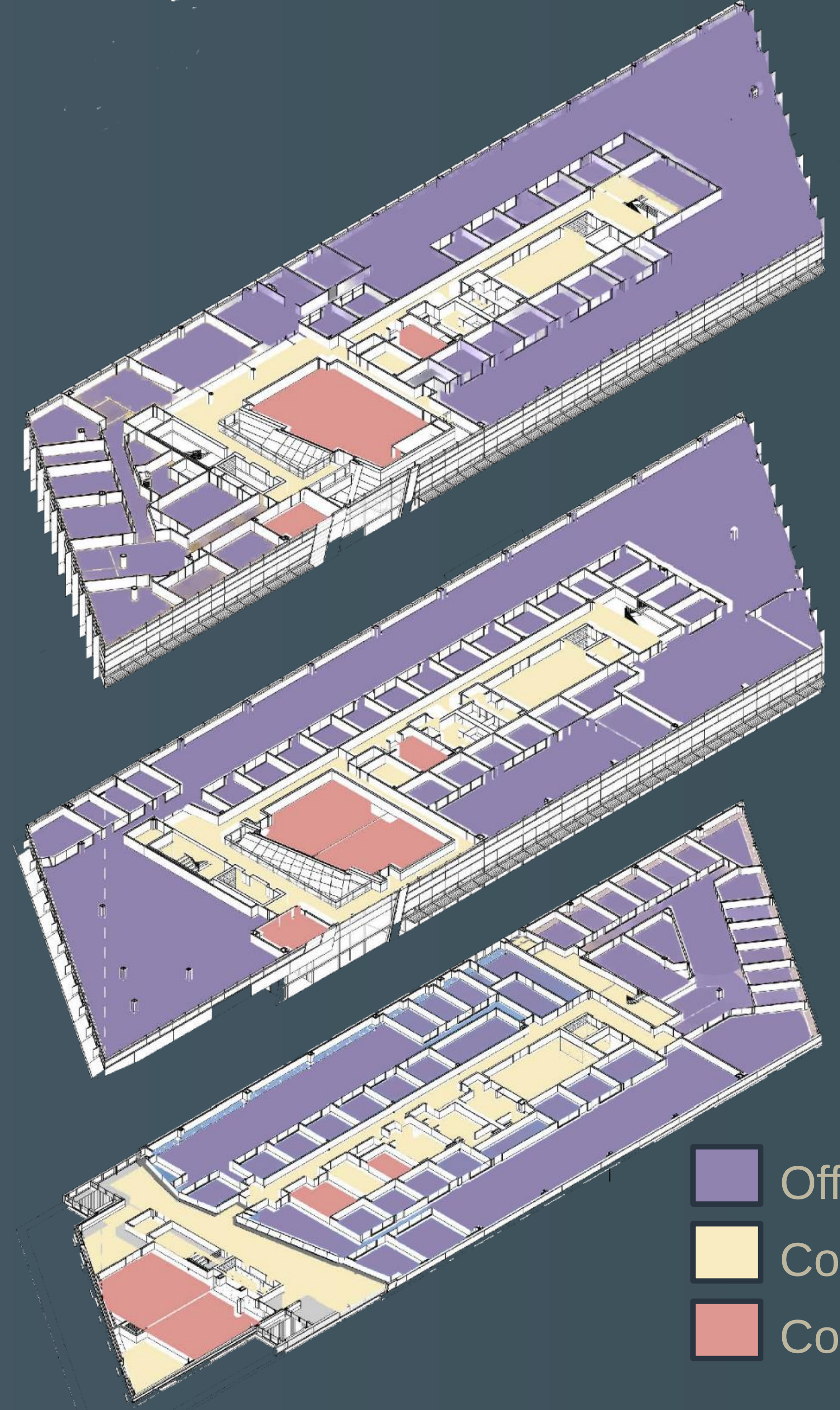


Table of Contents

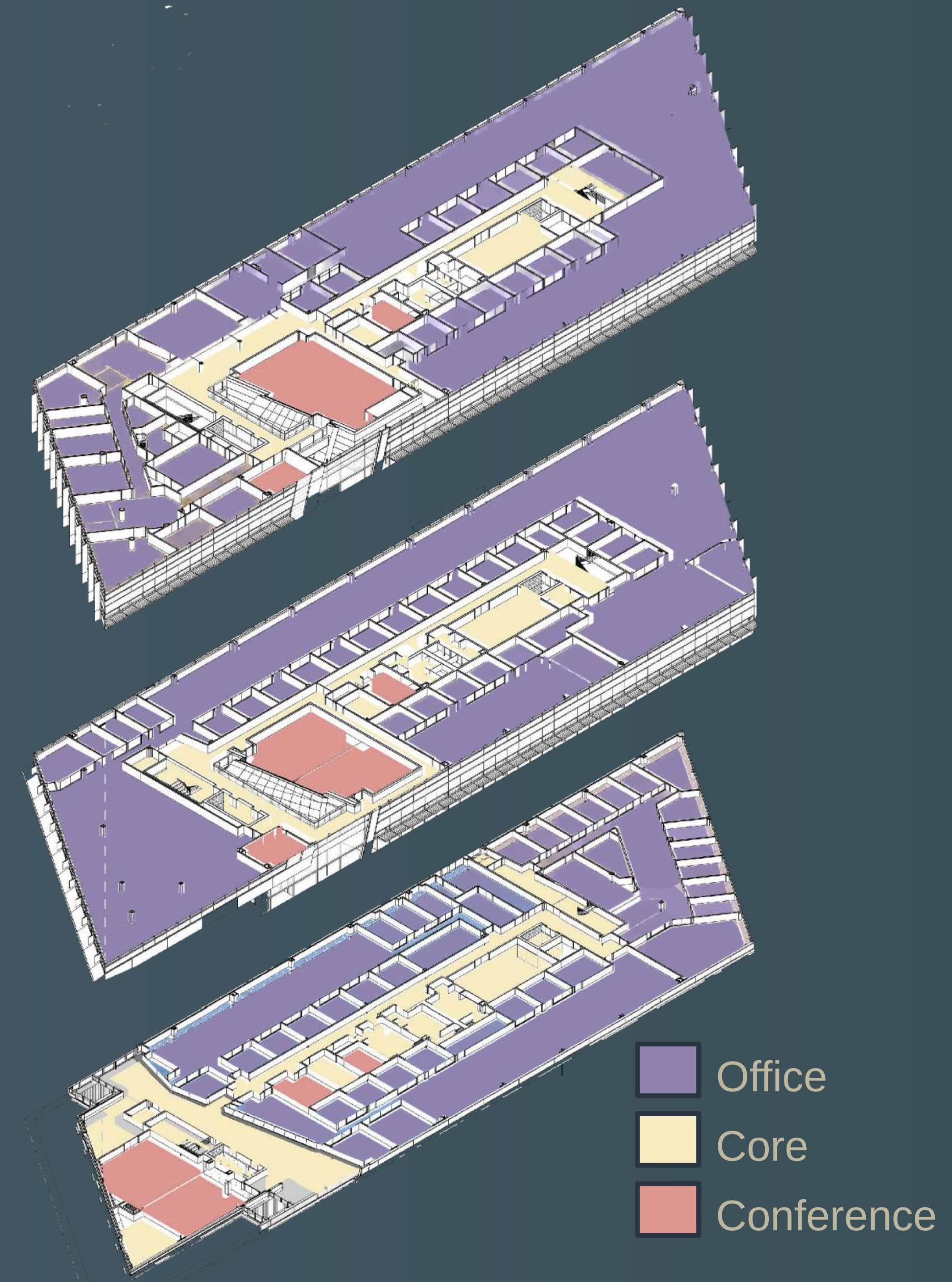


Table of Contents

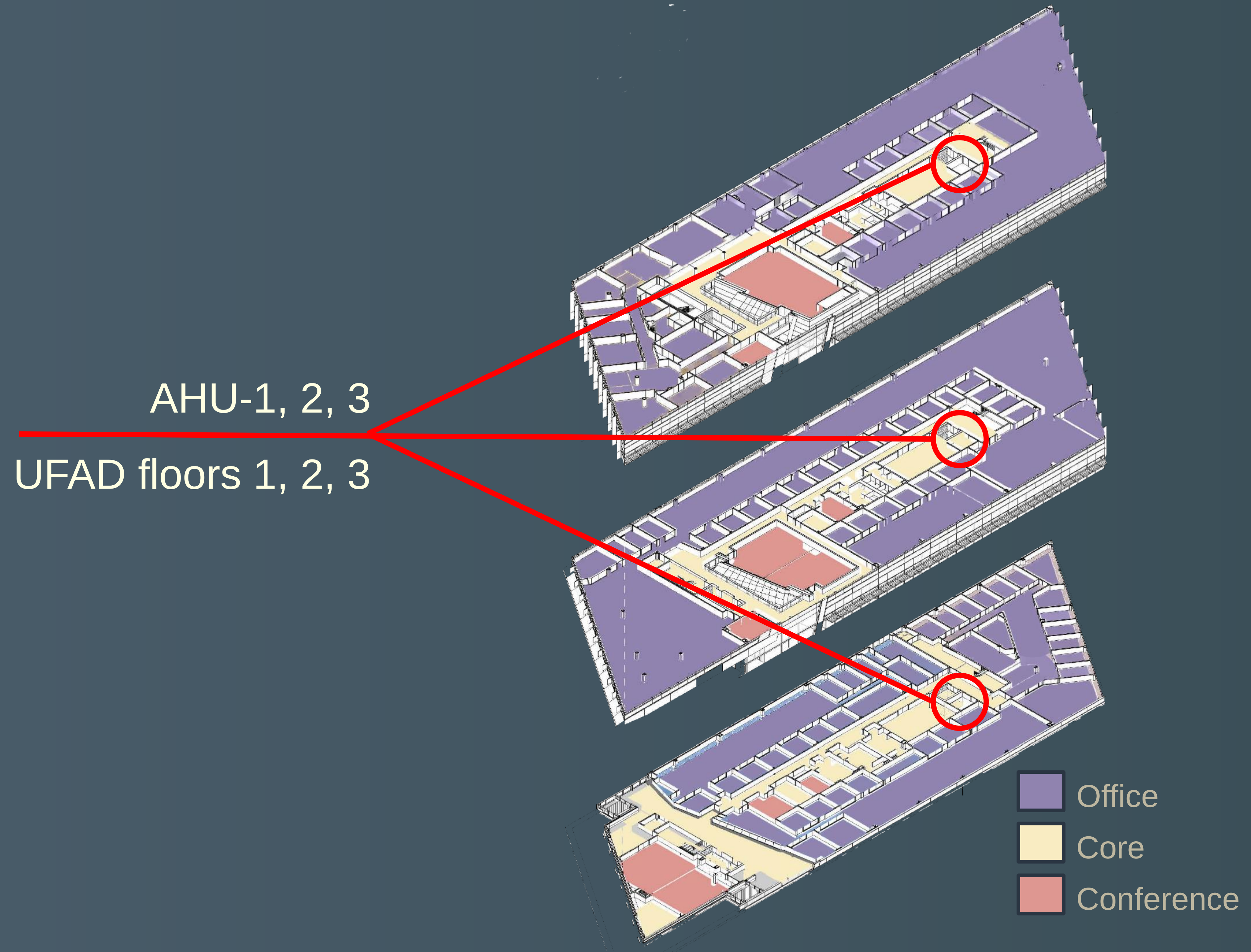


Table of Contents

Penthouse:

AHU-5: Conference 205 and 305

DOAS unit: AHU-1, 2, 3, 5

AHU-1, 2, 3

UFAD floors 1, 2, 3

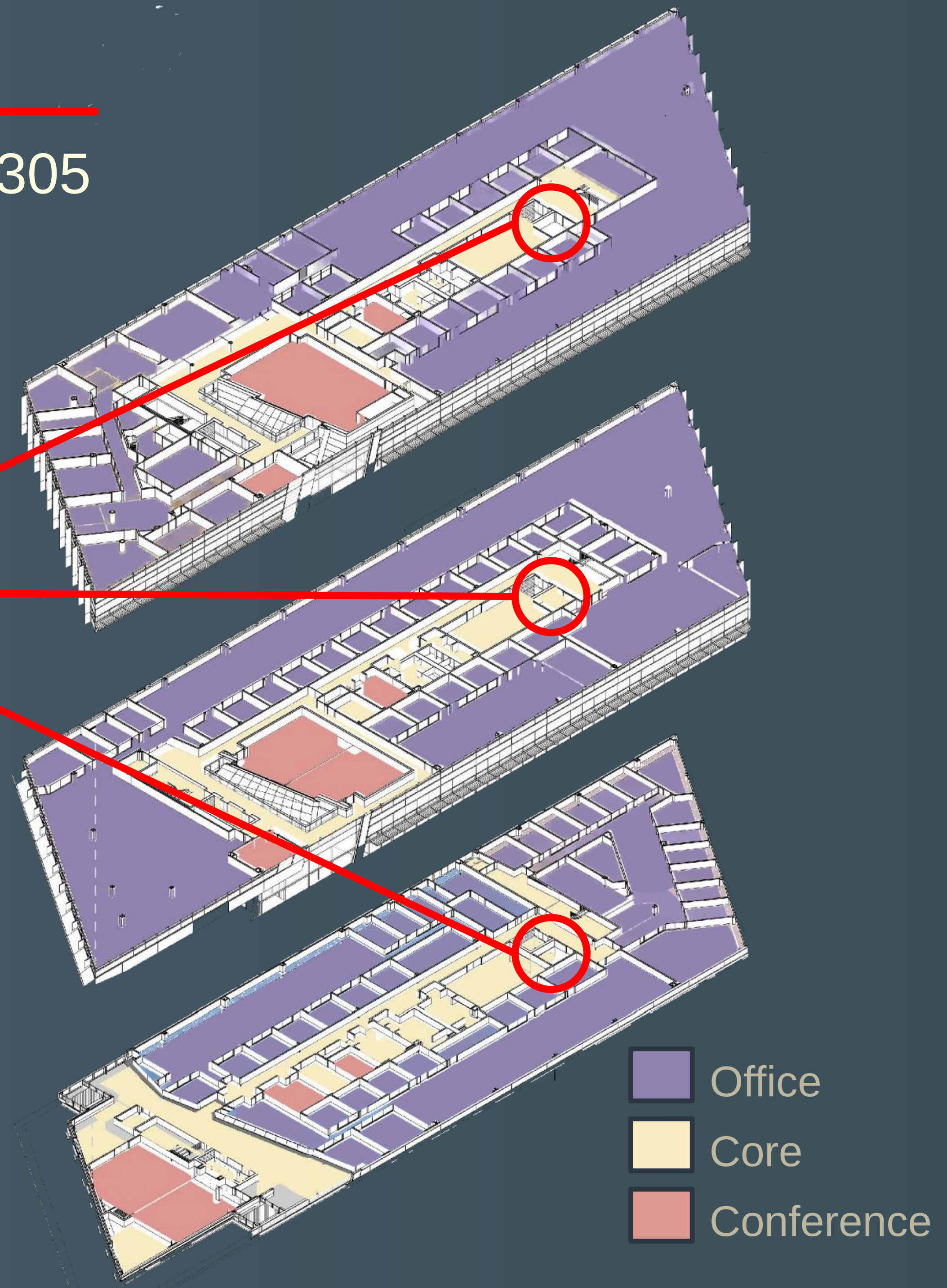


Table of Contents

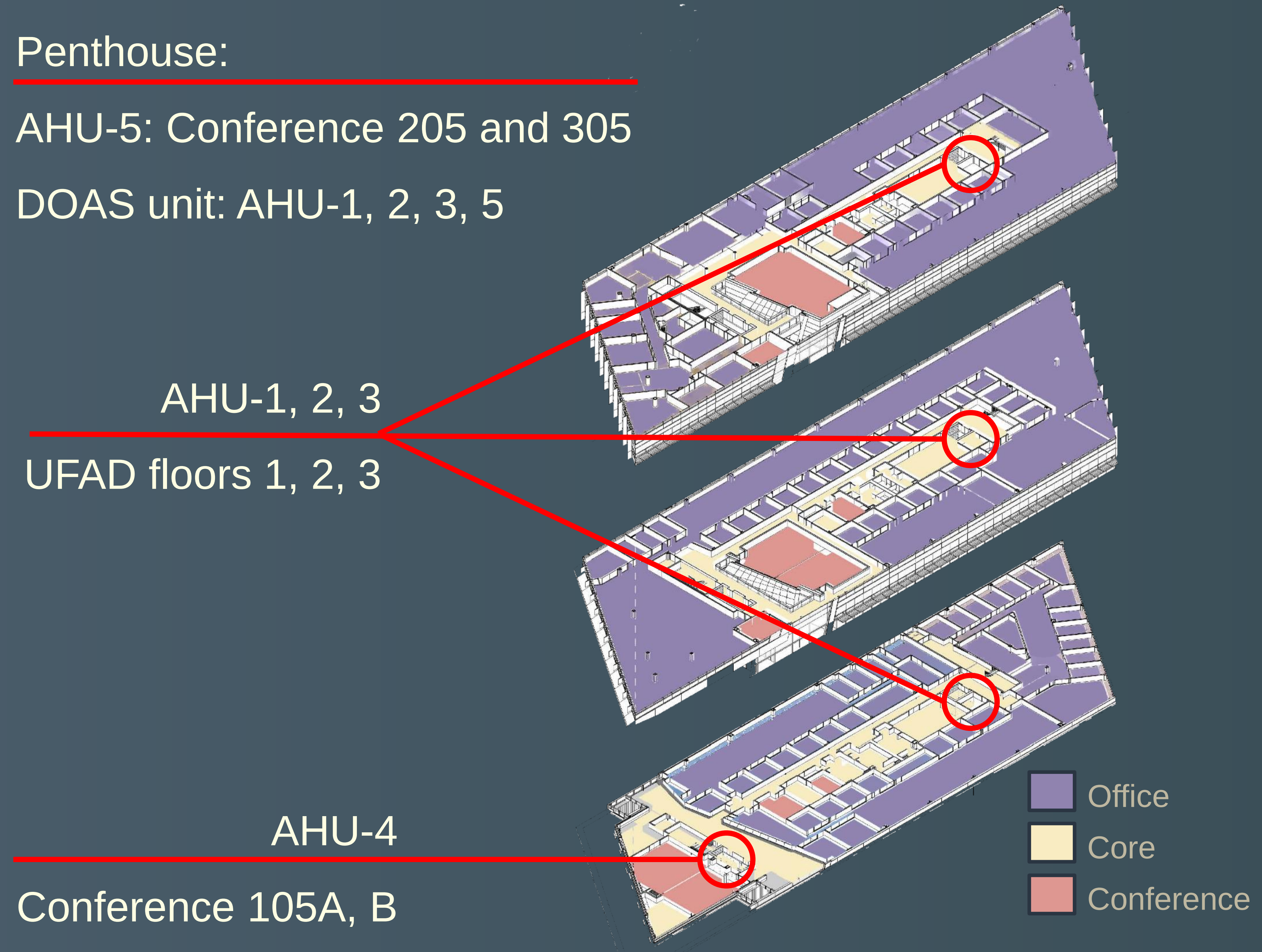
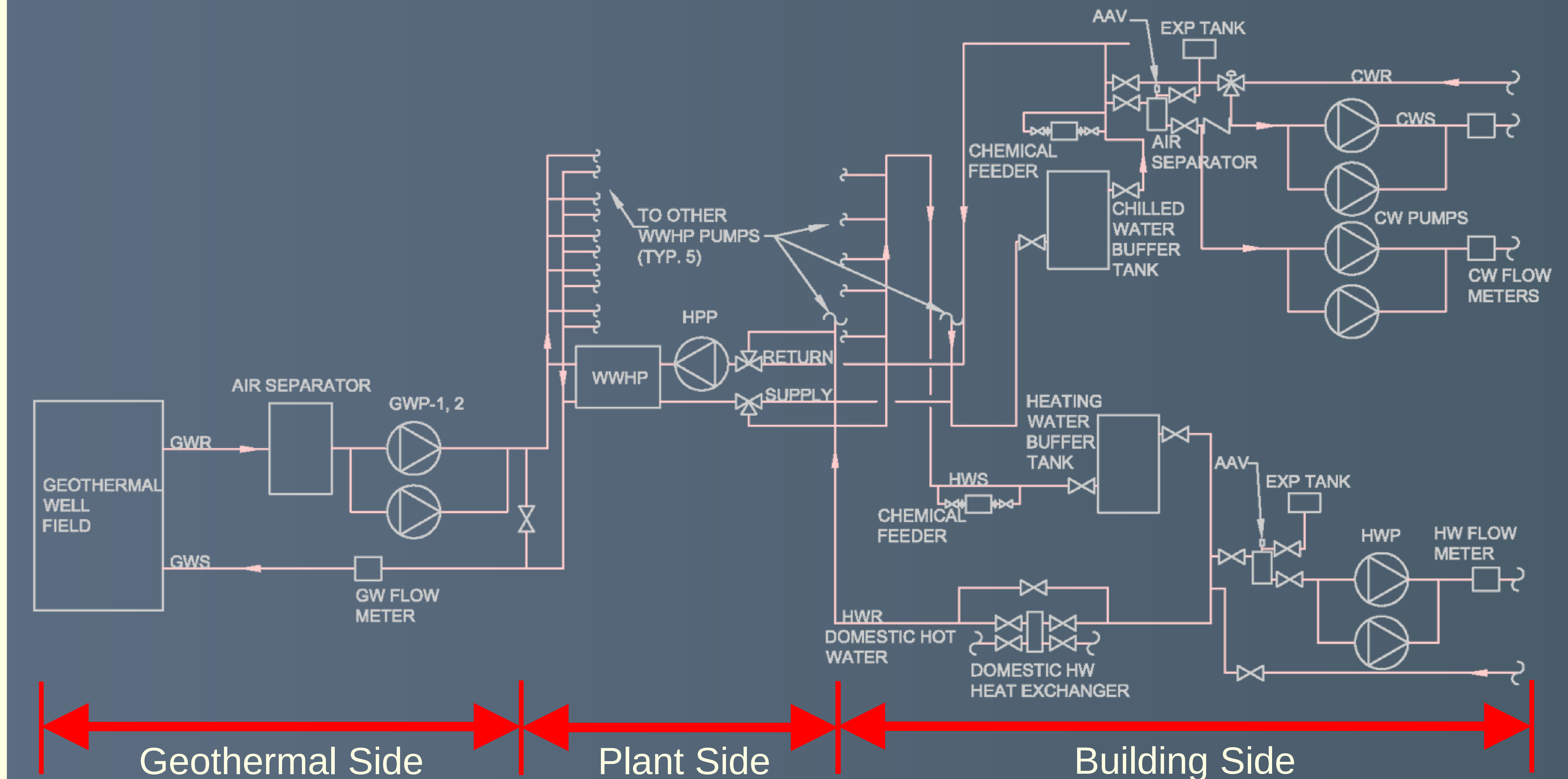


Table of Contents

NASA AOB1 – Valerie Miller



Penthouse:

AHU-5: Conference 205 and 305

DOAS unit: AHU-1, 2, 3, 5

AHU-1, 2, 3

UFAD floors 1, 2, 3

AHU-4

Conference 105A, B

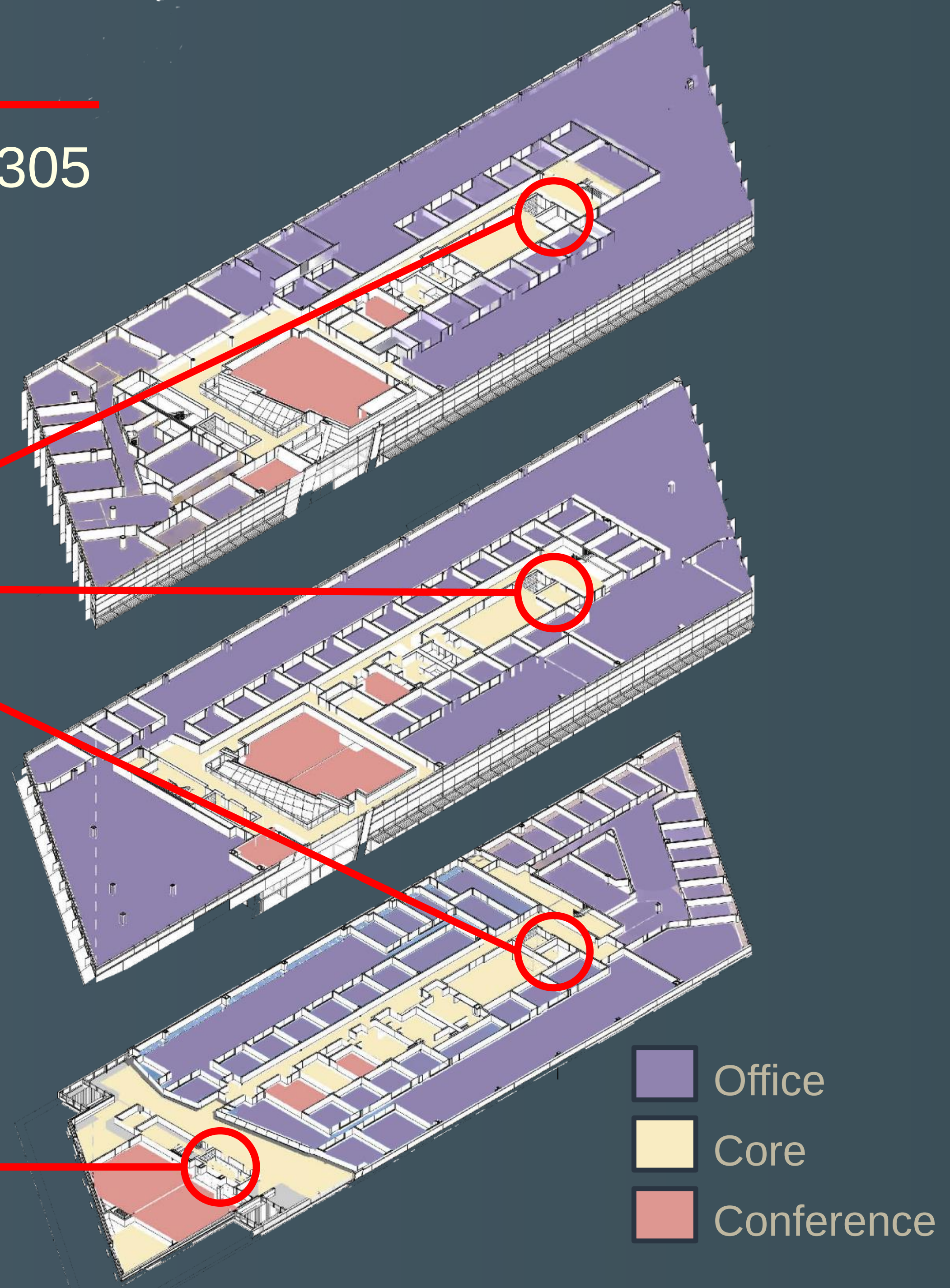


Table of Contents

Thesis Goals and Proposal

Thesis Goals and Proposal

Table of Contents

Goals:

- Decreased energy consumption
- Decreased emissions
- 20 year pay-back
- Naturally light space

Table of Contents

Thesis Goals and Proposal

Goals:

- Decreased energy consumption
- Decreased emissions
- 20 year pay-back
- Naturally light space

Depth study: Alternative Glazing Systems

Thesis Goals and Proposal

Goals:

- Decreased energy consumption
- Decreased emissions
- 20 year pay-back
- Naturally light space

All renderings from AECOM bridging drawings – www.aecom.com

Depth study: Alternative Glazing Systems

- Trace 700 load/energy model
- Cost analysis: initial, operating, life-cycle

Table of Contents

Thesis Goals and Proposal

Goals:

- Decreased energy consumption
- Decreased emissions
- 20 year pay-back
- Naturally light space

All renderings from AECOM bridging drawings – www.aecom.com

Depth study: Alternative Glazing Systems

- Trace 700 load/energy model
- Cost analysis: initial, operating, life-cycle

Breadth topic 1: Electric and Natural Lighting

- Lighting plan alterations
- Cost savings
- Alternative glazing effects on daylighting

Table of Contents

Thesis Goals and Proposal

Goals:

- Decreased energy consumption
- Decreased emissions
- 20 year pay-back
- Naturally light space

All renderings from AECOM bridging drawings – www.aecom.com

Depth study: Alternative Glazing Systems

- Trace 700 load/energy model
- Cost analysis: initial, operating, life-cycle

Breadth topic 1: Electric and Natural Lighting

- Lighting plan alterations
- Cost savings
- Alternative glazing effects on daylighting

Breadth topic 2: Emissions Analysis of PV glass

- Life-cycle emissions: manufacturing, generation

Table of Contents

Glazing definition's

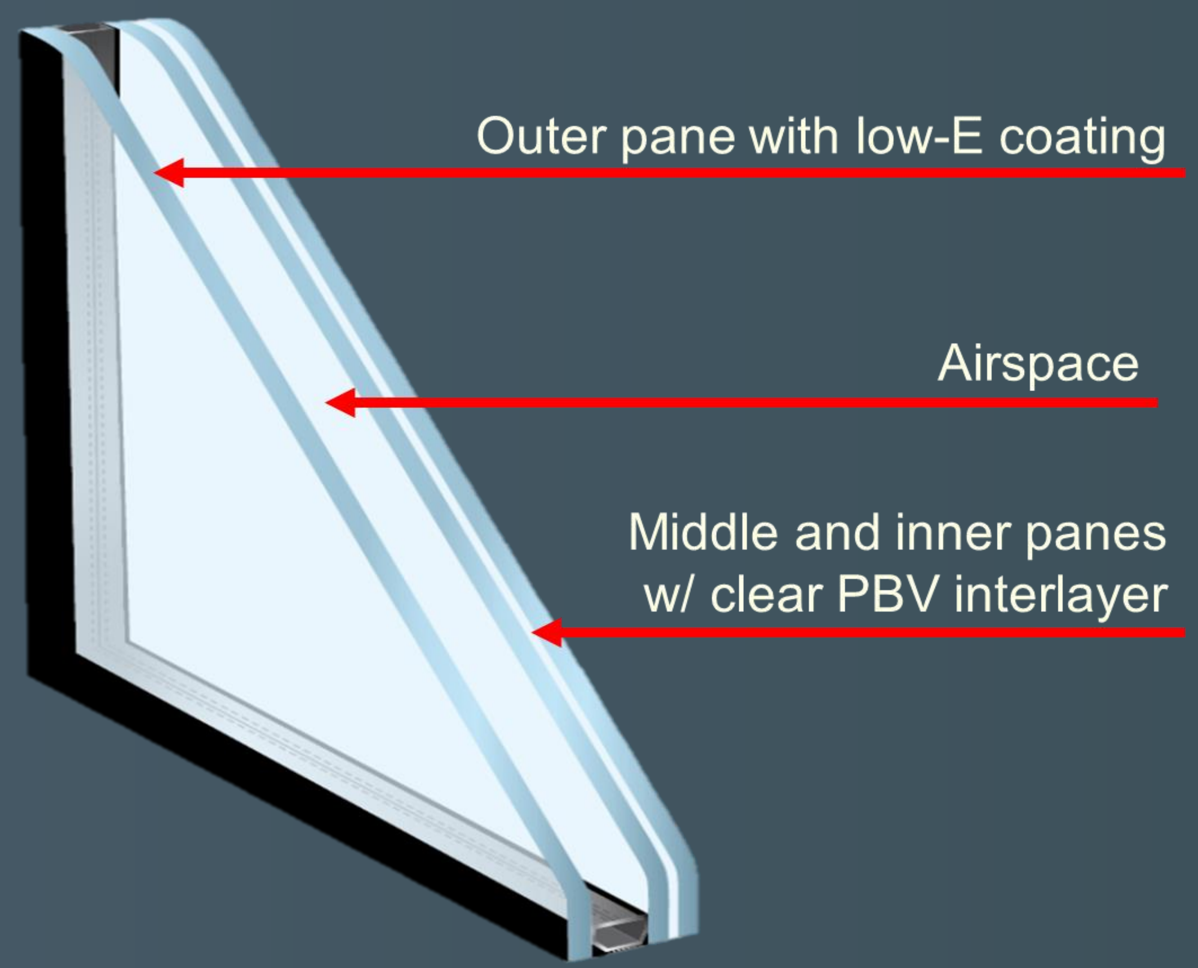
- Viracon
  - Low-E insulating laminated (original)
  - Triple insulating, single low-E
  - Triple insulating, double low-E
- Onyx Solar
  - Double pane, low-E photovoltaic glass

Table of Contents

Glazing definition's

Viracon
- Low-E insulating laminated (original)
- Triple insulating, single low-E
- Triple insulating, double low-E

Onyx Solar
- Double pane, low-E photovoltaic glass



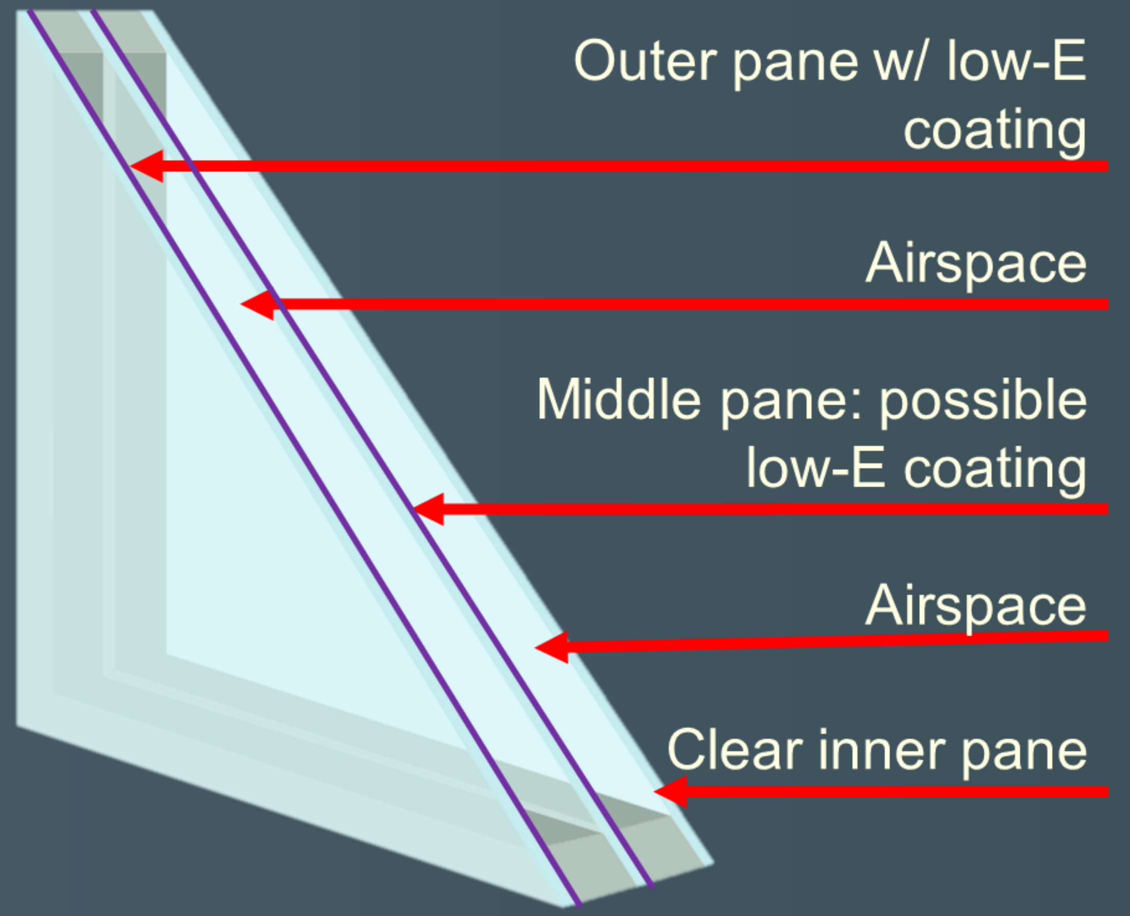
www.Viracon.com/pdf/ProductGuide.pdf

U-VALUE (ADJ)	SHGC (ADJ)
0.37	0.255

Table of Contents

Glazing definition's

- Viracon
  - Low-E insulating laminated (original)
  - Triple insulating, single low-E
  - Triple insulating, double low-E
- Onyx Solar
  - Double pane, low-E photovoltaic glass



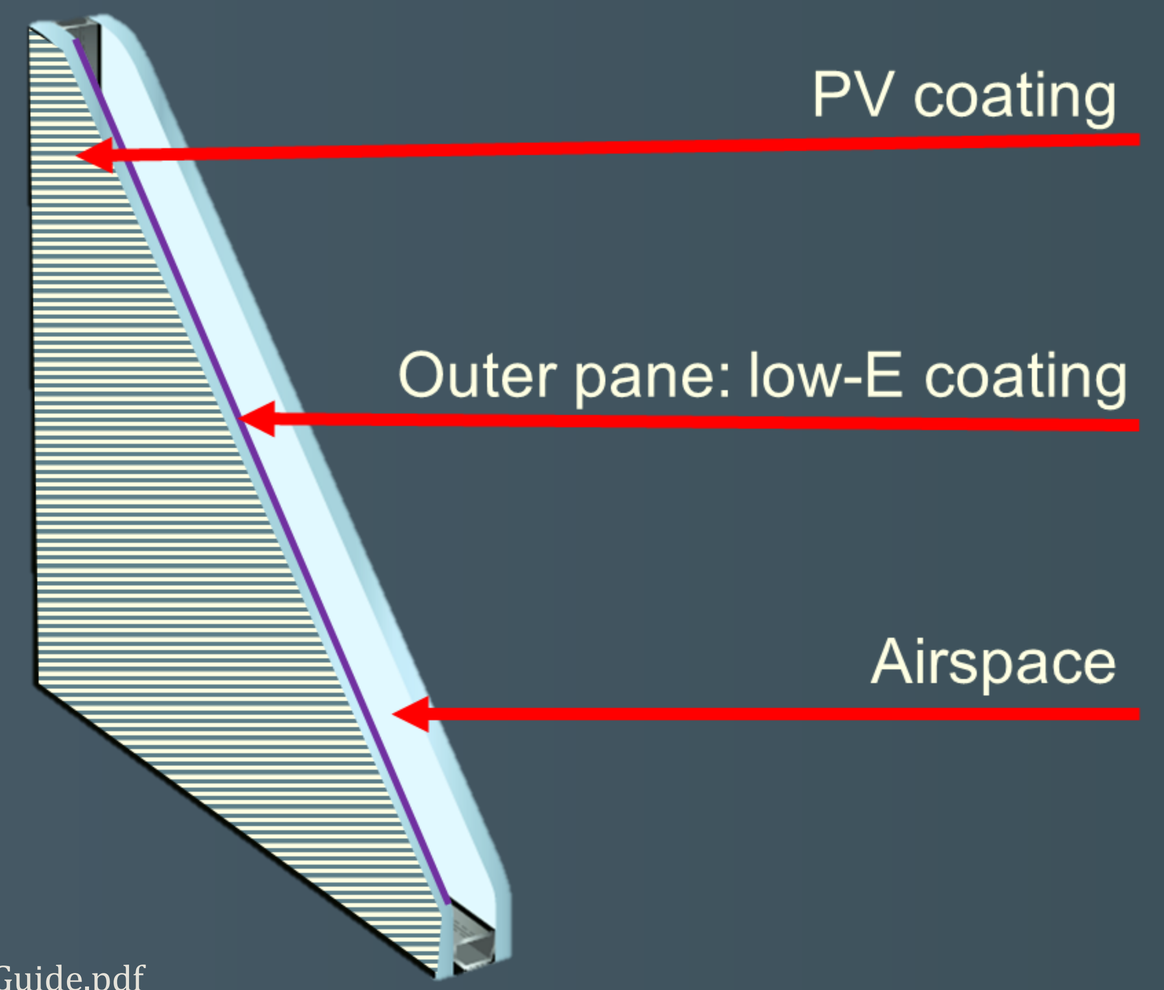
www.Viracon.com/pdf/ProductGuide.pdf

	U-VALUE (ADJ)	SHGC (ADJ)
SINGLE LOW-E	0.33	0.275
DOUBLE LOW-E	0.29	0.24

Glazing definition's

Viracon
- Low-E insulating laminated (original)
- Triple insulating, single low-E
- Triple insulating, double low-E

Onyx Solar
- Double pane, low-E photovoltaic glass



www.Viracon.com/pdf/ProductGuide.pdf

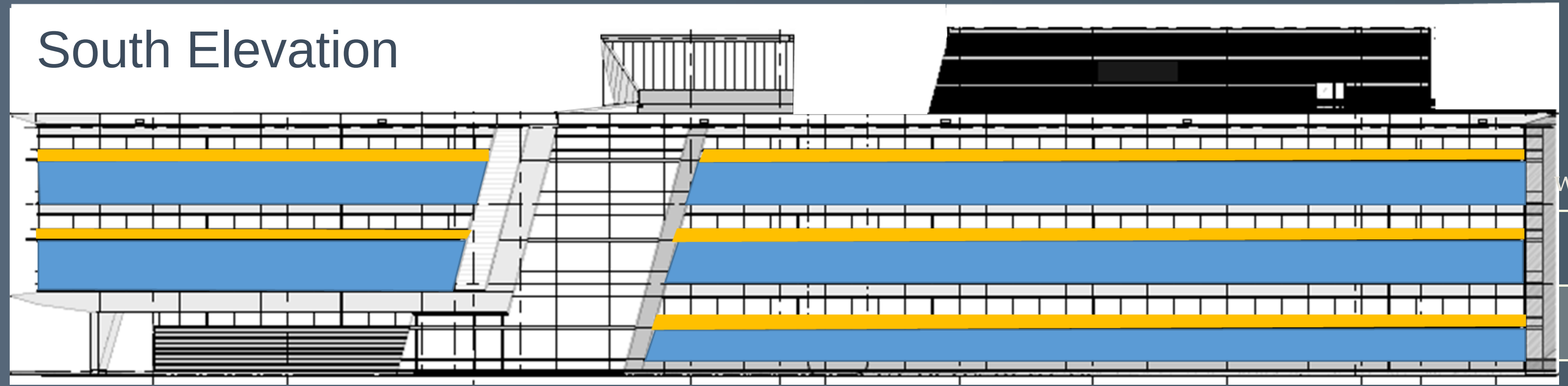
U-VALUE (ADJ)	SHGC (ADJ)
0.42	0.37

NASA AOB1 – Valerie Miller

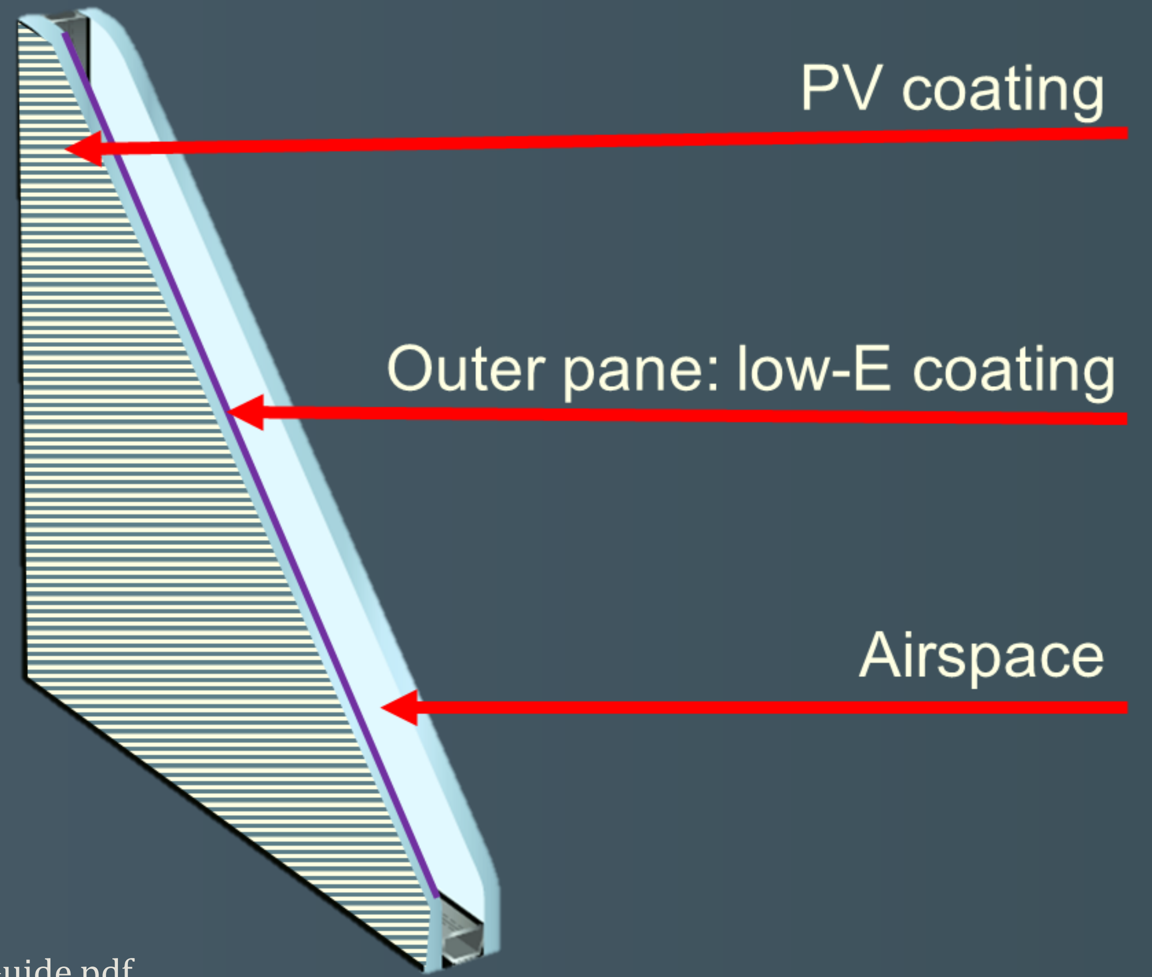
Glazing definition's

Viracon
- Low-E insulating laminated (original)
- Triple insulating, single low-E
- Triple insulating, double low-E

Onyx Solar
- Double pane, low-E photovoltaic glass



Construction docs provided by H.F. Lenz Co.



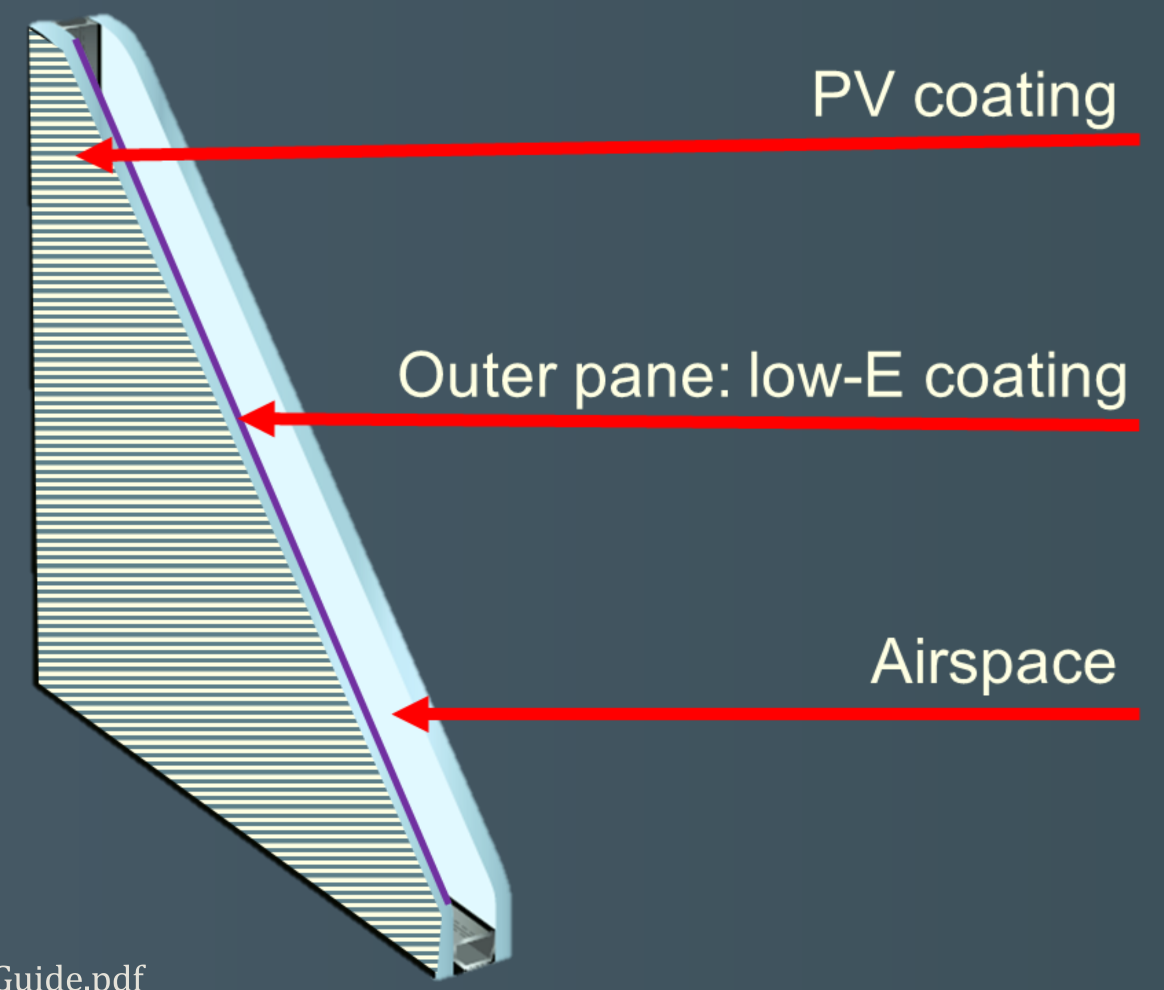
www.Viracon.com/pdf/ProductGuide.pdf

U-VALUE (ADJ)	SHGC (ADJ)
0.42	0.37

Glazing definition's

Viracon
- Low-E insulating laminated (original)
- Triple insulating, single low-E
- Triple insulating, double low-E

Onyx Solar
- Double pane, low-E photovoltaic glass
  - ➢ Produces 1,451 kWh/year
  - ➢ Saves $111/year

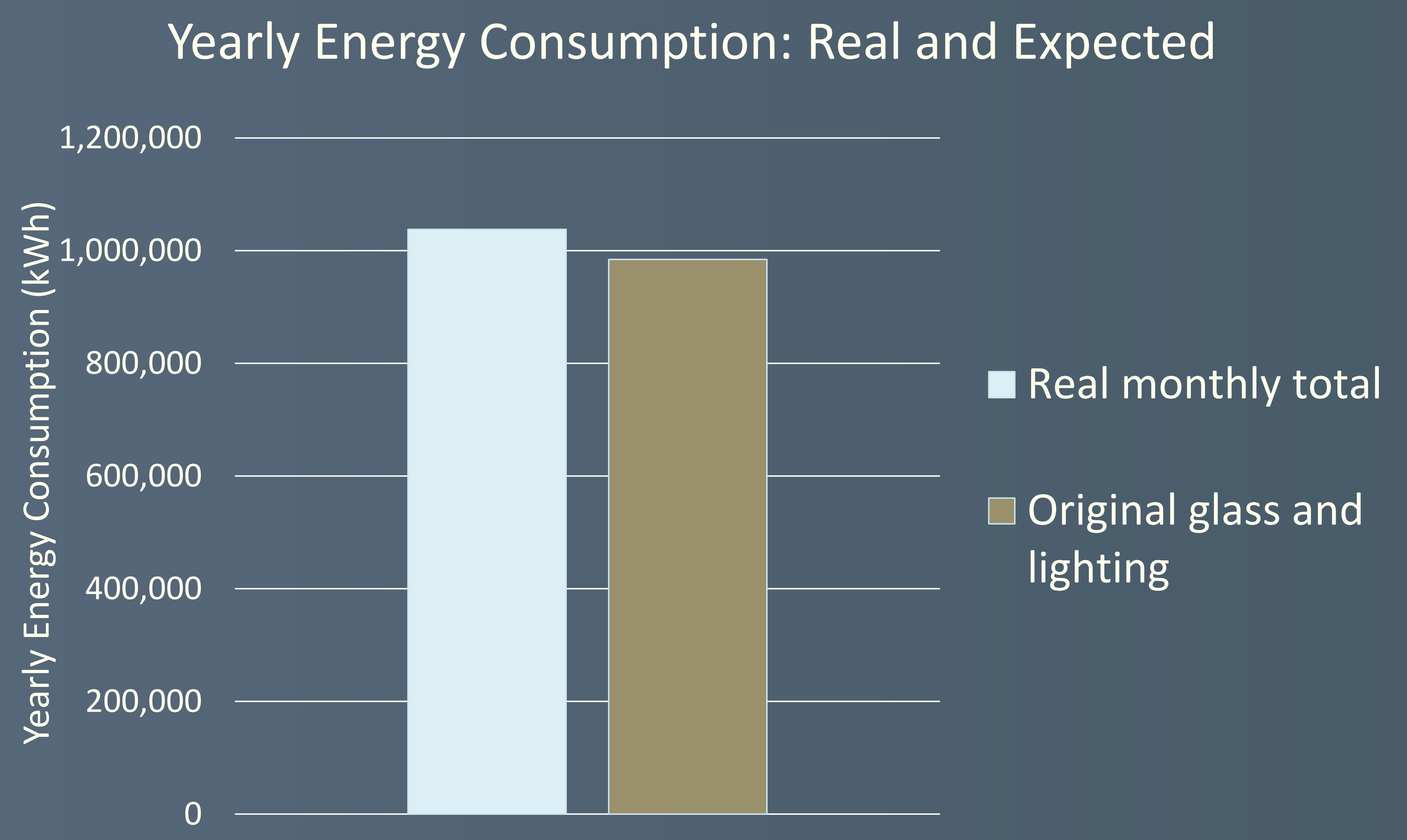


www.Viracon.com/pdf/ProductGuide.pdf

U-VALUE (ADJ)	SHGC (ADJ)
0.42	0.37

Table of Contents

Mechanical depth



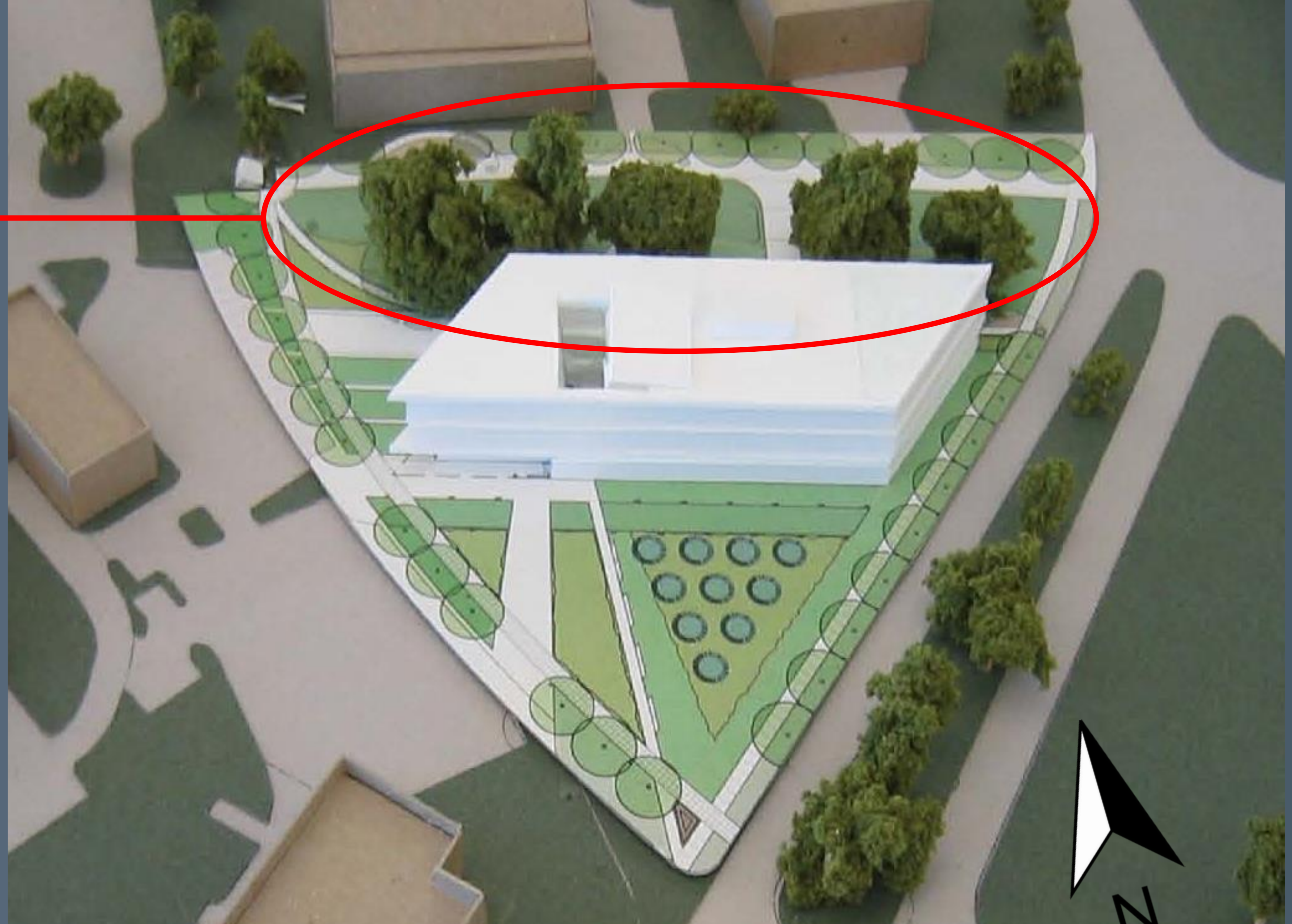
- Submeter: 1,037,990 kWh
- Trace 700 model: 984,526 kWh

~5.15% difference

Table of Contents

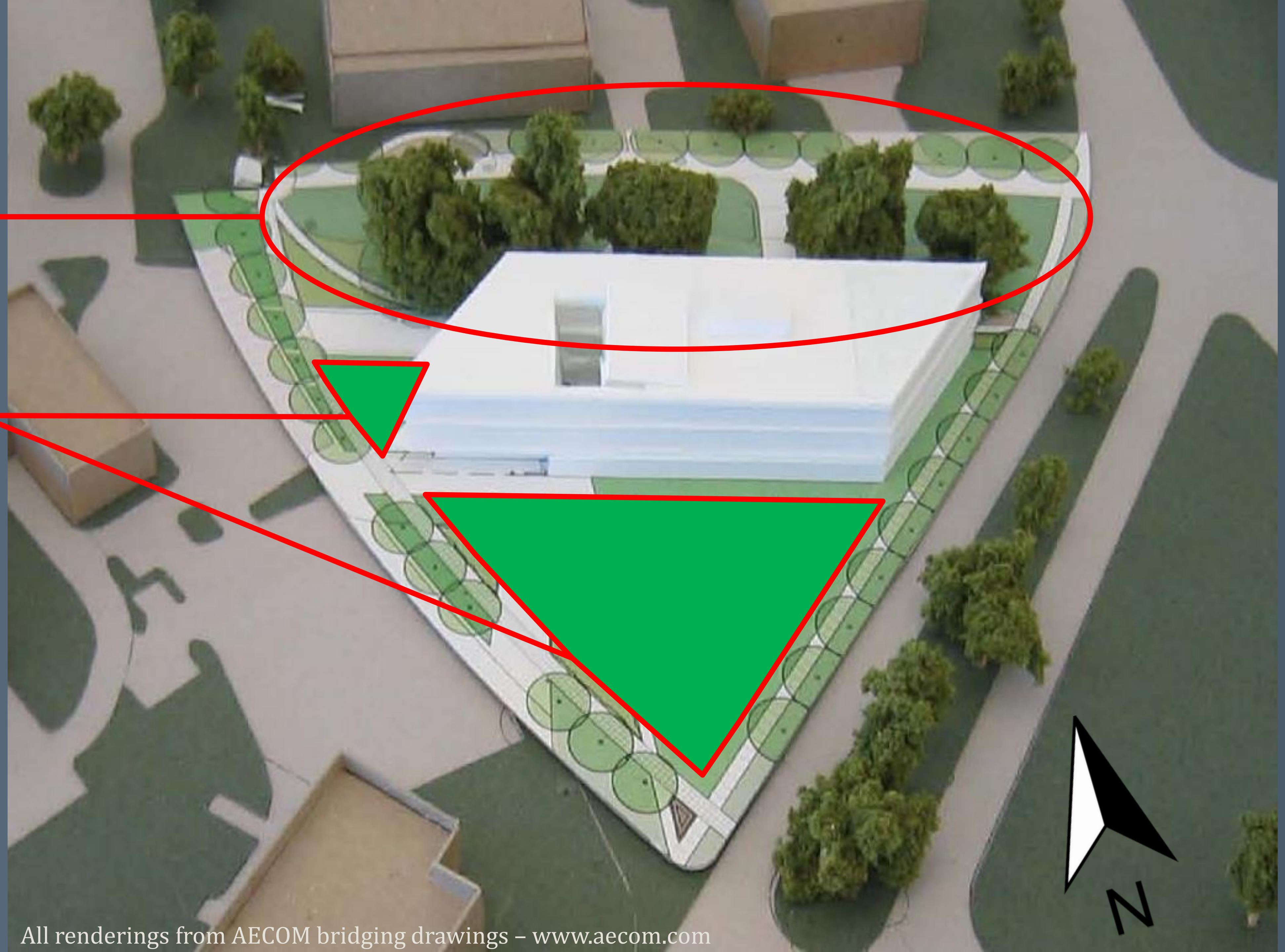
All renderings from AECOM bridging drawings – www.aecom.com

Table of Contents



All renderings from AECOM bridging drawings – www.aecom.com

Table of Contents



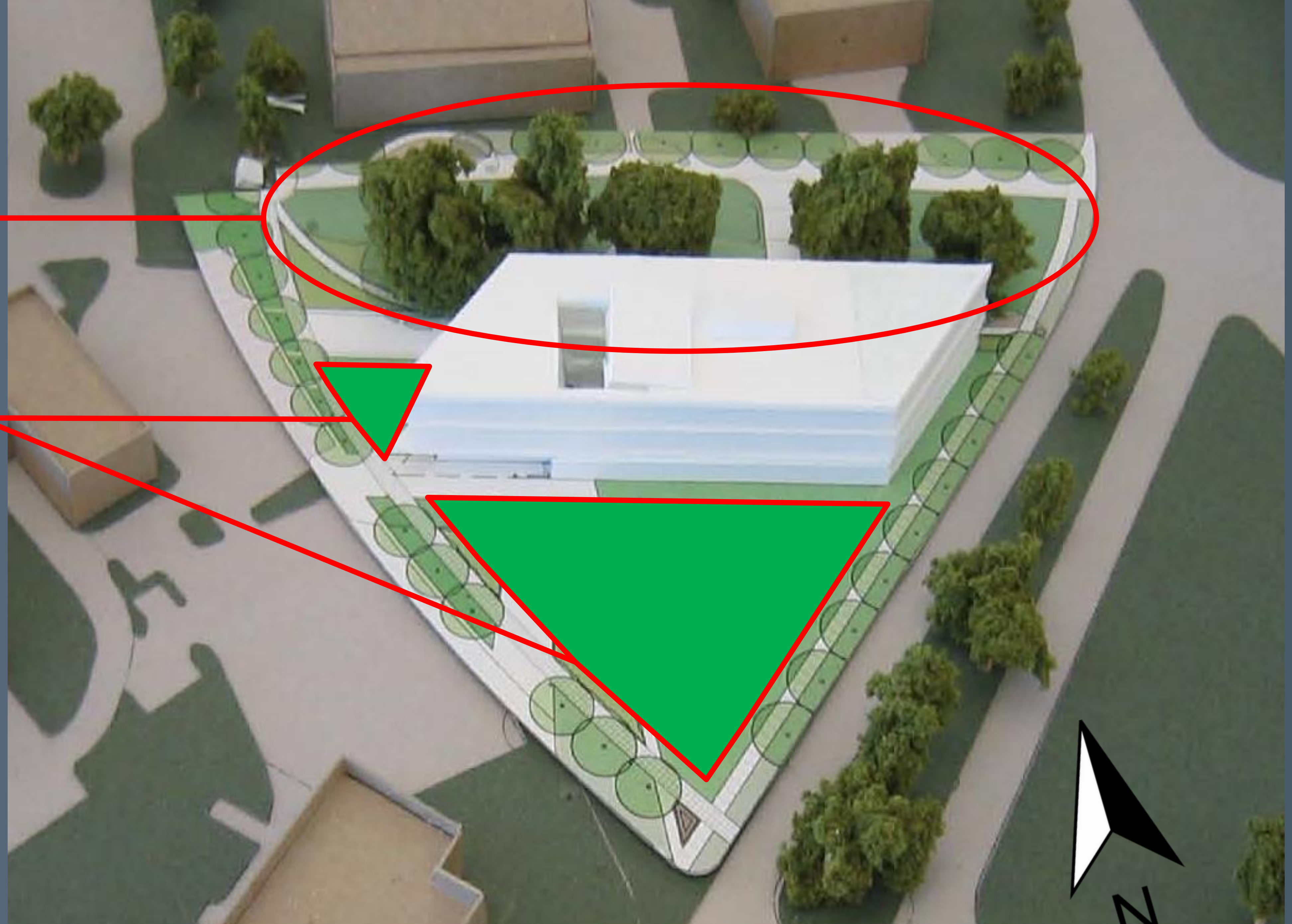
All renderings from AECOM bridging drawings – www.aecom.com

Table of Contents

Tree preservation area

Geothermal transfer field

- Building load capacity: 124 tons
- CANNOT exceed



All renderings from AECOM bridging drawings – www.aecom.com

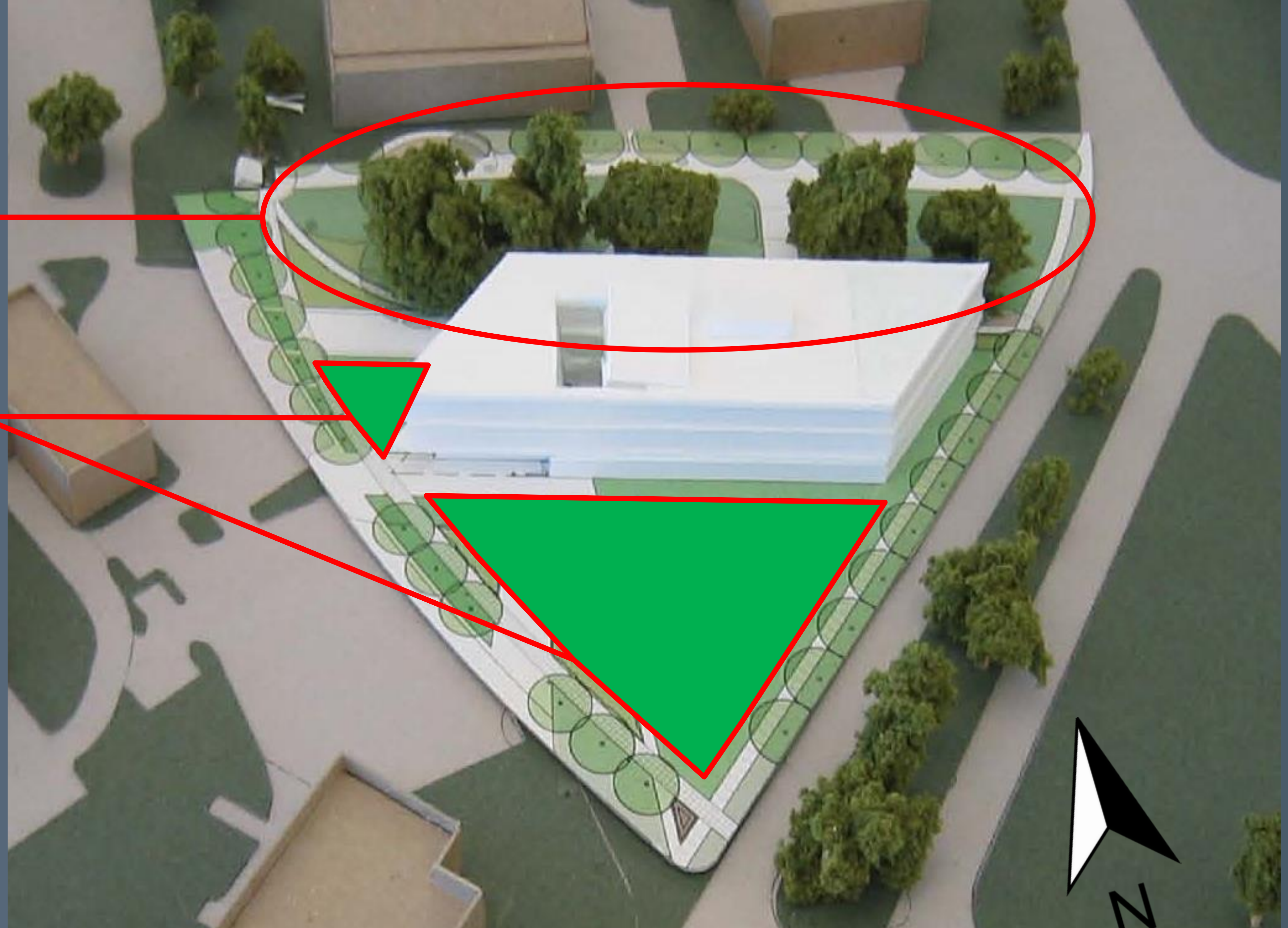
Table of Contents

NASA AOB1 – Valerie Miller

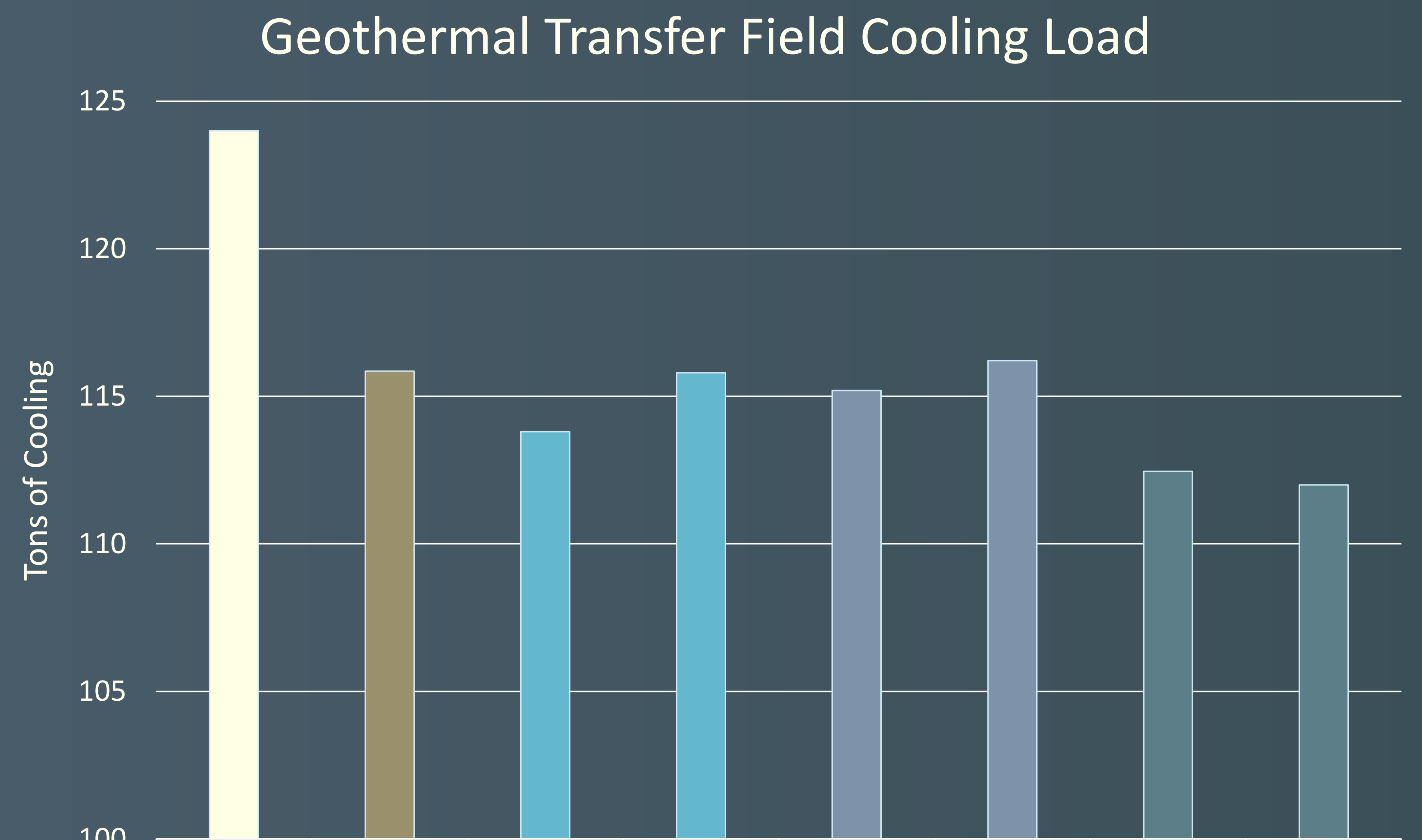
Tree preservation area

Geothermal transfer field

- Building load capacity: 124 tons
- CANNOT exceed

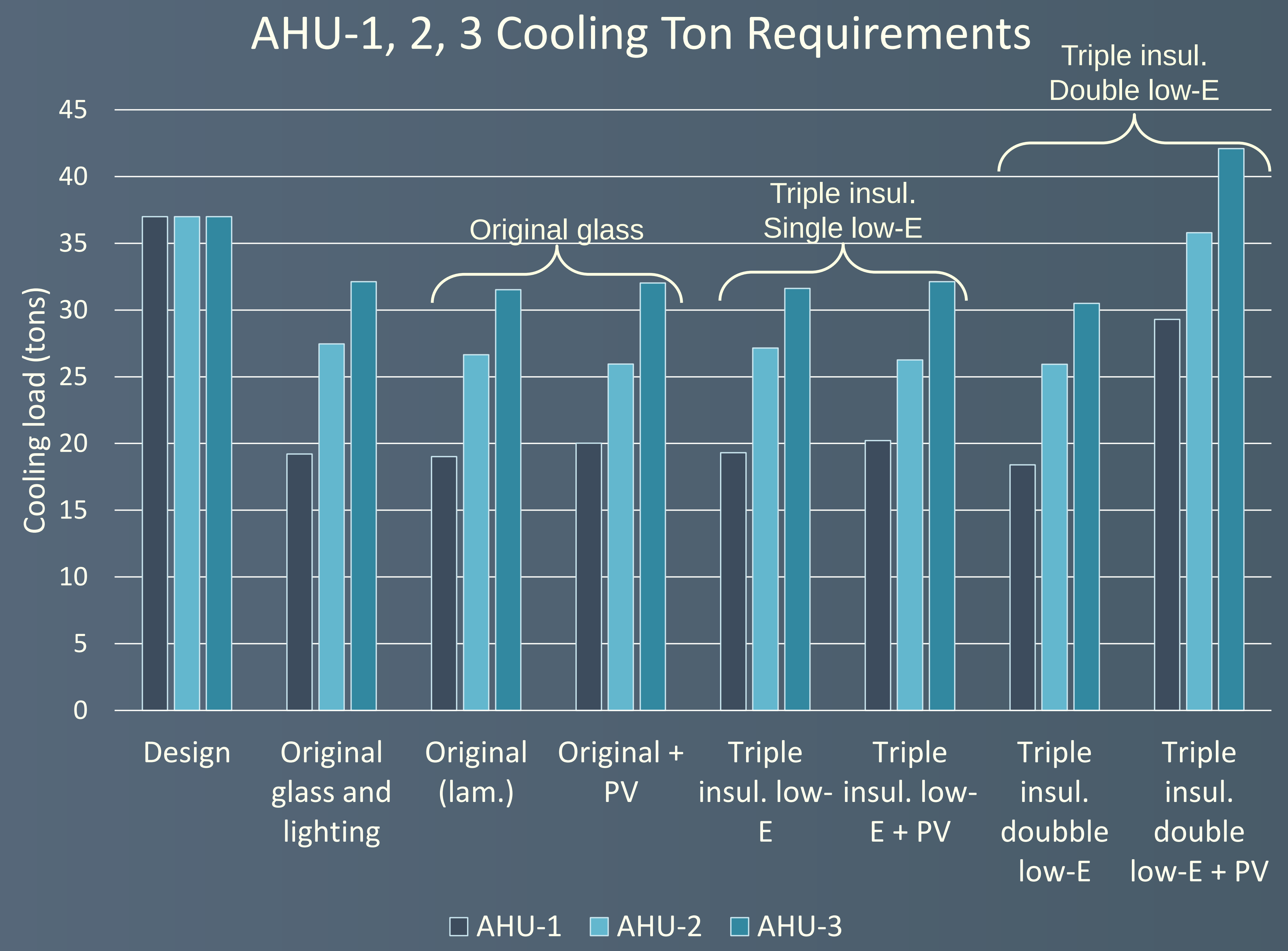


All renderings from AECOM bridging drawings – www.aecom.com



	Design	Original glass and lighting	Original (lam.)	Original (lam.) + PV	Triple insul. low-E	Triple insul. low-E + PV	Triple insul. doubble low-E	Triple insul. double low-E + PV
Series1	124	116	114	116	115	116	112	112

Table of Contents



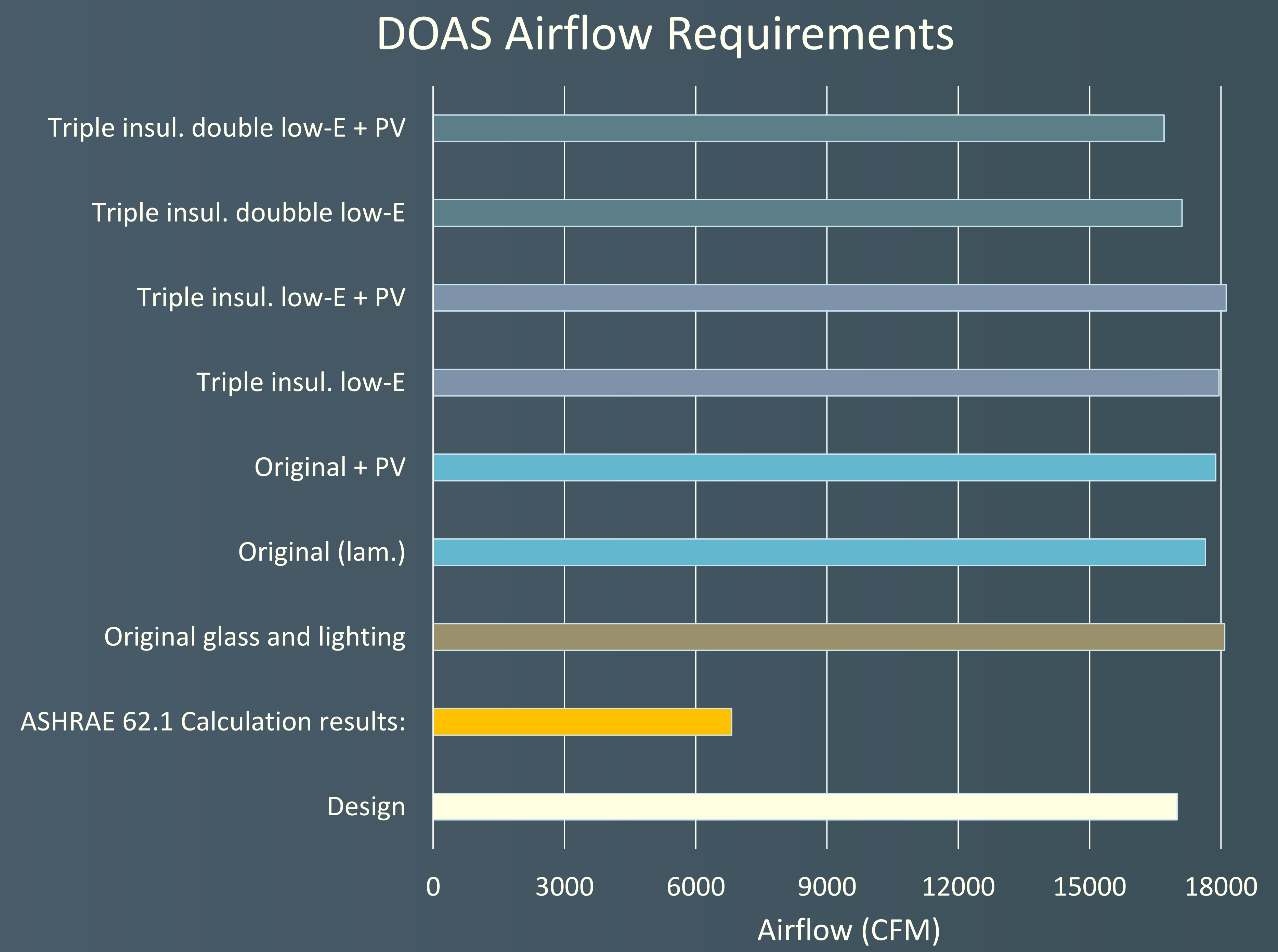


Table of Contents

Yearly Energy Consumption for Alternatives

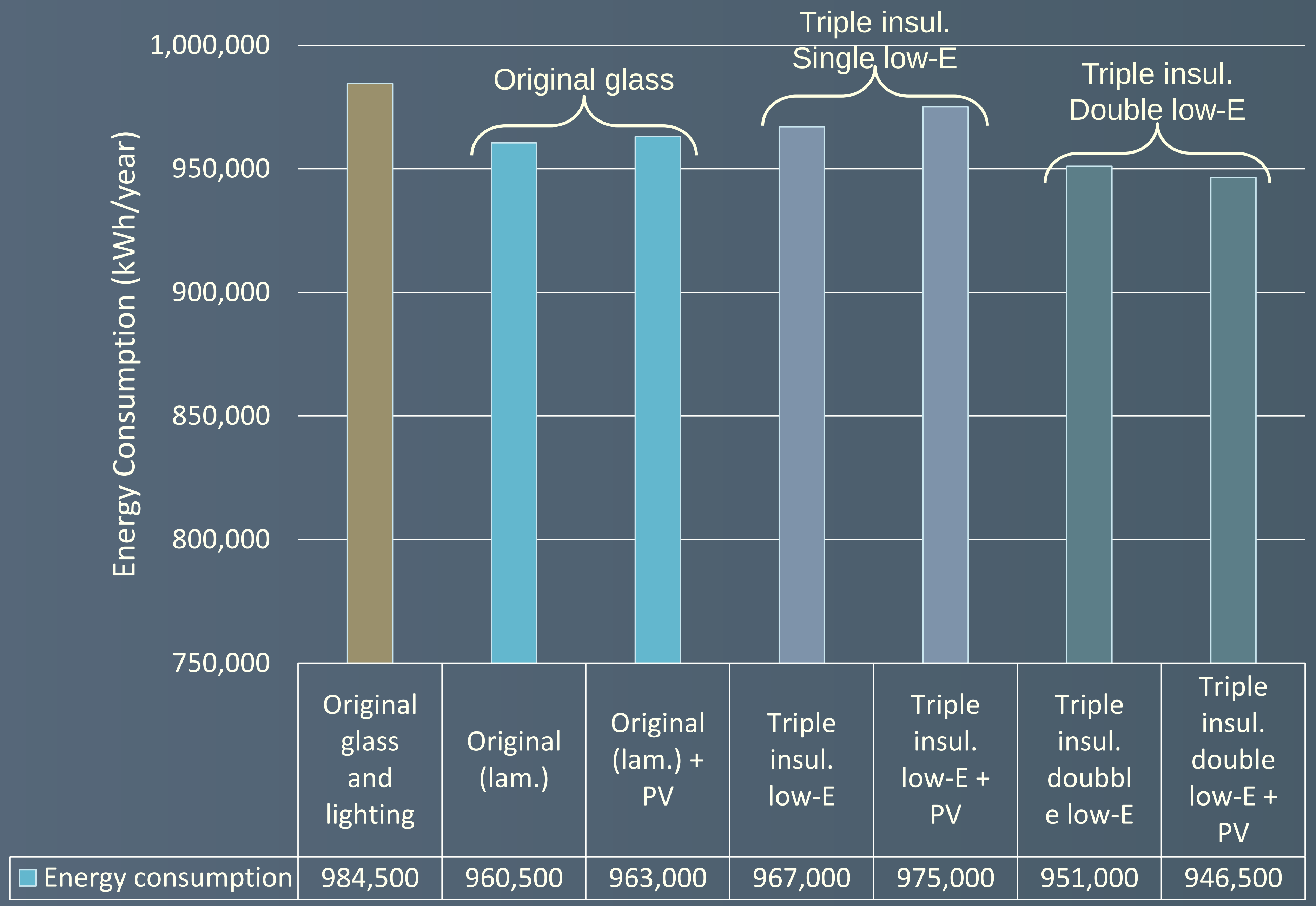
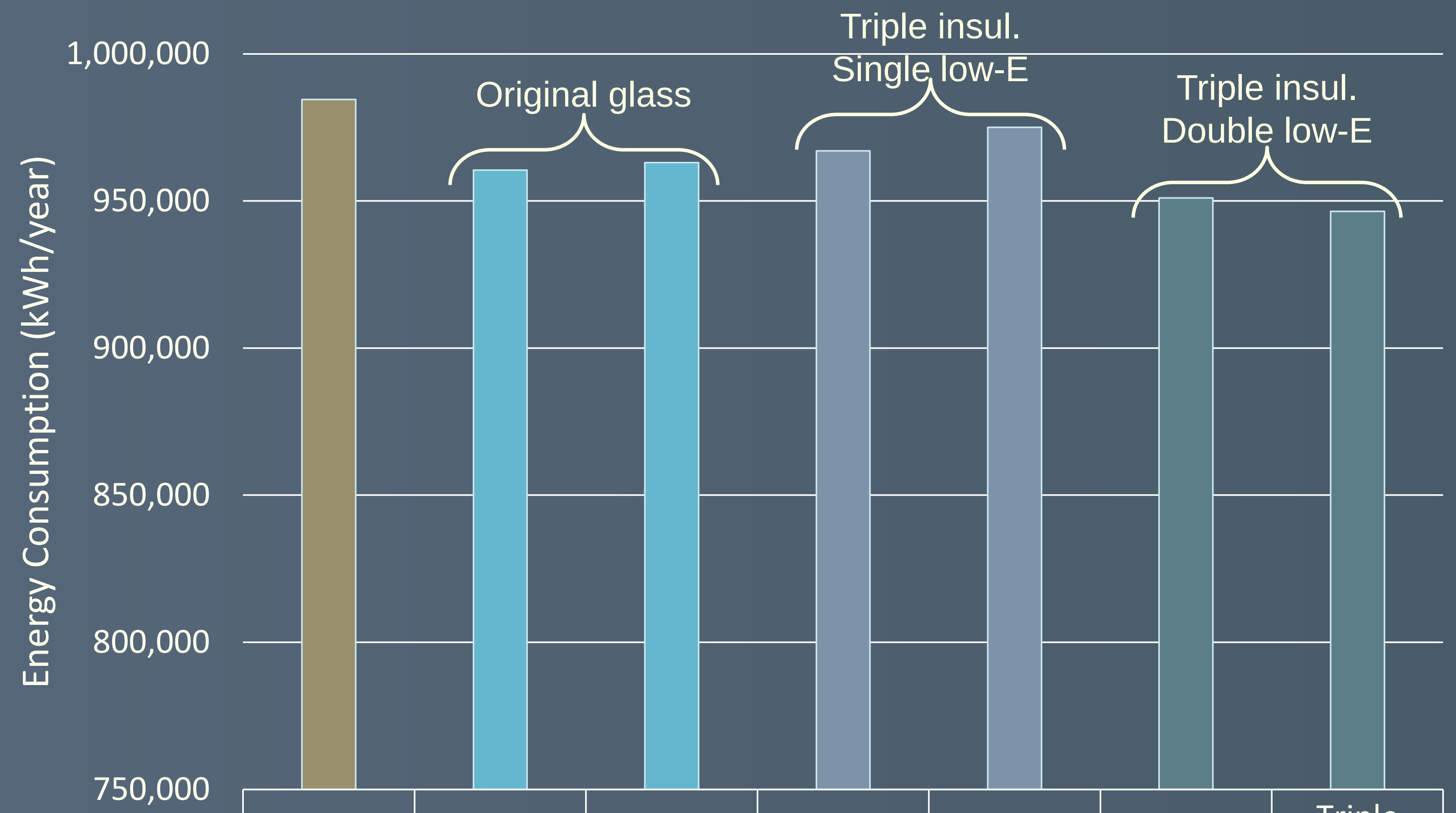


Table of Contents

Key points:

- Alternatives lower than original
- Triple low-E + PV high
- Triple double low-E options low

Yearly Energy Consumption for Alternatives

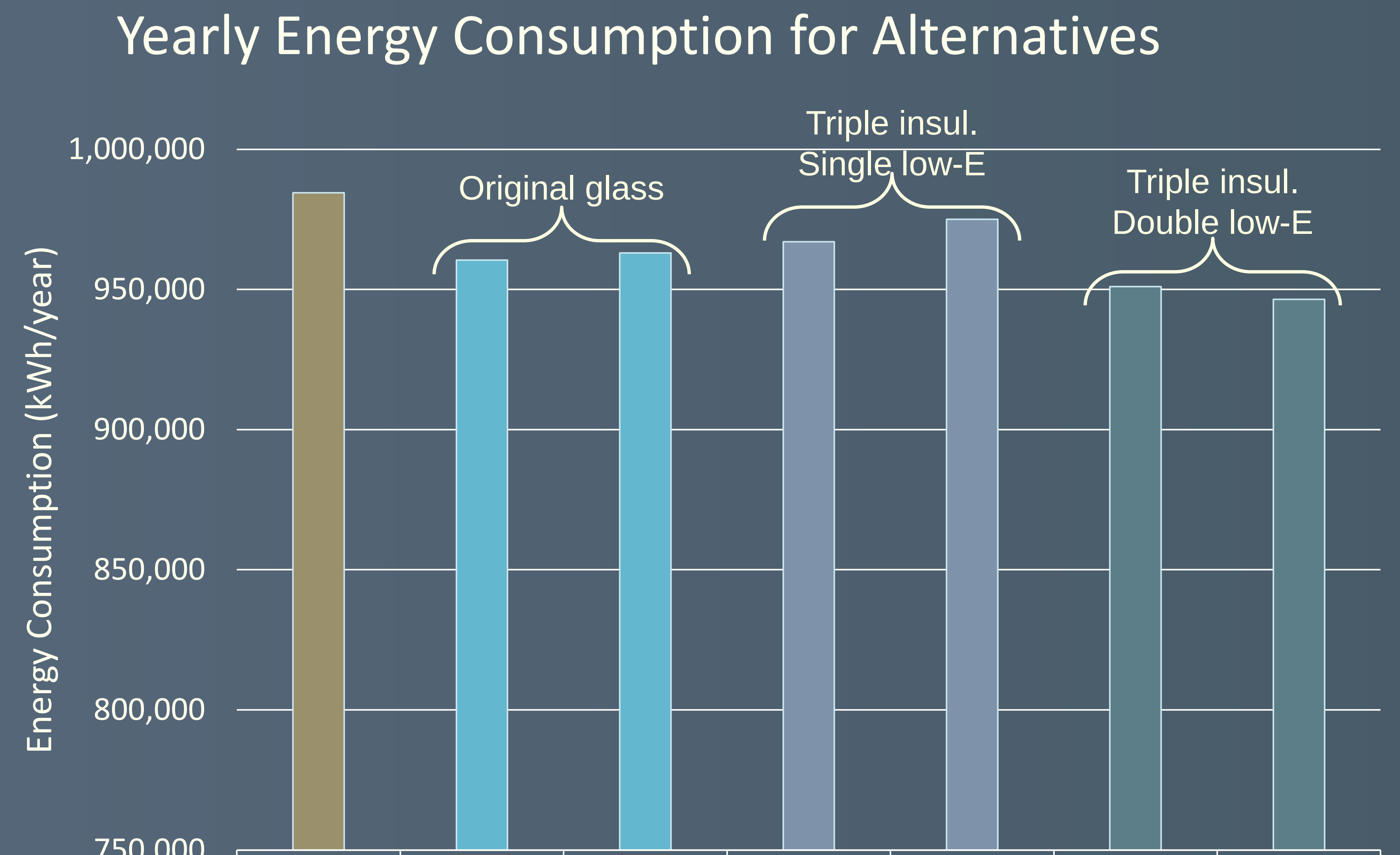


	Original glass and lighting	Original (lam.)	Original (lam.) + PV	Triple insul. low-E	Triple insul. low-E + PV	Triple insul. doubbl e low-E	Triple insul. double low-E + PV
Energy consumption	984,500	960,500	963,000	967,000	975,000	951,000	946,500

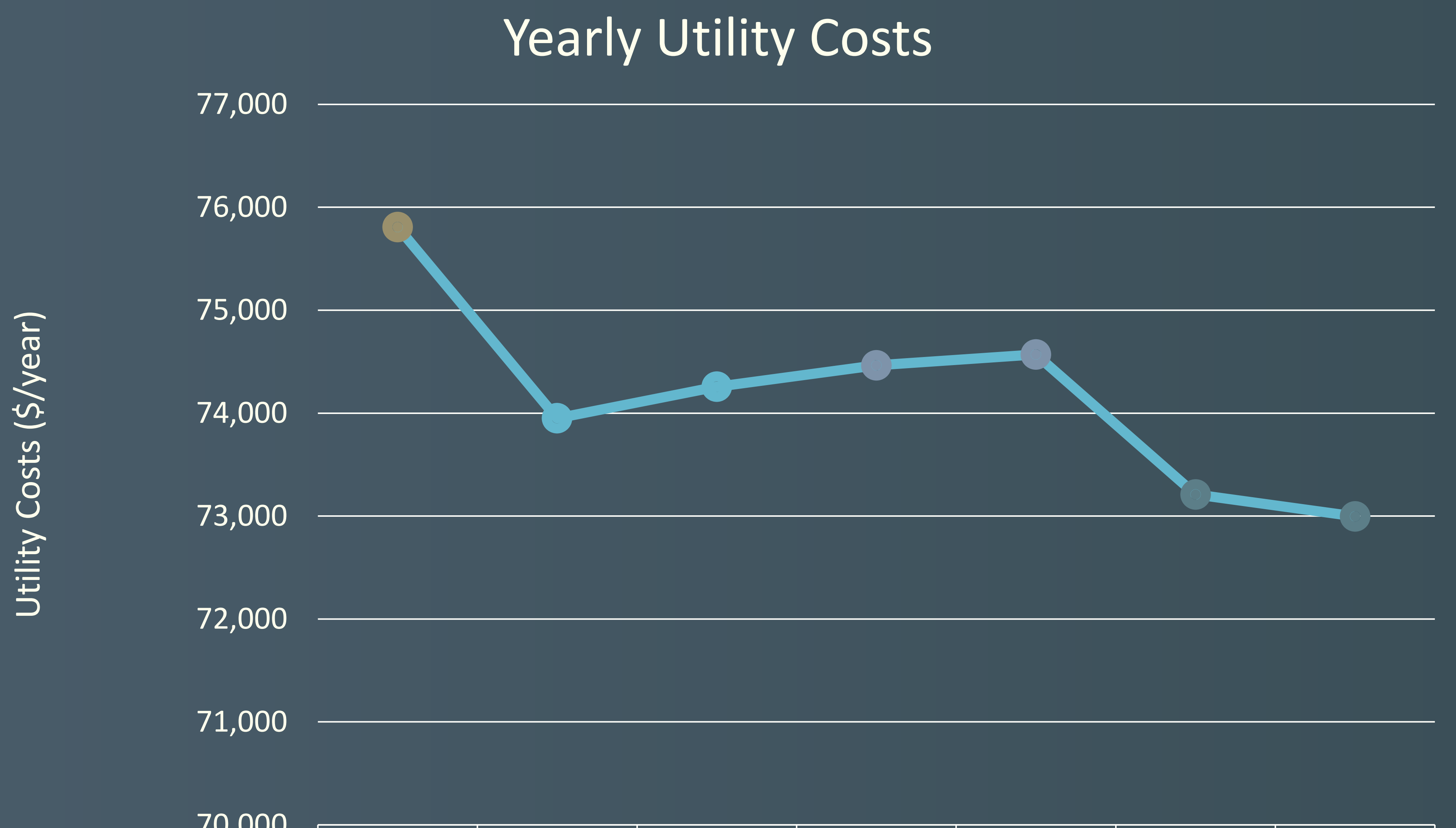
Table of Contents

Key points:

- Alternatives lower than original
- Triple low-E + PV high
- Triple double low-E options low
- Costs range $73-76k



	Original glass and lighting	Original (lam.)	Original (lam.) + PV	Triple insul. low-E	Triple insul. low-E + PV	Triple insul. doubbl e low-E	Triple insul. double low-E + PV
Energy consumption	984,500	960,500	963,000	967,000	975,000	951,000	946,500



	Original glass and lighting	Original (lam.)	Original (lam.) + PV	Triple insul. low-E	Triple insul. low-E + PV	Triple insul. double low-E	Triple insul. double low-E + PV
Yearly Utility Costs	75,808	73,951	74,257	74,466	74,571	73,209	72,997

Table of Contents

Initial Costs:

1. Glass
2. AHU Equipment

Initial Costs:

1. Glass
2. AHU Equipment

Viracon cost breakdown:

- Insulating laminated w/ low-E: $21.50/ft^2
- Triple IGU VRE1-54: $27.80/ft^2
- Triple insulating VRE1-54: $29.40/ft^2

Photovoltaic glass:

- +10% over two pane
  - Two pane glass: $11.10/ft^2
- +$1.60 for low-E
- $13.80/ft^2
- +Inverter: $5,159

ALTERNATIVE	COST OF GLASS
Original (lam.) glass	$320,762
Original (lam.)+ PV	$295,927
Triple insul. low-E	$422,616
Triple insul. low-E + PV	$373,828
Triple insul. double low-E	$446,939
Triple insul. double low-E + PV	$392,431

Table of Contents

Initial Costs:

1. Glass
2. AHU Equipment

		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	DOAS (ton/MBh)	Energy Recovery	Total equip cost:
Original glass and lighting	Total SA CFM:	8728	12707	12842	2387	3812	130/1037	18085	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Original (lam.)	Total SA CFM:	8583	12232	12533	2387	3812	129/1031	17644	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Original (lam.) + PV	Total SA CFM:	9166	11870	12813	2387	3812	130/1023	17882	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Triple insul. low-E	Total SA CFM:	8831	12560	12617	2374	3812	130/1004	17958	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Triple insul. low-E + PV	Total SA CFM:	9404	12061	12892	2374	3812	132/1027	18123	
	Cost:	$22,700	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$433,025
Triple insul. double low-E	Total SA CFM:	8317	11876	12037	2361	3812	127/962	17113	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Triple insul. double low-E + PV	Total SA CFM:	8317	11003	12037	2361	3812	125/942	16699	
	Cost:	$20,600	$22,700	$26,000	$7,400	$9,525	$311,000	$30,400	$427,625

Table of Contents

Initial Costs:

1. Glass
2. AHU Equipment

		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	DOAS (ton/MBh)	Energy Recovery	Total equip cost:
Original glass and lighting	Total SA CFM:	8728	12707	12842	2387	3812	130/1037	18085	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Original (lam.)	Total SA CFM:	8583	12232	12533	2387	3812	129/1031	17644	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Original (lam.) + PV	Total SA CFM:	9166	11870	12813	2387	3812	130/1023	17882	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Triple insul. low-E	Total SA CFM:	8831	12560	12617	2374	3812	130/1004	17958	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Triple insul. low-E + PV	Total SA CFM:	9404	12061	12892	2374	3812	132/1027	18123	
	Cost:	$22,700	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$433,025
Triple insul. double low-E	Total SA CFM:	8317	11876	12037	2361	3812	127/962	17113	
	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
Triple insul. double low-E + PV	Total SA CFM:	8317	11003	12037	2361	3812	125/942	16699	
	Cost:	$20,600	$22,700	$26,000	$7,400	$9,525	$311,000	$30,400	$427,625

TABLE OF CONTENTS

	TOTAL EQUIP COST:	GLASS SYSTEM COST:	1 YEAR OP COST:	20 YEAR LIFE-CYCLE COST:
Original glass and lighting	$431,000	$321,000	$76,000	$2,268,000
Original (lam.)	$431,000	$321,000	$74,000	$2,231,000
Original (lam.) + PV	$431,000	$296,000	$74,250	$2,212,000
Triple insul. low-E	$431,000	$423,000	$74,500	$2,343,000
Triple insul. low-E + PV	$433,000	$374,000	$74,500	$2,298,000
Triple insul. double low-E	$431,000	$447,000	$73,000	$2,342,000
Triple insul. double low-E + PV	$428,000	$392,500	$73,000	$2,280,000

Table of Contents

Payback periods:

- Immediate for original glass options
- 45+ triple low-E options
- 24+ triple double low-E options

	TOTAL EQUIP COST:	GLASS SYSTEM COST:	1 YEAR OP COST:	20 YEAR LIFE-CYCLE COST:
Original glass and lighting	$431,000	$321,000	$76,000	$2,268,000
Original (lam.)	$431,000	$321,000	$74,000	$2,231,000
Original (lam.) + PV	$431,000	$296,000	$74,250	$2,212,000
Triple insul. low-E	$431,000	$423,000	$74,500	$2,343,000
Triple insul. low-E + PV	$433,000	$374,000	$74,500	$2,298,000
Triple insul. double low-E	$431,000	$447,000	$73,000	$2,342,000
Triple insul. double low-E + PV	$428,000	$392,500	$73,000	$2,280,000

Table of Contents

Payback periods:

- Immediate for original glass options
- 45+ triple low-E options
- 24+ triple double low-E options

	TOTAL EQUIP COST:	GLASS SYSTEM COST:	1 YEAR OP COST:	20 YEAR LIFE-CYCLE COST:
Original glass and lighting	$431,000	$321,000	$76,000	$2,268,000
Original (lam.)	$431,000	$321,000	$74,000	$2,231,000
Original (lam.) + PV	$431,000	$296,000	$74,250	$2,212,000
Triple insul. low-E	$431,000	$423,000	$74,500	$2,343,000
Triple insul. low-E + PV	$433,000	$374,000	$74,500	$2,298,000
Triple insul. double low-E	$431,000	$447,000	$73,000	$2,342,000
Triple insul. double low-E + PV	$428,000	$392,500	$73,000	$2,280,000

-$111/year generated
=$2,209,769

Payback periods:

- Immediate for original glass options
- 45+ triple low-E options
- 24+ triple double low-E options

	TOTAL EQUIP COST:	GLASS SYSTEM COST:	1 YEAR OP COST:	20 YEAR LIFE-CYCLE COST:
Original glass and lighting	$431,000	$321,000	$76,000	$2,268,000
Original (lam.)	$431,000	$321,000	$74,000	$2,231,000
Original (lam.) + PV	$431,000	$296,000	$74,250	$2,212,000
Triple insul. low-E	$431,000	$423,000	$74,500	$2,343,000
Triple insul. low-E + PV	$433,000	$374,000	$74,500	$2,298,000
Triple insul. double low-E	$431,000	$447,000	$73,000	$2,342,000
Triple insul. double low-E + PV	$428,000	$392,500	$73,000	$2,280,000

-$111/year generated

=$2,209,769

Δ$: 20,932

Table of Contents

Breadth Topic:

Life-cycle Emissions of PV Glass

Table of Contents

Breadth Topic:
Life-cycle Emissions of PV Glass

Onyx Solar:
Low-E Photovoltaic
Transparent Glass

- Manufactured in Spain
- Thin film amorphous silicon (a-Si)
- Etched for desired Visible Light Transmittance (VLT)
- 3,575 ft^2 glass, 2,500 ft^2 PV
- 7,440 W peak power

Table of Contents

Breadth Topic:
Life-cycle Emissions of PV Glass

Onyx Solar:

Low-E Photovoltaic

Transparent Glass

- Manufactured in Spain
- Thin film amorphous silicon (a-Si)
- Etched for desired Visible Light Transmittance (VLT)
- 3,575 ft^2 glass, 2,500 ft^2 PV
- 7,440 W peak power

Research Method 1

E. Alsema, 1998

Area method: 11.15 kWh/ft^2

→ 39,861 kWh

Table of Contents

Breadth Topic:
Life-cycle Emissions of PV Glass

Onyx Solar:
Low-E Photovoltaic
Transparent Glass

- Manufactured in Spain
- Thin film amorphous silicon (a-Si)
- Etched for desired Visible Light Transmittance (VLT)
- 3,575 ft^2 glass, 2,500 ft^2 PV
- 7,440 W peak power

Research Method 1

E. Alsema, 1998

Area method: 11.15 kWh/ft^2

→ 39,861 kWh

Research Method 2

Environmental Science and Technology, 2013

Power output method: 4.5 kWh/W

→ 33,480 kWh

Table of Contents

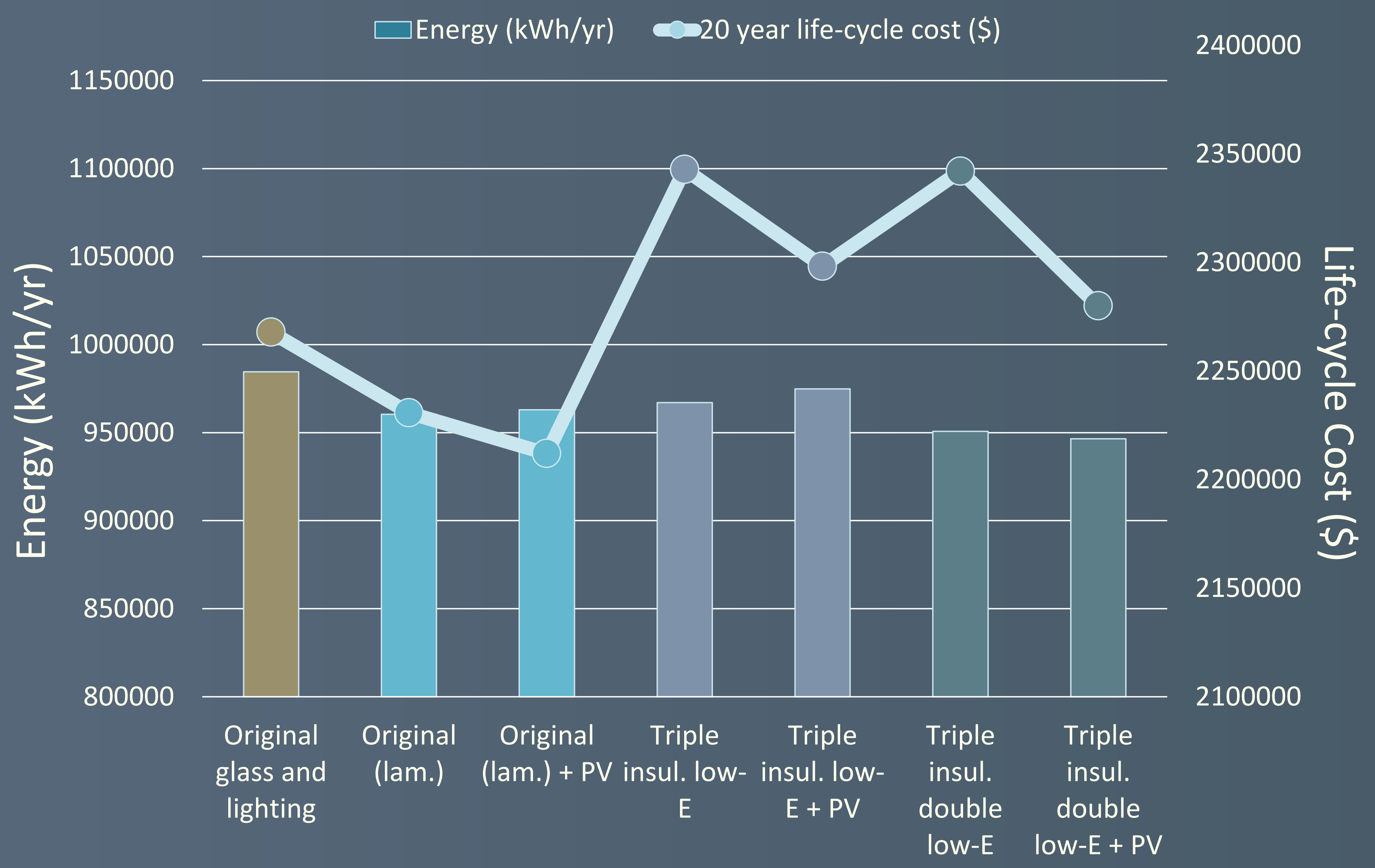
Breadth Topic:
Life-cycle Emissions of PV Glass

Onyx Solar:
Low-E Photovoltaic
Transparent Glass

Site CO_2 emission factor:	1.64 lb/kWh	
Spain CO_2 emission factor:	0.756 lb/kWh	
	Research method 1	**Research method 2**
Total power required for manufacturing:	39,861 kWh	33,480 kWh
CO_2 emitted in manufacturing:	30,131 lb	25,308 lb
kWh/year generated on-site by glass:	1,451 kWh	
CO_2/year saved from on-site generation:	2,380 lb	
CO_2 payback (years):	12.7	10.6

Table of Contents

Conclusion

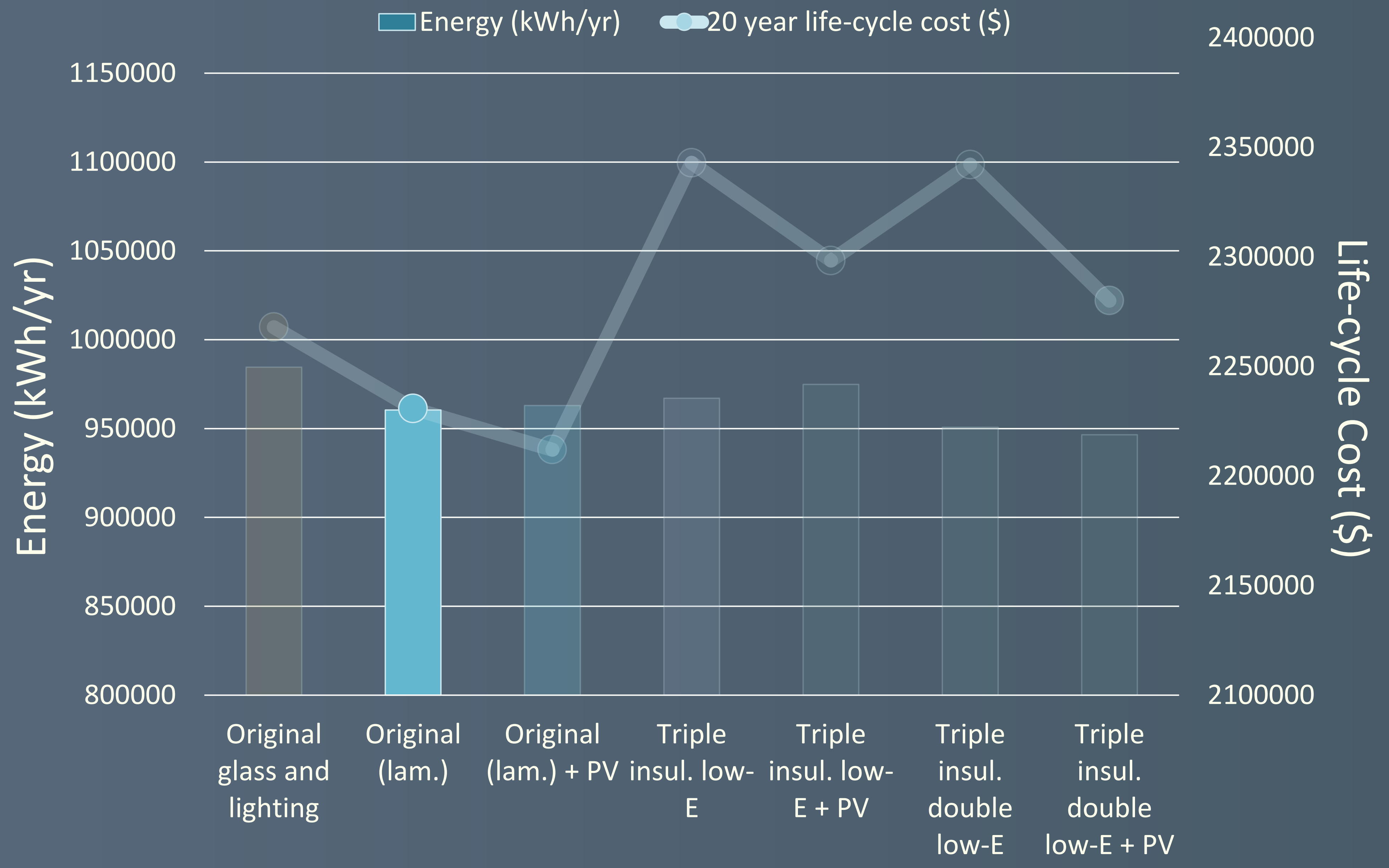


Key points:

- Yearly energy consumption/emissions
- Initial costs
- 20 year life-cycle

Table of Contents

Conclusion



Key points:

- Yearly energy consumption/emissions
- Initial costs
- 20 year life-cycle

Recommendations:

- ✓ New lighting plan
- ✗ Alternative glass types

Acknowledgements

Special thank you to the following:

- H.F. Lenz Company
- NASA Langley Research Center employees
- Viracon’s Jennifer Highfield
- Dr. Freihaut
- Dr. Mistrick
- Jackie Eury
- Architectural Engineering Department
- My friends, family, and the AE Class of 2015

NASA Langley Research Center
Administration Office Building One (AOB1)

Hampton, VA

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

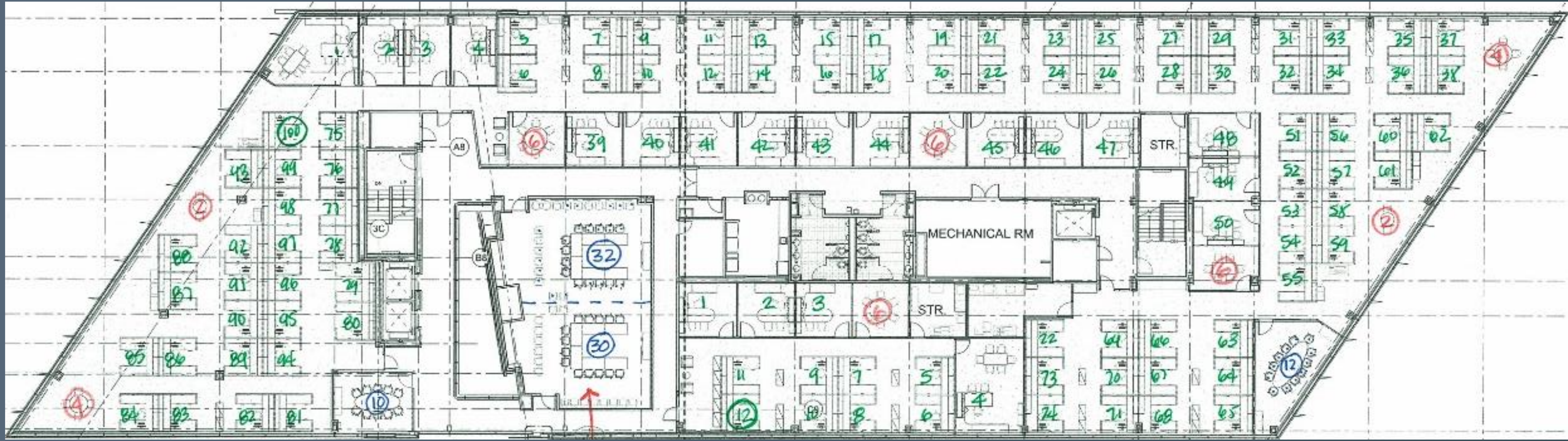
FLOOR ONE

Floor plans from CD's provided by H.F. Lenz Co.

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

FLOOR TWO



Floor plans from CD's provided by H.F. Lenz Co.

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

FLOOR THREE

Floor plans from CD's provided by H.F. Lenz Co.

APPENDICES

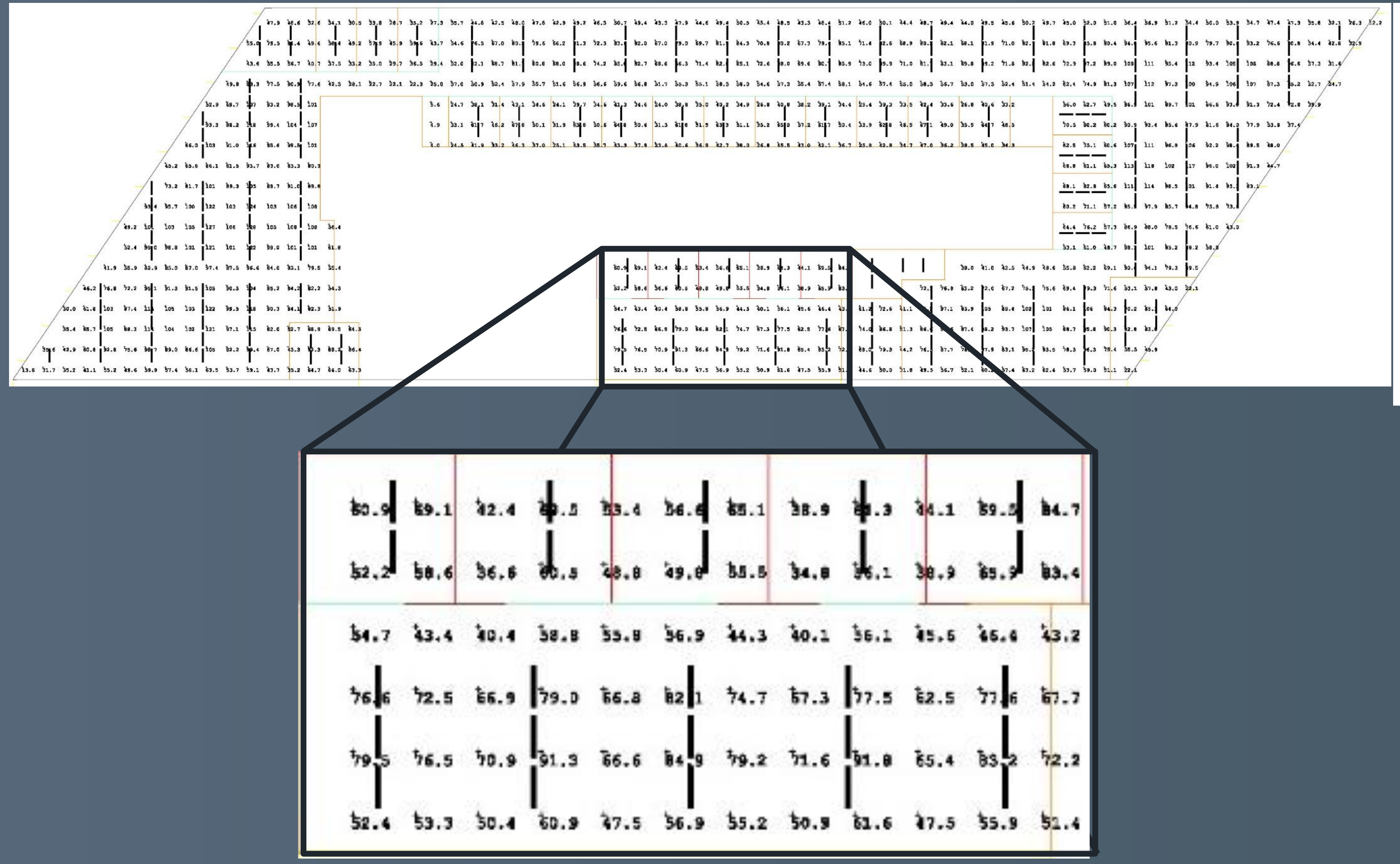
- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

NASA AOB1 – Valerie Miller

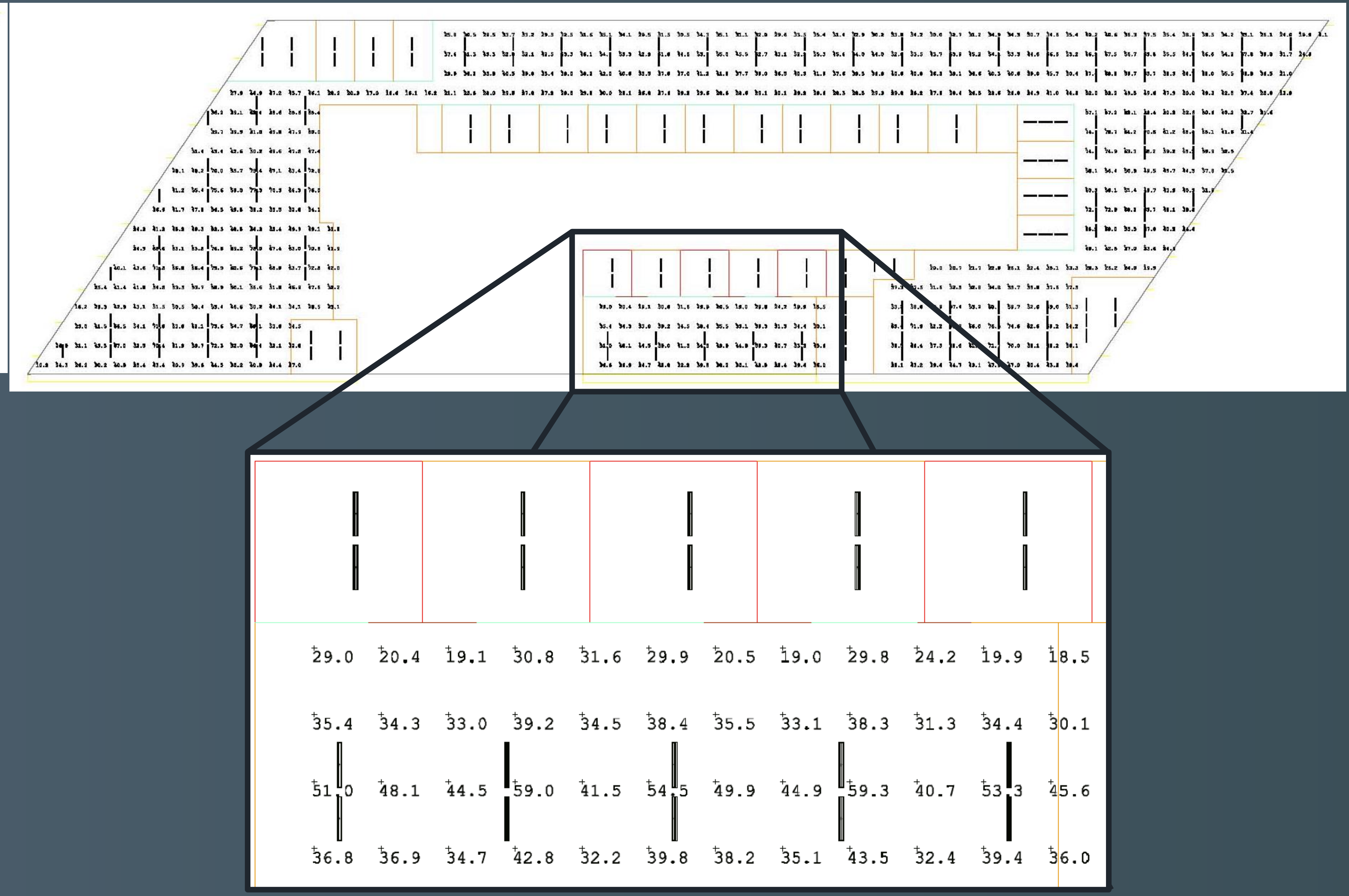
Goals:

- ❖ Lower illuminance on task plane (goal: 30-50 fc)
- ❖ Reduce initial cost of luminaires
- ❖ Reduce energy consumption
- ❖ Ensure ability to daylight space will not be compromised with alternative glazing systems

Original 2nd floor plan



Original 2nd floor plan



APPENDICES

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

NASA AOB1 – Valerie Miller

Goals:

- Lower illuminance on task plane (goal: 30-50 fc)
- Reduce initial cost of luminaires
- Reduce energy consumption
- Ensure ability to daylight space will not be compromised with alternative glazing systems

Building System Wiring

Material	Unit Cost	Quantity per lum.	Total Cost ($)
RMC	0.98/ft	0.375	146
conduit clips	1	0.005	2
RMC bodies and covers	10	0.063	24
RMC connectors	s2	0.012	5
J-boxes	3	0.016	6
Metal conduit	0.41/ft	0.003	1
MC connectors	2	0.010	4
ceiling supports	2	0.013	5
Labor	**Minutes**	**Quantity per lum.**	**Total Cost ($)**
start-up	45 total	45	49
install RMC	2/ft	0.013	5
install MC	1.5/ft	0.009	4
rough-in ceiling supports	10	0.063	26

Luminaires

Material	Unit Cost	Quantity in length (ft)	Total Cost ($)s
luminaires	40/ft	388	15,520
Labor	**Minutes**	**Quantity per lum.**	**Total Cost ($) @ $65/hr**
install luminaires	1.5/ft	0.009	4
make electrical room	15	0.094	39
remove luminaire bags	2	0.013	5
rough-in ceiling supports	15 total	15	16

Building System Wiring — Finelite Pendant

Material	Unit Cost	Quantity	Total Cost
Rigid metallic conduit (RMC)	$0.98/ft	60	$58.80
Conduit clips	$0.77 ea	5	$3.85
RMC bodies and covers	$10.05 ea	0	$0.00
RMC connectors	$1.90 ea	5	$9.50
J-boxes	$2.55 ea	8	$20.40
Metal conduit (MC)	$0.41/ft	30	$12.30
MC connectors	$1.55 ea	10	$15.50
Ceiling supports	$2.05 ea	26	$53.30
SUBTOTAL			**$173.65**
Labor	Minutes	Quantity Minutes	Total Cost @ $65/hr
Start-up	45 total	45	$48.75
Install RMC	2 per ft	120	$130.00
Install MC	1.5 per ft	45	$48.75
Rough-in ceiling supports	10 ea	260	$281.67
SUBTOTAL			**$509.17**

Cost example from Finelite ecatalog

Luminaires

Material	Unit Cost	Quantity	Total Cost
Luminaires	$35-$45/ft	160	$5,600–$7,200
SUBTOTAL			**$5,600–$7,200**
Labor	Minutes	Quantity Minutes	Total Cost @ $65/hr
Install luminaires	1.5/ft	240	$260.00
Make electrical conn.	15 ea	75	$81.25
Remove luminaire bags	2 ea	30	$32.50
Rough-in ceiling supports	15 tot	15	$16.25
SUBTOTAL			**$390.00**
TOTAL			**$6,673–$8,273**
Per Ft²			**$2.78–$3.45**

Appendices

Floor plans

Lighting breadth

Building submeter data

Trace 700 results

Cost analysis

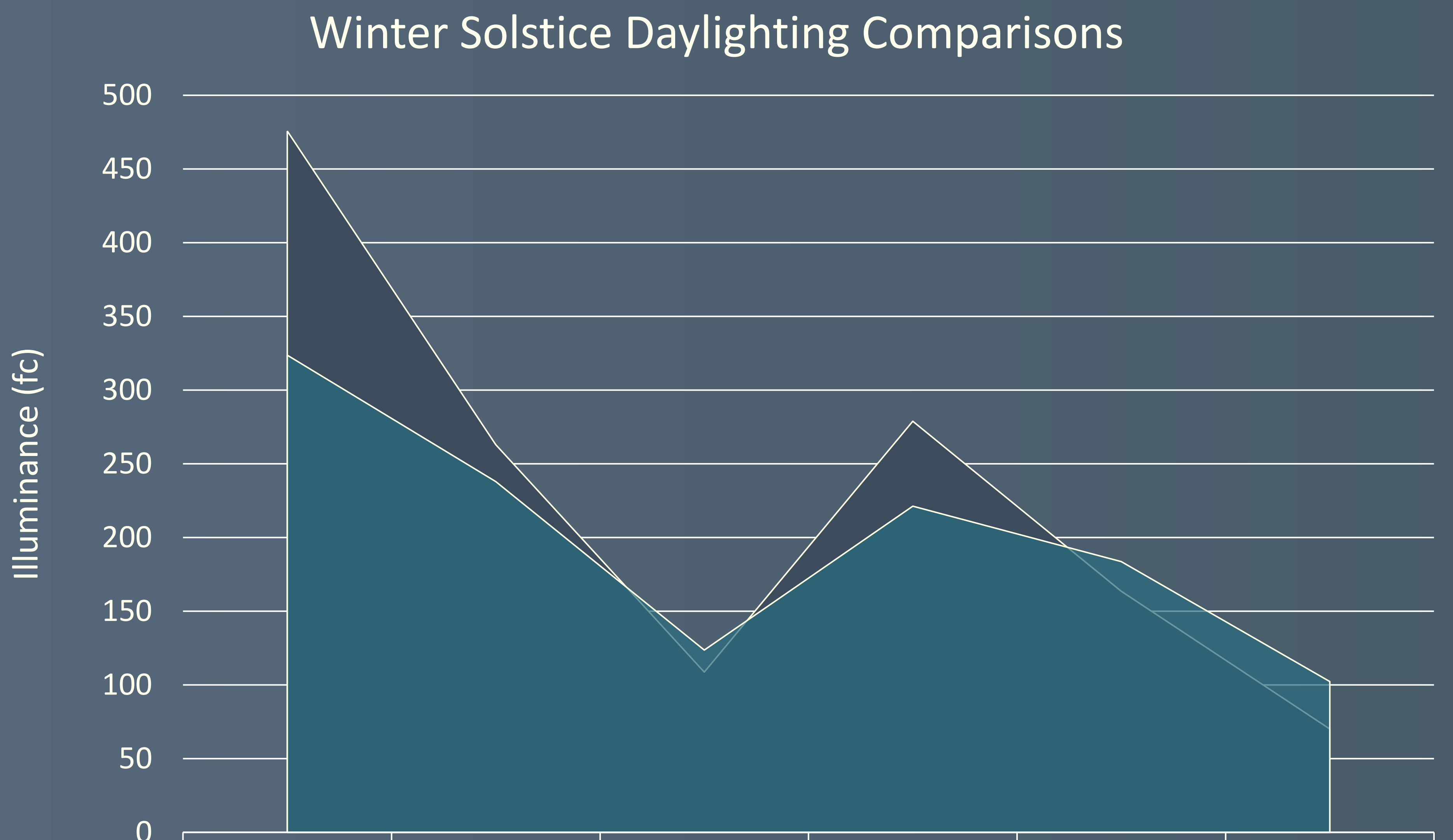
Environmental calculations

Pictures

NASA AOB1 – Valerie Miller

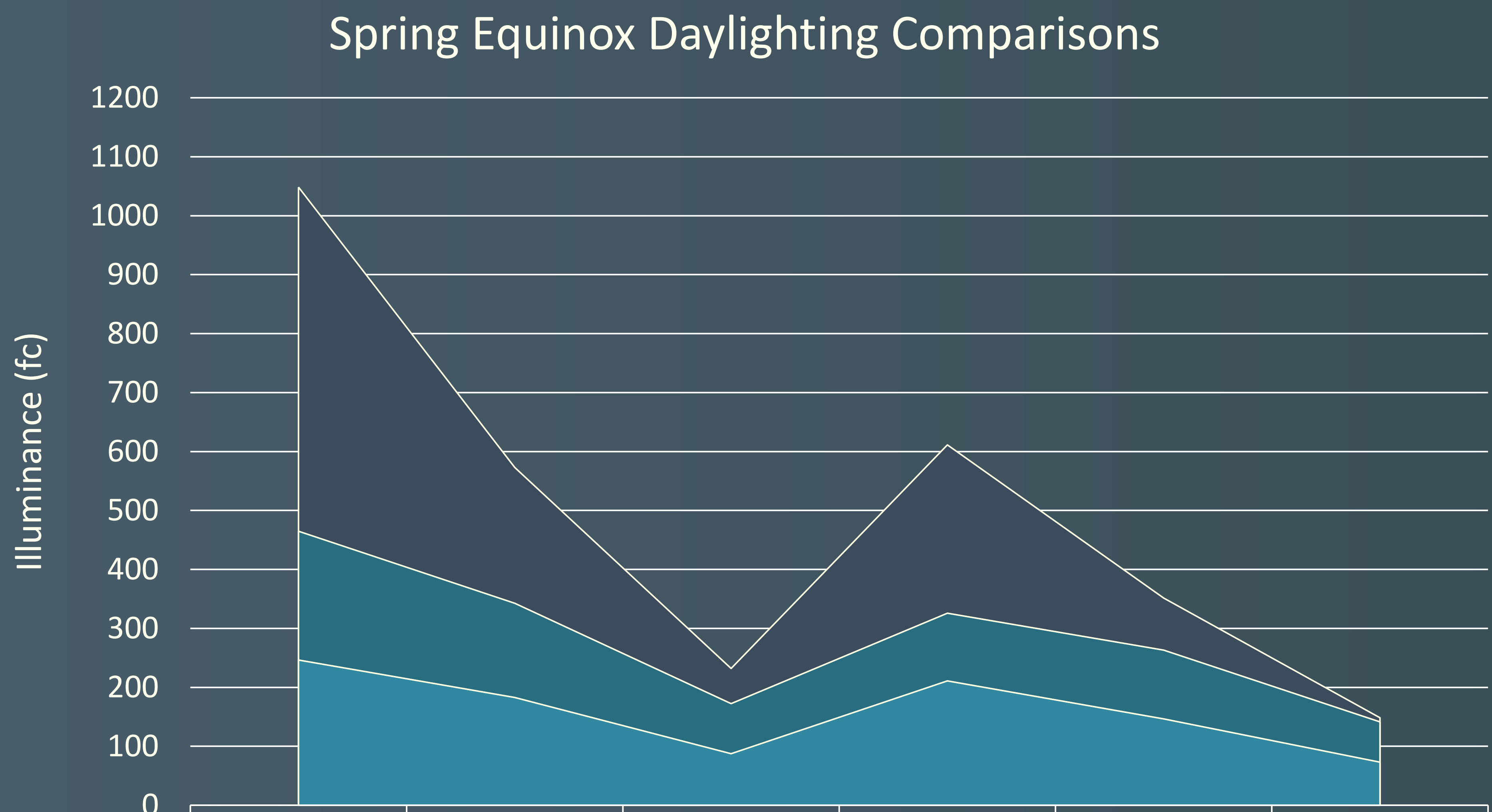
Goals:

- ❖ Lower illuminance on task plane (goal: 30-50 fc)
- ❖ Reduce initial cost of luminaires
- ❖ Reduce energy consumption
- ❖ Ensure ability to daylight space will not be compromised with alternative glazing systems



	MAX	AVG	MIN	MAX	AVG	MIN
	ORIGINAL GLASS			ALTERNATIVE GLASS		
8:00 AM	475.7678	262.98	108.7084	278.885	163.53	70.0934
12:00 PM	323.7109	237.96	123.6468	221.2734	183.66	102.2942

8:00 AM 12:00 PM



	MAX	AVG	MIN	MAX	AVG	MIN
	ORIGINAL GLASS			ALTERNATIVE GLASS		
8:00 AM	1048.484	572.91	232.0529	611.281	351.5	148.419
12:00 PM	464.8176	342.61	172.4139	325.7981	263.18	141.4369
5:00 PM	246.3688	182.8	87.4667	210.9798	146.5	73.1149

8:00 AM 12:00 PM 5:00 PM

Appendices

Floor plans

Lighting breadth

Building submeter data

Trace 700 results

Cost analysis

Environmental calculations

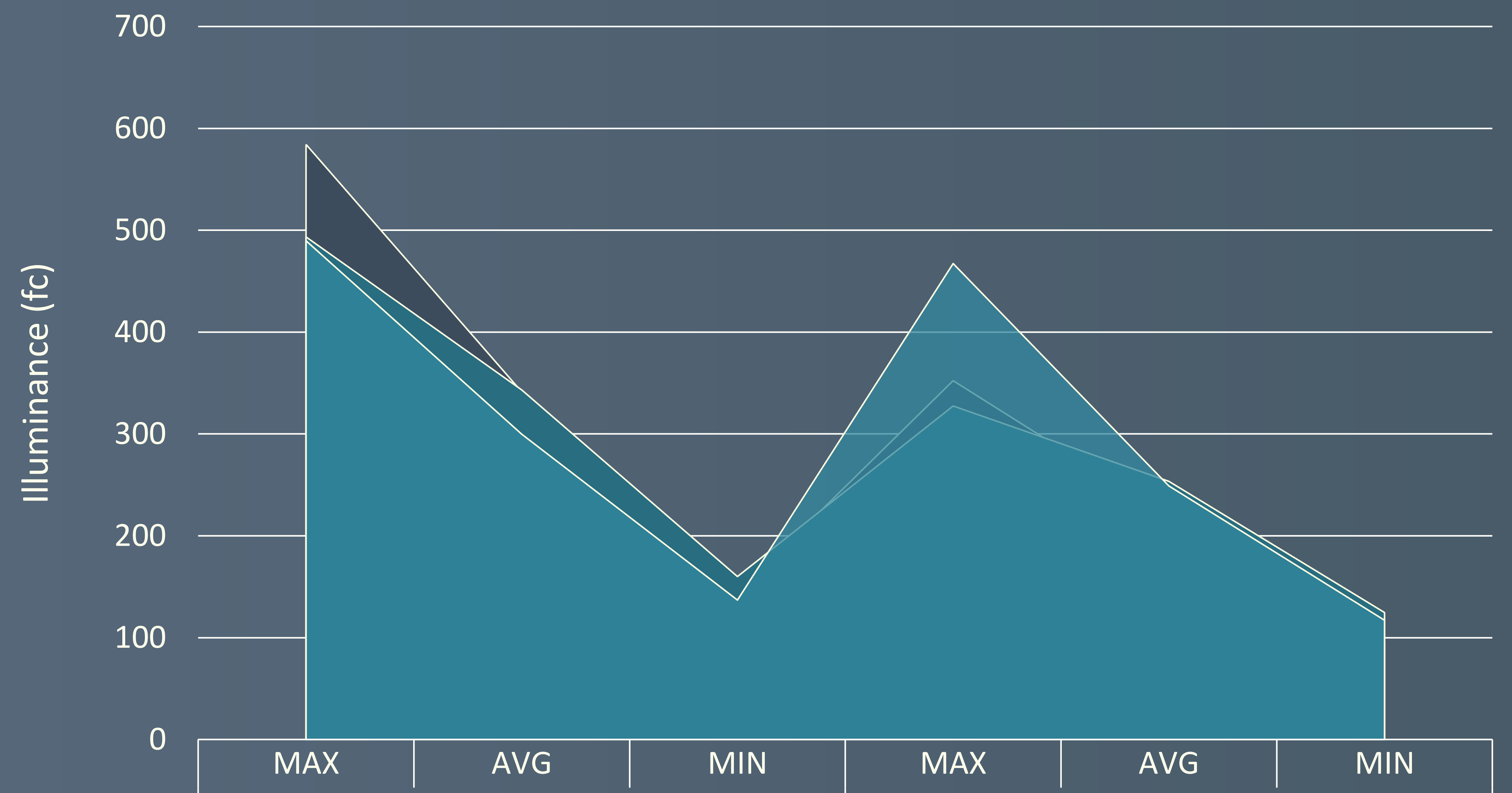
Pictures

NASA AOB1 – Valerie Miller

Goals:

- ❖ Lower illuminance on task plane (goal: 30-50 fc)
- ❖ Reduce initial cost of luminaires
- ❖ Reduce energy consumption
- ❖ Ensure ability to daylight space will not be compromised with alternative glazing systems

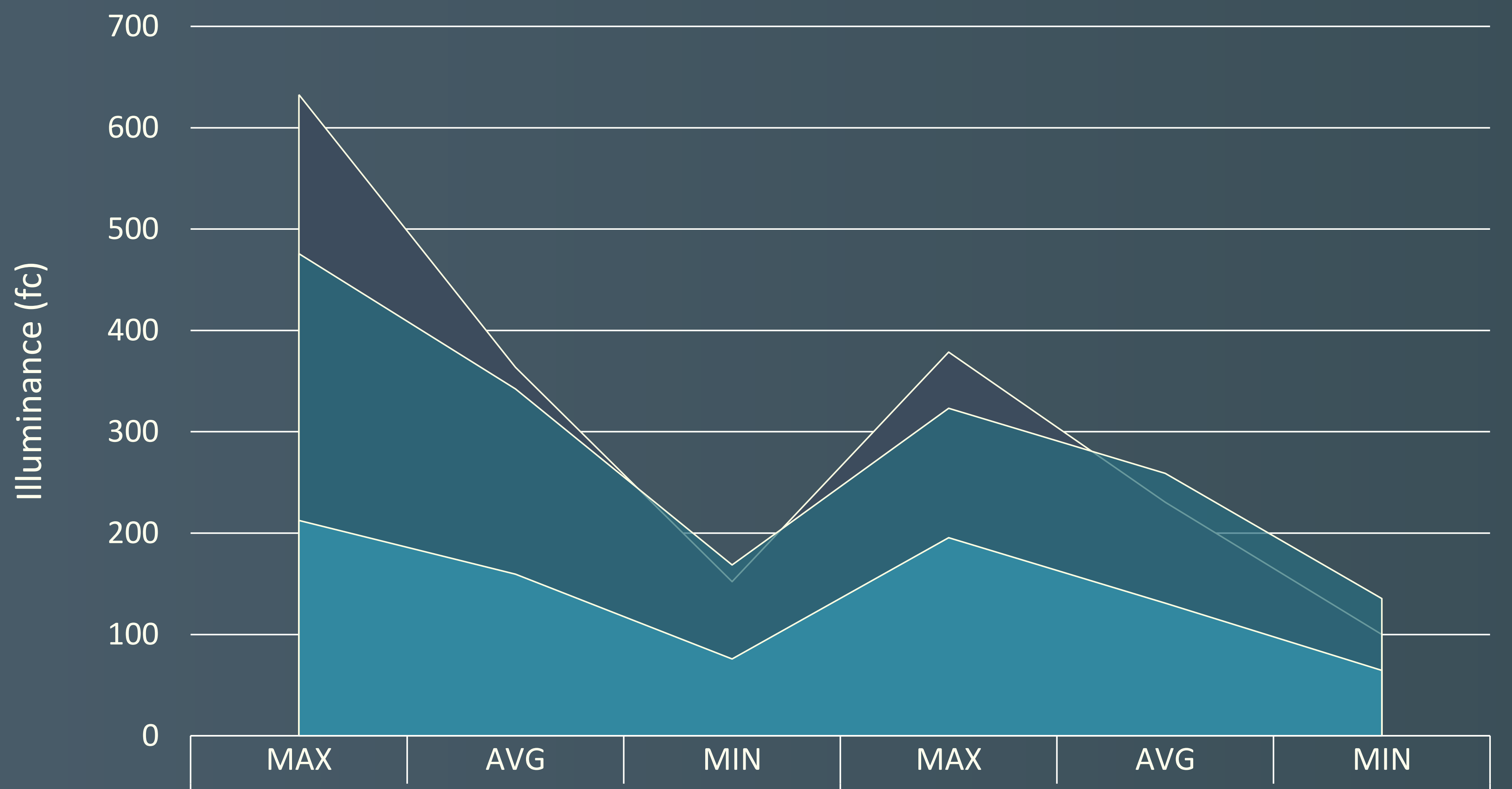
Summer Solstice Daylighting Comparisons



	ORIGINAL GLASS MAX	ORIGINAL GLASS AVG	ORIGINAL GLASS MIN	ALTERNATIVE GLASS MAX	ALTERNATIVE GLASS AVG	ALTERNATIVE GLASS MIN
8:00 AM	584.2779	341.39	144.2519	352.308	218.91	95.9521
12:00 PM	493.4727	343.23	160.0237	327.4791	253.51	124.6796
5:00 PM	489.6951	299.8	136.9317	467.3235	249.01	117.0824

8:00 AM 12:00 PM 5:00 PM

Fall Equinox Daylighting Comparisons



	ORIGINAL GLASS MAX	ORIGINAL GLASS AVG	ORIGINAL GLASS MIN	ALTERNATIVE GLASS MAX	ALTERNATIVE GLASS AVG	ALTERNATIVE GLASS MIN
8:00 AM	632.6481	363.62	152.1109	378.6266	230.5	99.956
12:00 PM	475.7522	342.26	168.6108	323.191	258.97	135.4142
5:00 PM	212.5249	159.49	75.8355	195.501	130.91	64.549

8:00 AM 12:00 PM 5:00 PM

Appendices

Floor plans

Lighting breadth

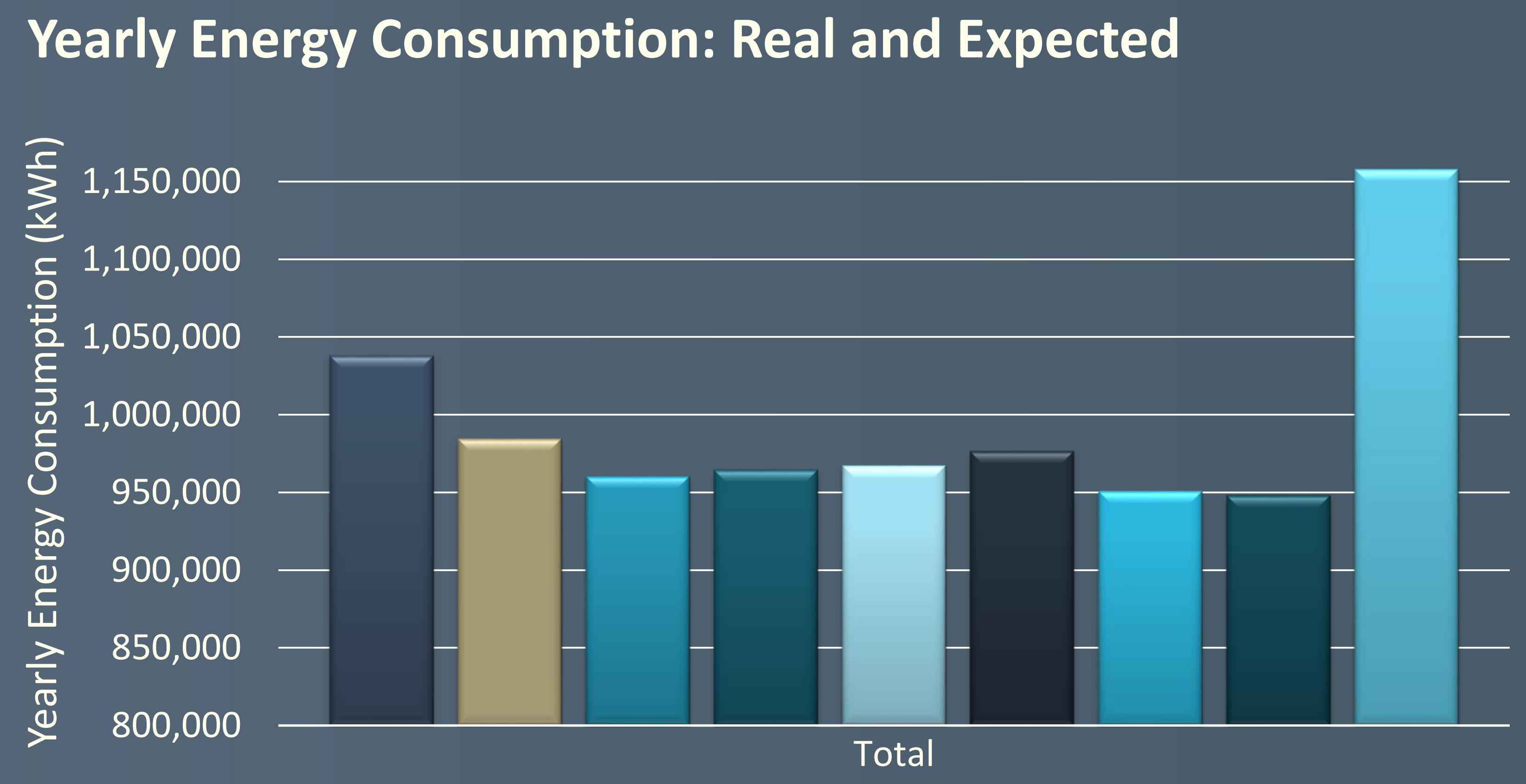
Building submeter data

Trace 700 results

Cost analysis

Environmental calculations

Pictures



	Total
Real monthly total	1,037,990
Original glass and lighting	984,526
Original glass and NEW lighting	960,399
Original + PV	964,375
Triple low-E	967,089
Triple low-E + PV	976,339
Triple doubble low-E	950,768
Triple double low-E + PV	948,017
Basic glass type	1,157,847

Real yearly kWh consumption from submeter data:

- ❖ 1,037,990 kWh

Trace 700 model yearly energy estimation for original model:

- ❖ 984,526 kWh

Difference between real and Trace 700 prediction:

- ❖ 53,464 kWh
- ❖ 5.15%

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

Thermal Properties: Curtainwall Adjustments

Kawneer 1600UT System

Adjust properties of glass for use in a curtain wall assembly

Glass U-Factor	Overall U-Factor
0.32	0.42
0.26	0.37
0.22	0.33
0.18	0.30
0.16	0.28

Glass SHGC	Overall SHGC
0.40	0.37
0.30	0.28
0.25	0.24

GLASS TYPE	MANUFACTURER	U-VALUE (ADJ)	SHGC (ADJ)
Original glass	Viracon – low-E insulating laminated	0.37	0.255
Triple Low-E	Viracon – triple insulating	0.33	0.275
Triple Double Low-E	Viracon – triple insulating w/ second low-E coating	0.29	0.24
Basic glass: double pane	NA – Trace 700 default	0.6*	0.71*
PV glass	Onyx Solar	0.42	0.37

***Note: this glass would not meet ASHRAE 90.1 requirements for this climate zone; these values are just for educational comparison purposes**

Appendices

Floor plans

Lighting breadth

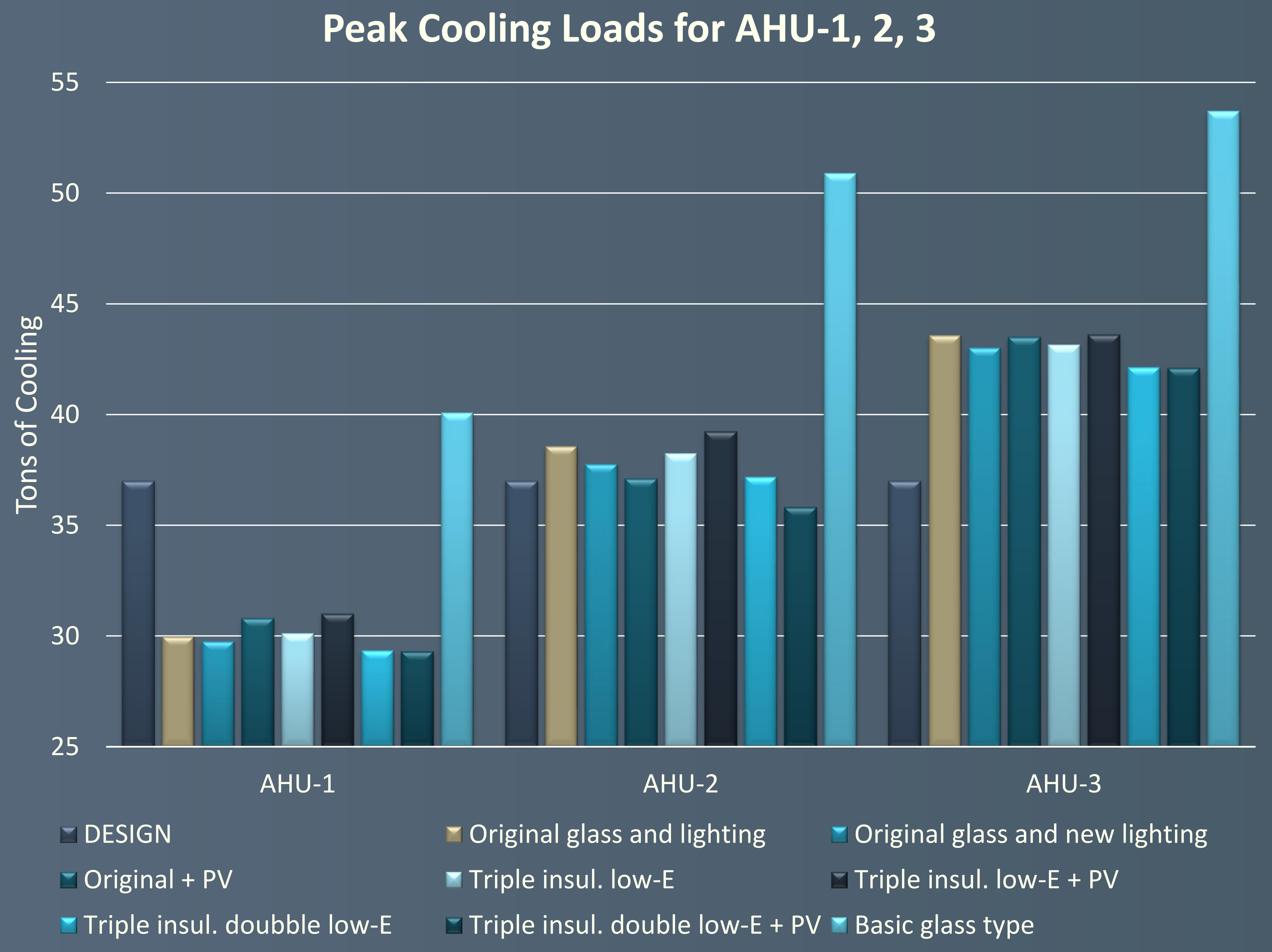
Building submeter data

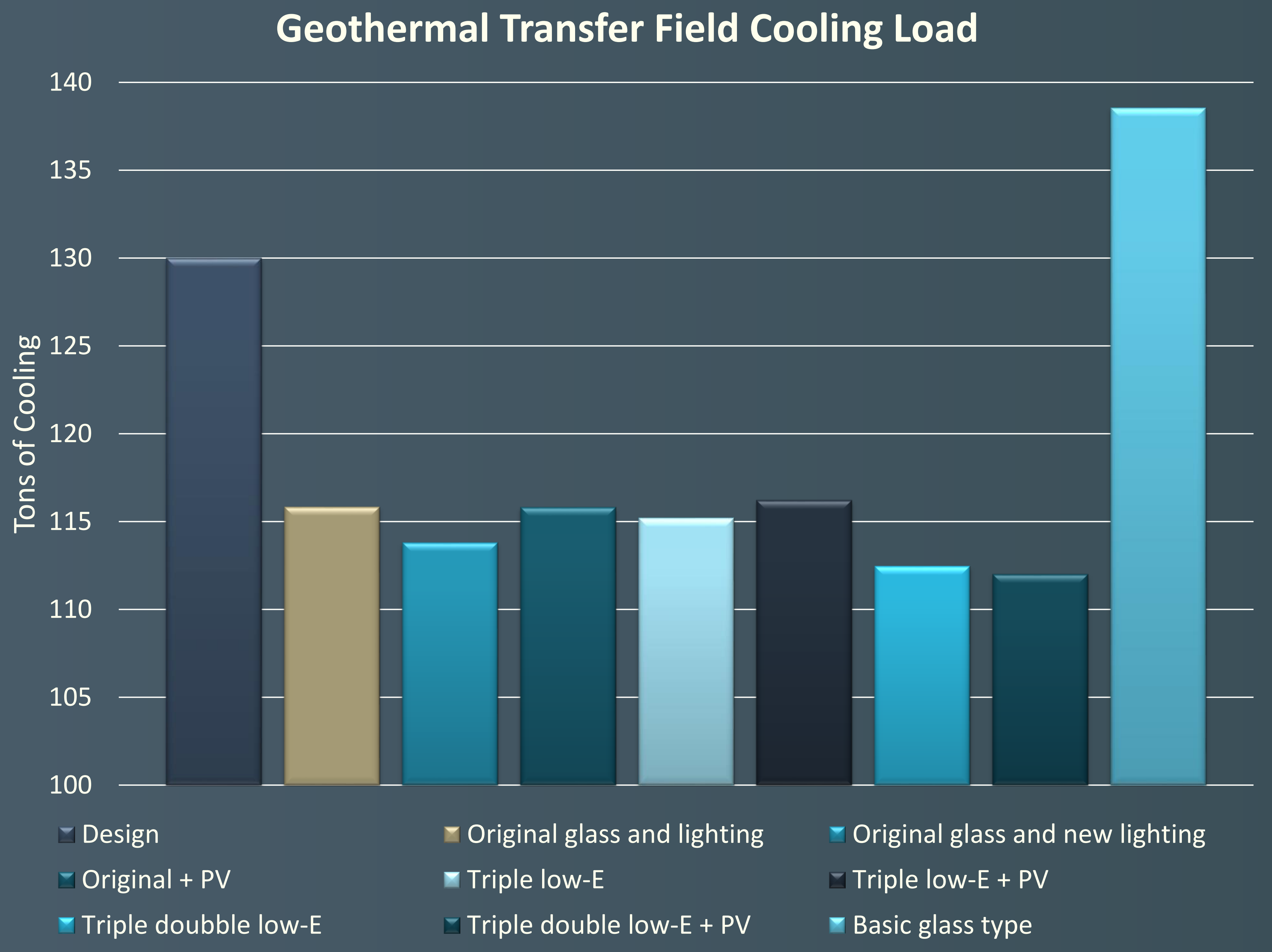
Trace 700 results

Cost analysis

Environmental calculations

Pictures





Appendices

Floor plans

Lighting breadth

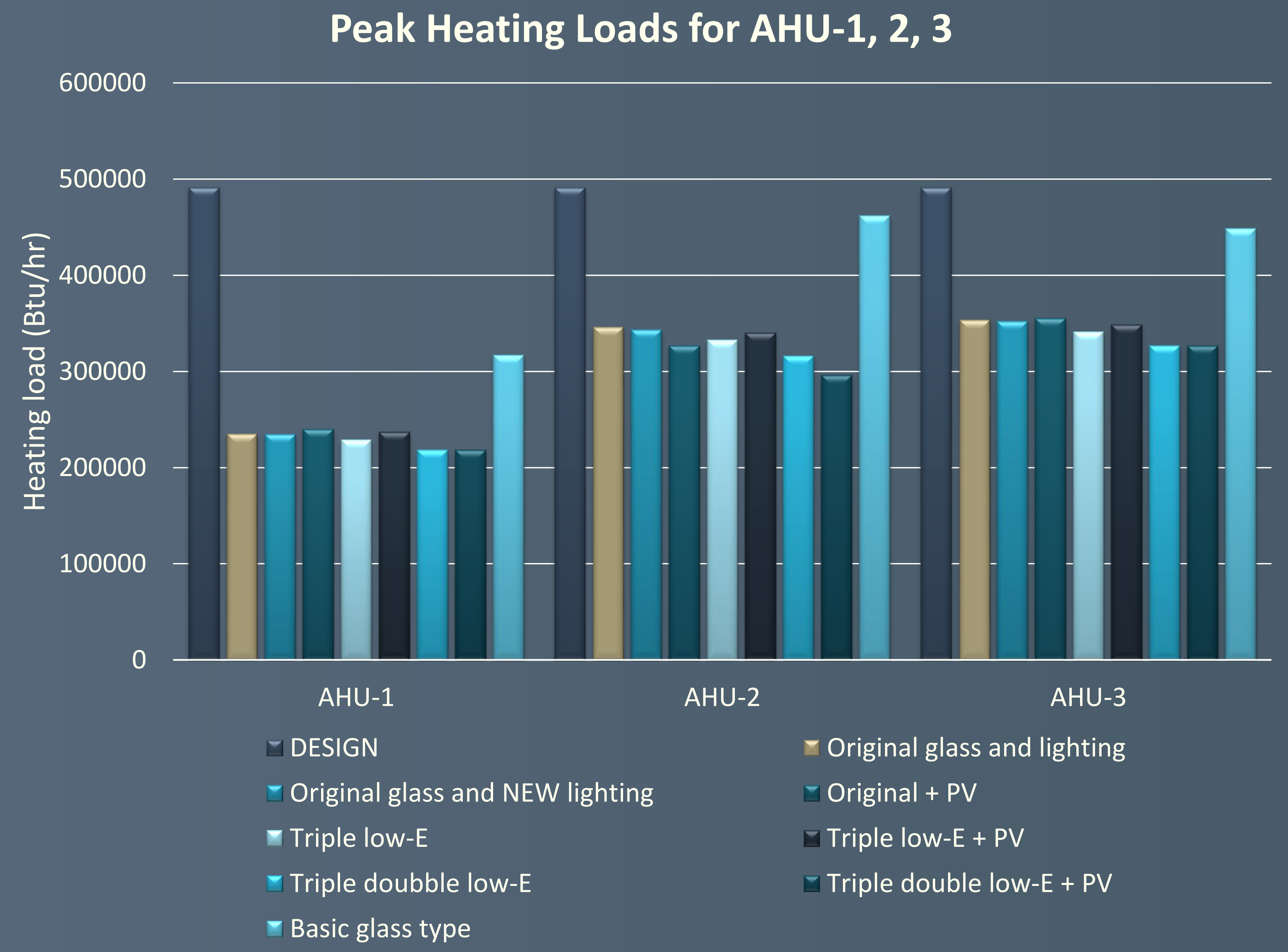
Building submeter data

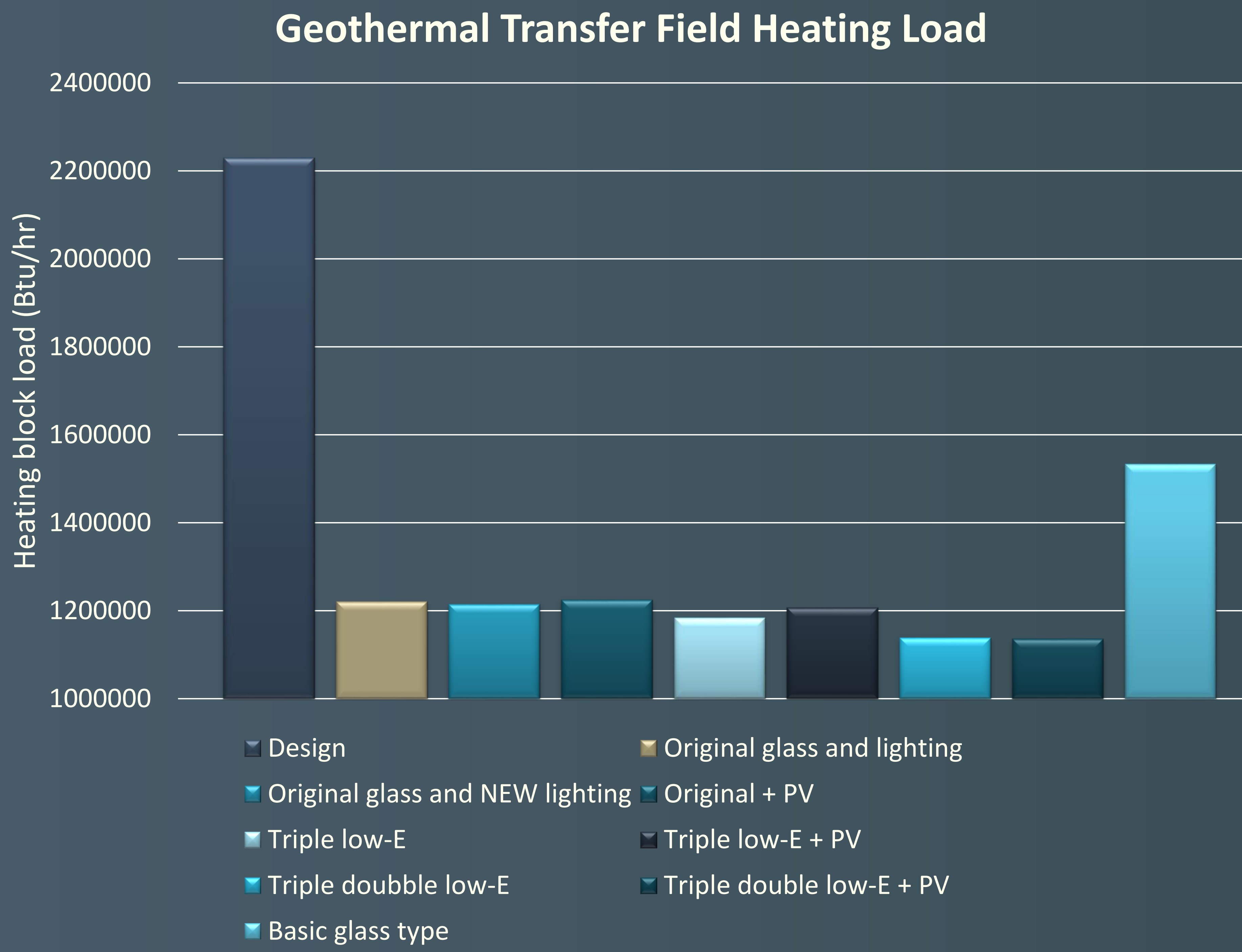
Trace 700 results

Cost analysis

Environmental calculations

Pictures





Appendices

Floor plans

Lighting breadth

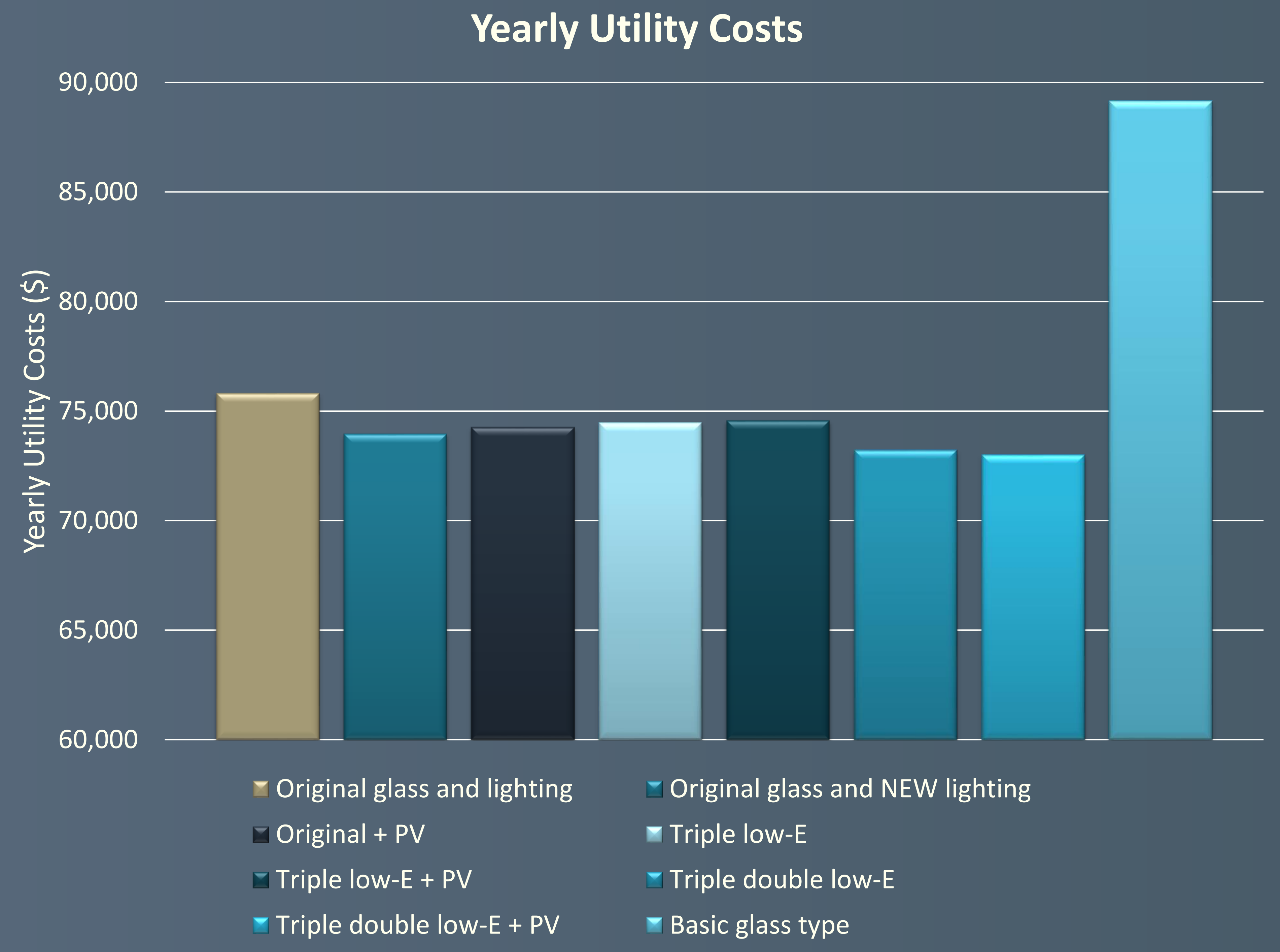
Building submeter data

Trace 700 results

Cost analysis

Environmental calculations

Pictures



Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

Glass costs

Item	Cost ($) per square foot	Notes
Triple IGU VRE1-54	27.80	Viracon
Triple insulating VRE1-54	29.40	Viracon
Argon filling addition	0.50	Viracon
Insulating laminated:	21.10	Viracon
Basic double pane glass:	11.10	RSMeans Assemblies Cost Data 2015
Double pane PV low-E glass:	12.71	Assuming a 10% increase in glass cost for PV

Alternative	Cost ($)
Original glass	320,762
Original + PV	290,768
Triple low-E	422,616
Triple low-E + PV	368,669
Triple double low-E	446,939
Triple double low-E + PV	387,272
Basic double pane glass	168,742

*An additional $5160 was added for an inverter for the PV alternatives

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

Equipment costs

Cost data from

RSMeans Mechanical

Cost Data 2015

		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5	DOAS (ton/MBh)	Energy Recovery	Total equip cost:
	Total SA CFM:	8728	12707	12842	2387	3812	130/1037	18085	
Original glass and lighting	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
	Total SA CFM:	8583	12232	12533	2387	3812	129/1031	17644	
Original glass and NEW lighting	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
	Total SA CFM:	9166	11870	12813	2387	3812	130/1023	17882	
Original + PV	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
	Total SA CFM:	8831	12560	12617	2374	3812	130/1004	17958	
Triple low-E	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
	Total SA CFM:	9404	12061	12892	2374	3812	132/1027	18123	
Triple low-E + PV	Cost:	$22,700	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$433,025
	Total SA CFM:	8317	11876	12037	2361	3812	127/962	17113	
Triple double low-E	Cost:	$20,600	$26,000	$26,000	$7,400	$9,525	$311,000	$30,400	$430,925
	Total SA CFM:	8317	11003	12037	2361	3812	125/942	16699	
Triple double low-E + PV	Cost:	$20,600	$22,700	$26,000	$7,400	$9,525	$311,000	$30,400	$427,625
	Total SA CFM:	15568	21490	18130	2459	3812	163/1329	28017	
Basic glass type	Cost:	$32,200	$42,900	$27,900	$7,400	$9,525	$505,000	$30,400	$655,325

Typical RSMeans Sizes (CFM):	**3,000**	**4,000**	9,200	**11,500**	**13,200**	**16,500**	**19,500**	**22,000**	**(DOAS) 140 tons**	**(DOAS) 170 tons**	**(ERV) 20,000**
Cost ($):	7,400	9,525	20,600	22,700	26,000	32,200	27,900	42,900	311,000	505,000	30,400

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

20 YEAR LIFE-CYCLE COSTS

	TOTAL EQUIP COST:	GLASS SYSTEM COST:	1 YEAR OP COST:	OPERATING COST FOR 20 YEARS:	20 YEAR LIFE-CYCLE COST:
Original glass and lighting	$430,925	$320,762	$75,808.45	$1,516,169	$2,267,856
Original glass and NEW lighting	$430,925	$320,762s	$73,950.74	$1,479,015	$2,230,702
Original + PV	$430,925	$295,927	$74,256.85	$1,485,137	$2,211,989
Triple low-E	$430,925	$422,616	$74,465.85	$1,489,317	$2,342,858
Triple low-E + PV	$433,025	$373,828	$74,570.78	$1,491,416	$2,298,269
Triple double low-E	$430,925	$446,939	$73,209.13	$1,464,183	$2,342,046
Triple double low-E + PV	$427,625	$392,431	$72,997.30	$1,459,946	$2,280,002
Basic glass type	$655,325	$168,742	$89,154.20	$1,783,084	$2,607,151

Appendices

Floor plans

Lighting breadth

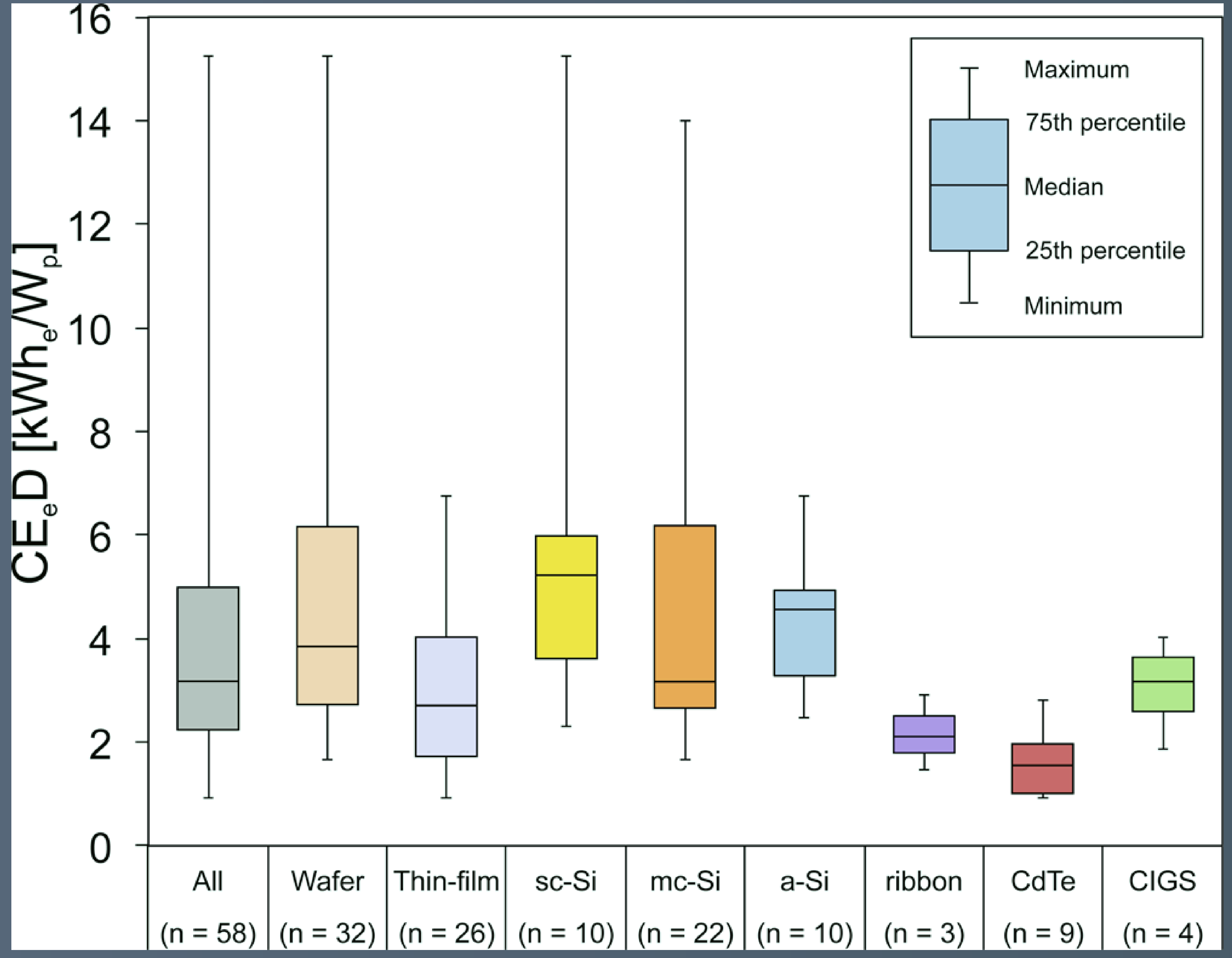
Building submeter data

Trace 700 results

Cost analysis

Environmental calculations

Pictures



Distribution of energy input to output of PV technologies, from Environmental Science and Technology article by M. Dale and S. Benson

APPENDICES

Floor plans

Lighting breadth

Building submeter data

Trace 700 results

Cost analysis

Environmental calculations

Pictures

Table 3 Total Emission Factors for Delivered Electricity (lb of pollutant per kWh of electricity)

Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_X	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_X	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

U.S. Emission Factors from NREL "Source Energy and Emission Factors for Energy Use in Buildings," 2007

Emissions per kWh of electricity generated

	$kgCO_2/kWh$	$kgCH_4/kWh$	kgN_2O/kWh
South Africa	1.069026617	0.00001131304	0.00001694748
South Asia	1.213800412	0.00001520917	0.00001755688
Southeast Asia/ASEAN	0.627076088	0.00001079622	0.00000567292
Spain	0.34287509	0.00000553451	0.00000307467
Sri Lanka	0.417247633	0.00001644053	0.00000328811
Sudan	0.614906086	0.00002436143	0.00000487229

Spain emission factor from Ecometrica "Technical Paper| Electricity-specific emission factors for grid electricity," 2011

Appendices

- Floor plans
- Lighting breadth
- Building submeter data
- Trace 700 results
- Cost analysis
- Environmental calculations
- Pictures

Calculations:

kWh generated = 1451 kWh/year (from manufacturer website application)

Pounds CO_2 saved/year = 1.64 lb CO_2/kWh x 1451 kWh/year (generated) = 2380 lb CO_2/year

Method 1:

kWh to manufacture = 11.15 kWh/ft2 x 3575 ft2 = 39861 kWh

(120 kWh/m2 = 11.15 kWh/ft2)

Pounds of CO_2 to manufacture = 0.755909 lb CO_2/kWh x 39861 kWh = 30131 lb CO_2

(0.342875 kg/kWh = 0.755909 lb/kWh)

CO_2 payback = 30131 lb CO_2/ 2380 lb CO_2/year = 12.66 years

APPENDICES

Calculations:

kWh generated = 1451 kWh/year (from manufacturer website application)

Pounds CO_2 saved/year = 1.64 lb CO_2/kWh x 1451 kWh/year (generated) = 2380 lb CO_2/year

Method 2:

Wp = 2.972 W/ft2 x 2500 ft2 = 7440 W

(32 Wp/m2 = 2.972 W/ft2)

kWh to manufacture = 4.5 kWh/Wp x 7440 Wp = 33480 kWh

Pounds of CO_2 to manufacture = 0.755909 lb CO_2/kWh x 33480 kWh = 25308 lb CO_2

(0.342875 kg/kWh = 0.755909 lb/kWh)

CO_2 payback = 25308 lb CO_2/ 2380 lb CO_2/year = 10.63 years

Appendices

Floor plans

Lighting breadth

Building submeter data

Trace 700 results

Cost analysis

Environmental calculations

Pictures

- Renderings from AECOM Basis of Design drawings
- Photos courtesy of H.F. Lenz Company

Appendices

Floor plans

Lighting breadth

Building submeter data

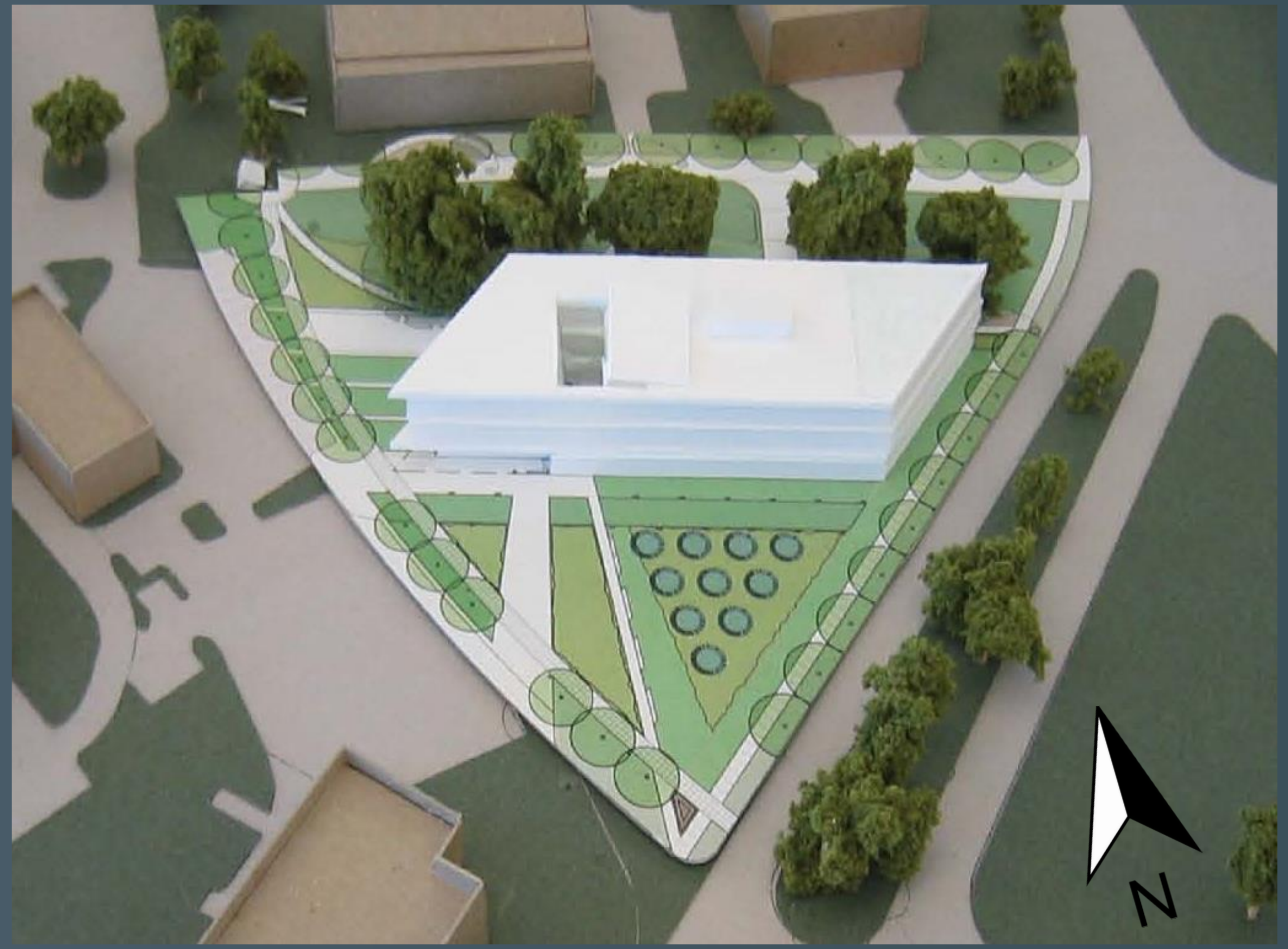
Trace 700 results

Cost analysis

Environmental calculations

Pictures

- ❖ Renderings from AECOM Basis of Design drawings
- ❖ Photos courtesy of H.F. Lenz Company



References

1. ANSI/ASHRAE. (2013). Standard 62.1-2013, *Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
2. ANSI/ASHRAE. (2013). Standard 90.1-2013, *Energy Standard for Buildings Except Low Rise Residential Buildings*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
3. ASHRAE. (2009). 2009 ASHRAE Handbook, *Fundamentals.*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.
4. Deru, M. P., Torcellini, P., & National Renewable Energy Laboratory (U.S.). (2007). *Source energy and emission factors for energy use in buildings* (Rev.). Golden, Colo.: National Renewable Energy Laboratory.
5. "Energy Balance of the Global Photovoltaic (PV) Industry - Is the PV Industry a Net Electricity Producer?" *Environmental Science and Technology* (2013). Print.
6. Energy Star (2014, September). Portfolio Manager, *U.S. Energy Use Intensity by Property Type*. Retrieved October 10, 2014, from https://portfoliomanager.energystar.gov/pdf/reference/US National Median Table.pdf
7. Flynn, J. (2008, January 1). Visualizing the Future of NASA Langley Research Center. Retrieved September 12, 2014. <http://proceedings.esri.com/library/userconf/feduc08/papers/feduc.pdf>.
8. "Onyx Solar - Building Integrated Photovoltaics (BIPV) - Photovoltaic Glass for Buildings." *Onyx Solar- Photovoltaic Building Materials*. Onyx Solar. Web. 1 Apr. 2015. <http://www.onyxsolar.com/>.
9. "PV FAQs." *National Renewable Energy Laboratory*. National Renewable Energy Laboratory, 1 Jan. 2004. Web. 4 Apr. 2015. <http://www.nrel.gov/docs/fy04osti/35489.pdf>.
10. Quinville, T. (2009, September 16). New Town NASA Langley Research Center's Revitalization Initiative Report to Hampton Roads SAME Chapter. Retrieved September 12, 2014, from http://posts.same.org/hamptonroads/NASANewTownSep2009.pdf
11. "Typical Foot Candle (FC) and LUX Ratings." *Lashen Electronics*. Lashen Electronics. Web. 1 Apr. 2015. <http://www.lashen.com/vendors/pelco/typical_light_levels.asp>.
12. U.S. Department of Energy (2008) Buildings Energy Data Book, *Buildings Energy Data Book.* Retrieved September 30, 2014. <http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.3.8>.
13. Vaughan, Adam. "Colourful 'solar Glass' Means Entire Buildings Can Generate Clean Power." *The Guardian*. The Guardian, 12 Feb. 2013. Web. 1 Apr. 2015. <http://www.theguardian.com/environment/2013/feb/12/printed-solar-glass-panels-oxford-photovoltaics>.
14. Ver-Bruggen, Sara. "Smart Glass." *Pv-magazine*. Pv Magazine, 1 Feb. 2013. Web. 1 Apr. 2015. <http://www.pv-magazine.com/archive/articles/beitrag/smart-glass-_100010161/572/#axzz3VJcQNnfP>.
15. *Viracon - Your Single-Source Architectural Glass Fabricator*. Viracon. Web. 1 Apr. 2015. <http://www.viracon.com/>.