EMD SERONO RESEARCH CENTER – EXISTING

BILLERICA, MA

SHIYUN (SHARON) CHEN | MECHANICAL

AE SENIOR THESIS

Outline

Building Overview

Existing Mechanical System

Dedicated Outdoor Air System/Active Chilled Beam

Heat Recovery Systems

Architectural Breadth

Conclusion

Outline

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Building Overview

Building: EMD Serono Research Center – existing

Building Location: Billerica, MA

Building Size: 56,700 SF

Number of Story: Basement + 2 Stories + Penthouse

Occupancy/ Function Type: Pharmaceutical Lab

Date of Construction: Nov,1999 – Marc,2002

Project Delivery Method: Fast - Track

Design Team

Owner: EMD Serono, Inc.

Architect: Ellenzweig Associate, Inc.

MEP Engineer: Bar, Rao + Athanas Consulting Engineers, LLC

Structural Engineer: LeMessurier Consulting Engineers

Landscape Architect: John G. Crowe Associates, Inc.

Contractor: Linbeck/Kennedy & Rossi

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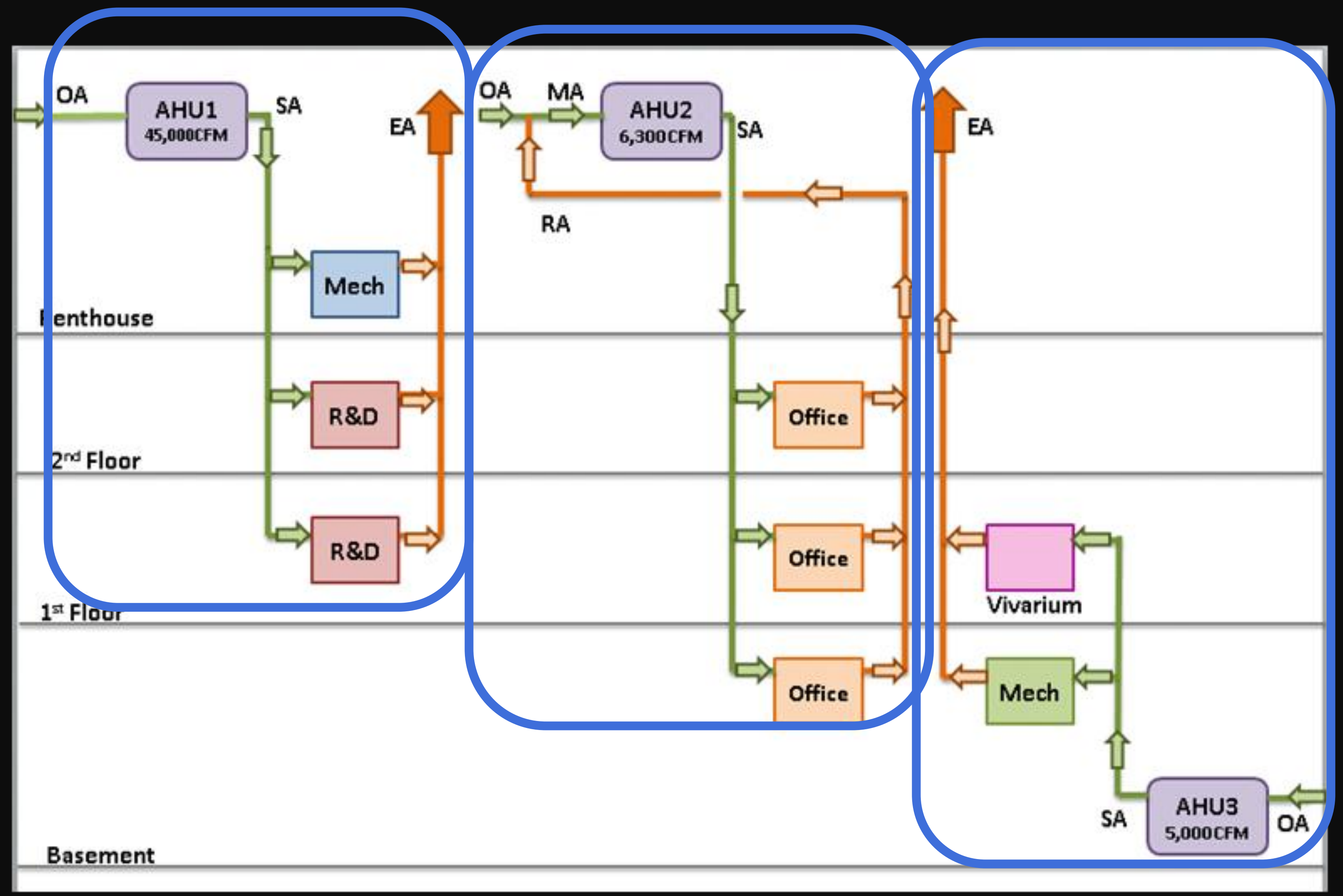
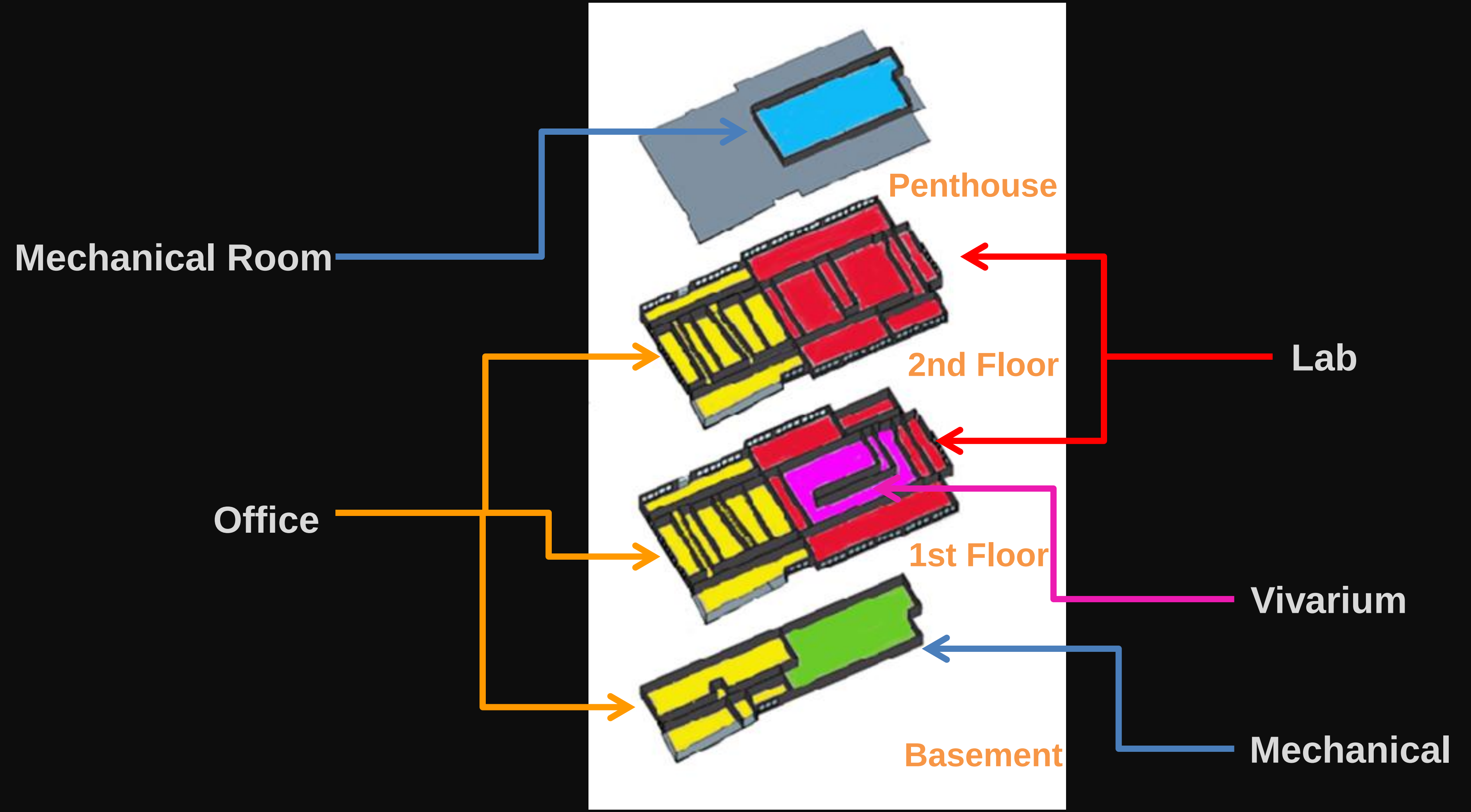
Existing Mechanical System

- (2) 100% OA Air Handling Units
- (1) OA + RA Air Handling Unit
- (1) 350 Ton Centrifugal Chiller
- (1) 60 Ton Air Cooled Chiller
- (2) Low Pressure Steam Boilers
- (2) Heat Exchangers





Building Division

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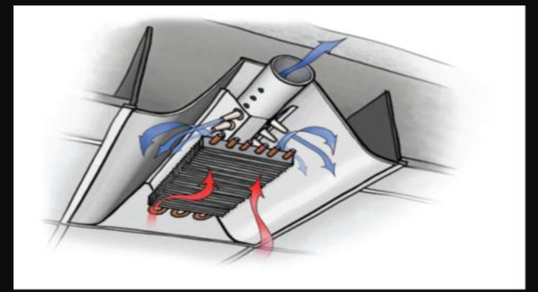
Redesign Goals

- ↓ ENERGY CONSUMPTION
- ↑ SYSTEM EFFICIENCY
- ↑ INDOOR AIR QUALITY
- ↑ THERMAL COMFORT

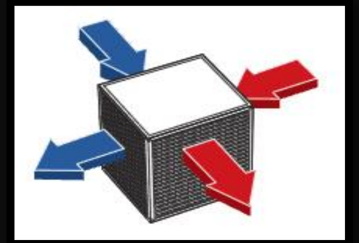
Solution

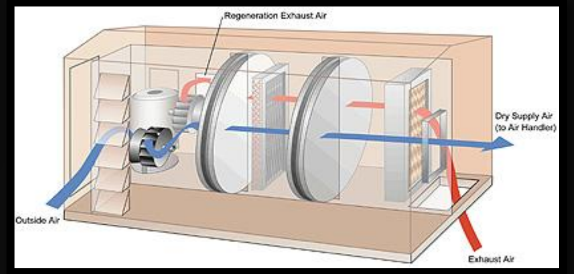
Dedicated Outdoor Air System



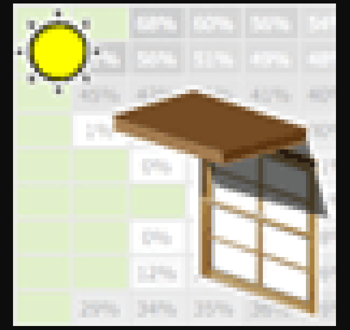
Active Chilled Beam System

Heat Recovery System





Solar Shading System



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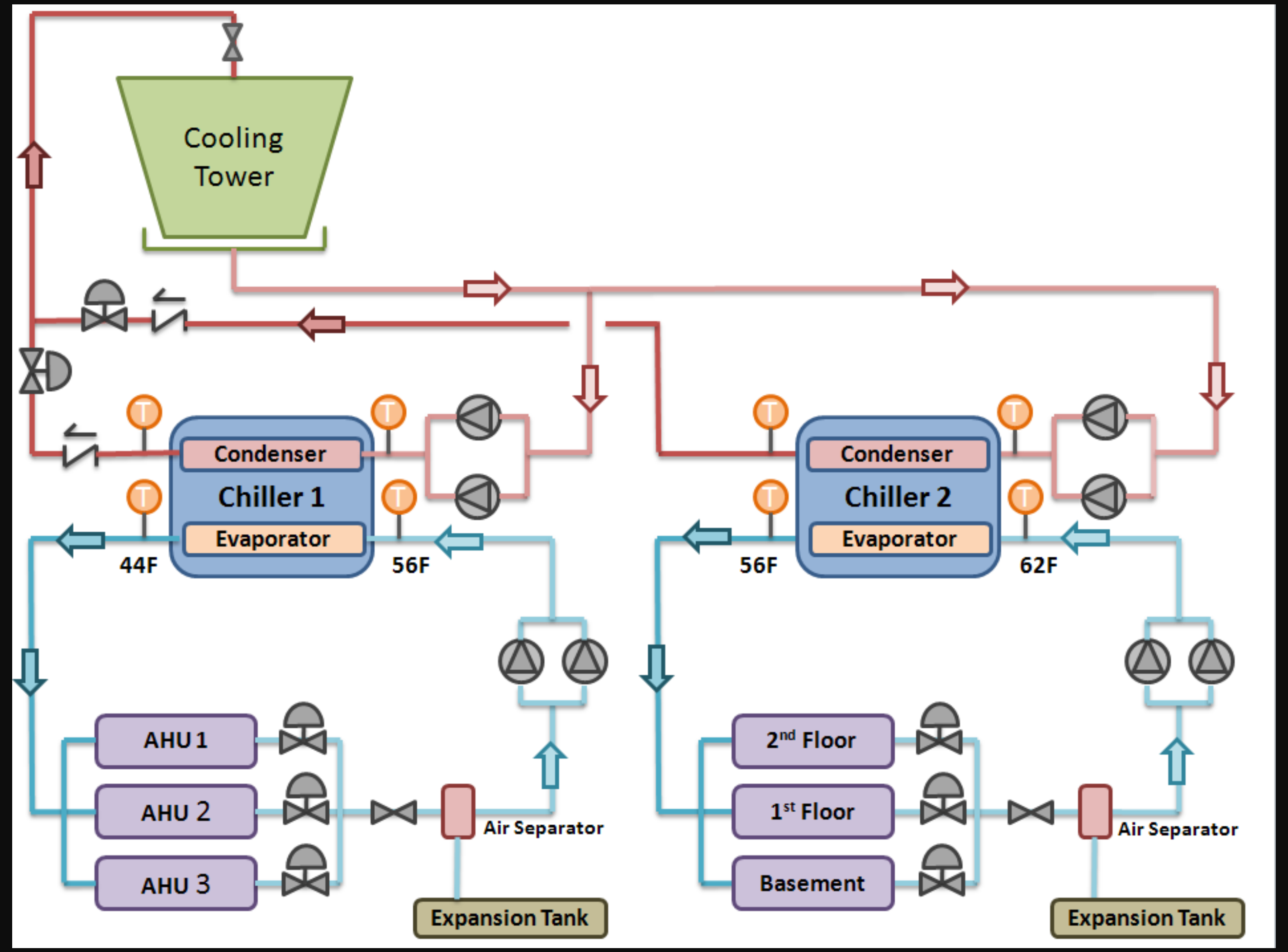
Active Chilled Beam Advantages

- Minimize Outdoor Air Conditioning
- Eliminate Reheat Energy
- More Efficient Chilled Water System
- Better Mixed Air Distribution
- More Uniform Temperature Distribution
- Improve Indoor Air Quality
- Lower Maintenance

DOAS + Active Chilled Beam



(1) 350 Ton Screw Chiller - AHUs

(1) 150 Ton Screw Chiller - ACBs

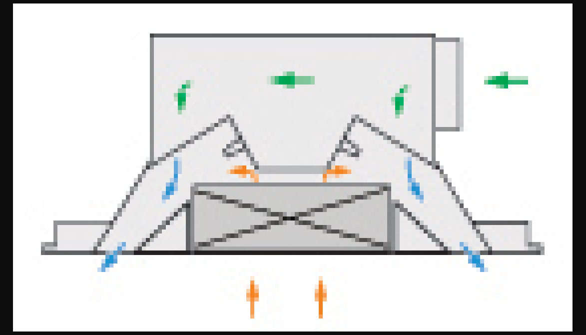
Chilled Beam Selection

17CFM/LF | 665 BTU/LF

TROX Technic

4 Pipe Chilled Beam, Model DID602, type “C” nozzle

NC25



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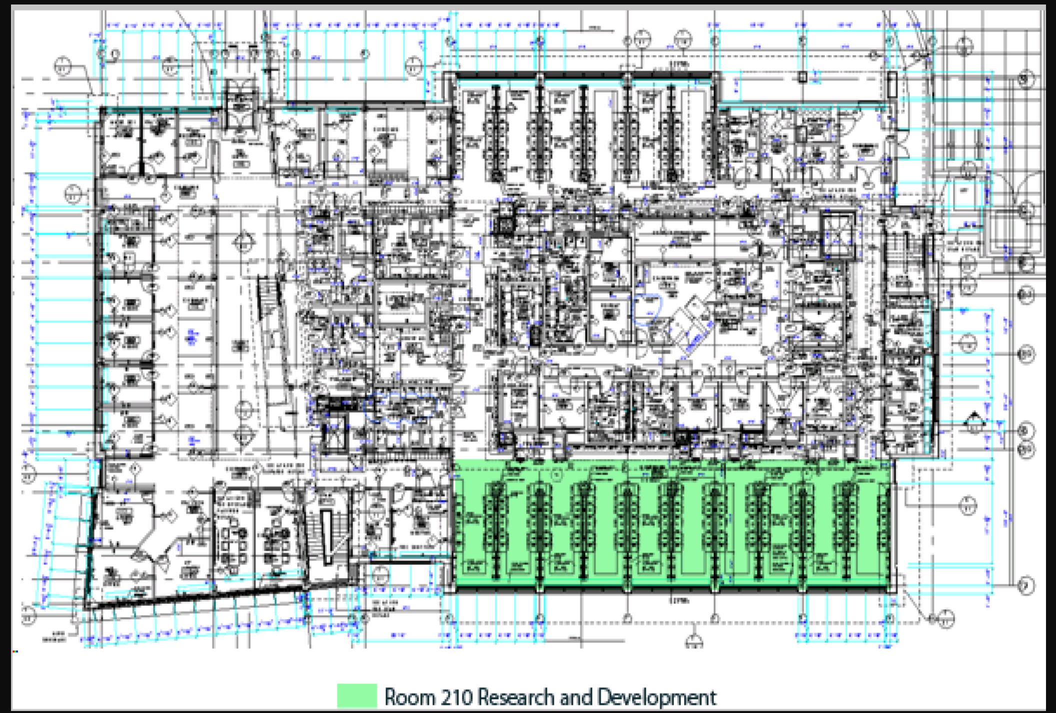
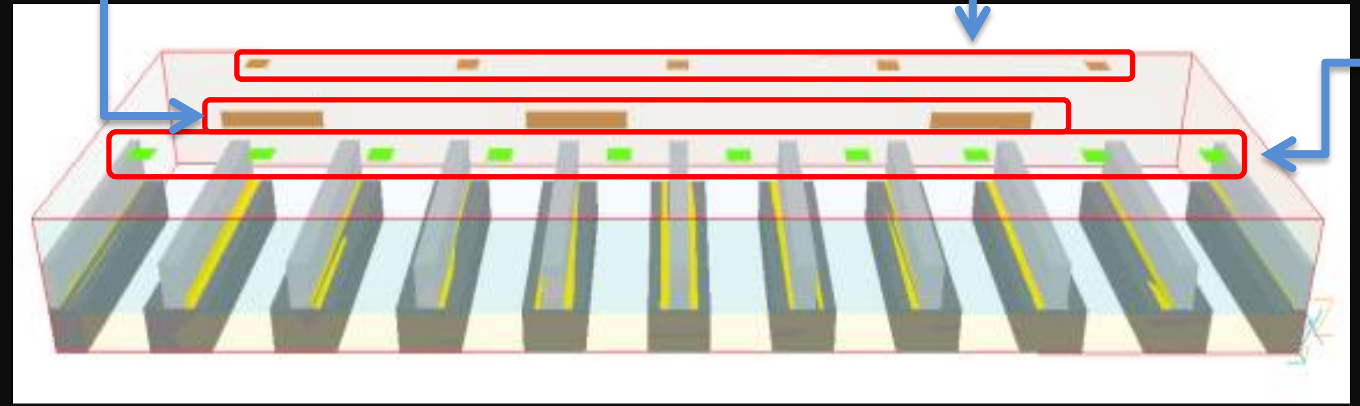


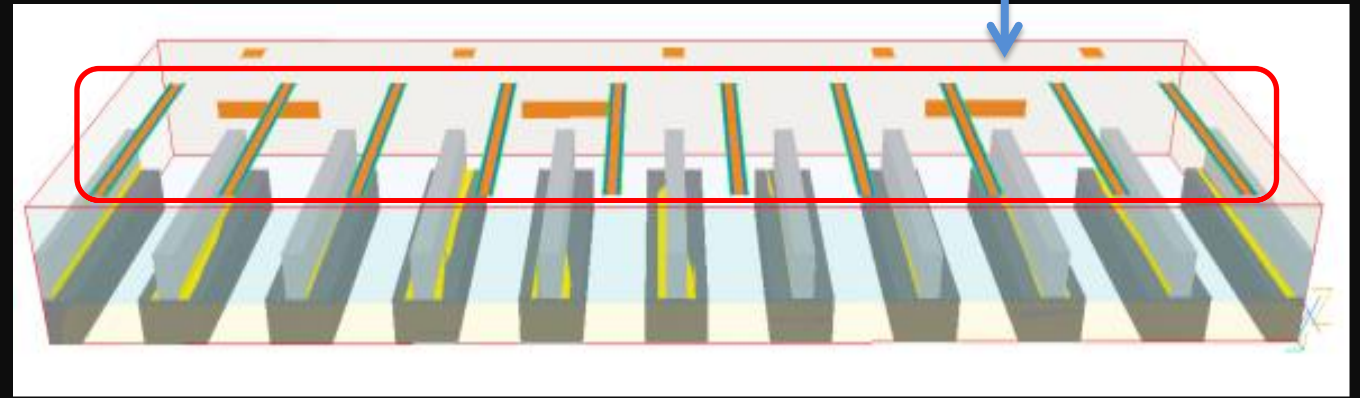
CFD Simulation

Fume Hood Sash
Exhaust Grills
Square VAV Diffusers



VAV

Active Chilled Beam



ACB

Existing VAV
Supply Air = Outside Air = 6000cfm
SA Temperature: 13C = 55.4F

DOAS+ACB
Supply Air = Outside Air + Recirculate Air
20,092cfm = 3,324cfm + 16,769cfm
SA Temperature: 19.64C = 67.4F

General Information					
	Grid Size	Turbulence Model	Numerical Scheme	Number of Iterations	Mass Residual
Existing System	108x218x61	KE model	Upwind	7000	1.30%
Active Chilled Beam System	52x459x35	KE model	Hybrid	5000	0.54%

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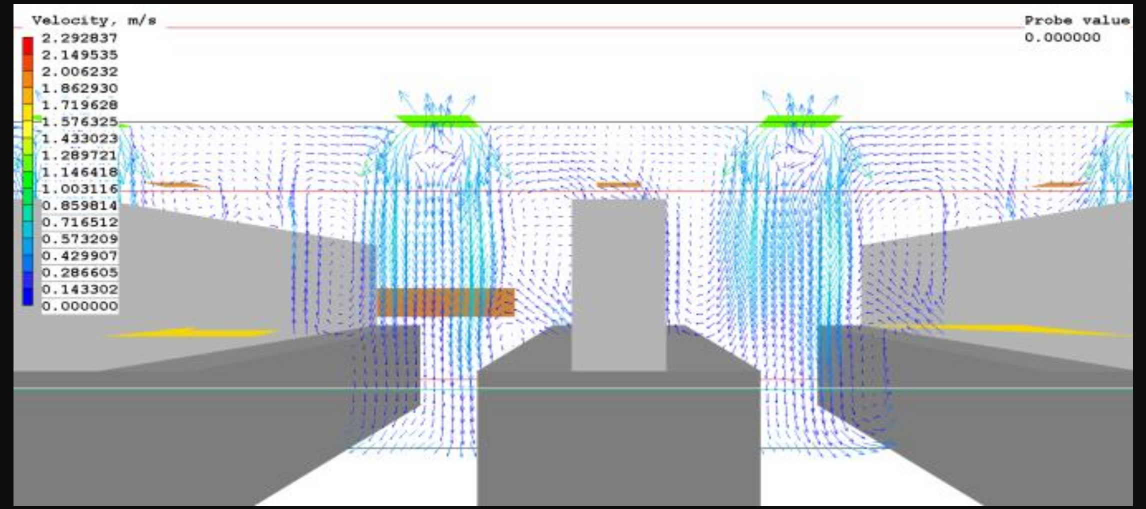
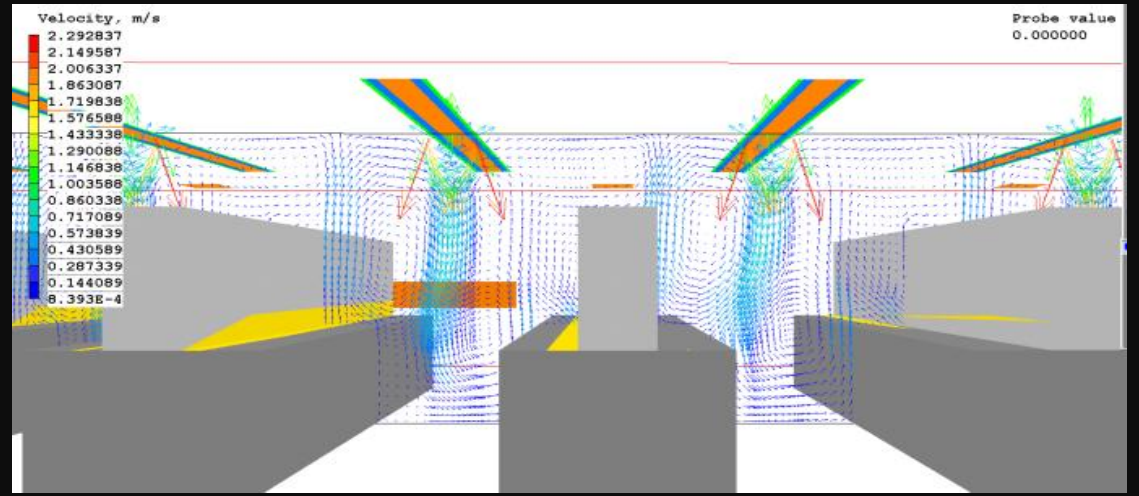


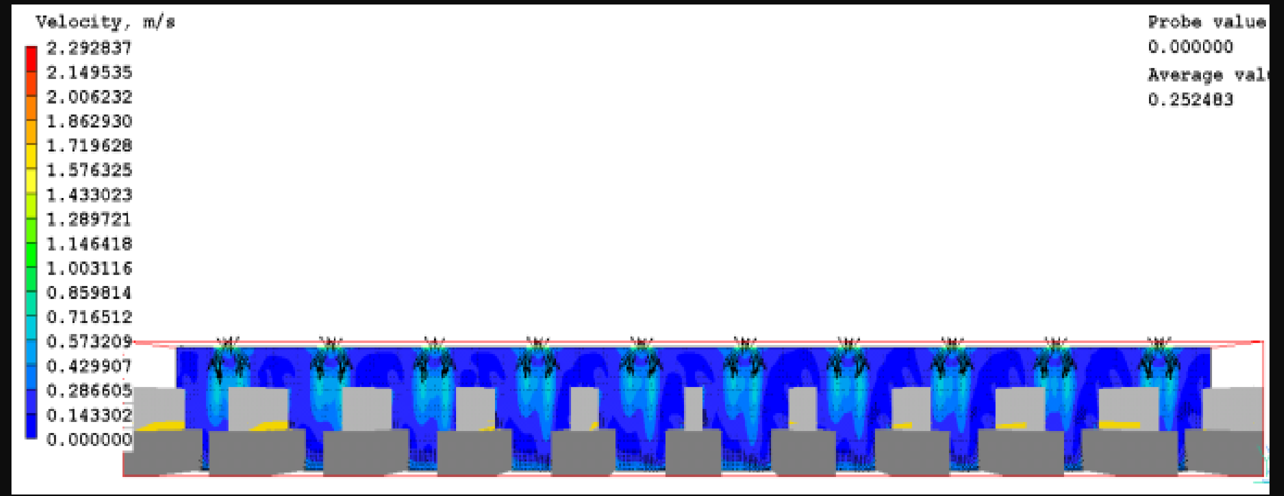
VAV



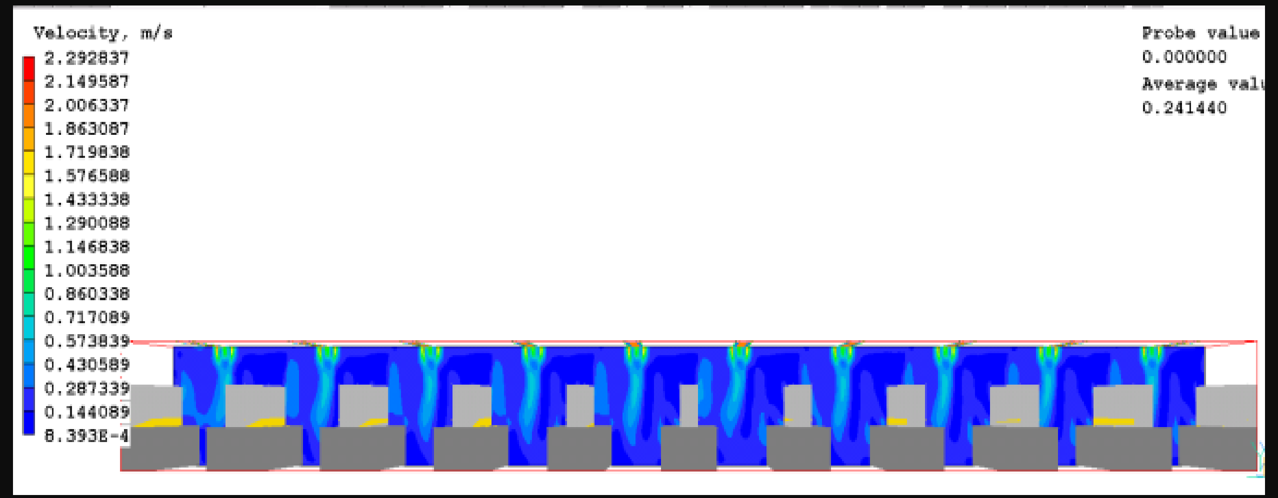
ACB

Closer View

Air Flow Comparison



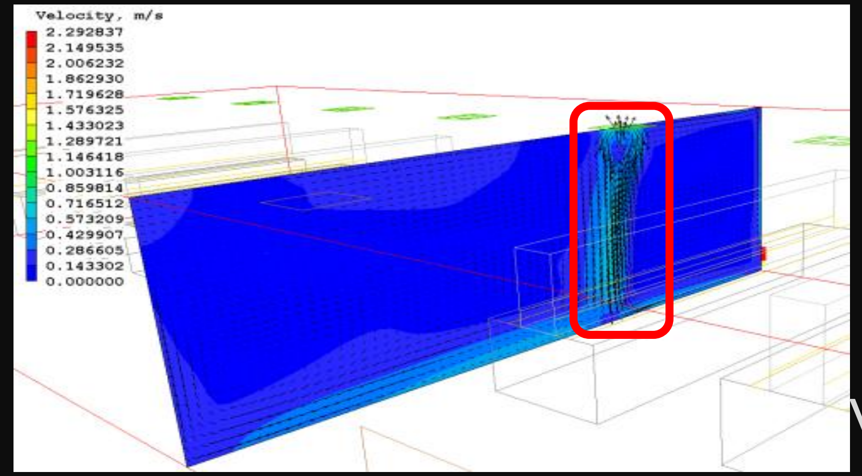
VAV



ACB

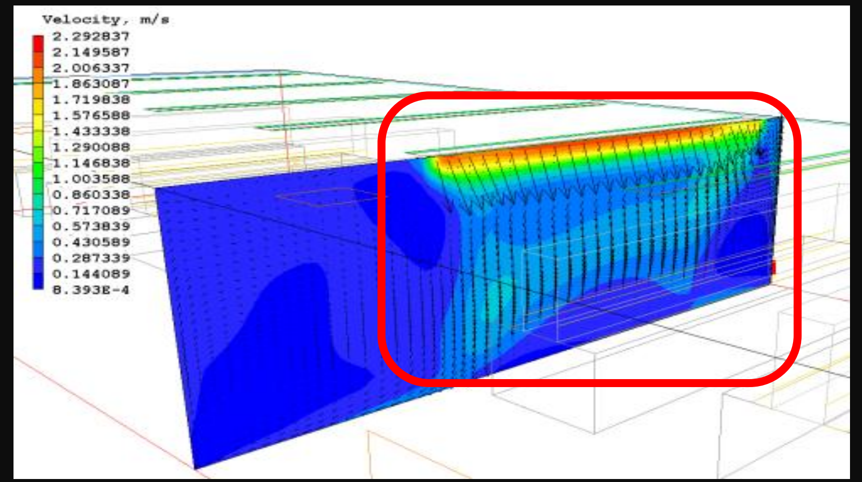
Overview

The Active Chilled Beam System provides a better mix air distribution than VAV system



VAV

VAV : supply air is closely concentrated beneath the square diffuser



ACB

ACB : air flow along chilled beam to spread air around

Side View

Outline

Overview

Existing Mechanical

Active Chilled Beam

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Conclusion

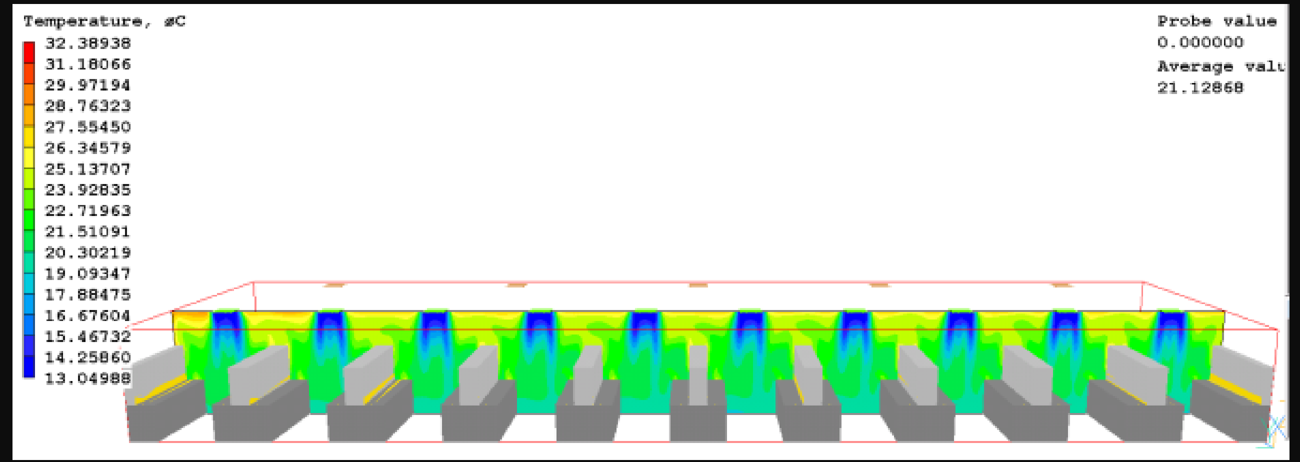
The Active Chilled Beam System provides a more uniform temperature distribution than VAV system

ASHRAE
<5F (2C) difference from ankles to head
To maintain thermal comfort and avoid draft

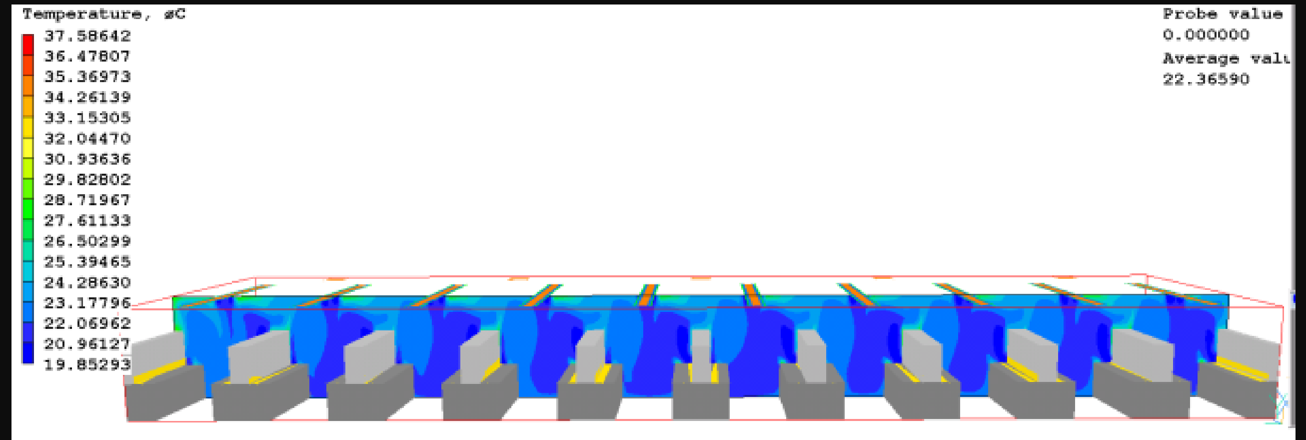
VAV
3F (2C) difference from ankles to head

ACB
0-2F (0-1C) difference from ankles to head

Temperature Distribution Comparison



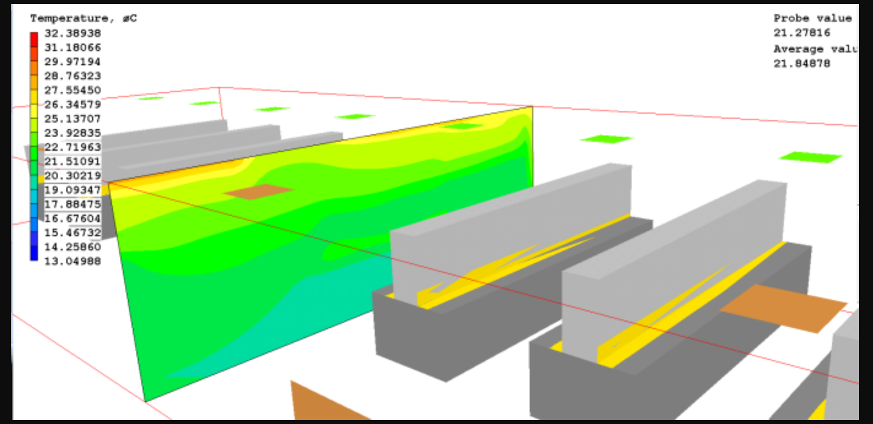
VAV



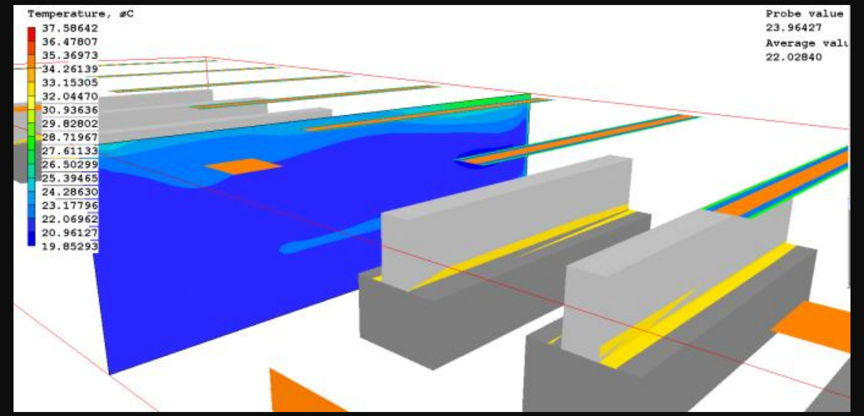
ACB

Overview

The Active Chilled Beam System has a smaller temperature gradient than VAV system



VAV



ACB

Side View

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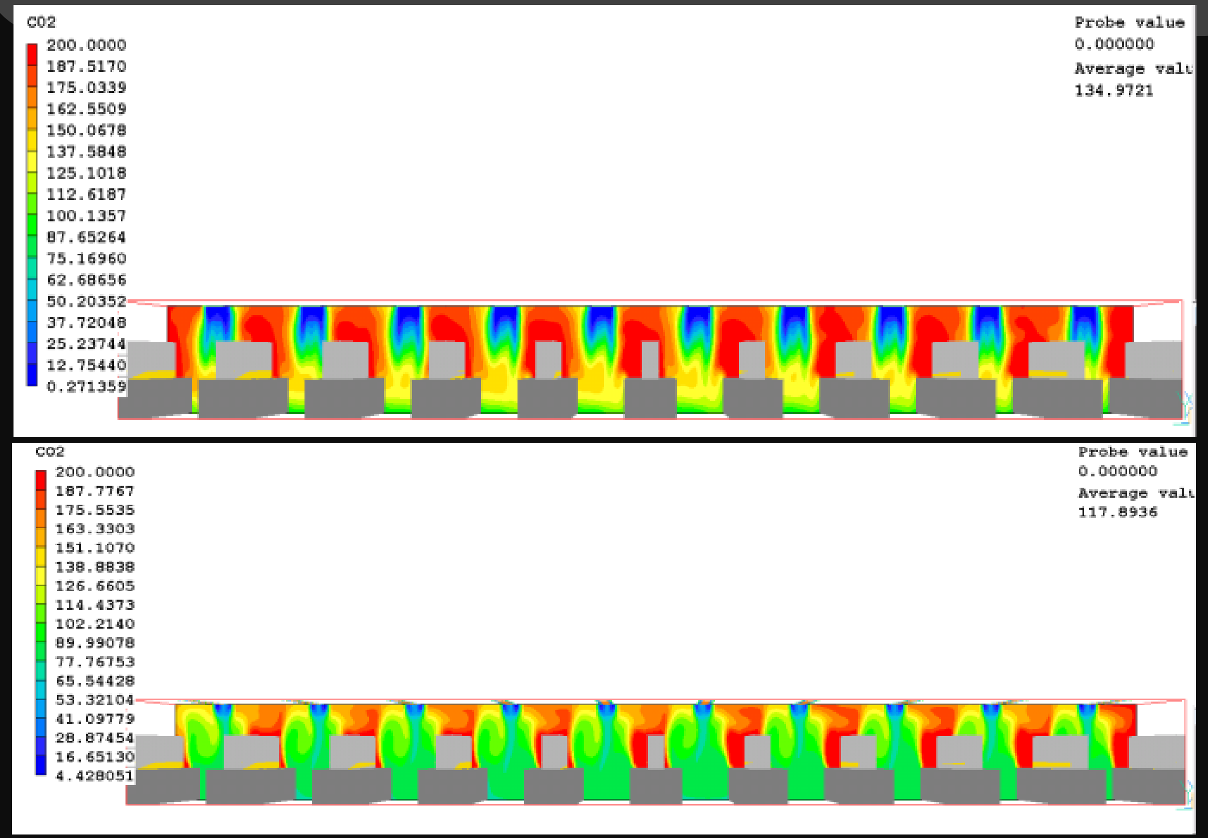
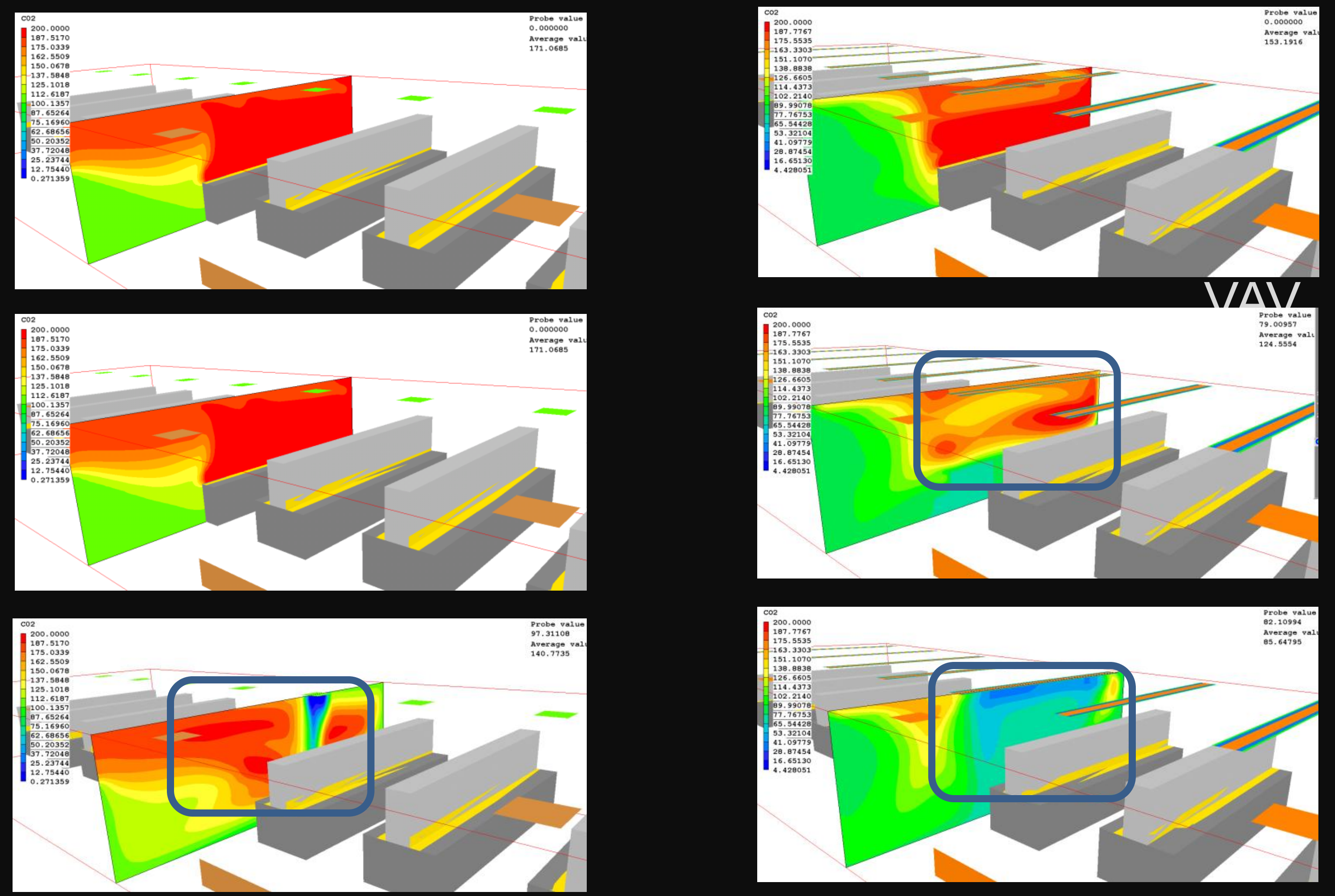
The Active Chilled Beam System provides greater ability to remove airborne contaminant from the space than VAV system



Overview

Contaminant Concentration Comparison

VAV | ACB



The ACB System achieves 75% concentration reduction while VAV system has only 25% reduction

	Source	Edge of Bench	Walkway
VAV	200 ppm	200 ppm	150 ppm
ACB	200 ppm	100-150 ppm	50 ppm

Outline

The DOAS + ACB system cost $621,276 more in first cost than the CAV/VAV sys.

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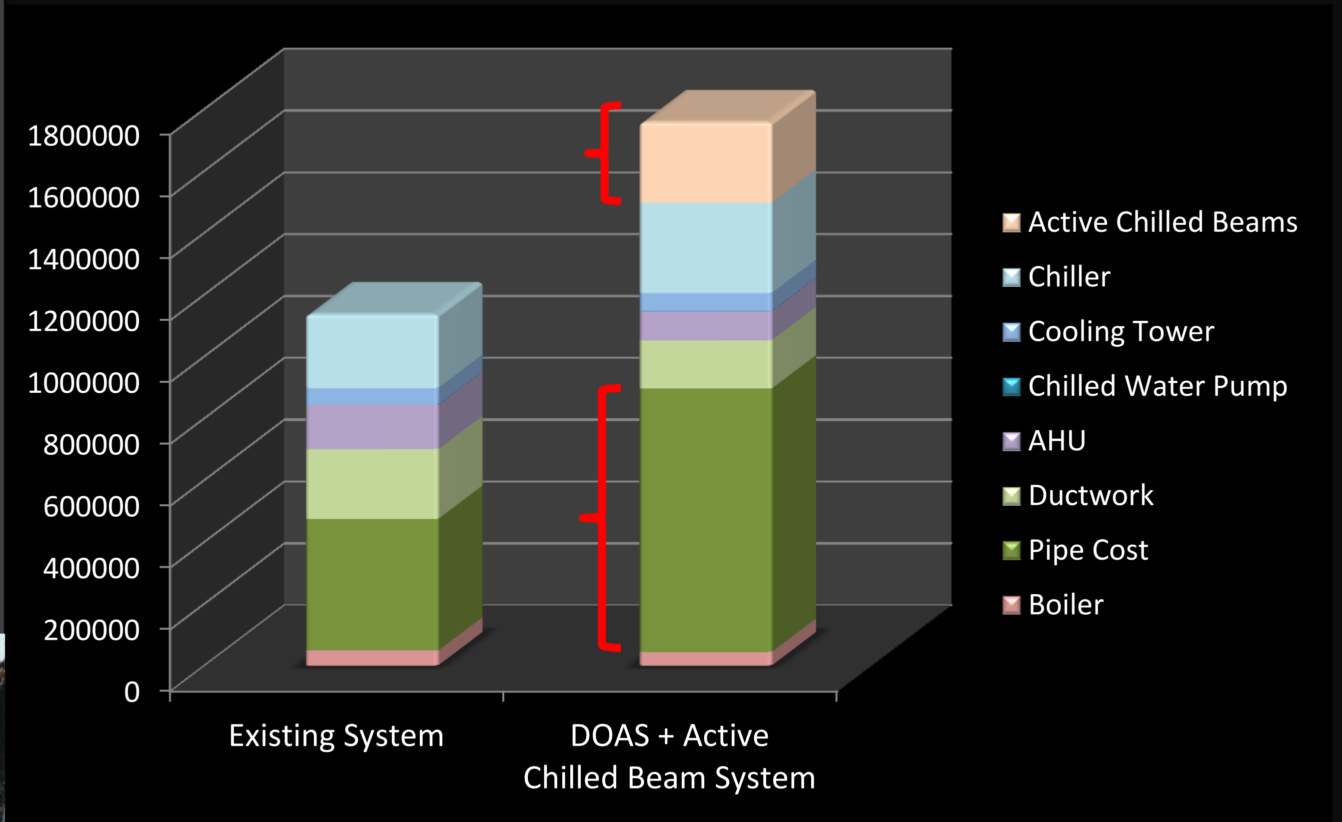
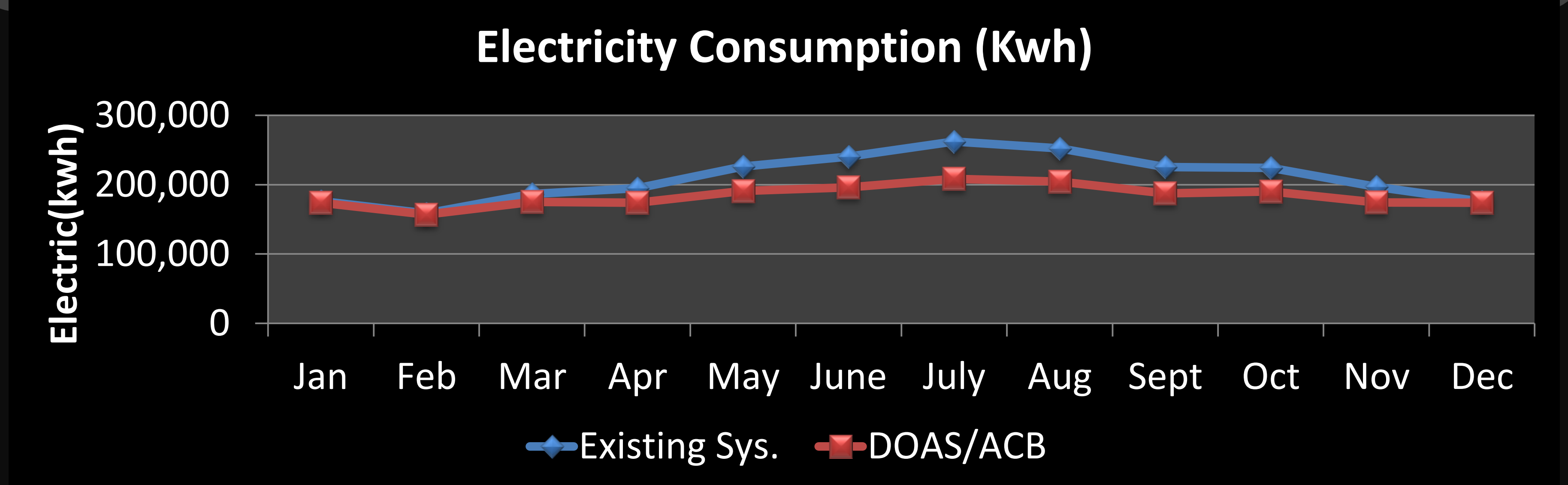
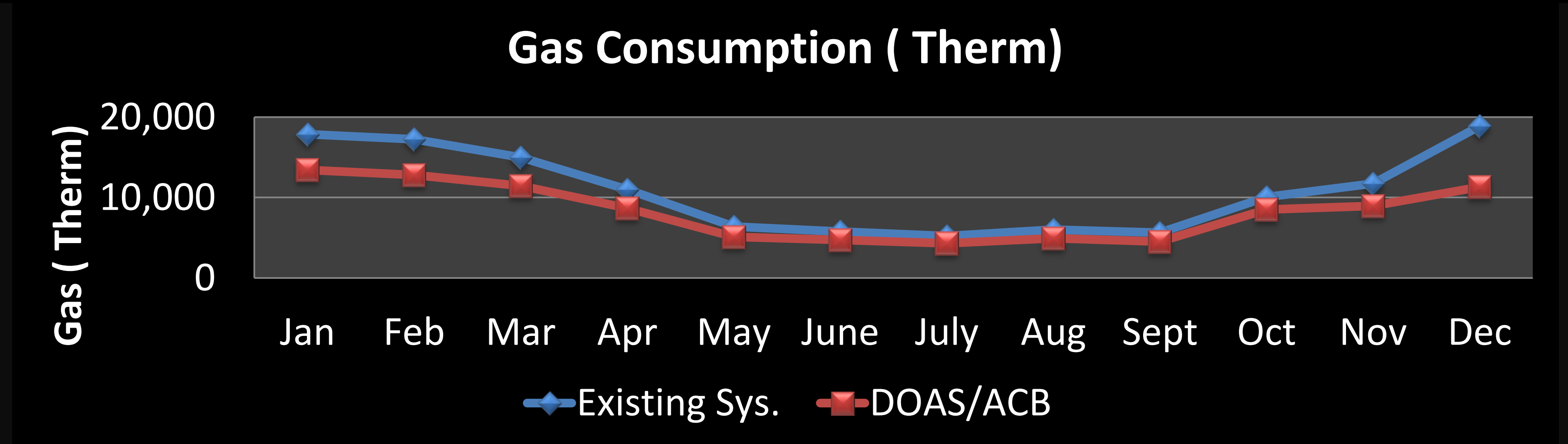


First Cost

The DOAS + Active Chilled Beam system
Saves 12.5% (313,789Kwh) electricity consumption in the summer & 24.5% (32.098Therm) gas consumption in the winter when compared to the existing CAV/VAV system





The DOAS + ACB system has a simple payback period of 9 years 5 months

Initial Cost Difference: $621,276

Annual Energy Saving: $66,078

Simple Payback: 9 years 5 months

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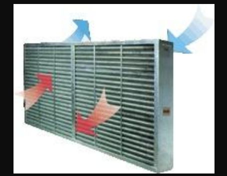
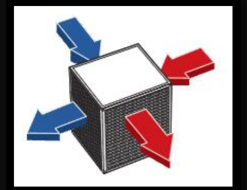
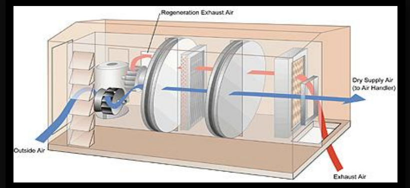
Heat Recovery System Analyzed



Heat Pipe



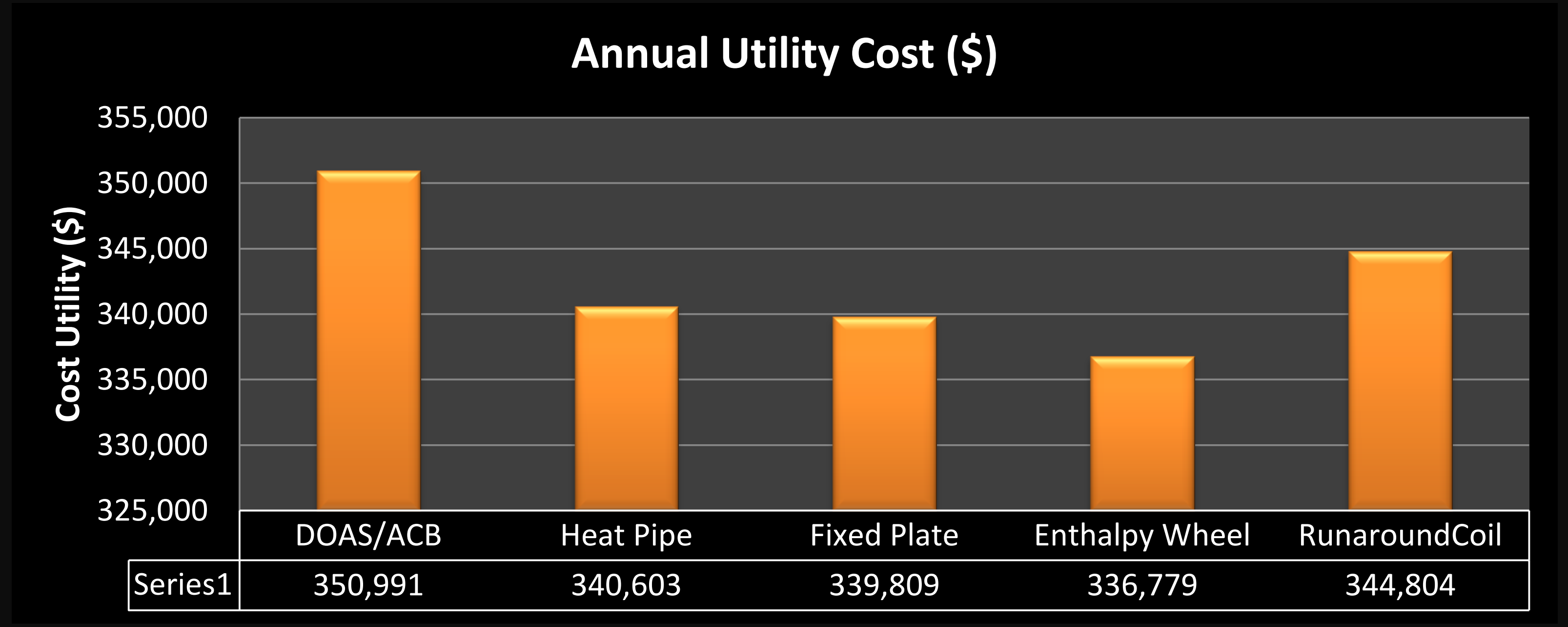
Fixed Plate

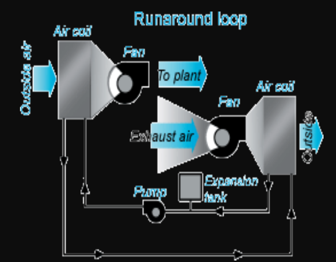


Enthalpy Wheel

Runaround Coil Loop

Utility Cost Comparison





All heat recovery systems are very cost effective with payback period of 0 to 5 months

Simple Payback Calculation Comparison				
	DOAS + ACB Total Cooling Load (Ton)			
	Heat Pipe	Fixed Plate	Enthalpy Wheel	Run Around Coil
Simple Payback	5 months	0	0	0

Outline

The **Runaround Coil** is chosen to be the **best suited** heat recovery system

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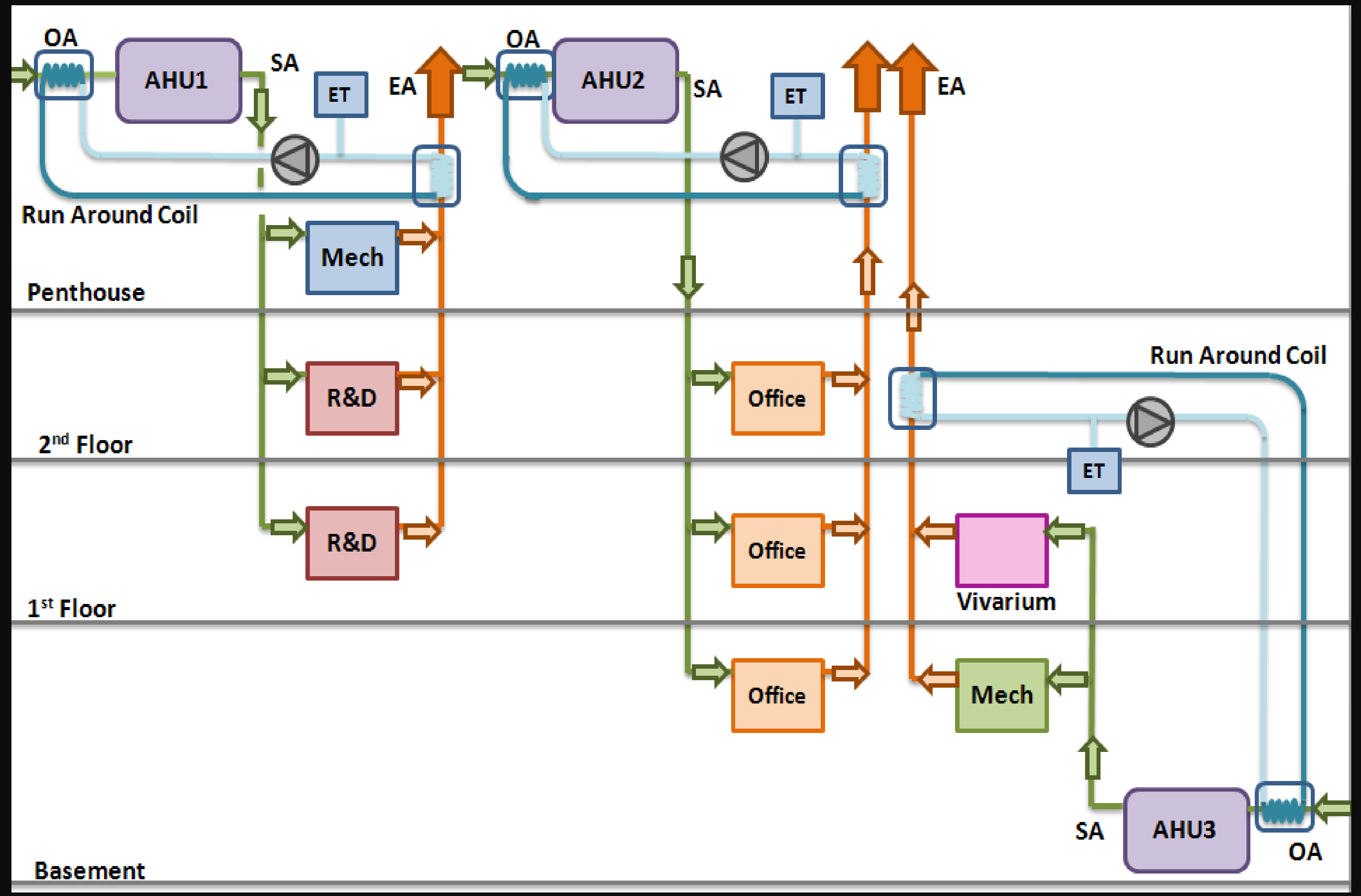
Systems Decision Matrix

	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
Efficiency	48-53	64-67	71-79	50
Energy Recovered	Sensible	Sensible	S+L	Sensible
Cross Contamination	No	No	Yes	No
Duct Adjacencies	Needed	Needed	Needed	Not Needed
Maintenance (1:lowest – 4:highest)	1	3	4	2

Runaround Loop Schematic



Runaround Coil system are chosen to implement on **all air handling units**

Run Around Coil Loop System Simply Payback Calculation Comparison

	AHU1	AHU2	AHU3	AHU1,3	AHU1,2,3
Additional Cost($)	3,287	2,056	4,211	-48,702	-46,646
Operating Saving($)	3,743	9,320	4,143	6,188	12,524
Simply Payback	11 months	3 months	1 year	0	0

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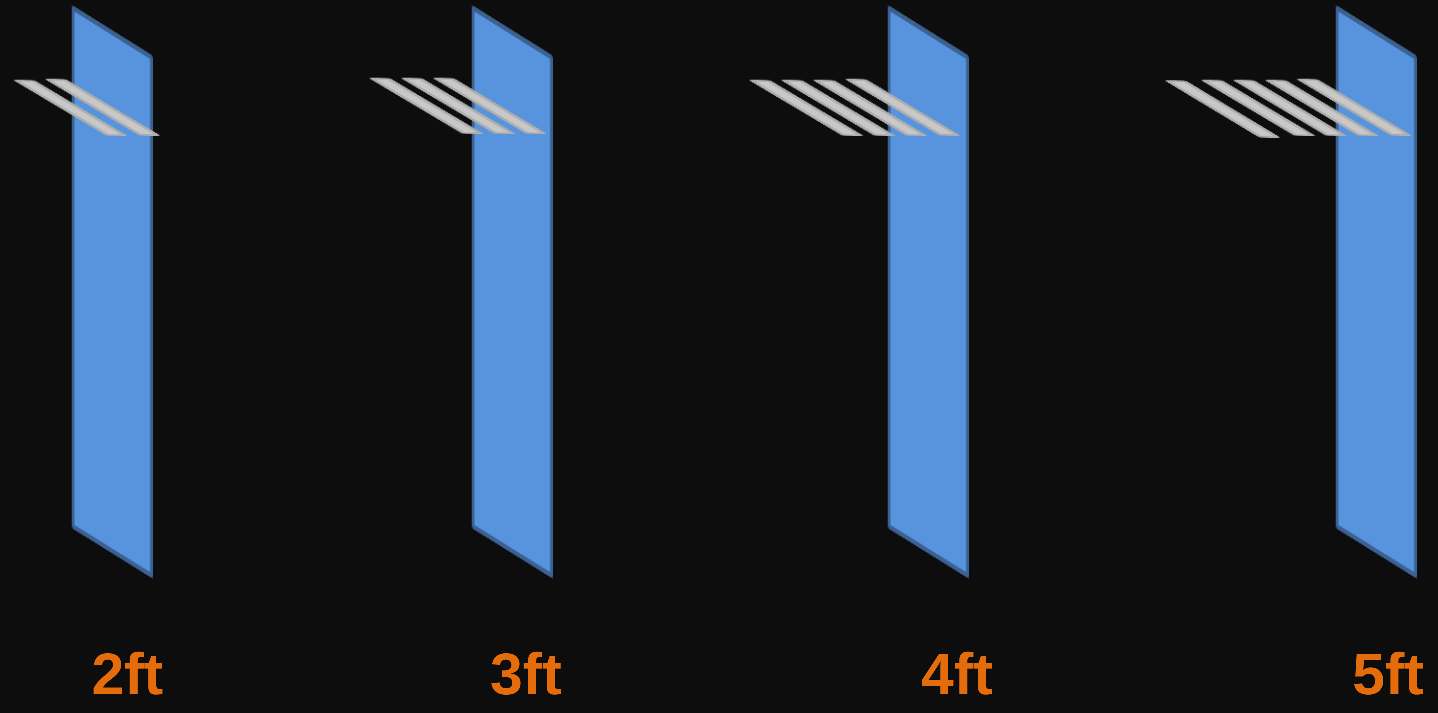
Latitude: 42° 33' 29" N

Longitude: 71° 16' 9" W

Solar Shading Systems



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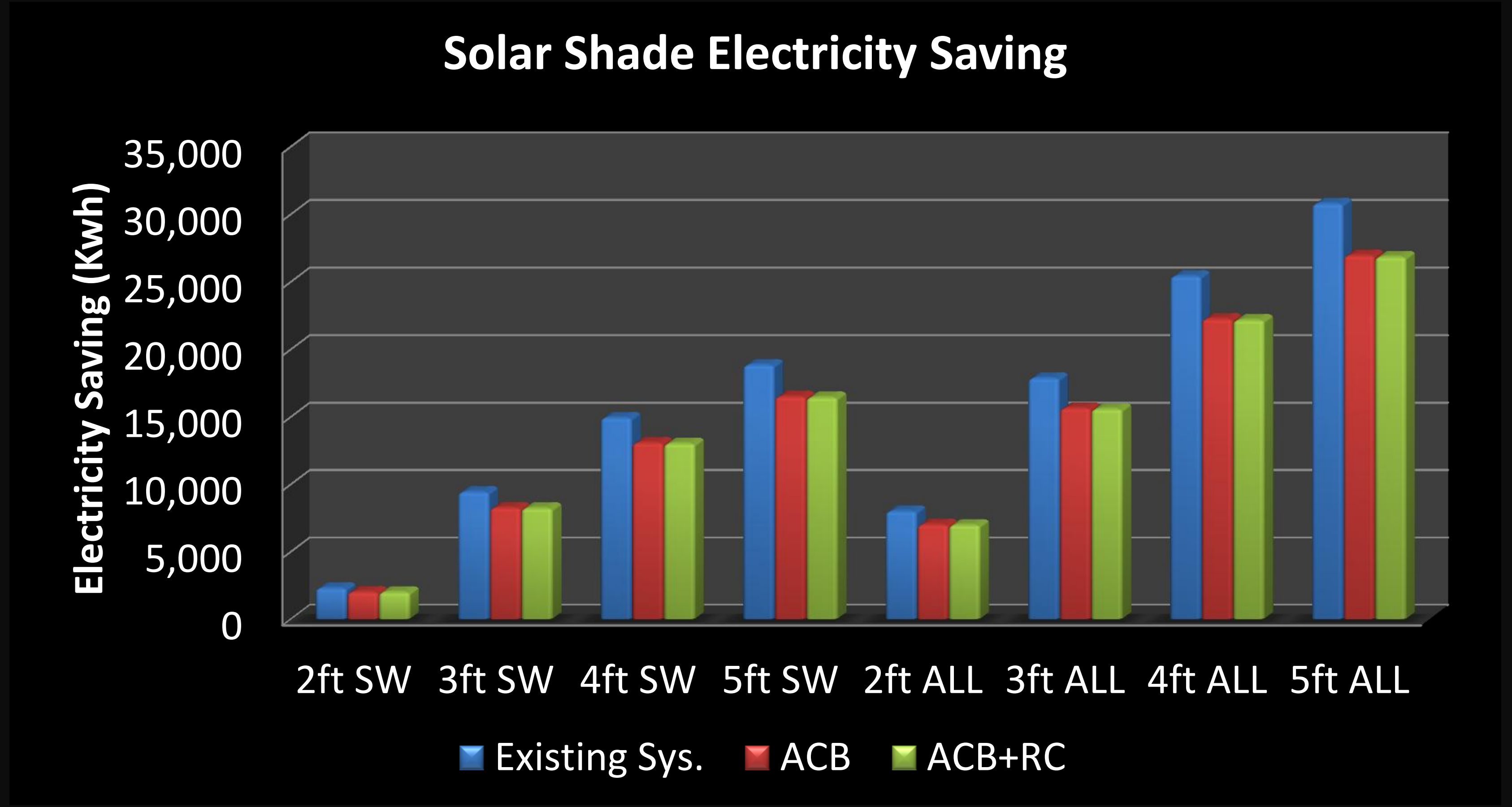
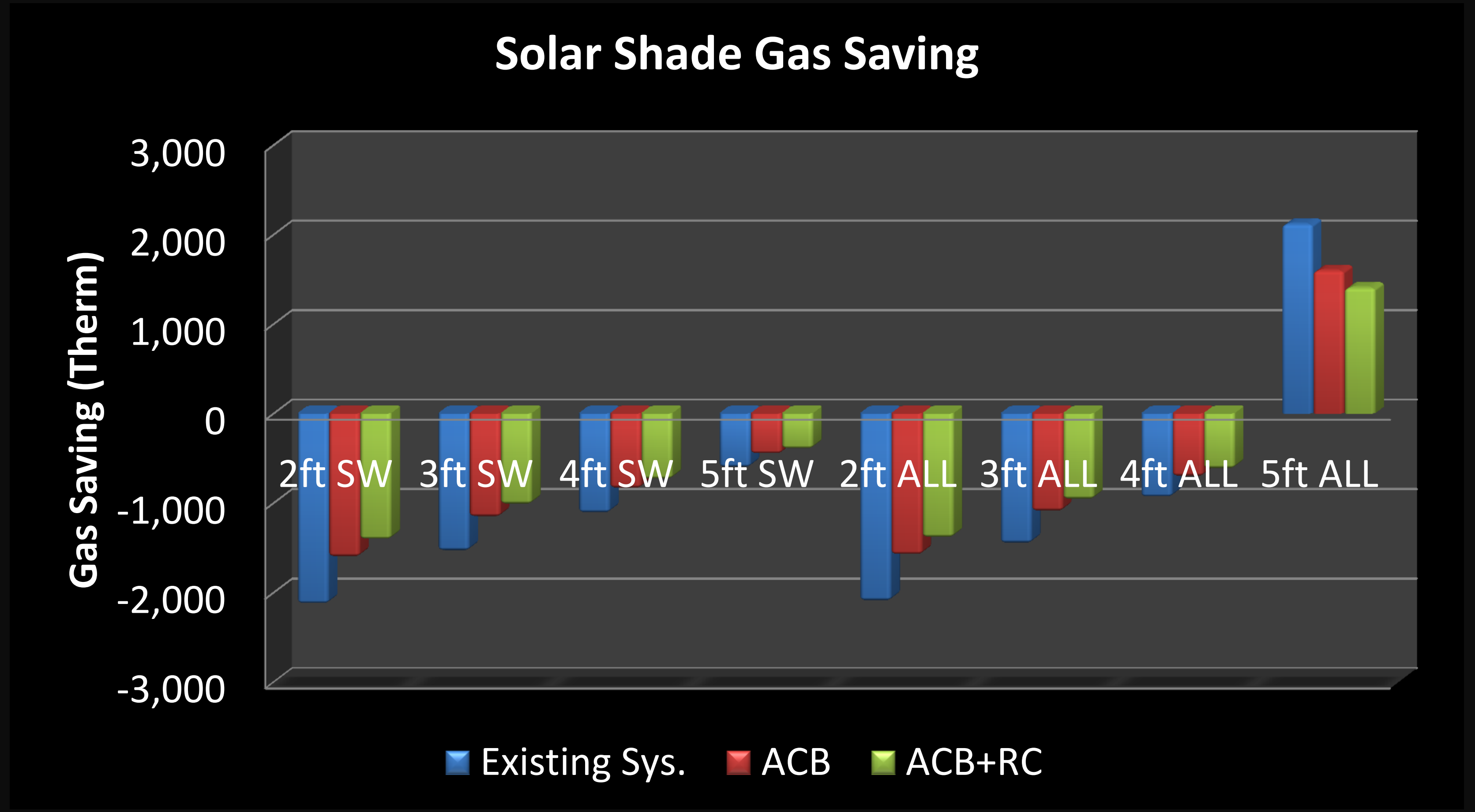
Solar shading system reduces solar load in the summer ➡ saves electricity consumption



Solar shading system reduces solar parameter heating in the winter ➡ penalty in gas consumption



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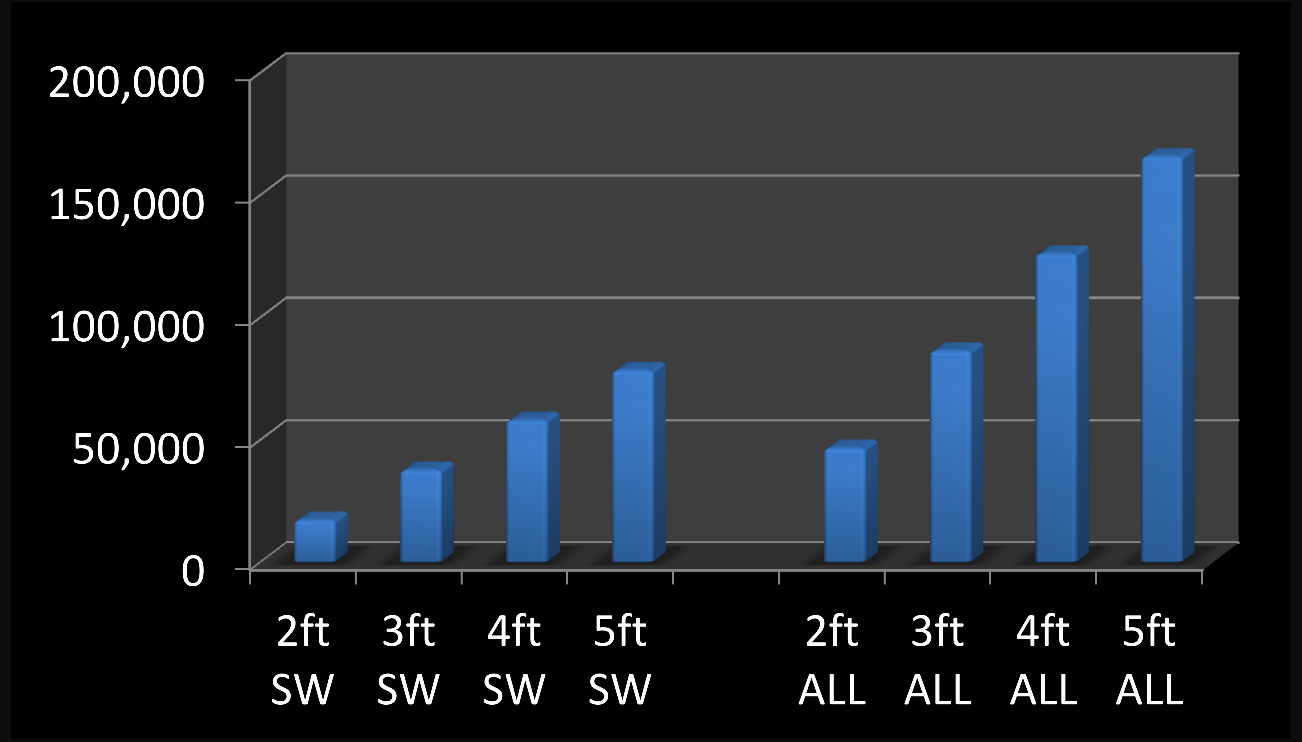
First costs of solar shading system range from $17,066 to $165,568



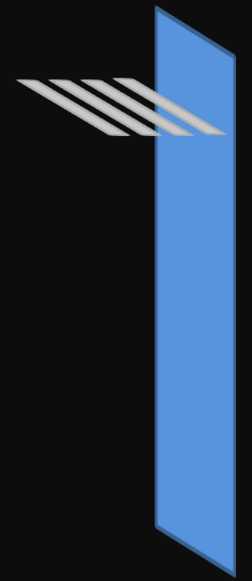
First Cost

Payback Periods of solar shading system range from 19 years to 43 years

Solar Shade System Simply Payback Period

	Solar Shade on South & West Walls				Solar Shade on All Walls			
	2ft	3ft	4ft	5ft	2ft	3ft	4ft	5ft
Existing System	32	19	19	20	36	28	28	22
ACB	38	23	23	24	43	33	34	26
ACB + RC	40	24	24	25	45	35	35	27

4ft overhang is selected as the optimal system



4ft Overhang

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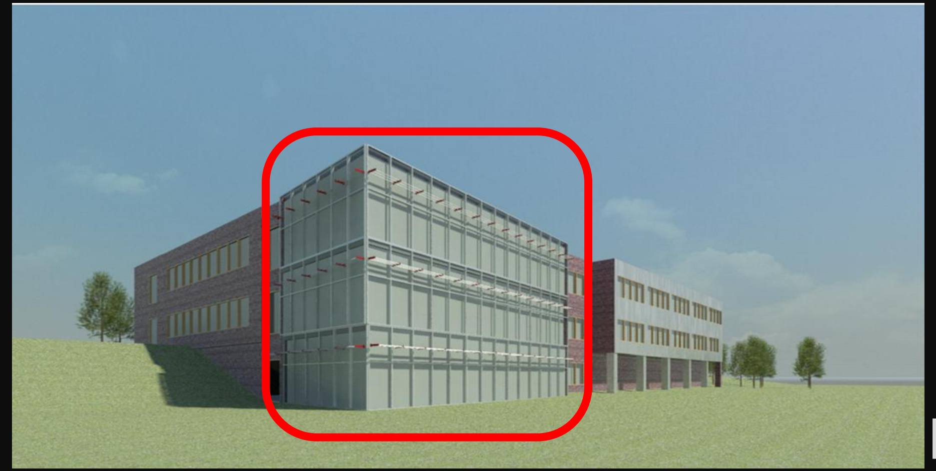

Existing

Solar Shade

North West Views

Existing

Solar Shade

West Views

Existing

Solar Shade

South Views

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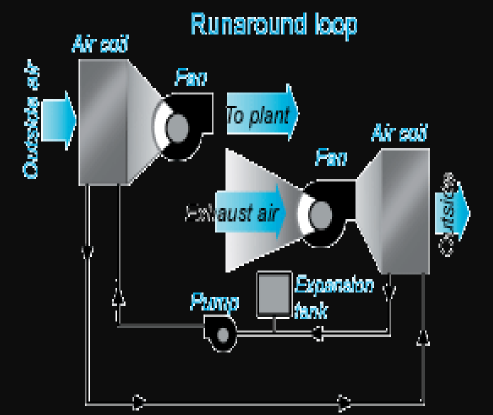

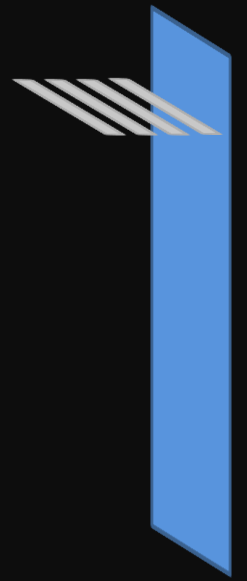

4ft Overhang

Conclusion

Overall Simply Payback Calculation				
	Existing System	DOAS/ACB	DOAS/ACB + Runaround Coil	DOAS/ACB + Runaround Coil + Solar Shade
Total	1,135,702	1,756,978	1,710,333	1,768,132
Cost Difference		621,276	574,631	632,430
Operating Saving		66,078	78,602	81,023
Simple Payback		9 years 5months	7 years 4 months	7 years 10 months

DOAS/ACB + Runaround Loop + Solar Shade

30-Year Life Cycle Cost Analysis				
	Existing System	DOAS/ACB	DOAS/ACB + Runaround Coi	DOAS/ACB + Runaround Coil + Solar Shade
First cost ($)	1,135,702	1,756,978	1,710,333	1,768,132
Maintenance Cost($)	4,044,980	56,235	57,935	57,935
Annual Natural Gas Cost($)	6,905,005	5,887,111	5,878,692	5,837,532
Annual Electricity Cost($)	2,449,416	2,098,641	1,932,969	1,919,440
Total	**14,535,103**	**9,798,965**	**9,579,929**	**9,583,039**

DOAS + Active Chilled Beam

- Minimize Outdoor Air Conditioning ➡ Downsize Ducting and AHUs
- Eliminate Reheat Energy ➡ Downsize Hot Water System
- More Efficient Chilled Water System
- Better Air Mixing and Temperature Distribution
- Greater Ability to Remove Airborne Contaminant ➡ Better Indoor Air Quality

Runaround Loop Heat Recovery System

- No Cross-Contaminant Issue
- 3.5% Reduction in Energy Usage
- Low Maintenance

Solar Shading System

- Energy and Cost Saving
- Consistent and sustainable appearance to the Building

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Acknowledgements

Special Thanks To:

AE Faculty

EMD Serono
BR+A Consulting Engineers
Ellenzweig Associate

Family & Friends

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Questions

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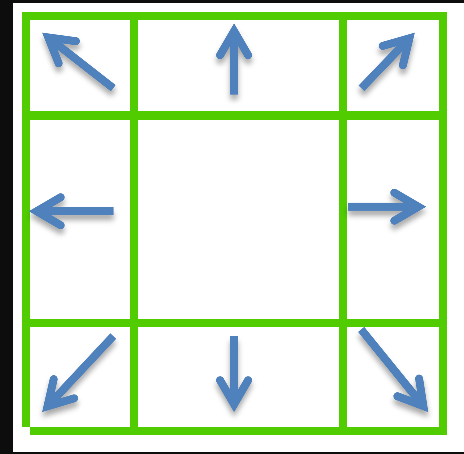
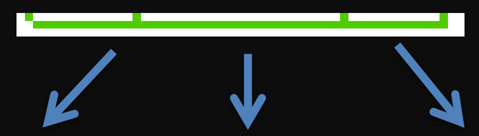
VAV Diffuser

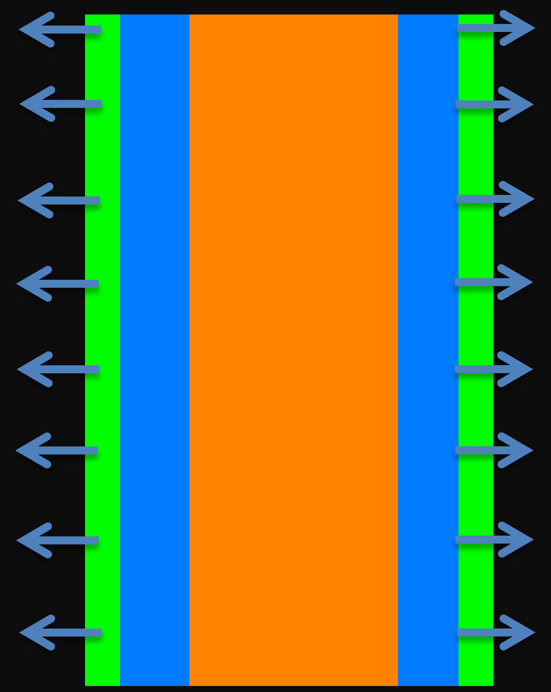


Top View

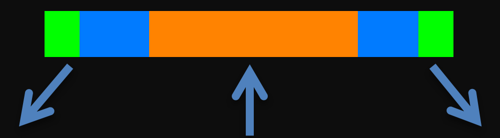


Cross Section

Active Chilled Beam



Top View



Cross Section

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Active Chilled Beam System	52x459x35	KE model	Hybrid	5000	0.54%

30ft W x 98ft L x 10ft H

Active Chilled Beam Selection Calculation				
Primary Airflow (cfm)	Secondary Cooling (Btuh)	Available Length (ft)	CFM/LF	BTUH/LF
3,324	133,000	200	17	665

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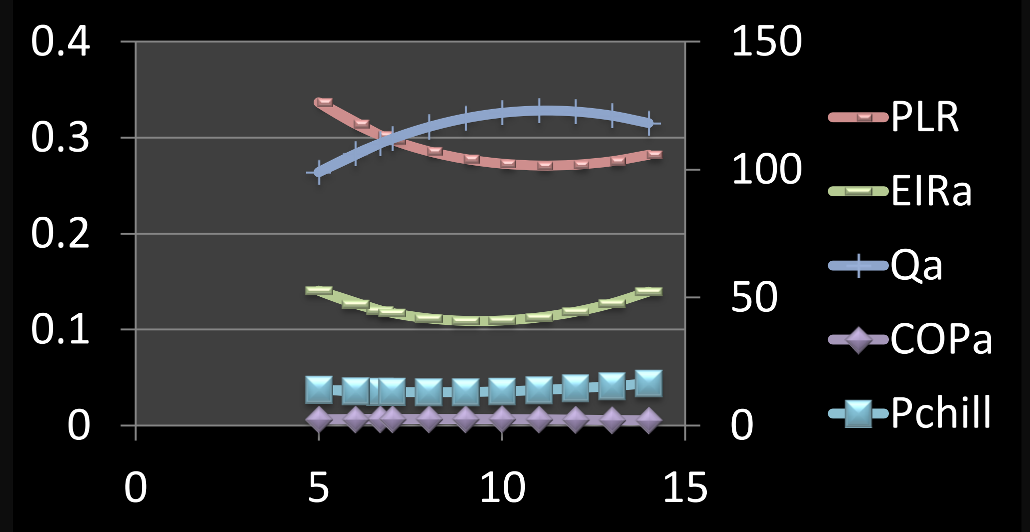
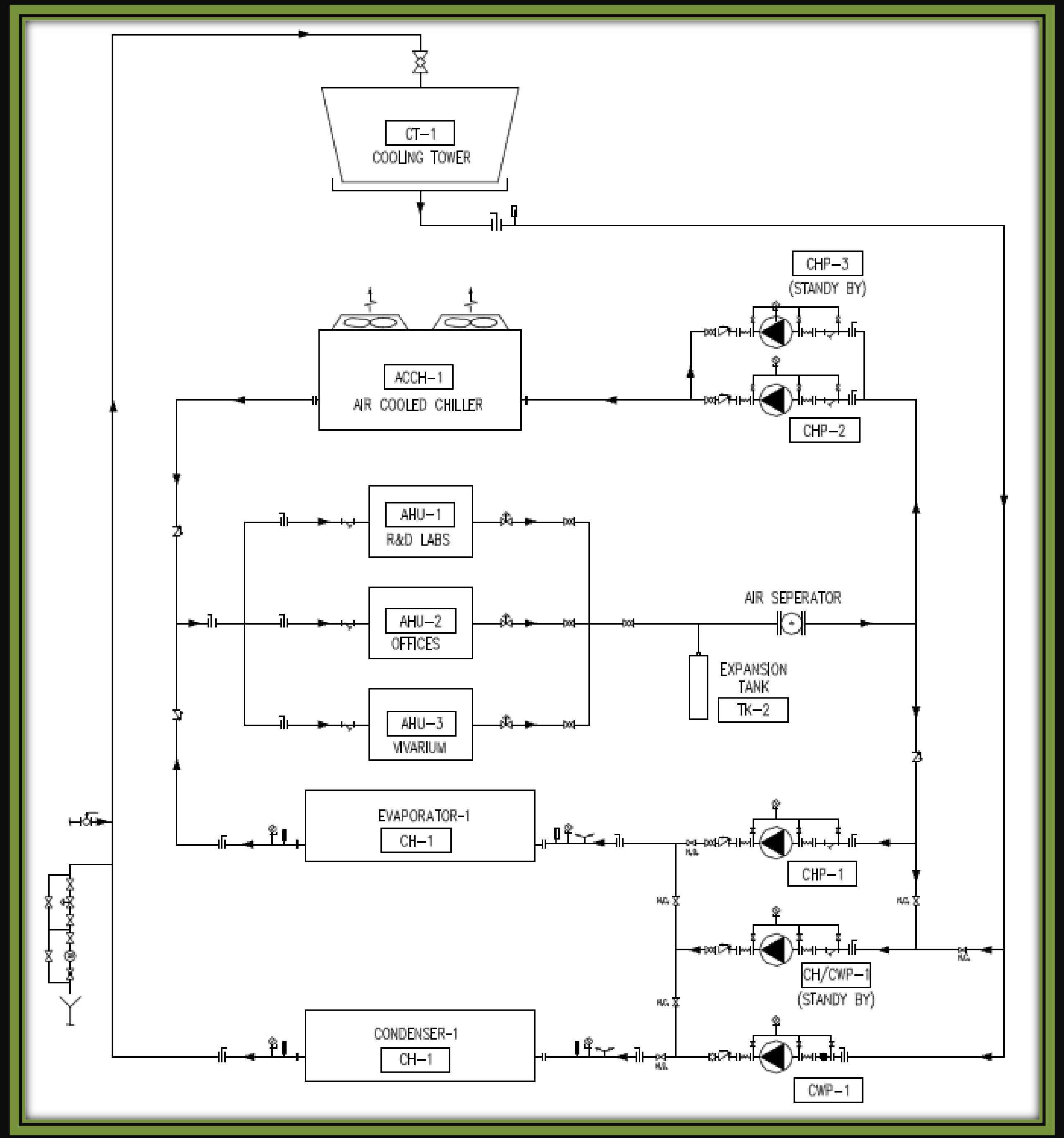
DOE2 polynomial model



COP vs Tchw and Tcond-e			Qr- 100 kV	100	COPr-2.75	0.363636					
	F1	F2	F3								
a	0.507883	1.03076	0.088065								
b	0.145228	-0.10354	1.137742								
c	-0.00626	0.007102	-0.22581								
d	-0.00112	0.009319									
e	-0.00013	0.000318									
f	-0.00028	-0.00104									
Tchw	Tcond-e	Ql	Twb	Func 1	Func 2	Func 3	Qa	PLR	EIRa	COPa	Pchill
6.67	18	33.33	15	1.102258	0.801494	0.411448	110.2258	0.302379	0.119918	2.521562	13.218
5	18	33.33	15	0.990132	0.867348	0.445467	99.0132	0.336622	0.1405	2.395889	13.91133
6	18	33.33	15	1.061465	0.823156	0.423052	106.1465	0.314	0.126632	2.479628	13.44153
7	18	33.33	15	1.120286	0.793168	0.406571	112.0286	0.297513	0.117265	2.5371	13.13704
8	18	33.33	15	1.166593	0.777384	0.39469	116.6593	0.285704	0.111573	2.560689	13.01603
9	18	33.33	15	1.200388	0.775804	0.386562	120.0388	0.27766	0.109053	2.546099	13.09062
10	18	33.33	15	1.22167	0.788429	0.38166	122.167	0.272823	0.109423	2.493304	13.36781
11	18	33.33	15	1.230439	0.815258	0.379687	123.0439	0.270879	0.112561	2.406513	13.84992
12	18	33.33	15	1.226695	0.85629	0.380526	122.6695	0.271706	0.118488	2.293118	14.53479
13	18	33.33	15	1.210438	0.911527	0.384227	121.0438	0.275355	0.127358	2.162062	15.41584
14	18	33.33	15	1.181668	0.980968	0.391011	118.1668	0.282059	0.13948	2.022224	16.48186

System Decision Matrix

Item	Existing VAV/CAV System	DOAS/ACB System	Net for DOAS/ACB System
AHU	Large	Small	+
Ductwork	Large	Small	+
Riser	Large	Small	+
Ceiling Space	Large	Small	+
Pipework	Small	Large	-
Fan Energy	High	Low	+
Pump Energy	Low	High	-
Occupant Satisfaction	Low	High	+
Air Side System Cost	Low	High	+
Water Side System Cost	Low	High	-
Individual Control	Low	High	+
Thermal Comfort	Low	High	+
Noise Level	High	Low	+
Maintenance	High	Low	+
Risk of Condensation	Low	High	-
System Complexity	Low	High	+
Control System Complexity	High	Low	+
Overall			+



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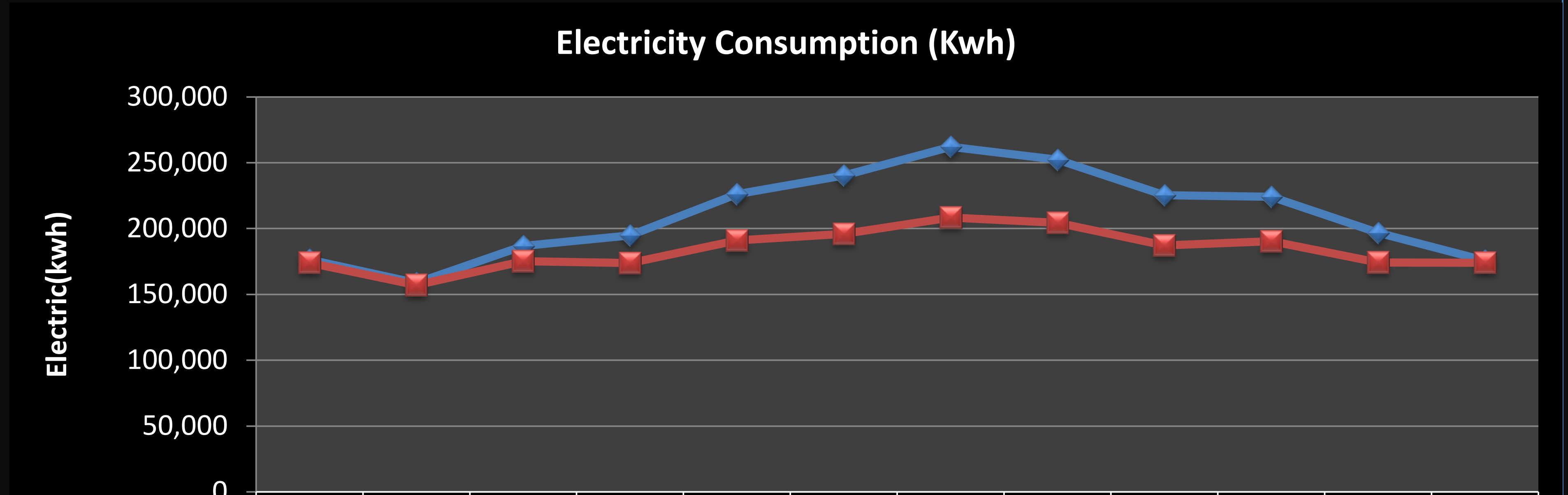
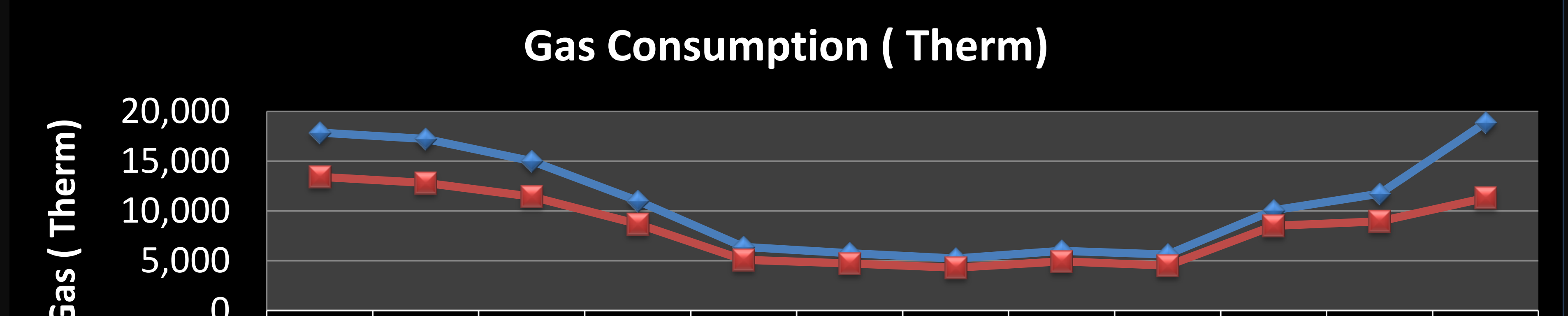
The **DOAS + Active Chilled Beam** system Saves **12.5%** (313,789Kwh) **electricity** consumption in the summer

24.5% (32.098Therm) **gas** consumption in the winter when compared to the **existing CAV/VAV** system



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	176,446	158,711	186,758	194,884	226,213	240,369	262,077	252,345	225,269	224,214	196,728	175,716
DOAS/ACB	174,021	157,128	175,255	173,894	191,078	195,936	208,366	204,297	187,296	190,313	174,322	174,035



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	17,862	17,233	15,005	11,014	6,381	5,767	5,225	6,000	5,630	10,067	11,746	18,874
DOAS/ACB	13,421	12,811	11,439	8,685	5,095	4,719	4,309	4,933	4,527	8,495	8,953	11,318

Air Flow Comparison

	Existing System	Active Chilled Beam System	
	Primary Airflow (cfm)	Primary Airflow (cfm)	Secondary Airflow (cfm)
AHU1	29,760	24,136	121,975
AHU2	34,876	12,679	70,411
AHU3	7,374	7,312	36,869
Total	72,010	44,127	229,255

38% (27883cfm) Outside Air Conditioning Reduction

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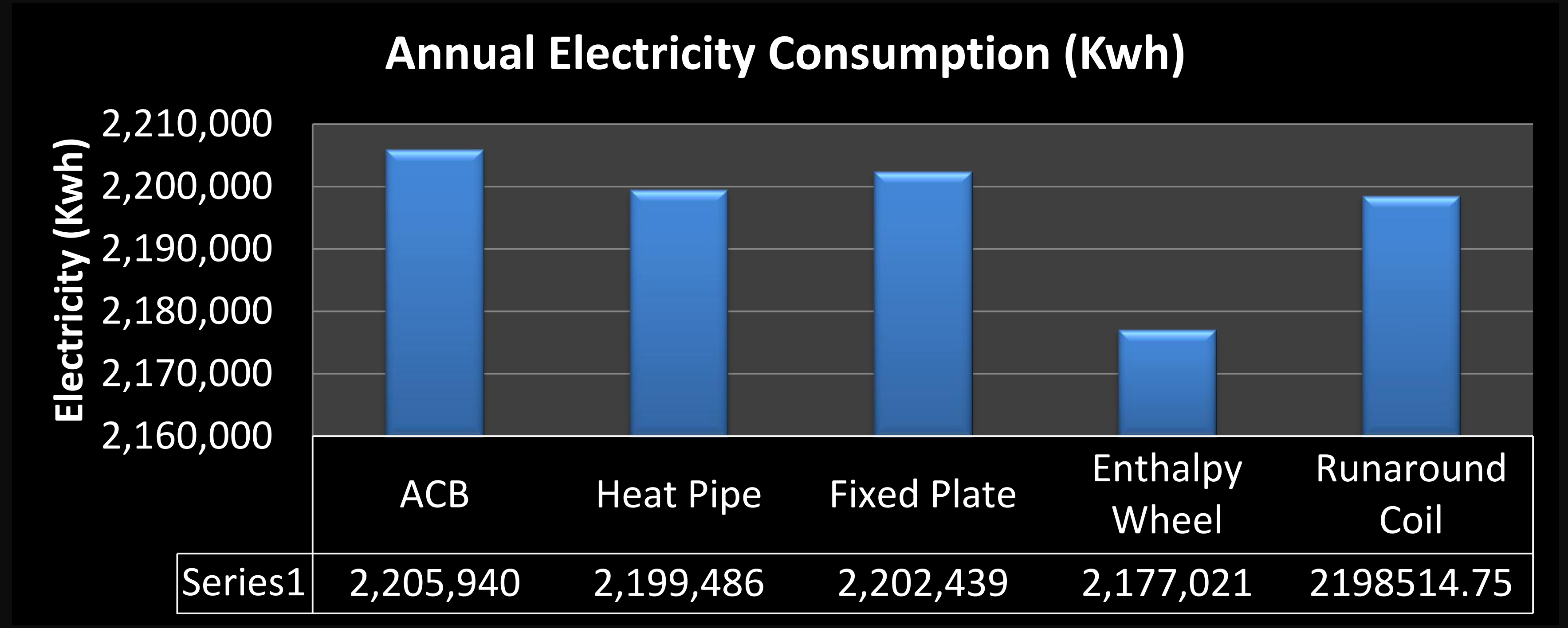
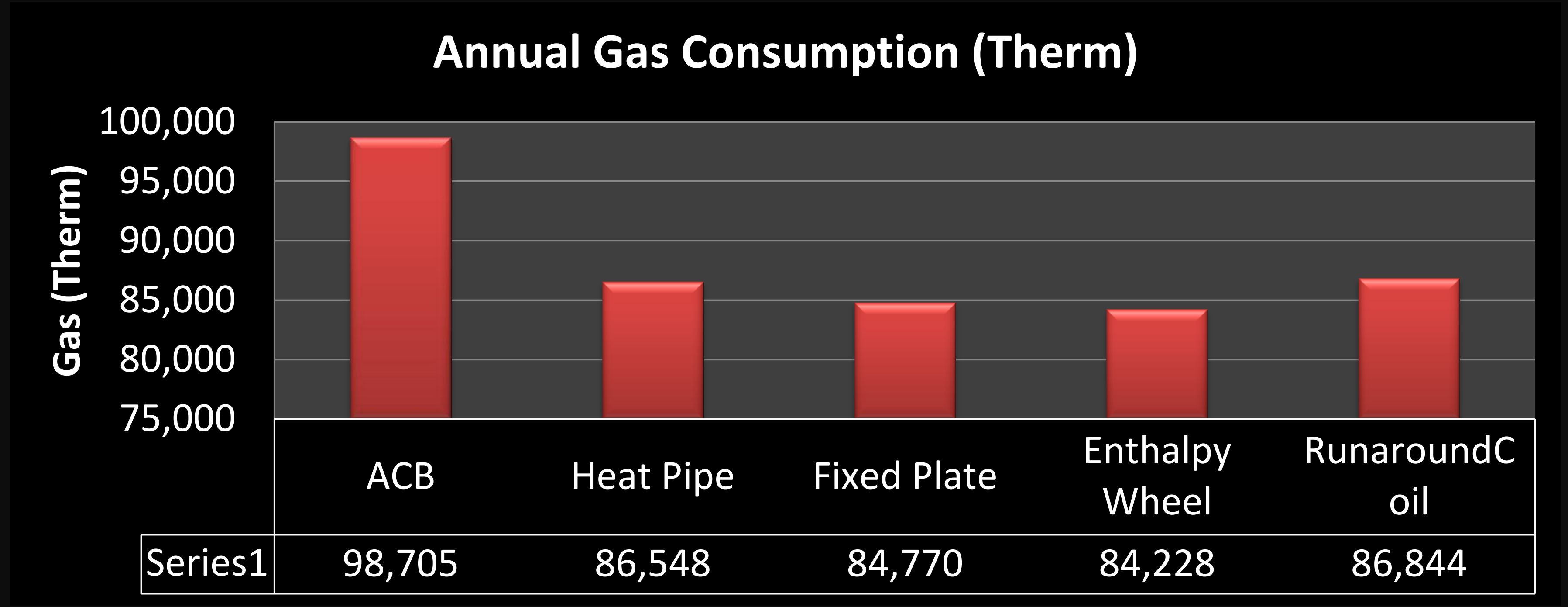


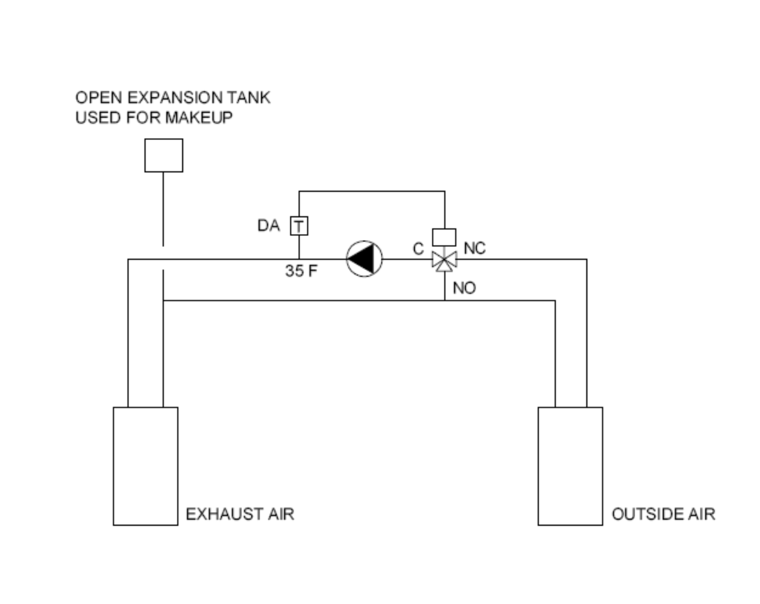
DOAS/ACB + Heat Recovery Systems Cooling Load Comparison

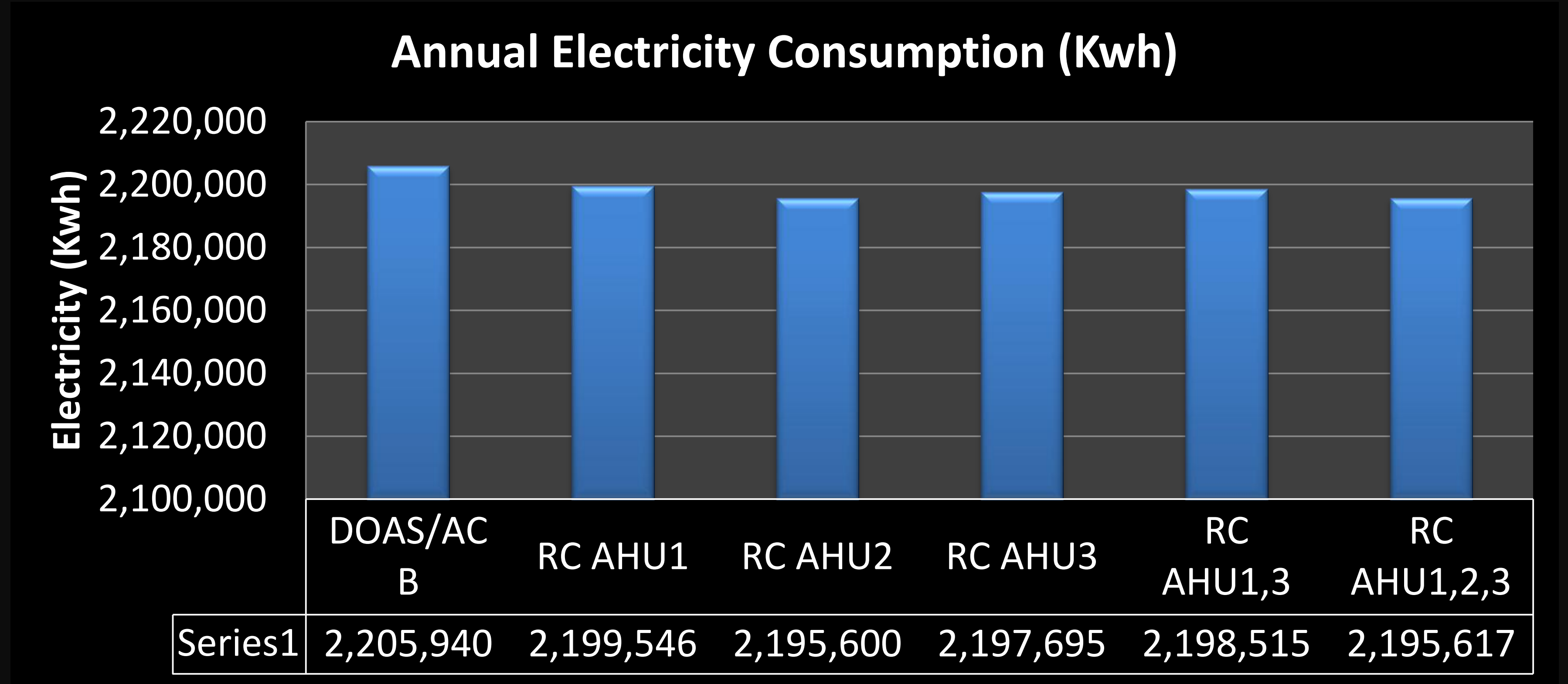
	DOAS + ACB Total Cooling Load (Ton)				
	No Heat Recovery	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
AHU1+ACB	300	272	269	176	271
AHU2+ACB	87	87	87	87	87
AHU3+ACB	87	68	68	44	67
Total	474	427	424	308	426
Difference	-	47	50	166	48
Difference %	-	9.9%	10.5%	35.0%	10.1%

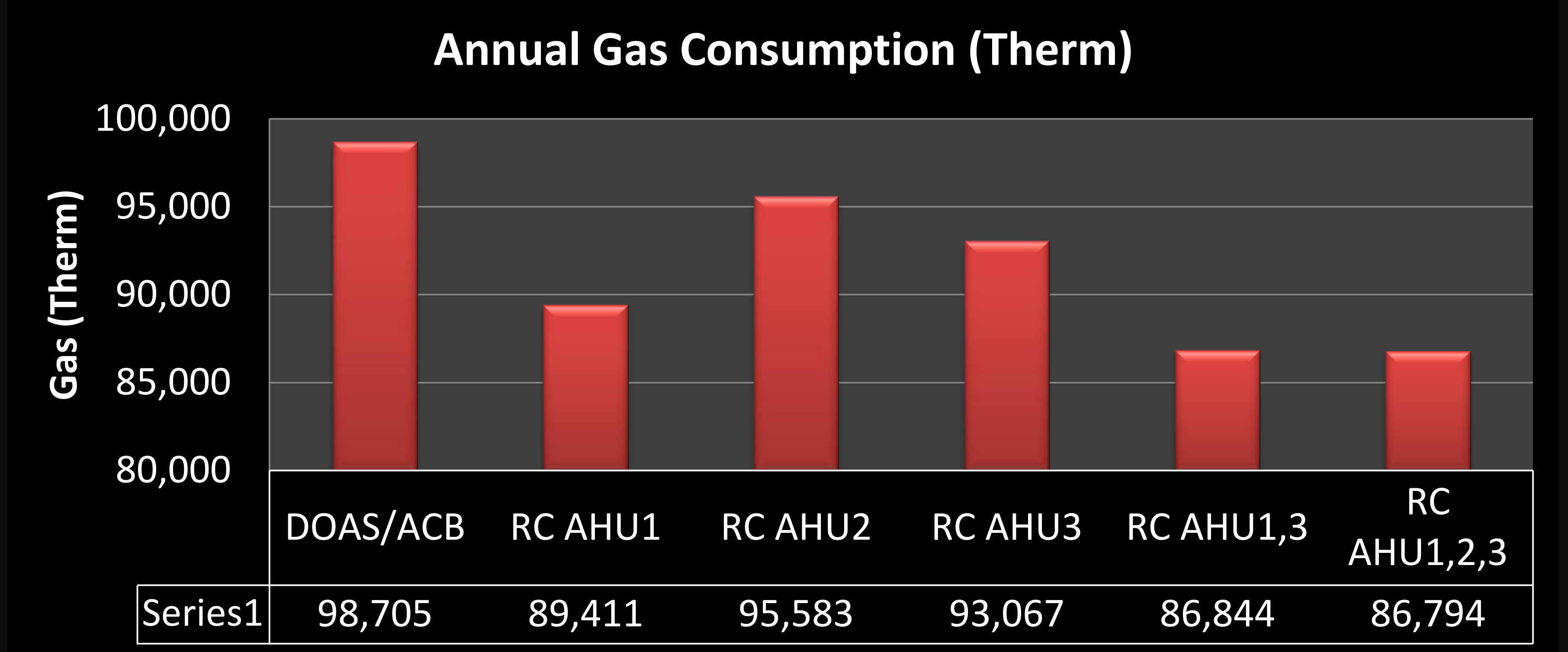


DOAS/ACB + Heat Recovery Systems Heating Load Comparison

	DOAS + ACB Total Heating Load (Mbh)				
	No Heat Recovery	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
AHU1+ACB	2221	1575	1425	1186	1603
AHU2+ACB	715	715	714	714	714
AHU3+ACB	640	349	316	258	353
Total	3576	2639	2454	2157	2669
Difference	-	937	1,122	1,419	907
Difference %	-	26.2%	31.4%	39.7%	25.4%







DOAS/ACB + Runaround Coil System Cooling Load Comparison (Ton)

	No Heat Recovery	With Run Around Coil Loop				
		AHU1	AHU2	AHU3	AHU1,2	AHU1,2,3
AHU1+ACBs	300	271	300	300	271	271
AHU2+ACBs	87	87	84	87	87	84
AHU3+ACBs	87	87	87	67	67	67
Total	474	446	471	455	426	423

DOAS /ACB + Runaround Coil System Heating Load Comparison (Mbh)

	No Heat Recovery	With Run Around Coil Loop				
		AHU1	AHU2	AHU3	AHU1,2	AHU1,2,3
AHU1+ACBs	2,221	1,603	2,221	2,221	1,603	1,603
AHU2+ACBs	715	714	641	714	714	641
AHU3+ACBs	640	640	640	353	353	353
Total	3,576	2,957	3,502	3,288	2,669	2,597

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621 Mbh of energy can be recovered by the runaround loop system

Recoverable Energy (Mbh)			
AHU1	AHU2	AHU3	Total
347	38	235	621

Overall Simply Payback Calculation

	Existing System	Active Chilled Beam System	ACB with Run Around Coil	ACB + Run Around Coil + Solar Shade
Chiller	238,100	292,000	239,000	239,000
Cooling Tower	53,750	57,650	57,650	57,650
Chilled Water Pump	987	1,139	1,139	1,139
Ductwork (4$/sf for VAV, 2.5$/sf for ACB)	225,368	156,745	156,745	156,745
Active Chilled Beams (260 beams for ACB system, $1000 each)	-	260,000	260,000	260,000
Runaround Loop Equipment	-	-	11,196	11,196
Solar Shading System (35$/sf + 15% labor cost)	-	-	-	57,799
AHU	143,450	93,650	91,650	91,650
Pipe Cost (49.5$/lf)	425,948	851,895	856,053	856,053
Boiler	48,100	43,900	36,900	36,900
Total	1,135,702	1,756,978	1,710,333	1,768,132
Cost Difference		621,276	574,631	632,430
Operating Saving		66,078	78,602	81,023
Simple Payback		9 years 5 months	7years 4 months	7 years 10 months

Annual System Cost Analysis

	Existing System	DOAS/ACB	DOAS/ACB + Runaround Coil	DOAS/ACB + Runaround Coil + Solar Shade
First cost ($)	1,135,702	1,756,978	1,710,333	1,768,132
Maintenance Cost ($/yr. for existing system; $/5years for redesign systems)	198,450	14,560	15,000	15,000
Annual Natural Gas Cost($)	296,098	252,449	252,088	250,323
Annual Electricity Cost($)	119,135	102,074	94,016	93,358

30-Year Life Cycle Cost Analysis

	Existing System	DOAS/ACB	DOAS/ACB + Runaround Coil	DOAS/ACB + Runaround Coil + Solar Shade
First cost ($)	1,135,702	1,756,978	1,710,333	1,768,132
Maintenance Cost($)	4,044,980	56,235	57,935	57,935
Annual Natural Gas Cost($)	6,905,005	5,887,111	5,878,692	5,837,532
Annual Electricity Cost($)	2,449,416	2,098,641	1,932,969	1,919,440
Total	14,535,103	9,798,965	9,579,929	9,583,039

Uniform Present Value(UPV) discount factors adjusted for fuel price escalation for Massachusetts State OMB discount rate 1.9% from year 1 to 10, 2.7% discount rate from year 11 to 30.

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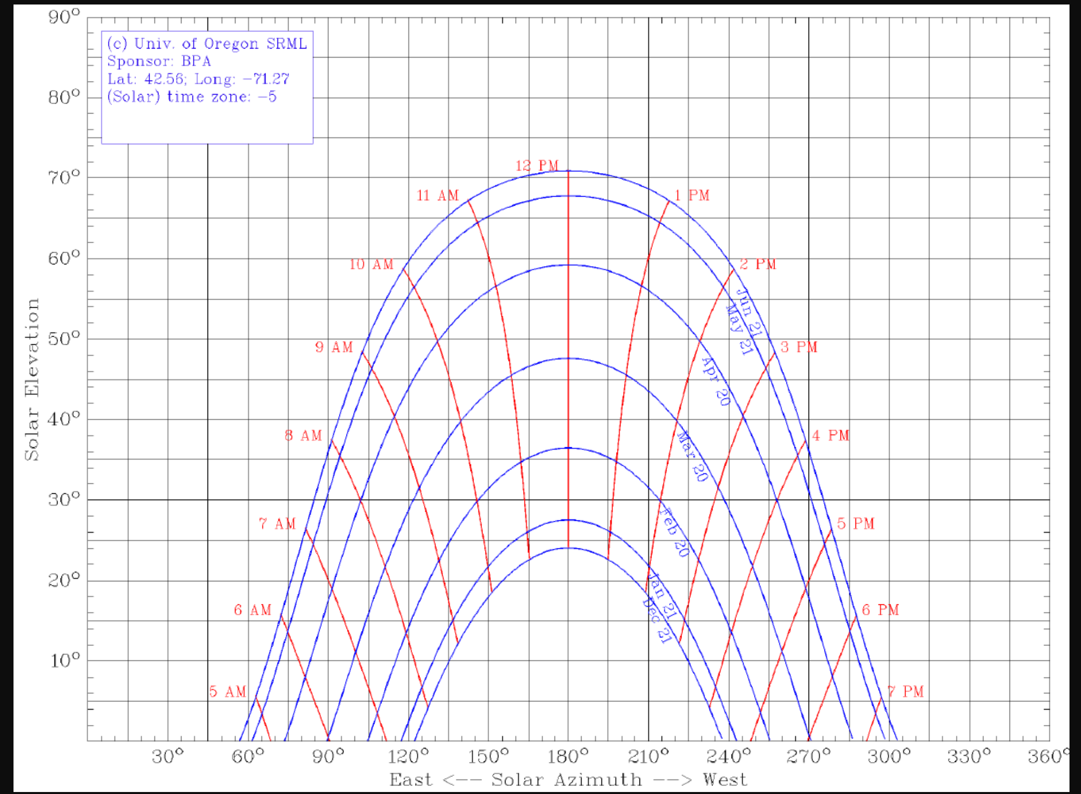
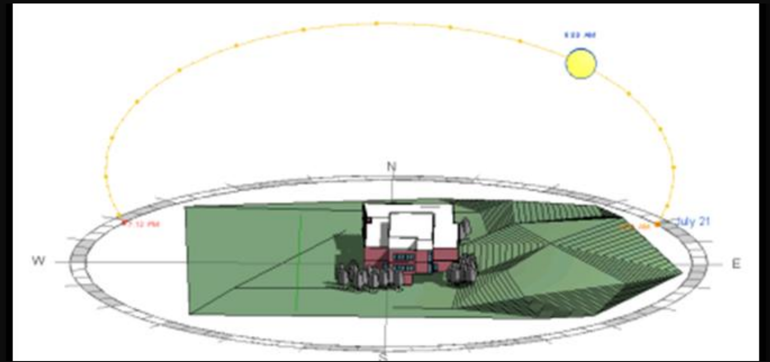
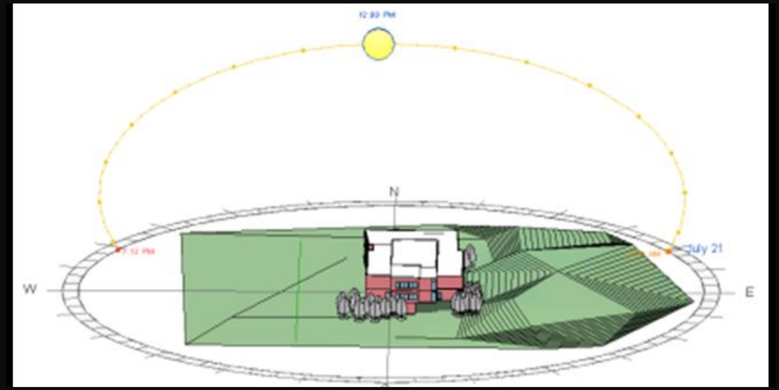
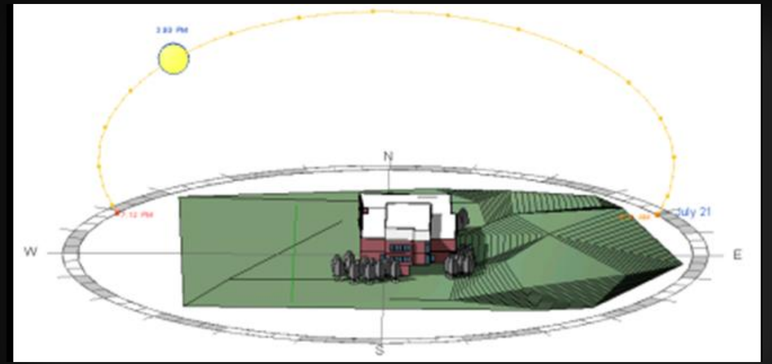


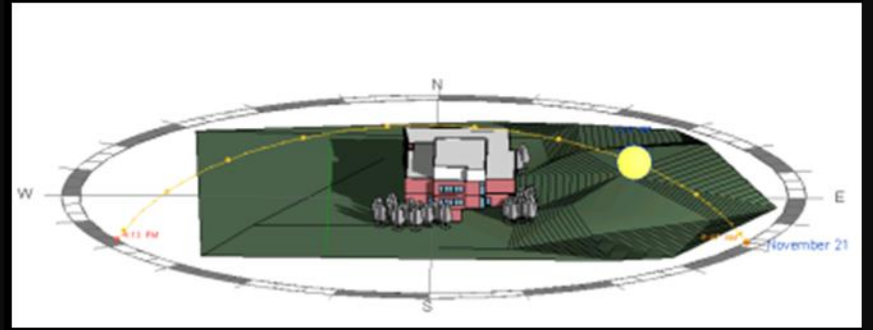
Sun Path in Summer

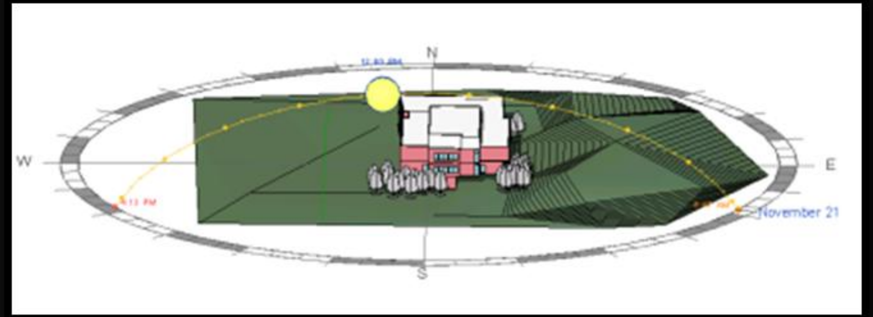


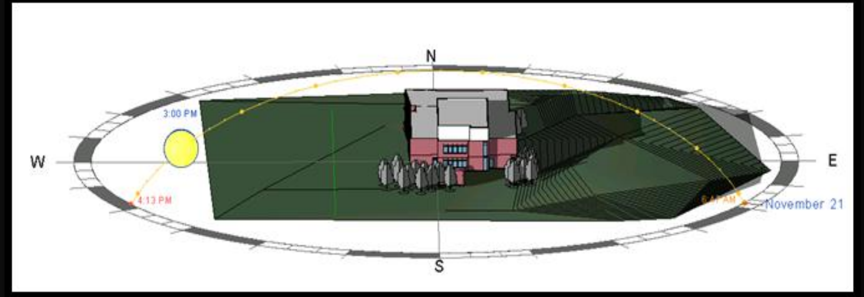




Sun Path in Winter







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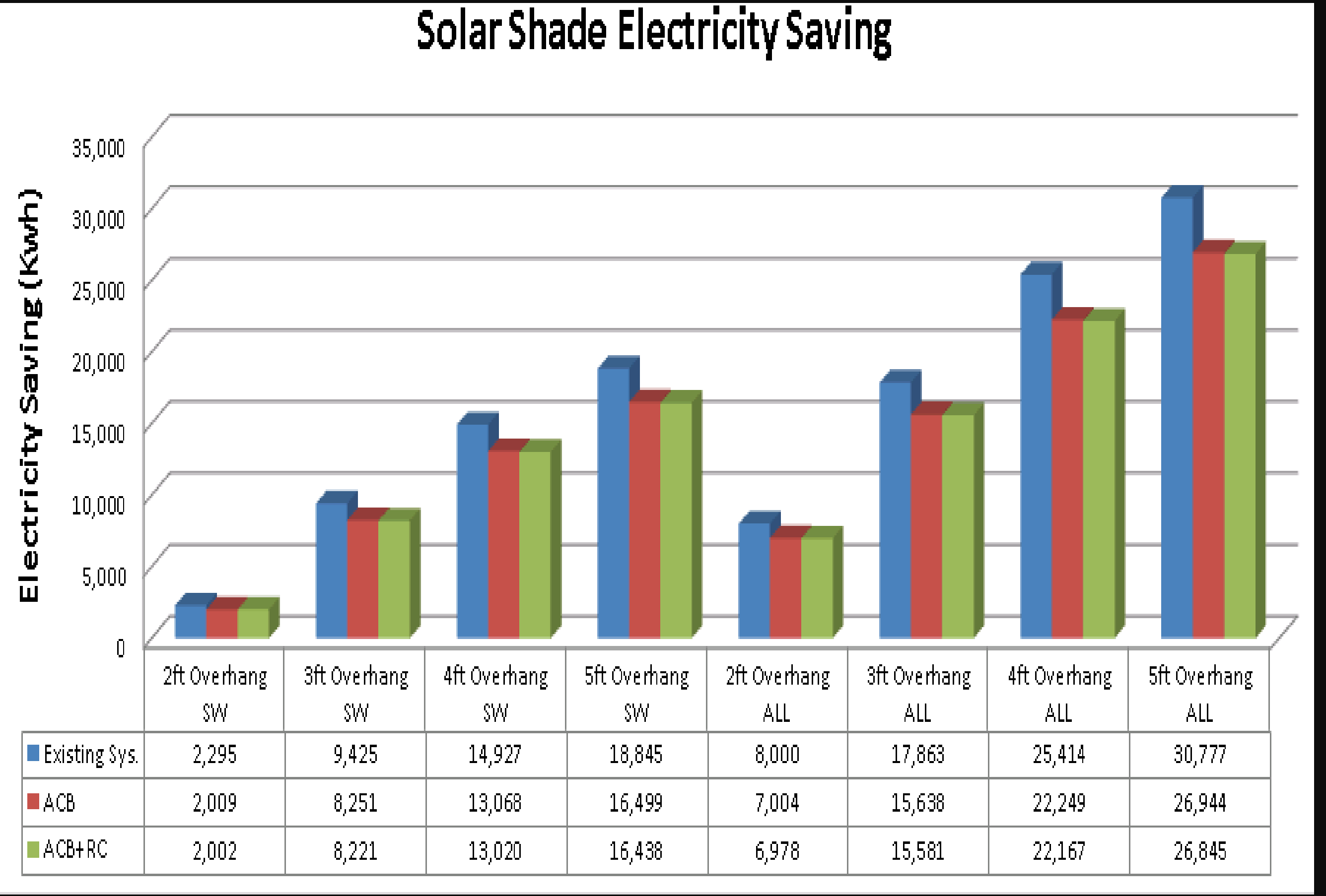
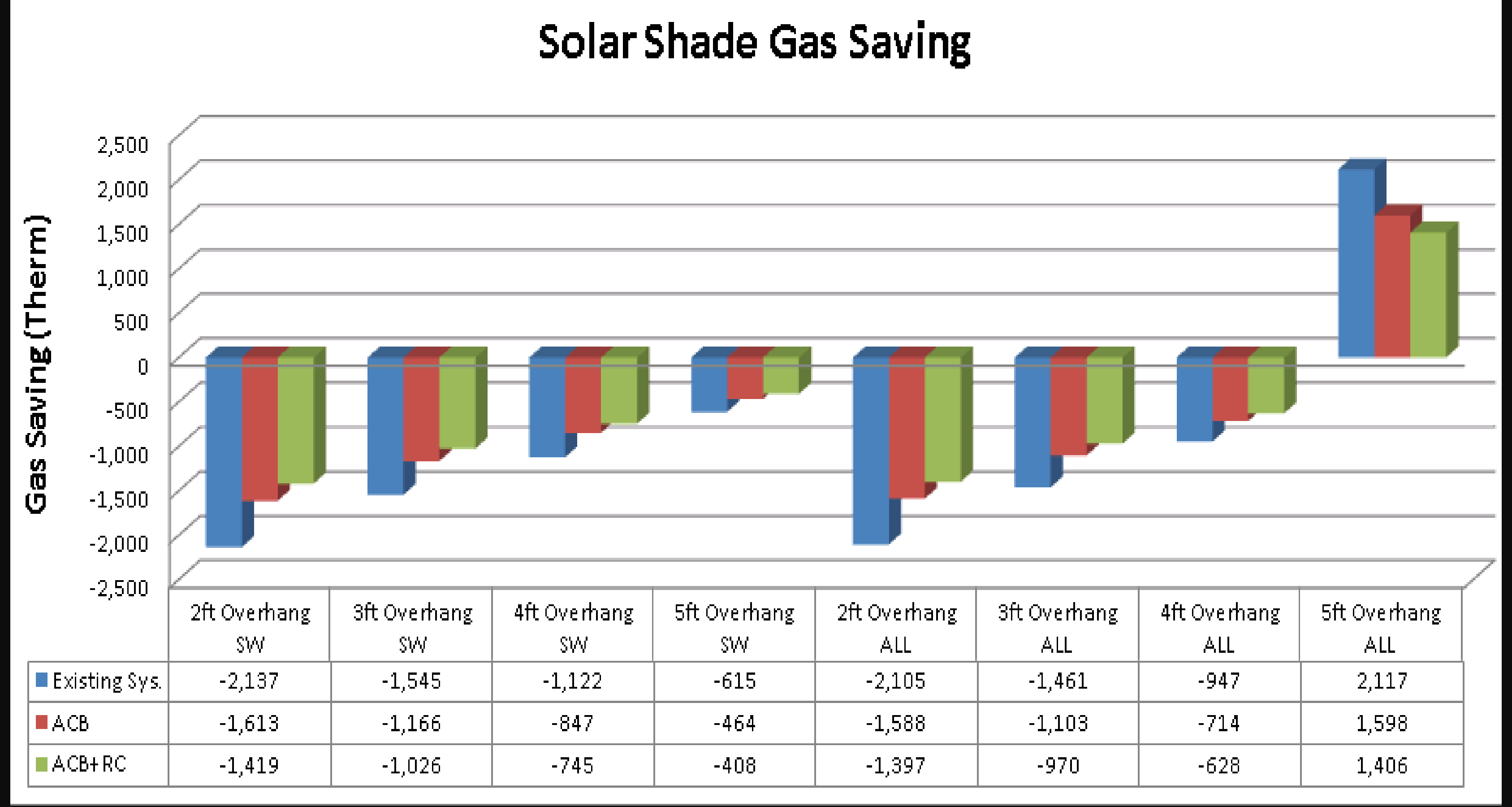
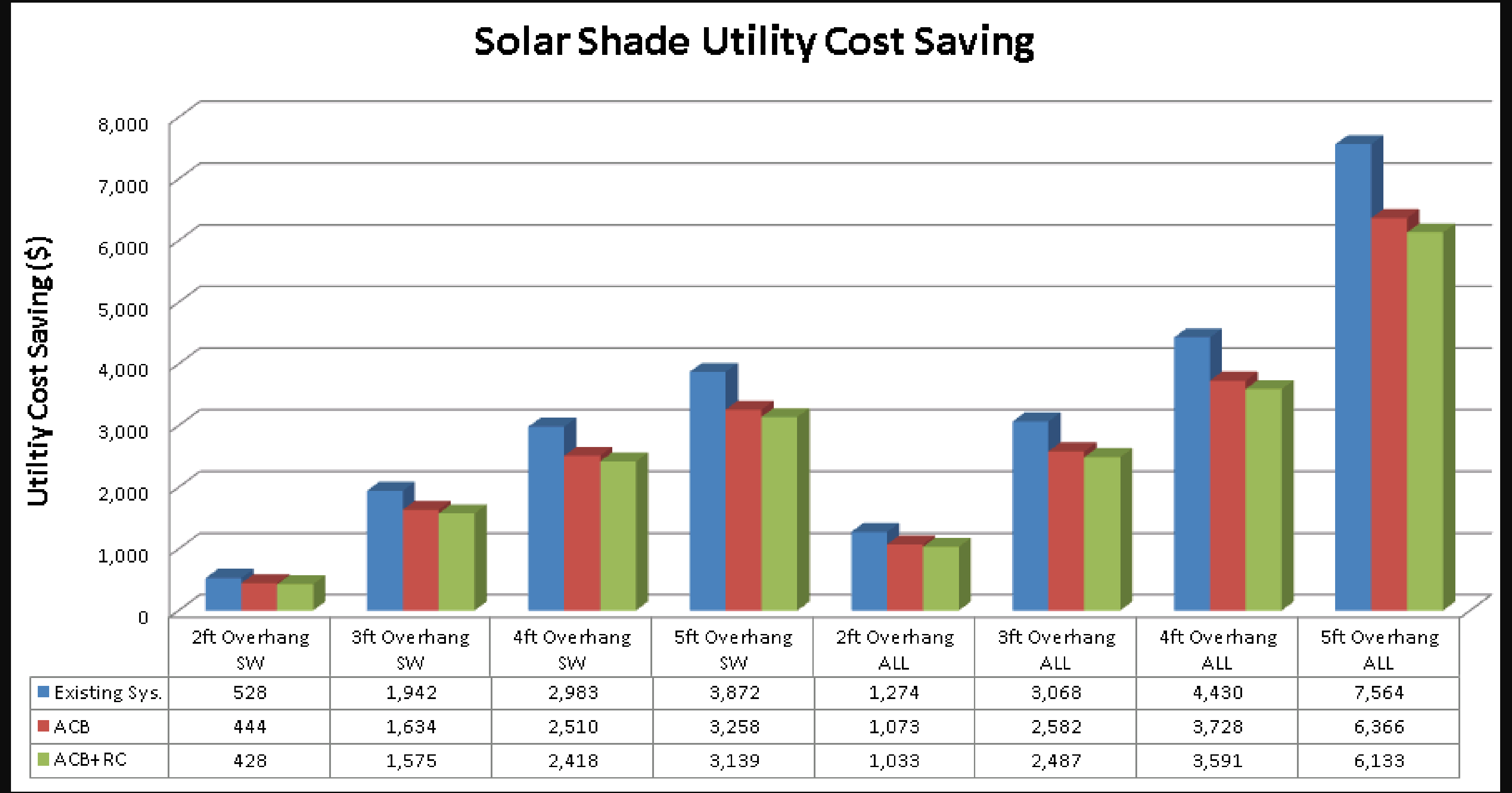


	2ft Overhang SW	3ft Overhang SW	4ft Overhang SW	5ft Overhang SW	2ft Overhang ALL	3ft Overhang ALL	4ft Overhang ALL	5ft Overhang ALL
Existing Sys.	2,295	9,425	14,927	18,845	8,000	17,863	25,414	30,777
ACB	2,009	8,251	13,068	16,499	7,004	15,638	22,249	26,944
ACB+RC	2,002	8,221	13,020	16,438	6,978	15,581	22,167	26,845



	2ft Overhang SW	3ft Overhang SW	4ft Overhang SW	5ft Overhang SW	2ft Overhang ALL	3ft Overhang ALL	4ft Overhang ALL	5ft Overhang ALL
Existing Sys.	-2,137	-1,545	-1,122	-615	-2,105	-1,461	-947	2,117
ACB	-1,613	-1,166	-847	-464	-1,588	-1,103	-714	1,598
ACB+RC	-1,419	-1,026	-745	-408	-1,397	-970	-628	1,406



	2ft Overhang SW	3ft Overhang SW	4ft Overhang SW	5ft Overhang SW	2ft Overhang ALL	3ft Overhang ALL	4ft Overhang ALL	5ft Overhang ALL
Existing Sys.	528	1,942	2,983	3,872	1,274	3,068	4,430	7,564
ACB	444	1,634	2,510	3,258	1,073	2,582	3,728	6,366
ACB+RC	428	1,575	2,418	3,139	1,033	2,487	3,591	6,133

Solar Shade System Cost Analysis

	South & West Solar Shade				All Sides Solar Shade			
	2ft	3ft	4ft	5ft	2ft	3ft	4ft	5ft
Total Length (ft)	1,012	1,518	2,024	2,530	1,973	2,960	3,946	4,933
Solar Shade Cost	14,840	32,550	50,260	67,970	40,390	74,918	109,445	143,973
Installation Cost	2,226	4,883	7,539	10,196	6,059	11,238	16,417	21,596
Total Cost ($)	**17,066**	**37,433**	**57,799**	**78,166**	**46,449**	**86,155**	**125,862**	**165,568**

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LEED Credits
Optimize Energy Performance
Controllability of Systems – Thermal Comfort

Possible Credits
Enhanced Commissioning
Measurement and Verification
Outdoor Air Delivery Monitoring
Thermal Comfort - Verification