Erin Miller

MECHANICAL OPTION

The Pennsylvania State University
Architectural Engineering Senior Thesis

April 15, 2014

theAUDITORIUM

FRANCIS MICHAEL PERFORMING ARTS ACADEMY LEMMA, MN

theAUDITORIUM

FRANCIS MICHAEL PERFORMING ARTS ACADEMY LEMMA, MN

WORLD-CLASS PERFORMING ARTS FACILITY

WORLD-CLASS PERFORMING ARTS FACILITY

PROPER FACILITIES

WORLD-CLASS PERFORMING ARTS FACILITY

PROPER FACILITIES

ACOUSTICALLY CORRECT

WORLD-CLASS PERFORMING ARTS FACILITY

PROPER FACILITIES

ACOUSTICALLY CORRECT

ECONOMICALLY FEASIBLE

WORLD-CLASS PERFORMING ARTS FACILITY

PROPER FACILITIES

ACOUSTICALLY CORRECT

ECONOMICALLY FEASIBLE

CONSCIOUS CONSUMPTION

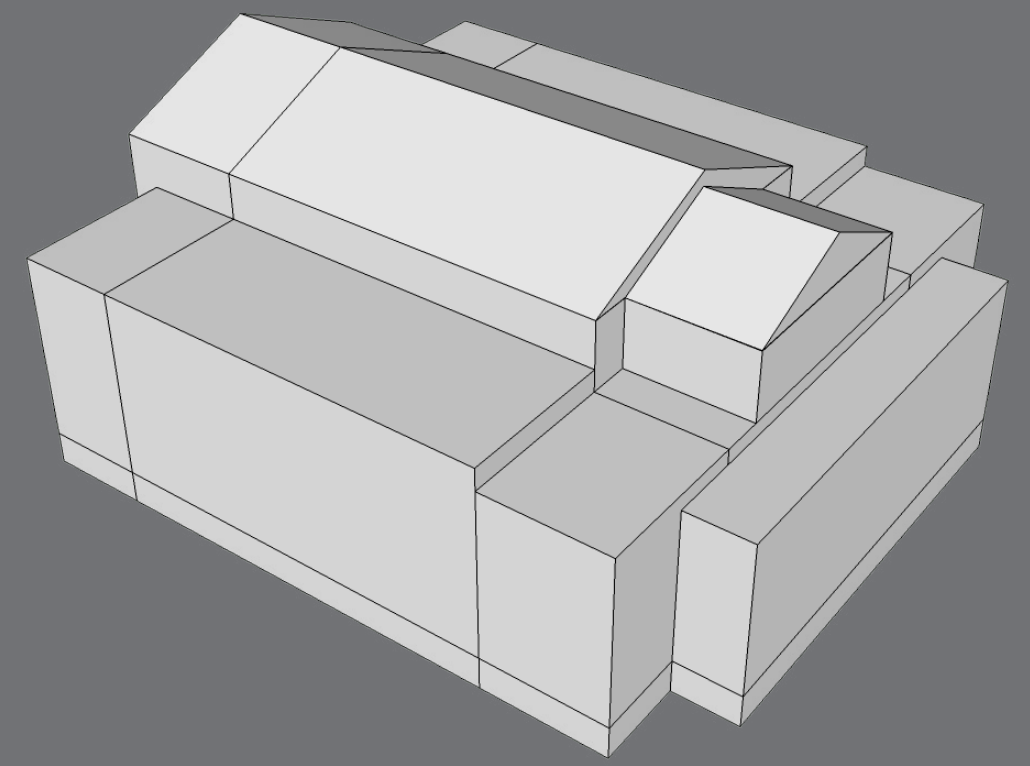
GENERAL INFORMATION

OWNER:
FRANCIS MICHAEL PERFORMING ARTS ACADEMY

LOCATION:
LEMMA, MINNESOTA

GROSS BUILDING AREA:
170,000 SF

THE AUDITORIUM



GENERAL INFORMATION

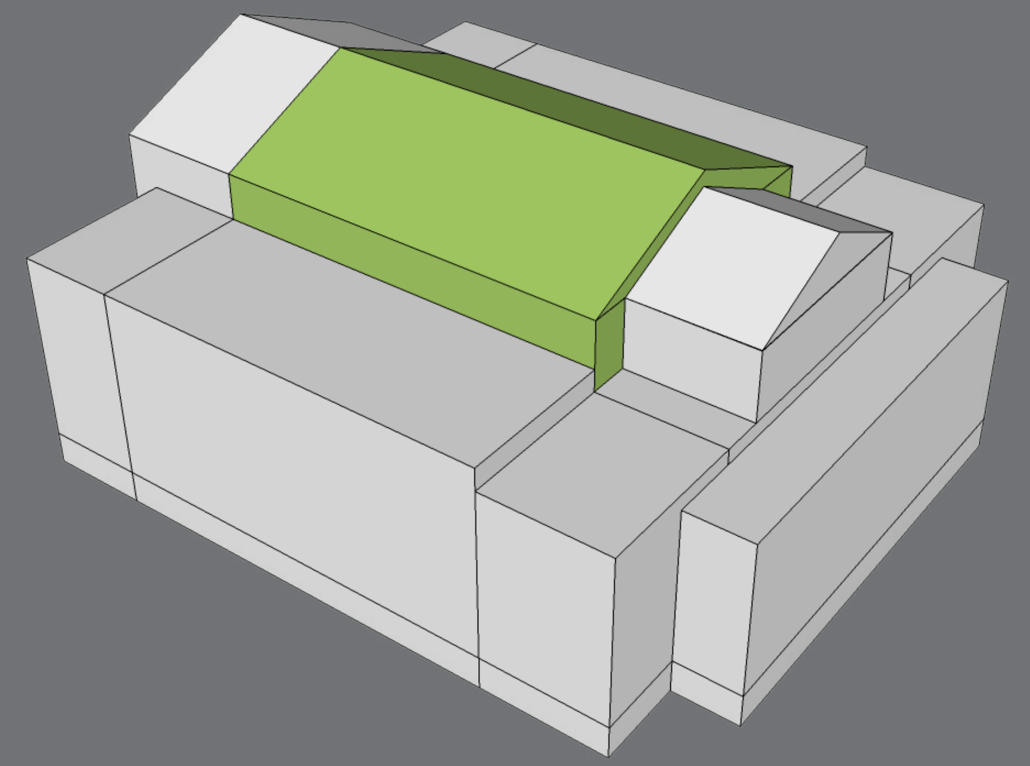
THEATER
2,800 SEATING CAPACITY

STAGE HOUSE

PERFORMANCE SUPPORT SPACES

PUBLIC SPACES
ATRIUM
HONORS PROGRAM FACULTY OFFICES
STUDENT LOUNGES

PROGRAM AREAS



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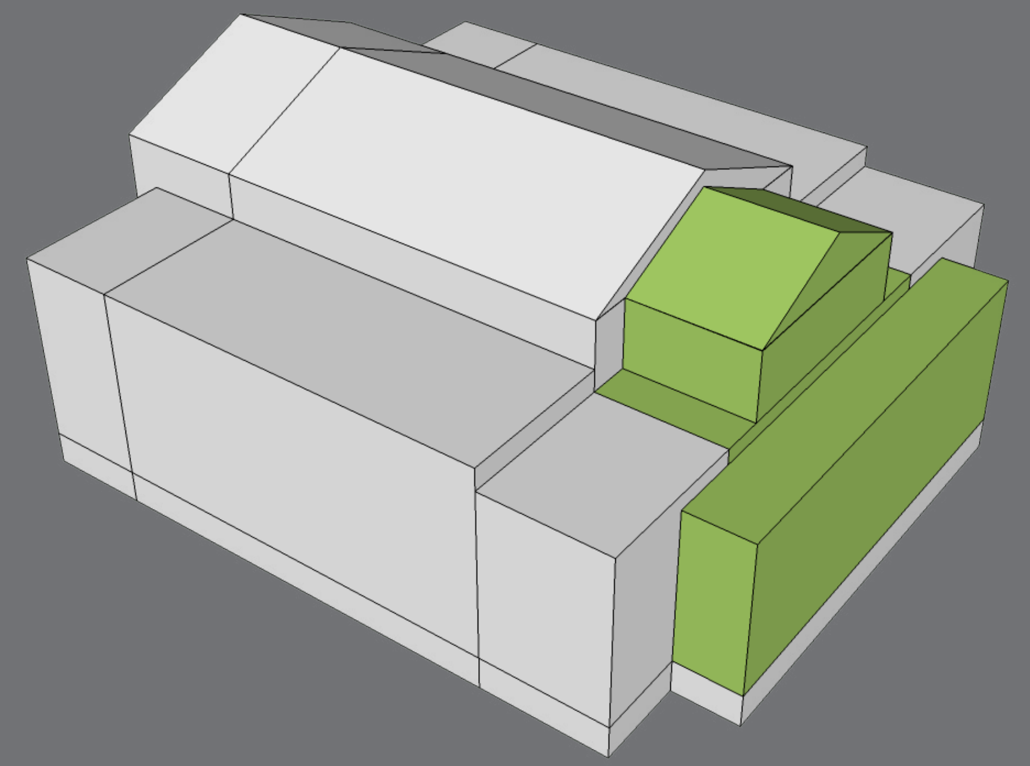

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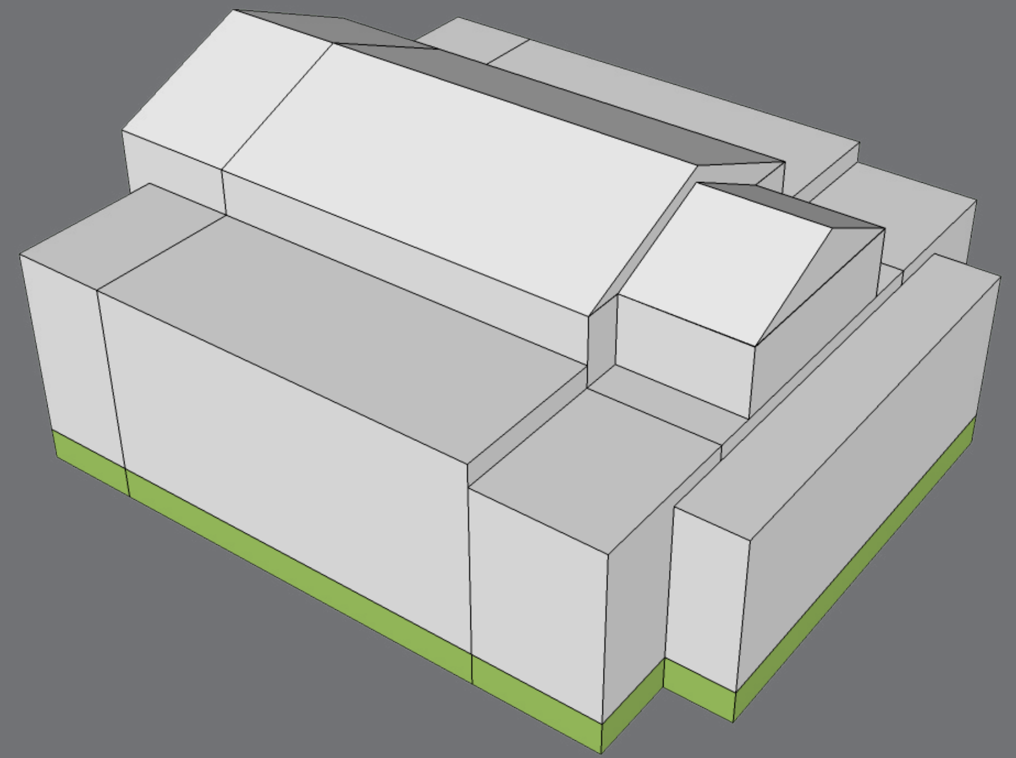

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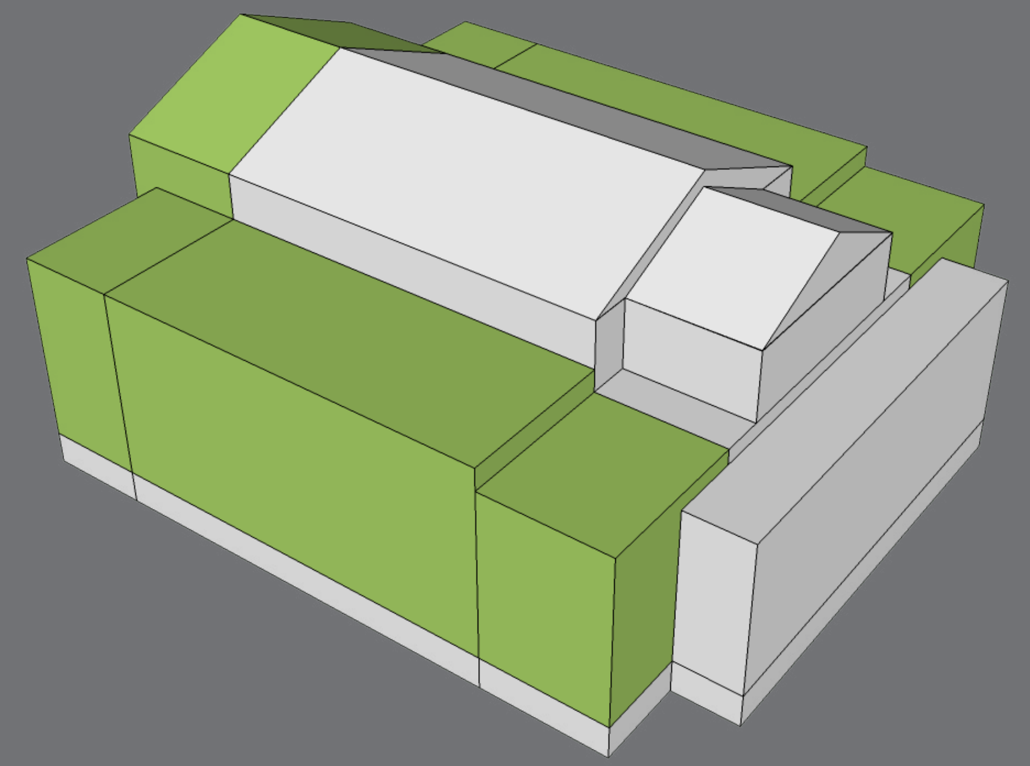

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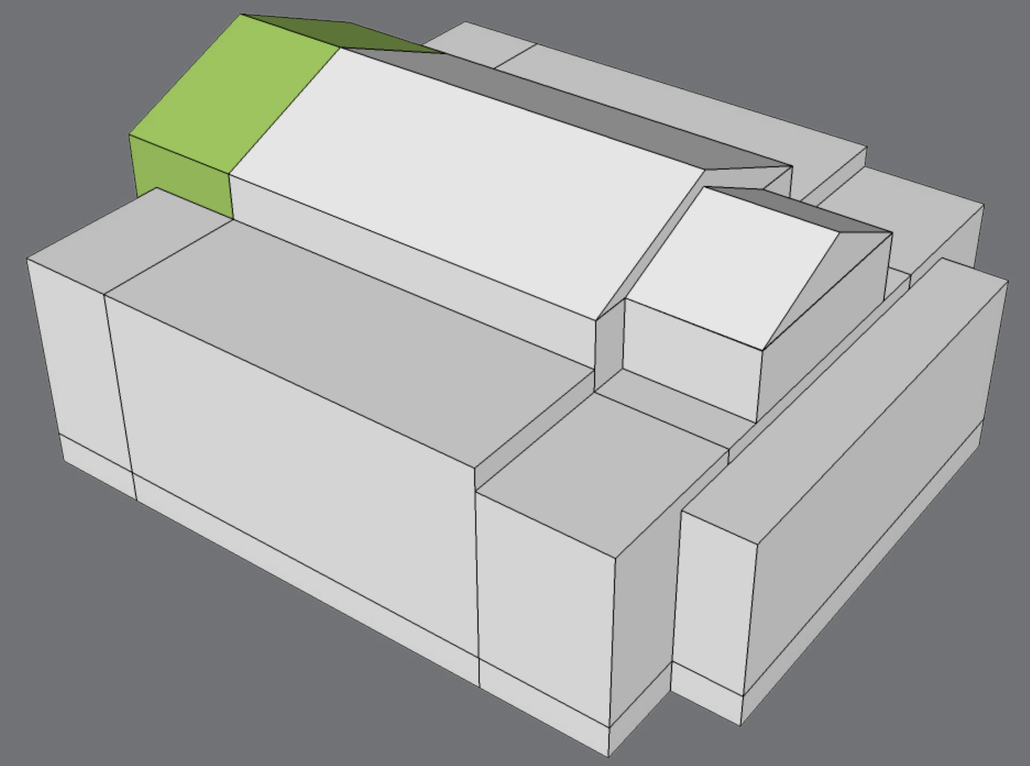

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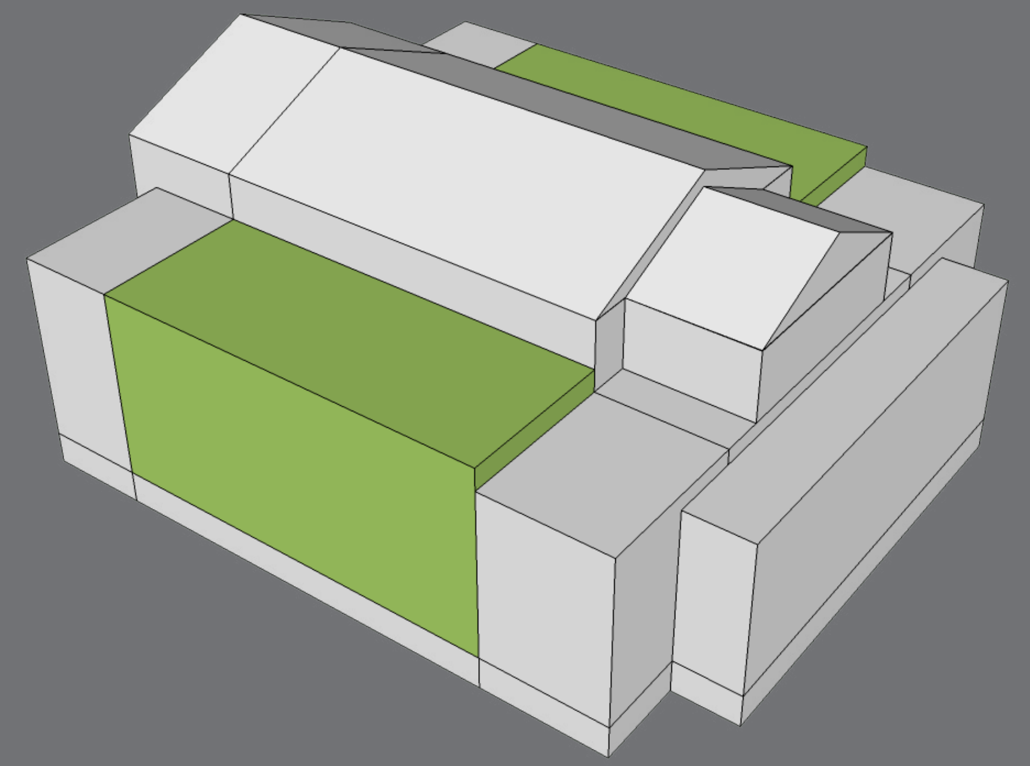

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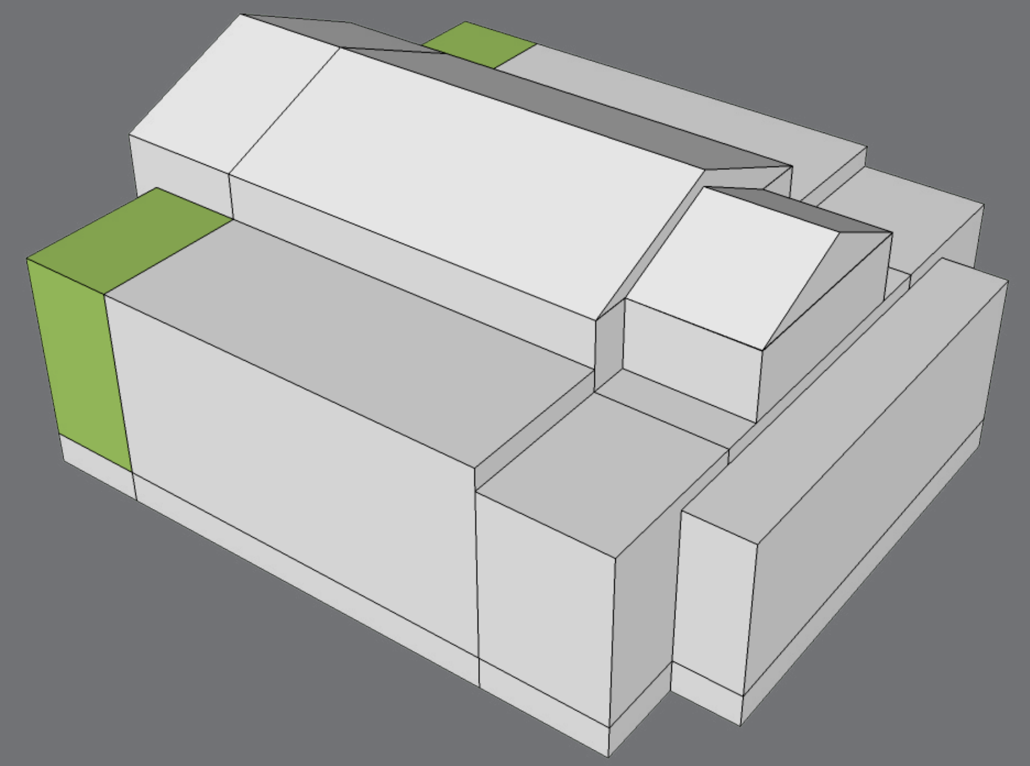

ACTIVE CHILLED BEAMS

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OPTION B
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SYSTEM ZONING
ENERGY IMPACT
FIRST COST

ACOUSTIC ANALYSIS

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CLOSING

ACTIVE CHILLED BEAMS

DESIGN CHARACTERISTICS

4 PIPE SYSTEM - SUPPLY & RETURN HOT WATER AND CHILLED WATER

INDUCED ROOM AIR RECIRCULATED/RECONDITIONED

57 °F CHILLED WATER SUPPLY TEMPERATURE

120 °F HOT WATER SUPPLY TEMPERATURE

SIZING

MINIMUM REQUIRED VENTILATION AIR

PRIMARY AIRFLOW SIZED TO ACCOMMODATE LATENT LOAD

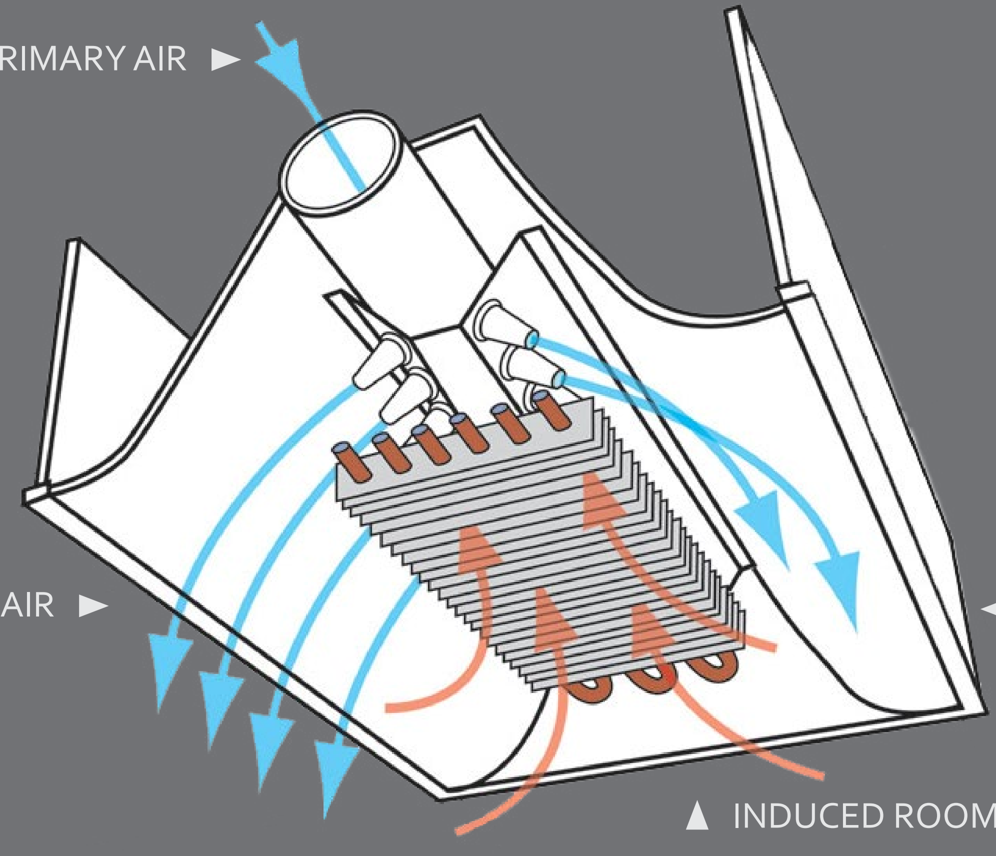
CONSTRUCTION CONCERNS

4 PIPING CONNECTIONS

PRIMARY AIR CONNECTION

PRECISE PLACEMENT WITHIN SUSPENDED CEILING GRID

SCHEMATIC



BuildingGreen.com (Modified)

ACTIVE CHILLED BEAMS - OPTION A

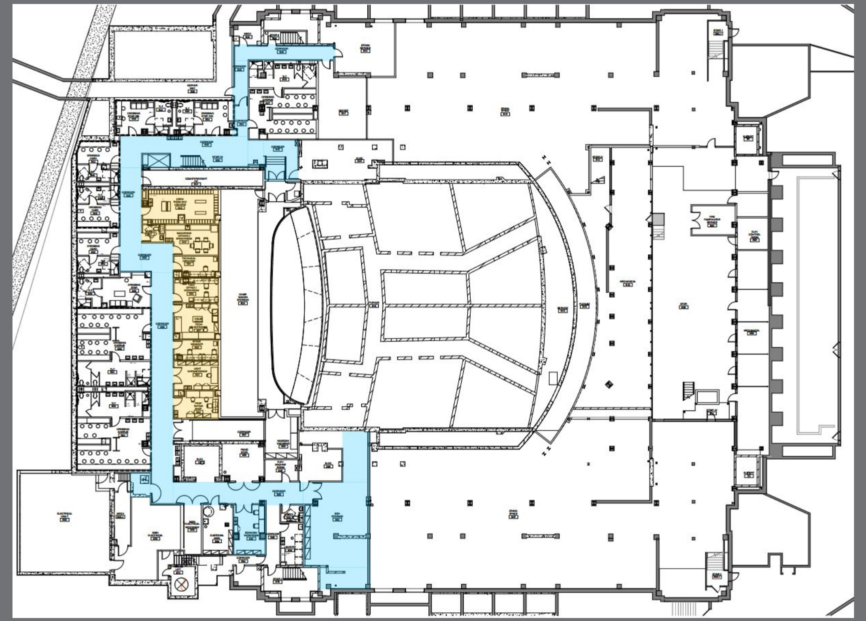
BASELINE

15 BASEMENT ROOMS
16 ACTIVE CHILLED BEAMS
2% BUILDING AREA

OPTION A

BASEMENT & GROUND FLOOR ROOMS
42 ACTIVE CHILLED BEAMS ADDED
4.7% BUILDING AREA CHANGED

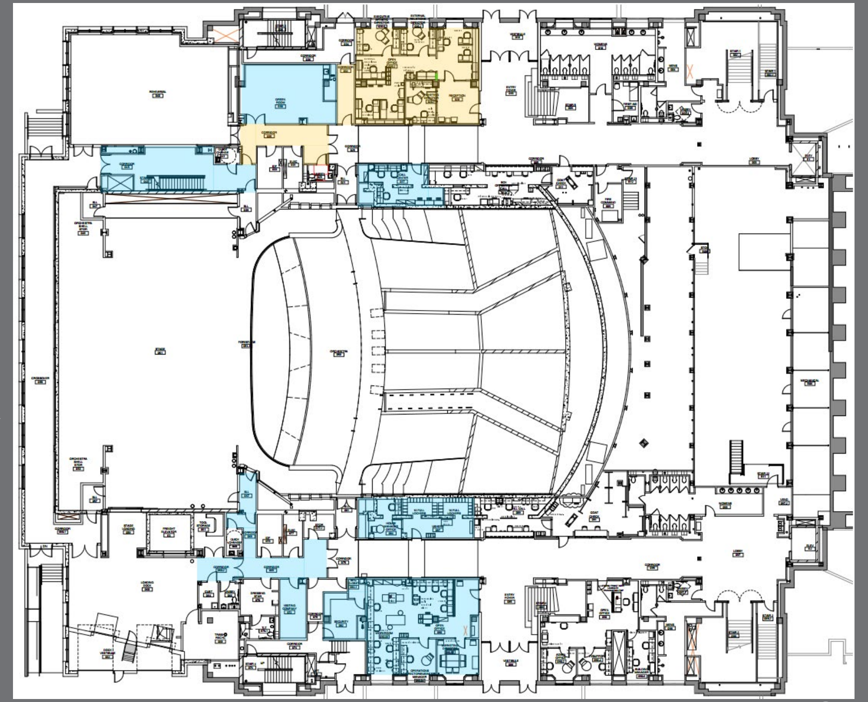
SYSTEM ZONING - OPTION A



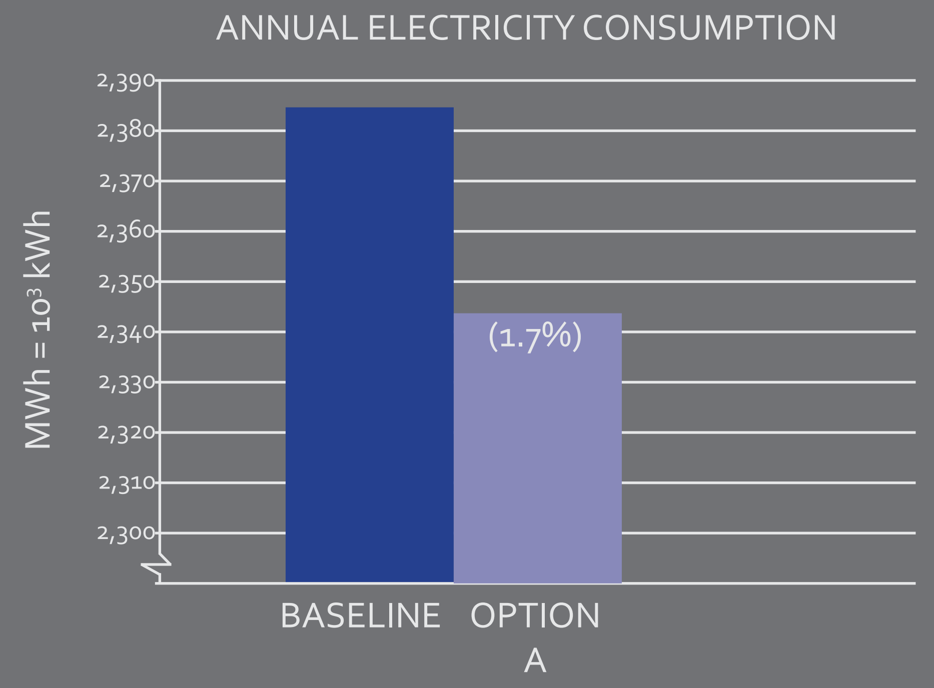
◄ BASEMENT FLOOR CHILLED BEAM EXPANSION

BASELINE
OPTION A

GROUND FLOOR CHILLED BEAM EXPANSION ►



ACTIVE CHILLED BEAMS - OPTION A



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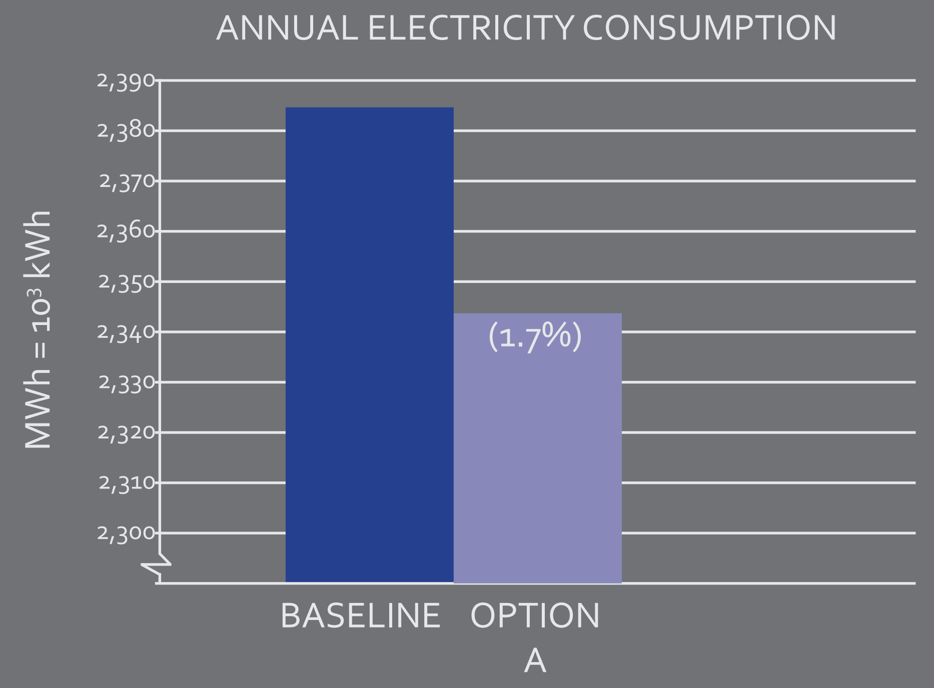
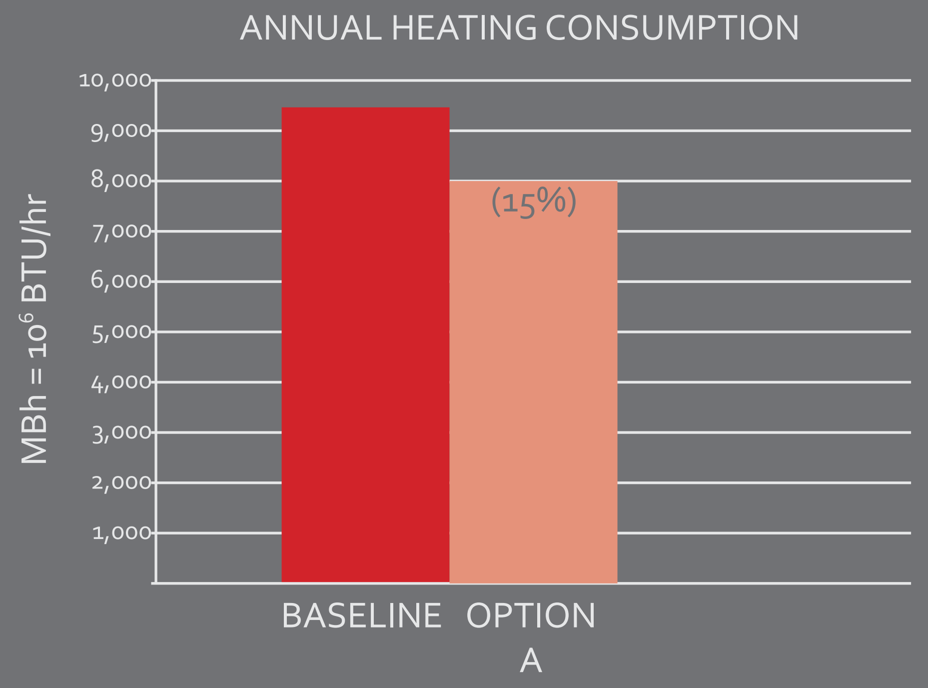
ACTIVE CHILLED BEAMS - OPTION A





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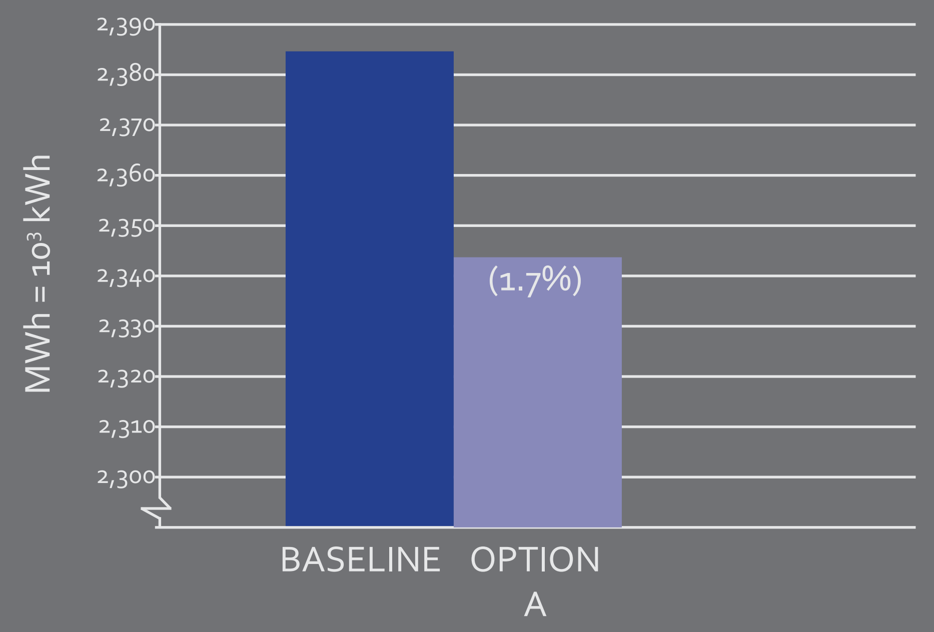
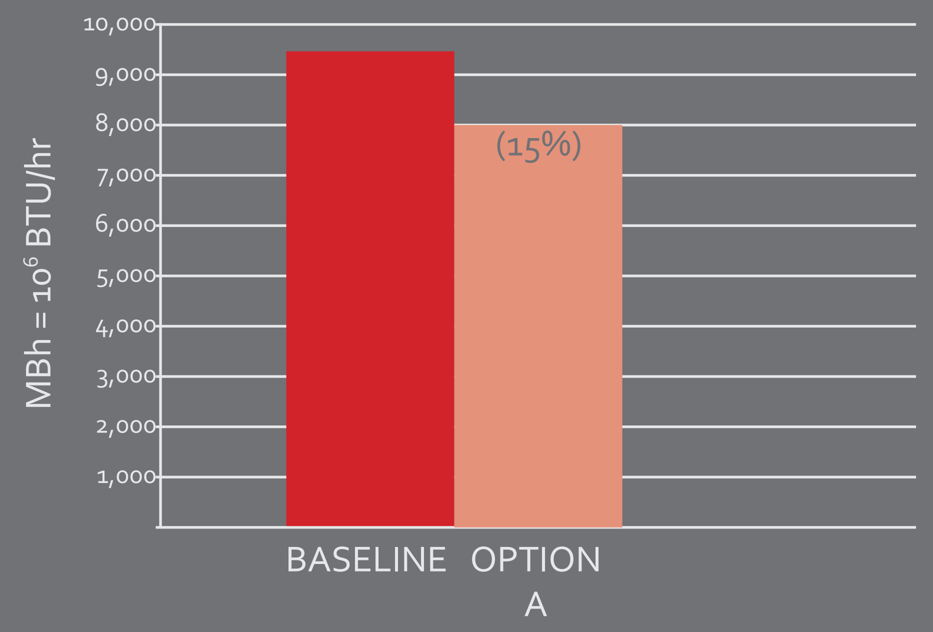
ACTIVE CHILLED BEAMS - OPTION A

ANNUAL ELECTRICITY CONSUMPTION



ANNUAL HEATING CONSUMPTION



COMPARISON MATRIX

		BASELINE	OPTION A	
ANNUAL COMPARISON		*MODELED*	*vs. BASELINE*	
ENERGY	[MBh]	17,544	(1,591)	-9%
ELECTRICITY	[MWh]	2,386	(42)	-2%
HEATING	[MBh]	9,408	(1,447)	-15%
AIRFLOW *AHU-1*	[CFM]	65,906	(6,519)	-10%
AHU-2	[CFM]	49,725	(163)	0%
AHU-3	[CFM]	16,599	(383)	-2%
AHU-5	[CFM]	5,131	86	2%
EMISSIONS	[lb CO2]	232,395	(36)	-0.02%
UTILITY COSTS	[$]	$ 279,697.47	$ (15,348.65)	-5%

MECHANICAL FIRST COST	[$]	$ 8,472,706.00	+ $ 121,606.23	1%

ACTIVE CHILLED BEAMS - OPTION B

BASELINE

15 BASEMENT ROOMS
16 ACTIVE CHILLED BEAMS
2% BUILDING AREA

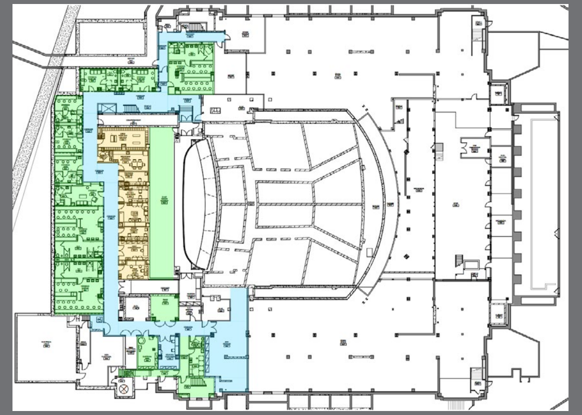
OPTION A

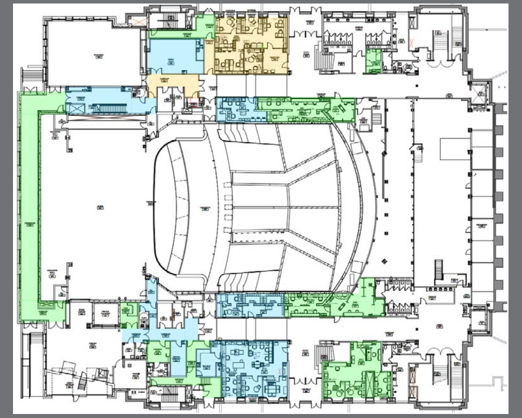
BASEMENT & GROUND FLOOR ROOMS
42 ACTIVE CHILLED BEAMS ADDED
4.7% BUILDING AREA CHANGED

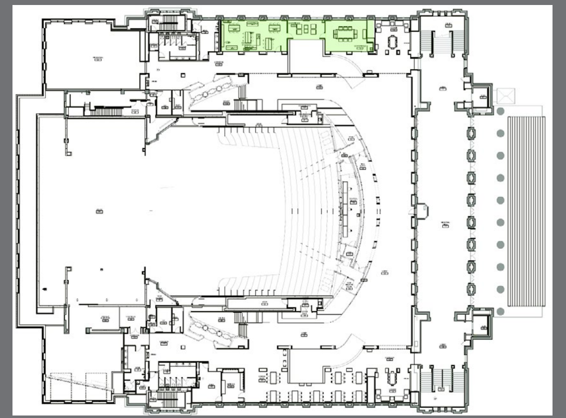
OPTION B

BASEMENT, GROUND, 1st, 2nd & 3rd FLOOR ROOMS
98 ACTIVE CHILLED BEAMS ADDED
19% BUILDING AREA CHANGED

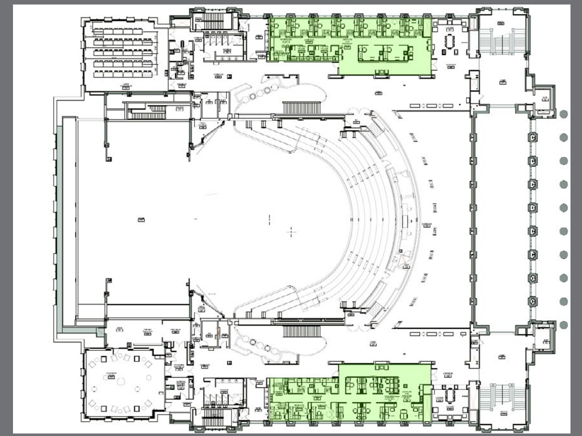
SYSTEM ZONING - OPTION B

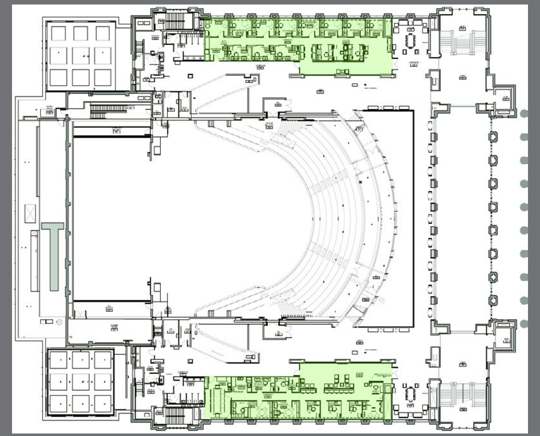

▲ BASEMENT FLOOR CHILLED BEAM EXPANSION


▲ GROUND FLOOR CHILLED BEAM EXPANSION

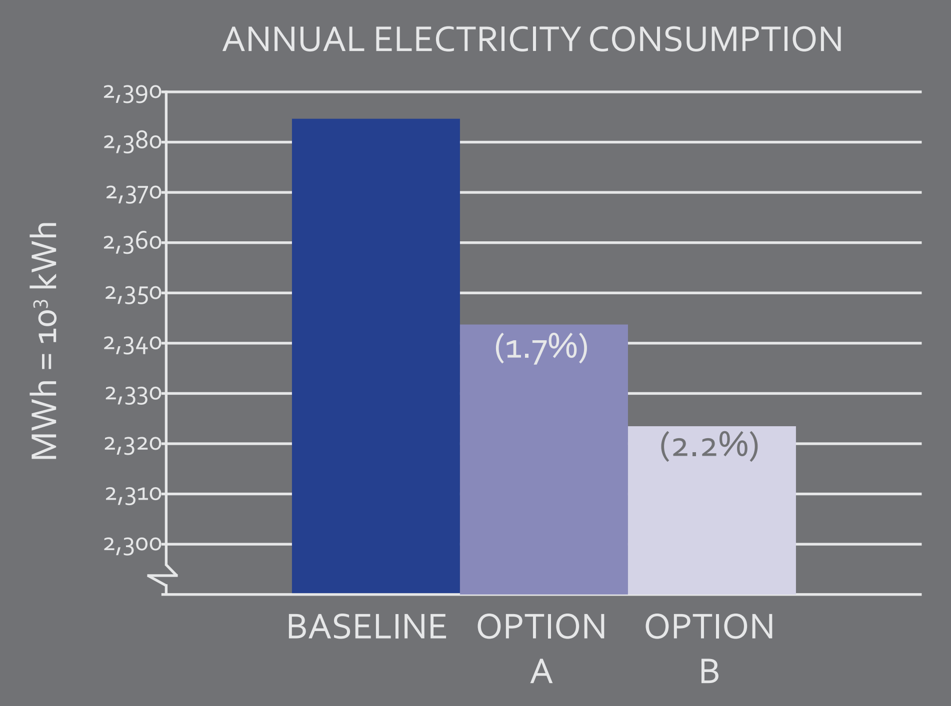

▲ FIRST FLOOR CHILLED BEAM EXPANSION

BASELINE
OPTION A
OPTION B

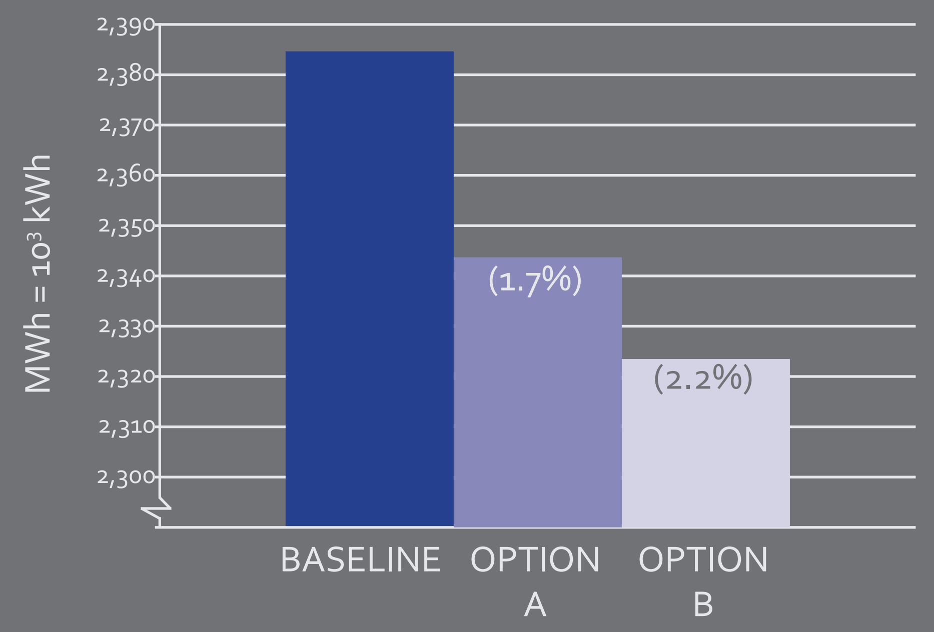

▲ SECOND FLOOR CHILLED BEAM EXPANSION

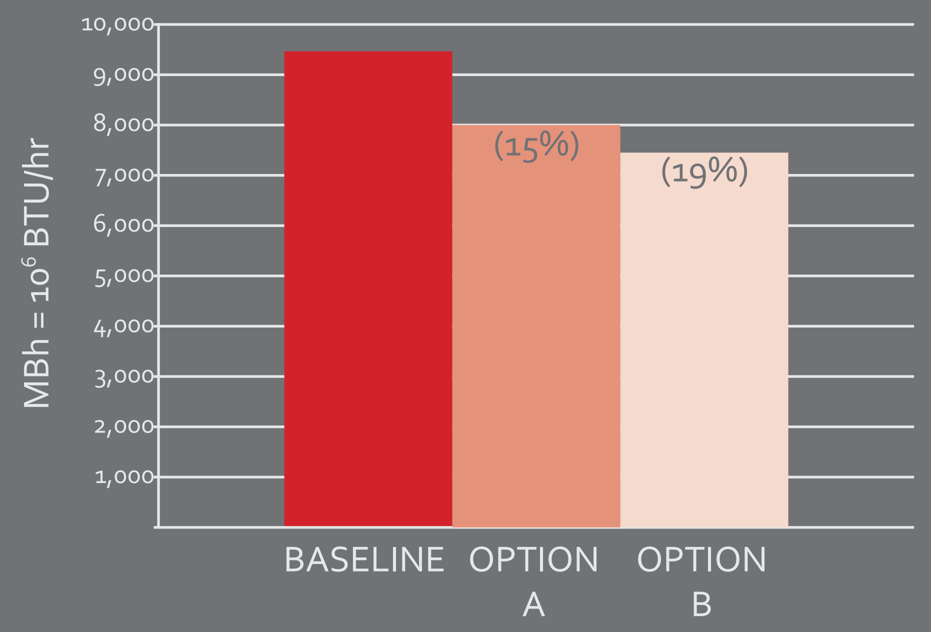

▲ THIRD FLOOR CHILLED BEAM EXPANSION

ACTIVE CHILLED BEAMS - OPTION B

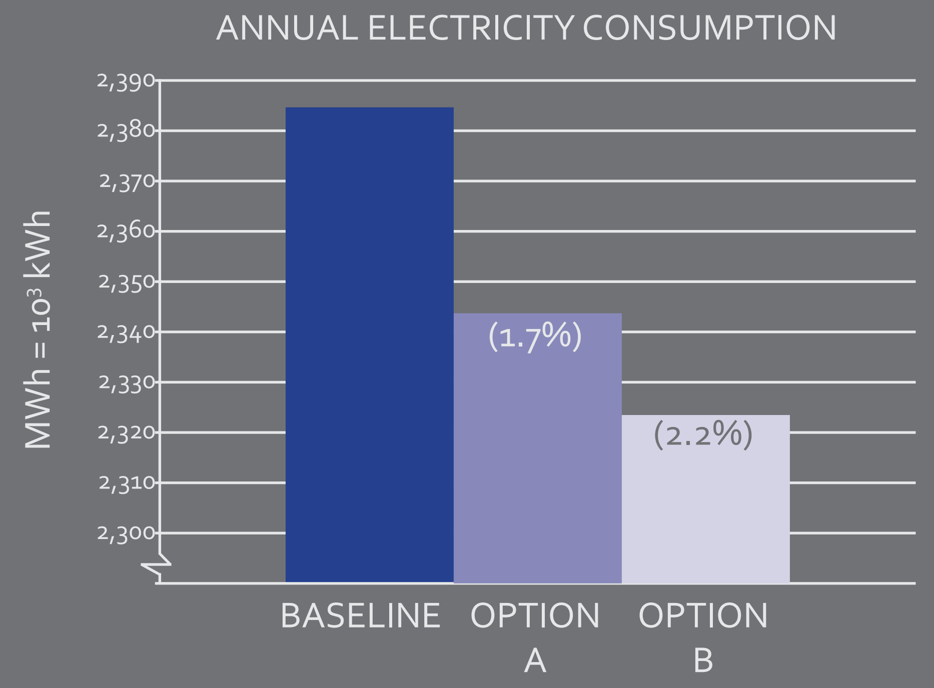


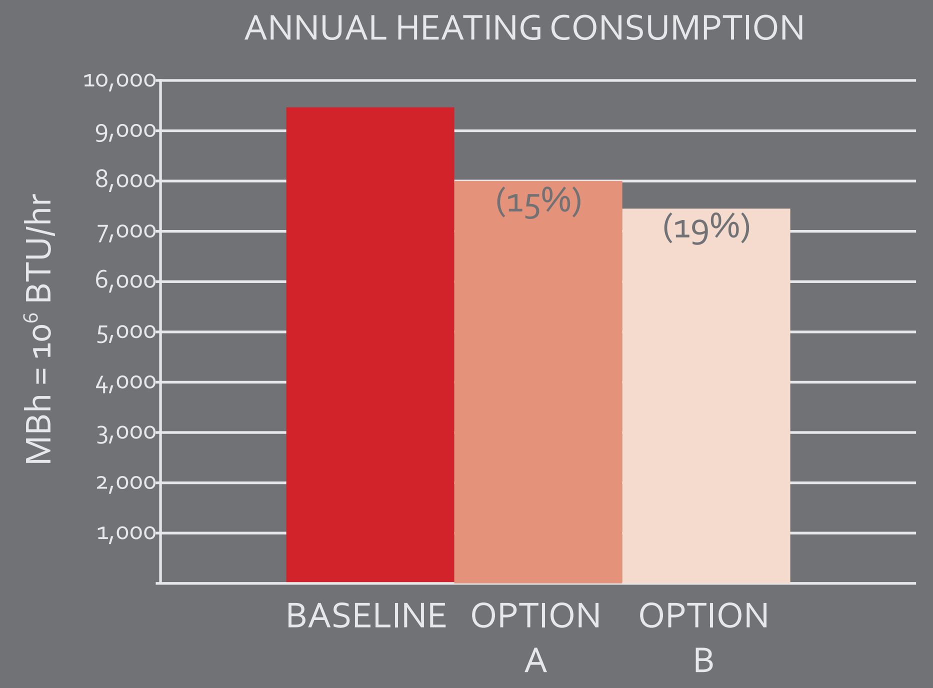
ACTIVE CHILLED BEAMS - OPTION B





ACTIVE CHILLED BEAMS - OPTION B





COMPARISON MATRIX

			BASELINE	OPTION A		OPTION B	
ANNUAL COMPARISON			*MODELED*	*vs. BASELINE*		*vs. BASELINE*	
ENERGY		[MBh]	17,544	(1,591)	-9%	(1,923)	-11%
ELECTRICITY		[MWh]	2,386	(42)	-2%	(58)	-2%
HEATING		[MBh]	9,408	(1,447)	-15%	(1,750)	-19%
AIRFLOW	*AHU-1*	[CFM]	65,906	(6,519)	-10%	(18,942)	-29%
	AHU-2	[CFM]	49,725	(163)	0%	(163)	0%
	AHU-3	[CFM]	16,599	(383)	-2%	(383)	-2%
	AHU-5	[CFM]	5,131	86	2%	3,325	65%
EMISSIONS		[lb CO2]	232,395	(36)	-0.02%	2,720	1.2%
UTILITY COSTS		[$]	$ 279,697.47	$ (15,348.65)	-5%	$ (18,804.99)	-7%
MECHANICAL FIRST COST		[$]	$ 8,472,706.00	+ $ 121,606.23	1%	+ $ 488,520.15	6%

DEMAND CONTROL VENTILATION [DCV]

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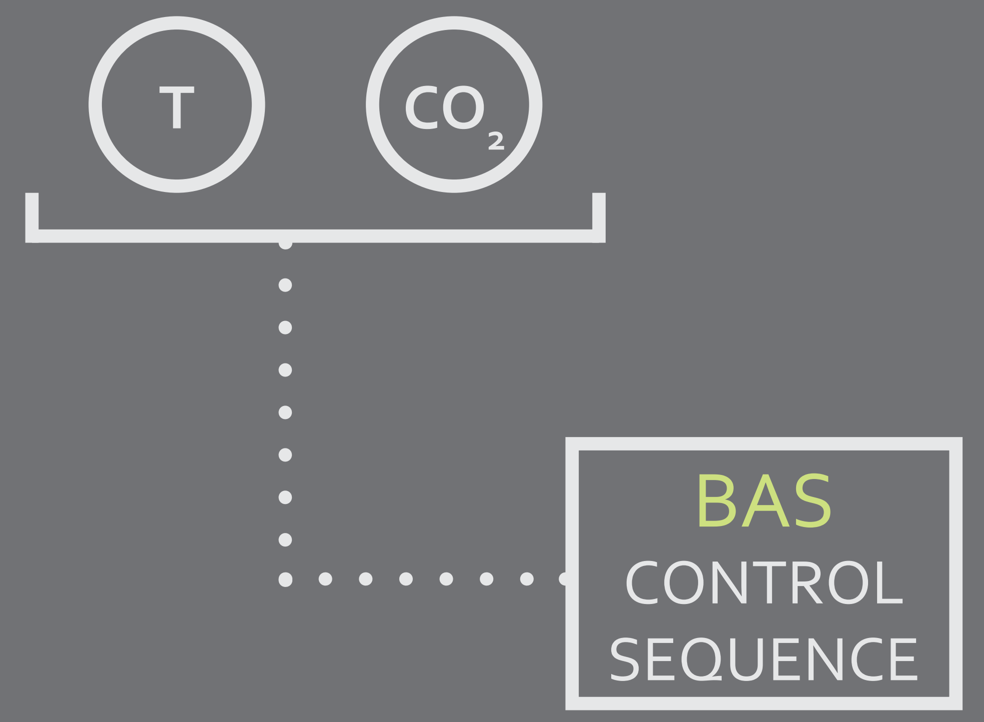

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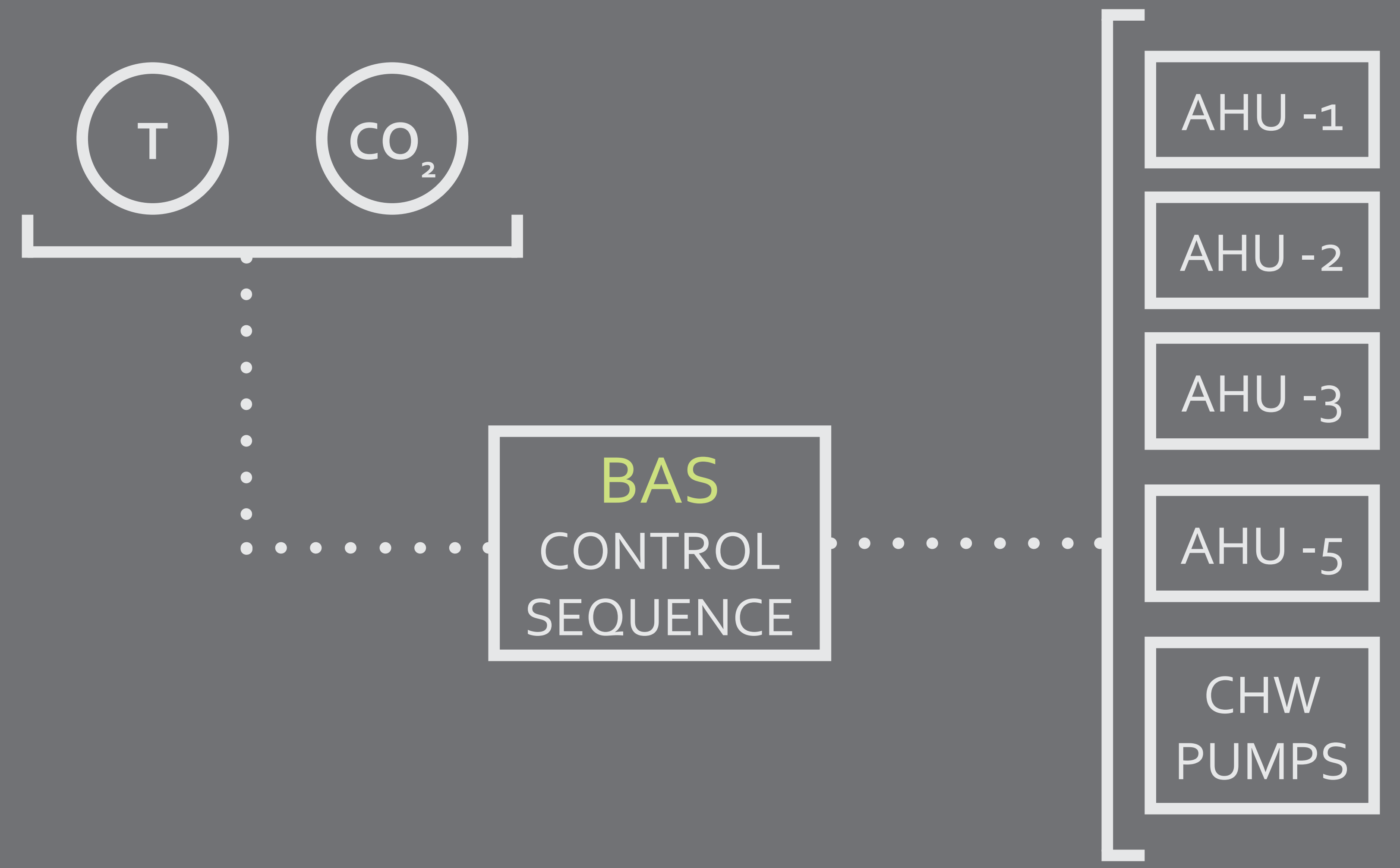

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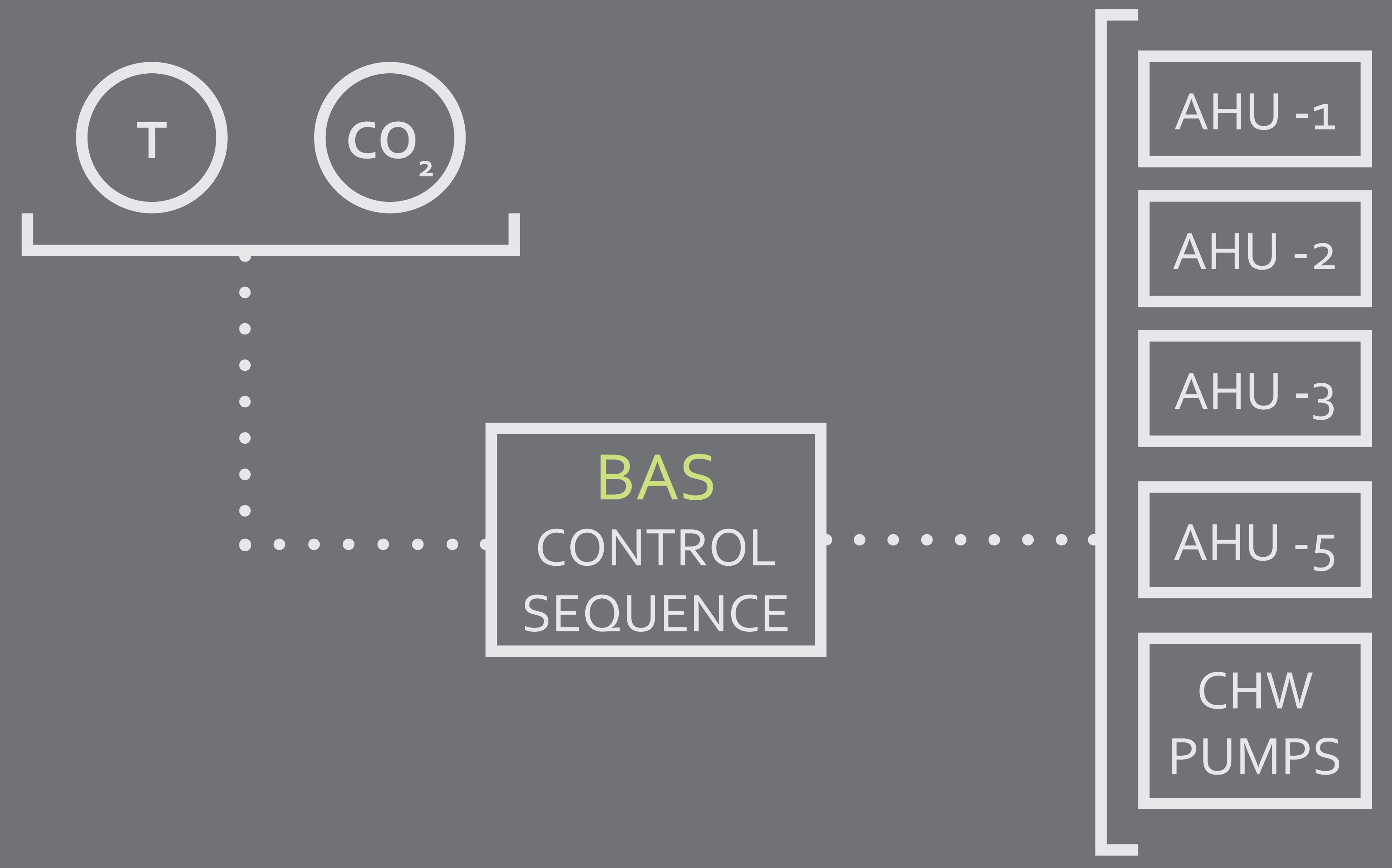
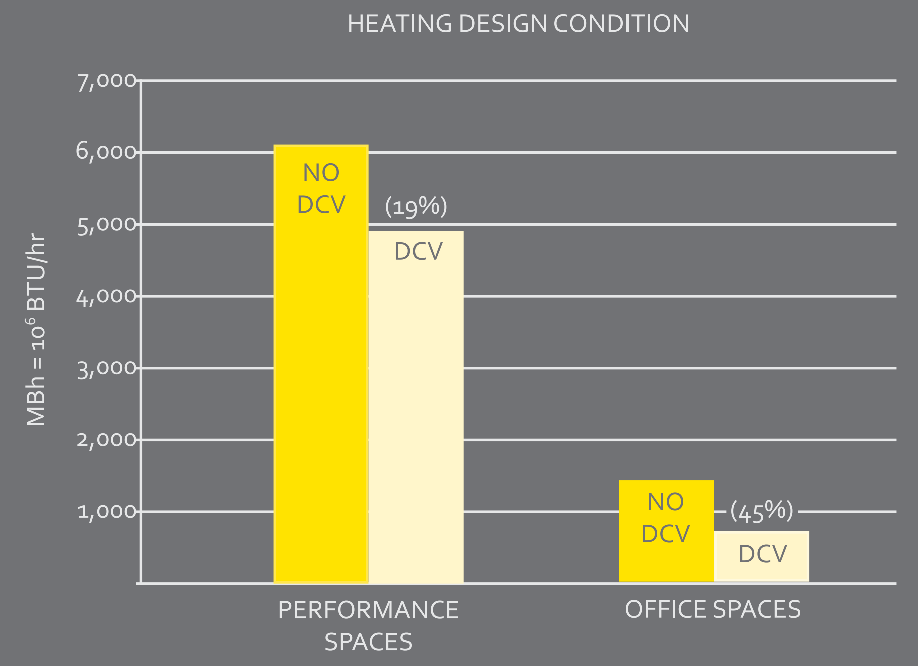
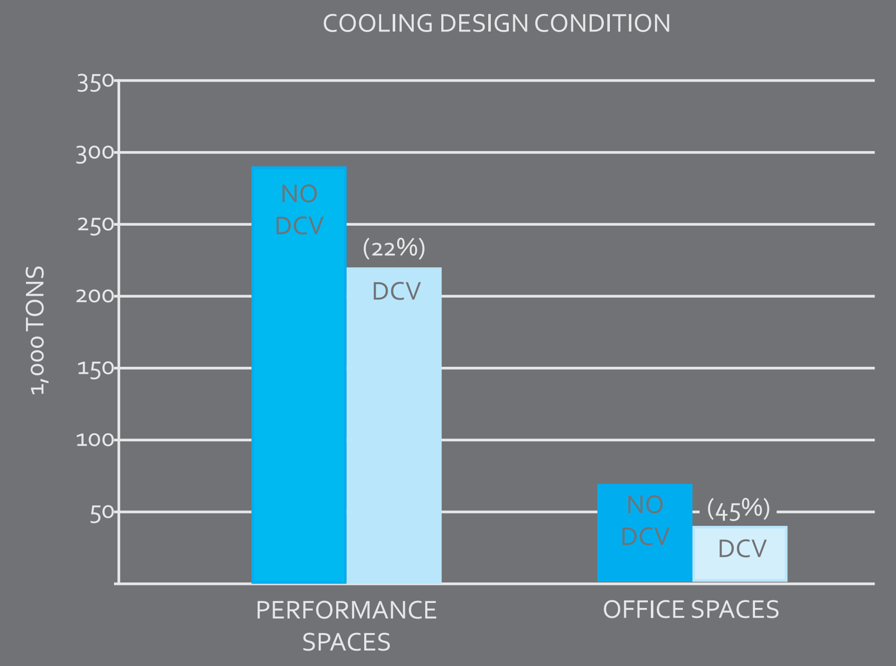


CALCULATED RESULTS





OCCUPANCY ASSUMPTIONS

NORMAL WORK WEEK [8 AM - 6 PM]

NO SHOWS MONDAY - THURSDAY

PERFORMANCES:
- FRIDAY @ 7PM
- SATURDAY @ 2PM & 7PM
- SUNDAY @ 2PM

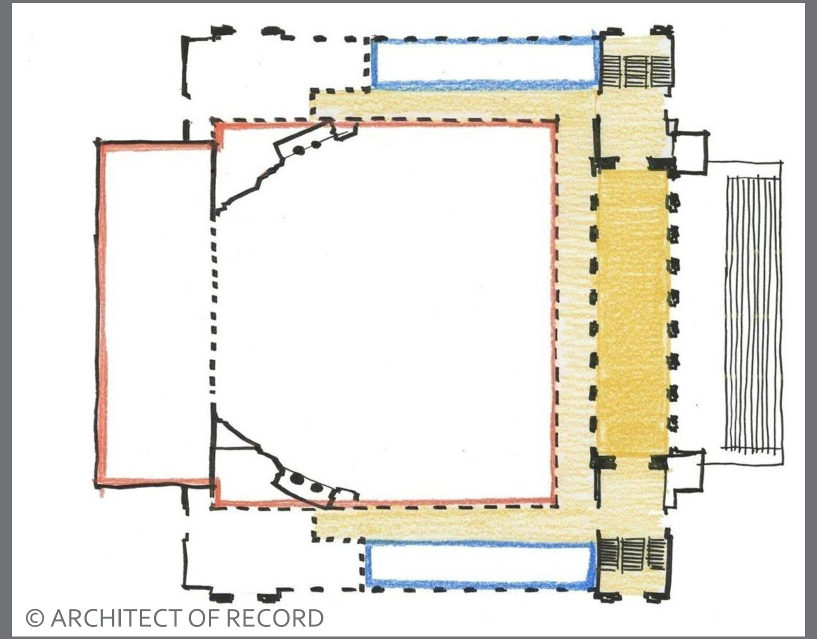
BENEFITS

DECREASED EQUIPMENT RUNTIME

BETTER SERVES ACTUAL BUILDING LOADS

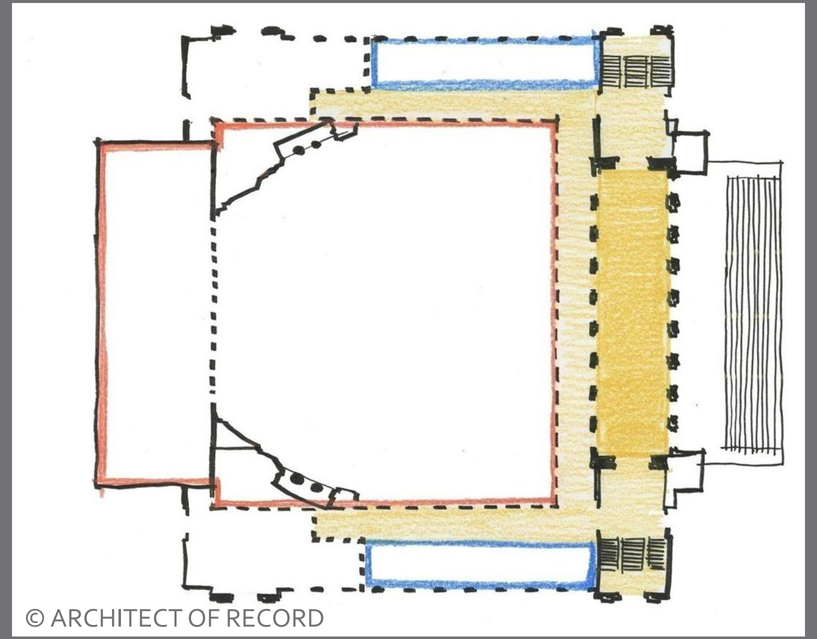
IMPROVED LOAD FOLLOWING

ACOUSTIC ANALYSIS



▲ORIGINAL THEATER GEOMETRY

ACOUSTIC ANALYSIS



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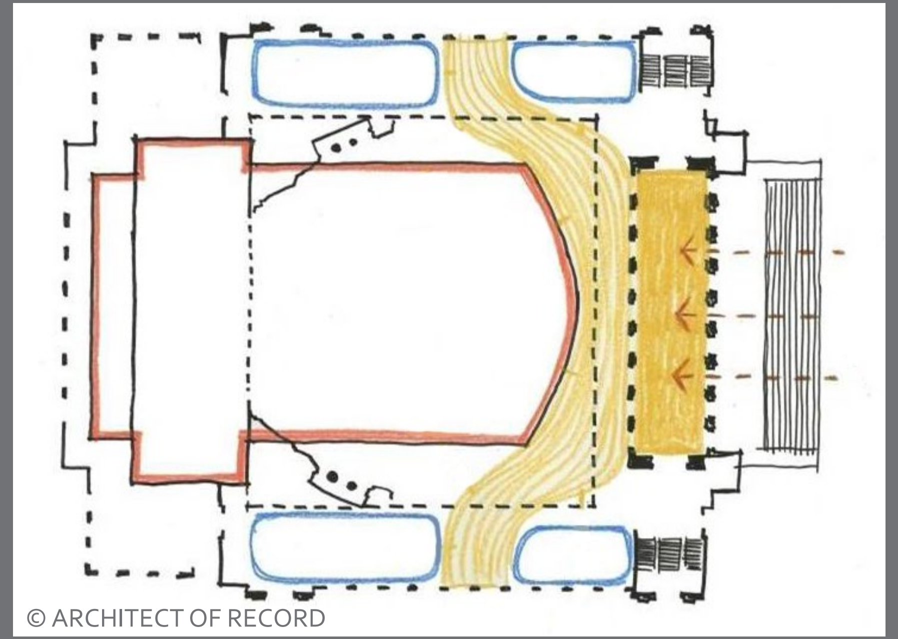

▲CURRENT THEATER GEOMETRY

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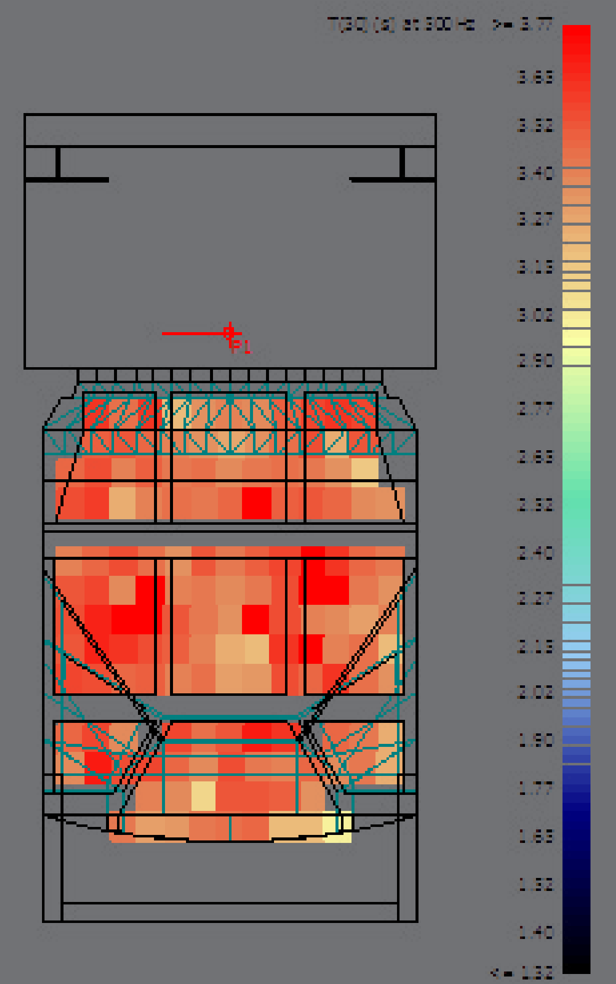
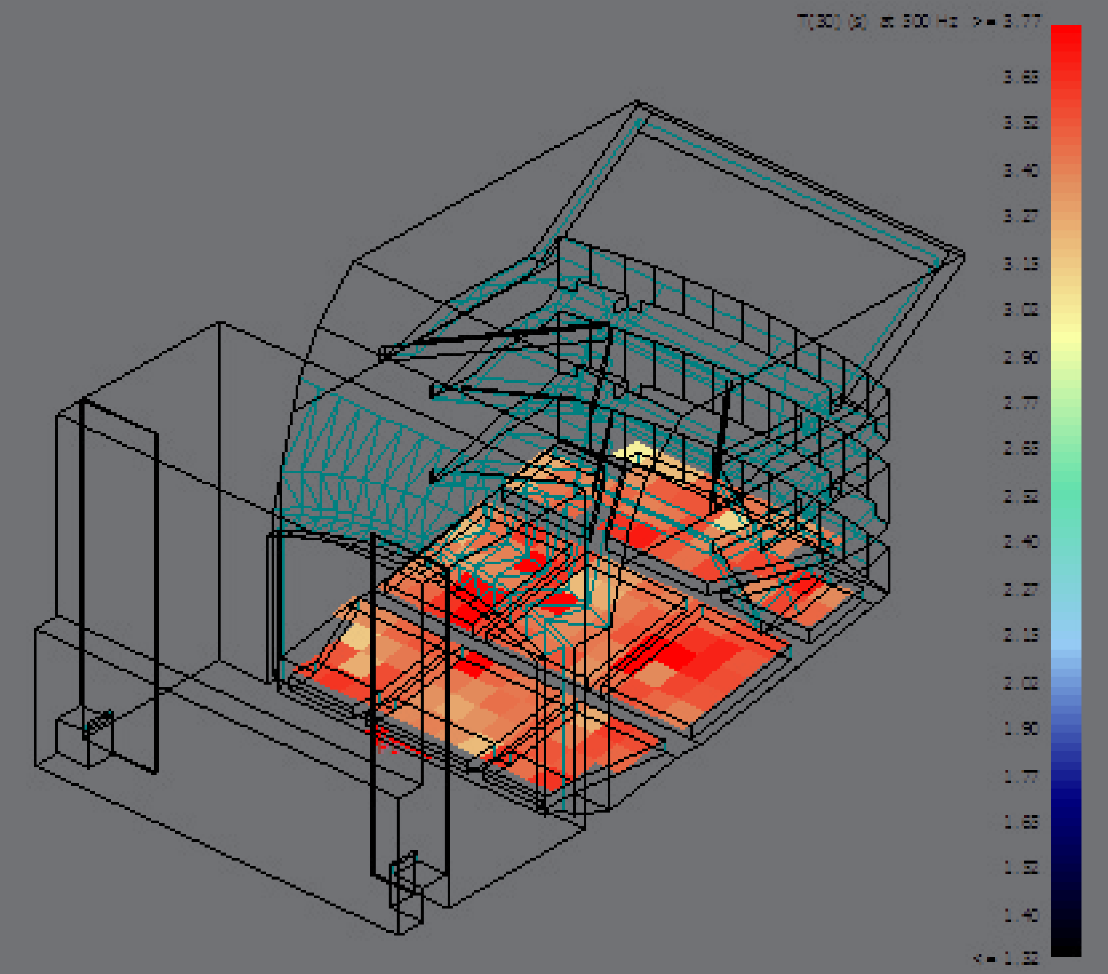
ODEON REVERBERATION TIME STUDY



▲ORCHESTRA LEVEL SEATING REVERBERATION TIME GRID RESPONSE



▲ORCHESTRA LEVEL SEATING REVERBERATION TIME GRID RESPONSE [ISOMETRIC]

DESIGN REQUIREMENTS
T(30) = 1.6 - 2.0 seconds

RESULTS

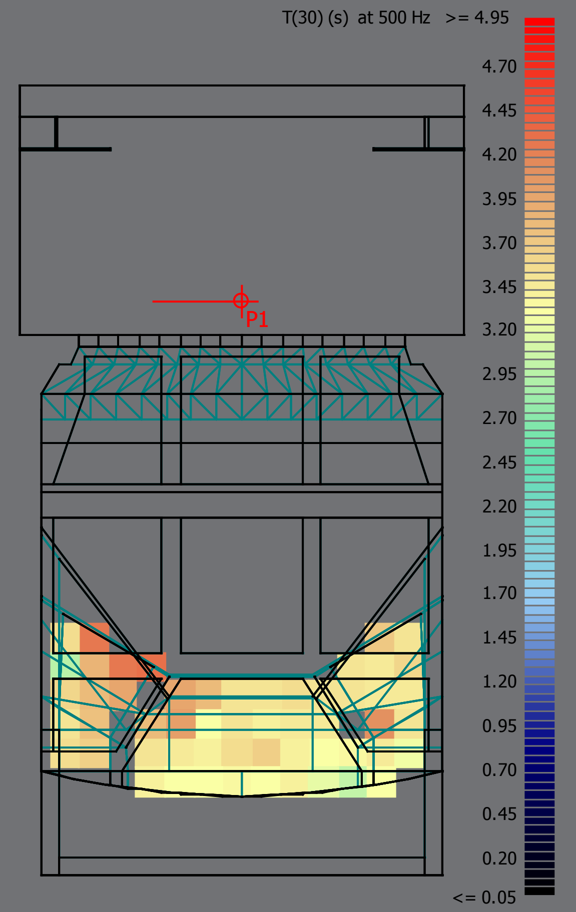
ORCHESTRA LEVEL
T(30) ~ 3.0 - 3.5 seconds

FIRST BALCONY
T(30) ~ 3.2 - 3.5 seconds

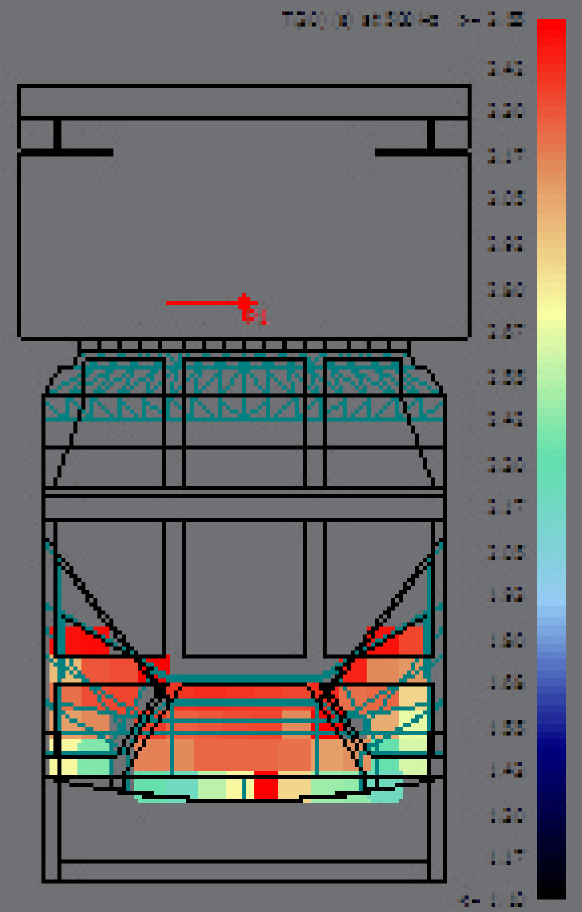
SECOND BALCONY
T(30) ~ 2.5 - 3.5 seconds

THIRD BALCONY
T(30) ~ 2.6 - 3.3 seconds

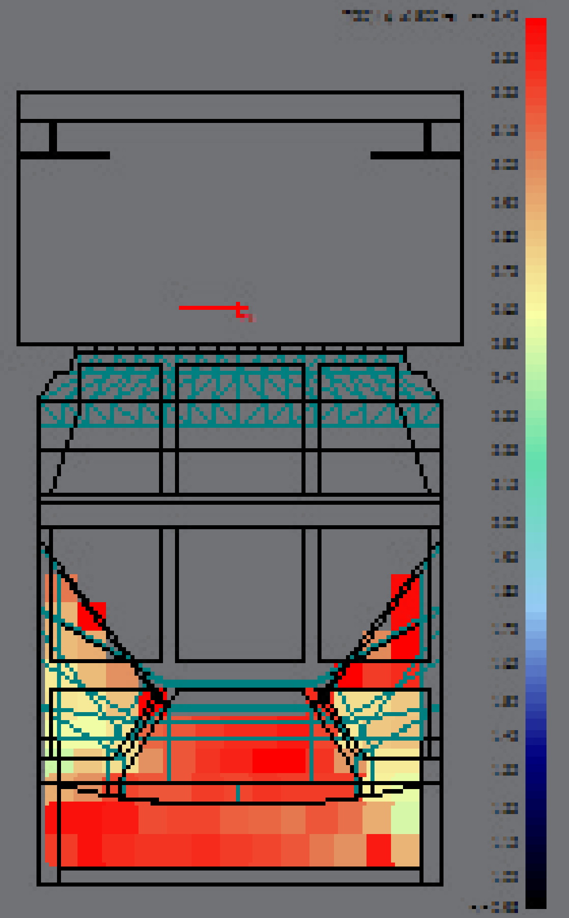
ODEON REVERBERATION TIME STUDY



▲FIRST BALCONY SEATING REVERBERATION TIME GRID RESPONSE



▲SECOND BALCONY SEATING REVERBERATION TIME GRID RESPONSE



▲THIRD BALCONY SEATING REVERBERATION TIME GRID RESPONSE

DESIGN REQUIREMENTS

T(30) = 1.6 - 2.0 seconds

RESULTS

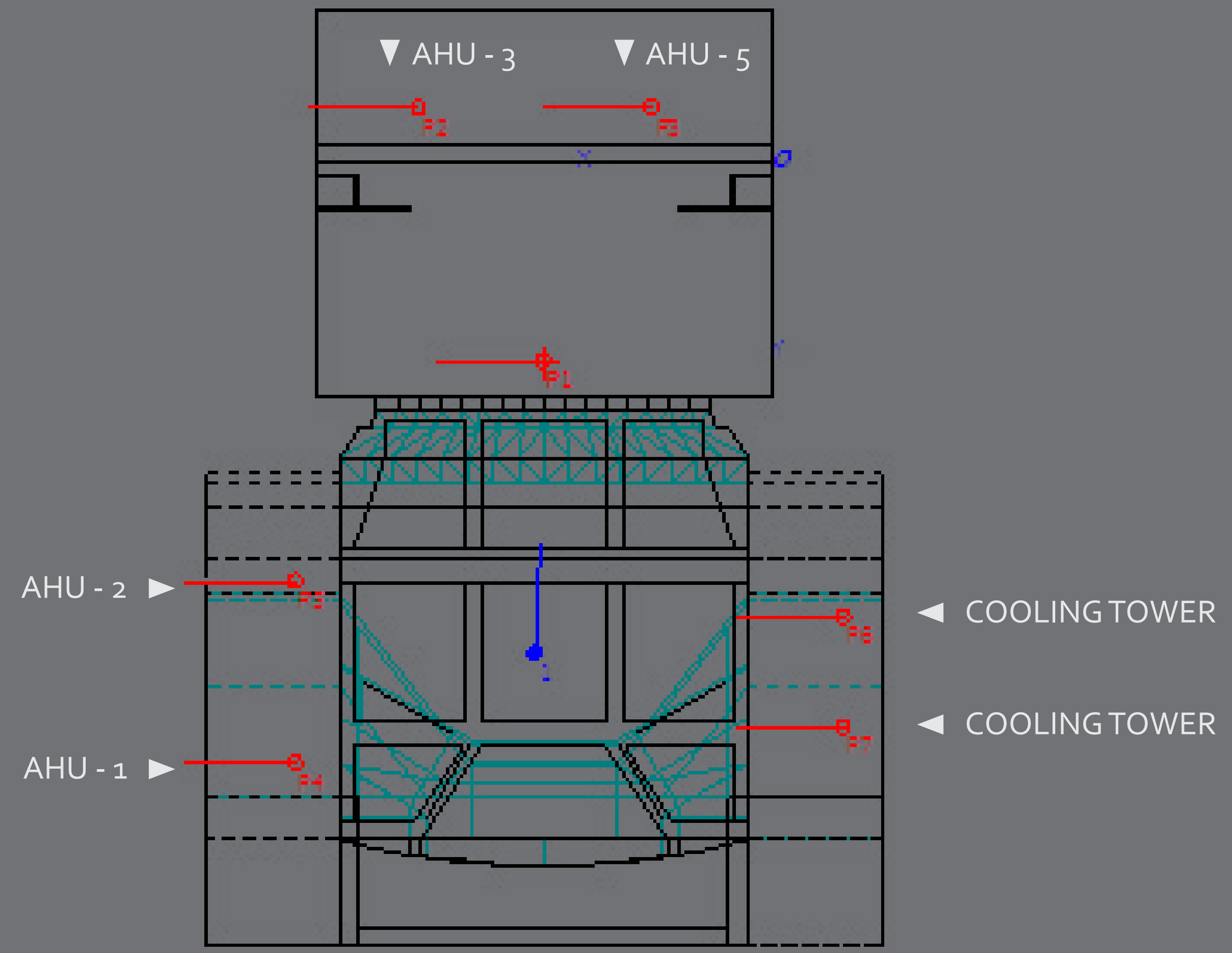
ORCHESTRA LEVEL
T(30) ~ 3.0 - 3.5 seconds

FIRST BALCONY
T(30) ~ 3.2 - 3.5 seconds

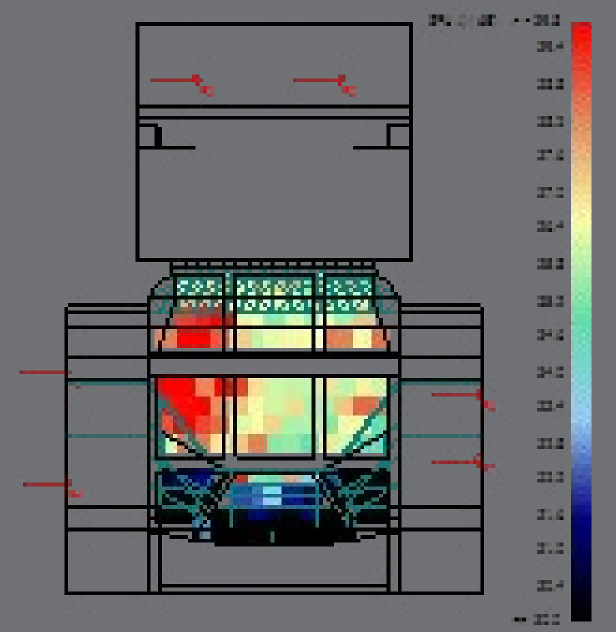
SECOND BALCONY
T(30) ~ 2.5 - 3.5 seconds

THIRD BALCONY
T(30) ~ 2.6 - 3.3 seconds

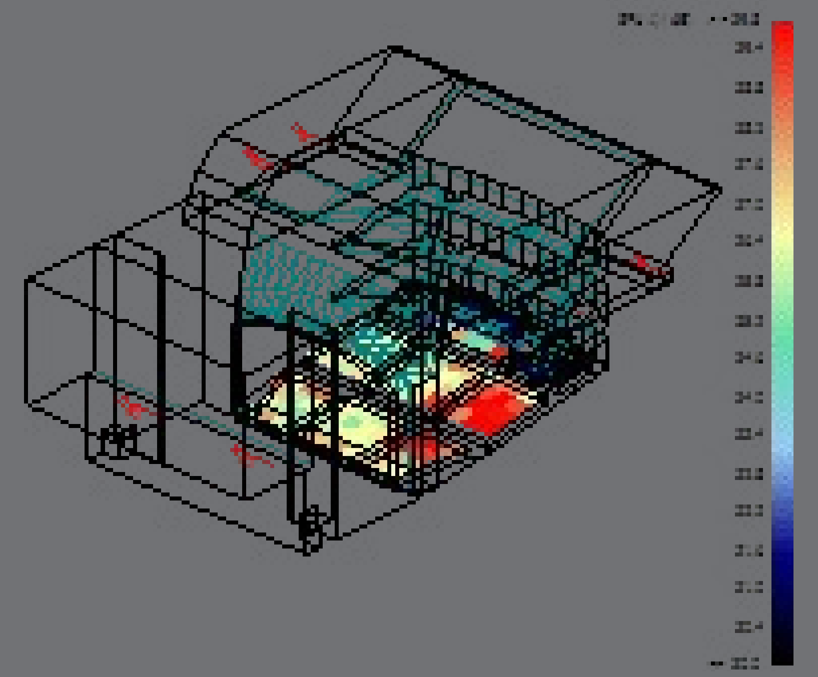
ROOFTOP HVAC EQUIPMENT IMPACT



ODEON BACKGROUND NOISE LEVEL STUDY



▲ORCHESTRA LEVEL SEATING SPL(A) GRID RESPONSE



▲ORCHESTRA LEVEL SEATING SPL(A) GRID RESPONSE [ISOMETRIC]

DESIGN REQUIREMENTS
SPL(A) = 25 - 30 dBA (NC - 20)

RESULTS

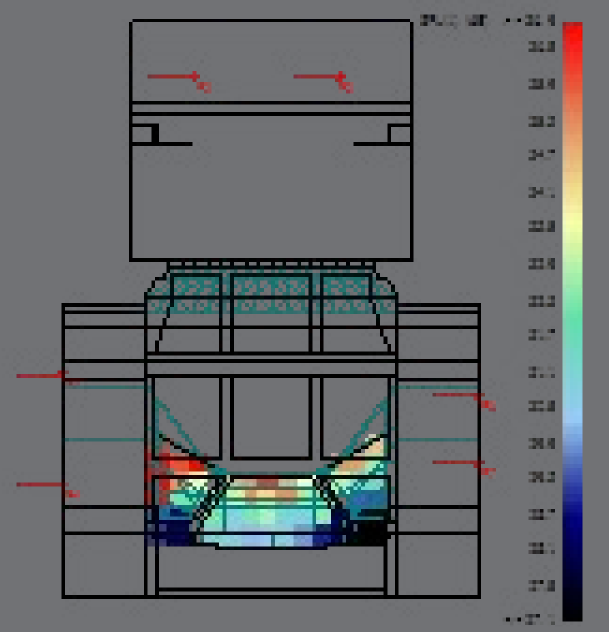
ORCHESTRA LEVEL
SPL(A) ~ 30 - 40 dBA (NC - 35)

FIRST BALCONY
SPL(A) ~ 27 - 37 dBA (NC - 32)

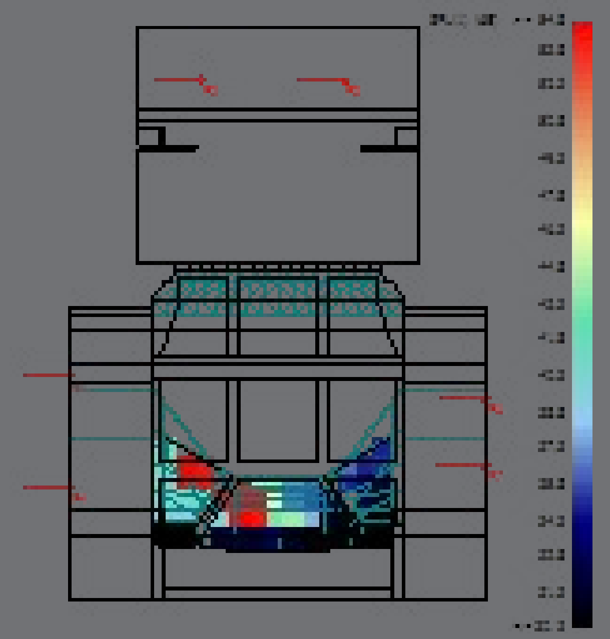
SECOND BALCONY
SPL(A) ~ 32 - 52 dBA (NC - 47)

THIRD BALCONY
SPL(A) ~ 42 - 58 dBA (NC - 53)

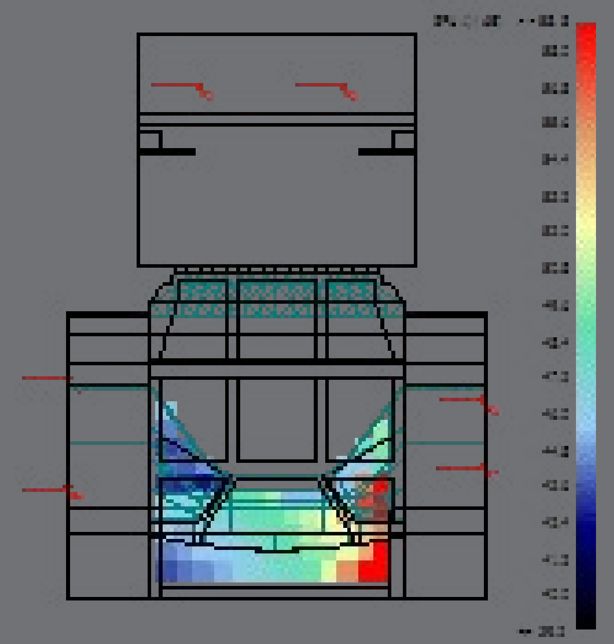
ODEON BACKGROUND NOISE LEVEL STUDY



▲FIRST BALCONY SEATING
SPL(A) GRID RESPONSE



▲SECOND BALCONY SEATING
SPL(A) GRID RESPONSE



▲THIRD BALCONY SEATING
SPL(A) GRID RESPONSE

DESIGN REQUIREMENTS

SPL(A) = 25 - 30 dBA (NC - 20)

RESULTS

ORCHESTRA LEVEL
SPL(A) ~ 30 - 40 dBA (NC - 35)

FIRST BALCONY
SPL(A) ~ 27 - 37 dBA (NC - 32)

SECOND BALCONY
SPL(A) ~ 32 - 52 dBA (NC - 47)

THIRD BALCONY
SPL(A) ~ 42 - 58 dBA (NC - 53)

RECOMMENDATION

CHILLED BEAM ANALYSIS

OPTION A

42 ACTIVE CHILLED BEAMS
$15,348 ANNUAL ENERGY SAVINGS
$121,606 ADDED FIRST COST
$97,596 TCO SAVINGS (20 YEARS)

OPTION B

98 ACTIVE CHILLED BEAMS
$18,805 ANNUAL ENERGY SAVINGS
$488,620 ADDED FIRST COST
- $214,529 TCO SAVINGS (20 YEARS)

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RECOMMENDATION

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DEMAND CONTROL VENTILATION ANALYSIS

45% ENERGY SAVINGS (OFFICE)
20% ENERGY SAVINGS (PERFORMANCE)

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RECOMMENDATION

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DEMAND CONTROL VENTILATION ANALYSIS

45% ENERGY SAVINGS (OFFICE)
20% ENERGY SAVINGS (PERFORMANCE)

ACOUSTIC ANALYSIS

~NC - 35 BACKGROUND NOISE LEVEL

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ACKNOWLEDGMENTS

Ed Clements	Project Manager - HGA
Jeff Harris	Mechanical Department Leader - HGA
Dr. Laura Miller	Senior Energy Program Engineer - Penn State OPP
Andrew Rhodes	Project Manager - Southland Industries
Dr. Steven Treado	Advisor/Associate Professor - Penn State AE Department
Dr. Michelle Vigeant	Advisor/Assistant Professor - Penn State Acoustics & AE Department

Penn State Architectural Engineering Department Faculty & Staff
A E Class of 2014
Family & Friends

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© ARCHITECT OF RECORD

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