Selected System Redesign and Analysis

The Pennsylvania State University

Architectural Engineering

Senior Thesis

Bucks County Justice Center

Doylestown, PA

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Lighting/Electrical

Thesis Adviser: Dr. Richard Mistrick

Electrical Adviser: Gary Golaszewski

4/8/2015

Analysis and models are located at Y:\Lange_Thesis\Report_Files

Bucks County Justice Center
Doylestown, PA

Image 1 — Exterior rendering of the front apex

Project Statistics

Occupancy: Assembly, Business, Institutional, Storage
Size: 273,000 GSF
Levels: 7 levels above grade (with penthouse)
2 levels below grade
Dates of construction: July 2011-Early 2015
Overall Project Cost: approximately $84 million

Project Team

Owner: County of Bucks
General Contractor: Ernest Bock & Sons, Inc.
Architect: HOK
Civil: Carroll Engineering Corporation
MEP: H. F. Lenz
Structural: Harman Group
Security and Code Consulting: Brinjac Engineers
Telecom, A-V, and Acoustics: Acentech Incorporated
Elevators: John Van Deusen
Lighting: Tigue Lighting
Fall Protection: Lerch Bates Incorporated

Image 2 — Exterior rendering of the south wing

Architecture

This building is in the shape of a 'V' with the main entrance located at the apex facing east. (see Image 1 to the left) and is occupied by courtrooms, offices, holding cells, secure parking, and other supporting spaces. Part of a historic building on the site will be incorporated into the new structure. (see the bottom left of Image 2 below) The exterior façade is curtain wall with precast concrete panels faced with brick and terracotta. Vision, translucent, spandrel, and fritted glass are utilized based on the orientation of the window and the use of the space.

Lighting and Electrical

A 3200A 480/277V unit substation, located in the penthouse, is supplied by a 2000kVA transformer with a 34.5kV primary. Four 480/277V vertical bus ducts distribute normal power from the penthouse to the dimmer panels, lighting and distribution transformers. 120/208V is used for receptacles and small equipment. A 1000KW/1250kVA diesel generator provides emergency power. Interior lighting is predominantly linear fluorescent fixtures with LED accent lighting. The courtroom lighting is controlled through central dimming panels located on each floor.

Mechanical

The chilled water and hot water plants are located in the penthouse. There are seven water based variable volume air units. Pressurization fans are provided for each stair tower. Dedicated heat pumps with a water/glycol loop are provided for telecom/data closets and server rooms. CO monitoring is provided for the garage with exhaust fan control.

Structural

The building is a steel framed structure supported by spread footings and strip footings. The columns, beams, and girders are primarily wide flange. A braced frame lateral system is utilized. The floor system is a concrete slab with welded wire reinforcing on metal deck with composite beam framing.

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Disclaimer

While great efforts have been taken to provide accurate and complete information in this report, please be aware that this report is strictly an academic exercise. Modifications and changes related to the original building designs and construction methodologies for this senior thesis project are solely the interpretation of Joshua Lange. Changes and discrepancies in no way imply that the original design contained errors or was flawed. Differing assumptions, code references, requirements, and methodologies have been incorporated into this thesis project; therefore, investigation results may vary from the original design.

Executive Summary

The following report presents several analyses of various systems of the Bucks County Justice Center (BCJC) which is a 273,000 SF courthouse located in eastern Pennsylvania. This report has five major sections: a lighting depth, an electrical depth, an acoustical breadth, an MAE acoustical breadth, and a mechanical breadth.

The lighting depth of this report details the lighting redesign for four unique spaces in the BCJC. The criteria for these designs included qualitative criteria as well as illuminance values and ratios from the IES Handbook and control and LPD requirements from ASHRAE. All of the spaces met the control requirements, all of the spaces have LPD's that are significantly below the maximum, and all of the spaces are within reasonable conformance with the illuminance value and ratio targets.

The electrical depth analyzed the effects of the lighting depth on the electrical distribution system, studied the fault current available at various locations throughout the building, and gives an analysis of the feasibility of a DC distribution system being used to increase electrical efficiency.

The acoustical breadth of this report gives an analysis of the RT of Ceremonial Courtroom 4100, establishes a target RT, and makes recommendations to bring the RT into closer conformity with the target.

The MAE acoustical breadth gives an analysis of the influence of the sound reinforcement system in Ceremonial Courtroom 4100 on speech intelligibility. This analysis looks at both SPL and STI to determine the effects of the system. The system greatly improves the SPL distribution as well as greatly increasing STI, but STI still only has a value that is on the low end of "good".

Finally, the mechanical breadth examines the practicality of a CHP system being used for this building. This analysis revealed that the building does not have a high enough consistent thermal load to make a CHP system feasible. Because of this the payback period is much longer than is acceptable to most investors.

Acknowledgements

I would like to thank Mr. Gerald Anderson for allowing me to use the Bucks County Justice Center as my thesis building.

I would like to thank Mr. Scott Mack and the team at H.F. Lenz for their help in selecting the BCJC as my thesis building, providing me with project documentation, and for providing consultation at various times throughout this project.

I would like to thank the following for their guidance on this project:

Dr. Richard Mistrick

Mr. Gary Golaszewski

Dr. Michelle Vigeant

Dr. James Freihaut

Thank you all for your assistance in making this report a reality!

Introduction

General Information
Project Name: Bucks County Justice Center
Location: Doylestown, PA
Owner: Bucks County
Occupancy: Assembly, Business, Institutional, Storage
Size: 272,856 SF Gross Square Footage IBC 2006
Levels: 7 stories above grade (including the penthouse)
2 stories below grade

Project Team
Owner/tenant: County of Bucks
General Contractor: Ernest Bock & Sons, Inc.
CM: N/A
Architect: HOK
Civil: Carroll Engineering Corporation
MEP: H. F. Lenz
Structural: The Harman Group
Security and Code Consulting: Brinjac Engineers
Telecommunications, Data, Audio Visual, and Acoustic: Acentech Incorporated
Elevators: John Van Deusen
Lighting: Tigue Lighting
Fall Protection: Lerch Bates Incorporated

Construction Information
Construction Start: Ground Breaking July 2011
Grand Opening: January 10, 2015
Cost: $84 million total project cost
Project Delivery: Design-Bid-Build

Architecture
This project is the location for the county courthouse including courtrooms, offices, holding cells, and other supporting spaces. Part of an existing historic building on the site was incorporated into the new structure (please see the historical requirements section below). The building is in the shape of a 'V' with the main entrance located at the apex. The building is across the street from the existing courthouse with the main entrance facing the existing building. Two sides of the building border streets with the remaining sides being adjacent to parking. See Figure 1 and Figure 2 below.

Figure 1 - Site Plan

Figure 2 - Exterior Render of the Main Entrance

Codes:
International Building Code 2006
ICC Electrical Code 2006
International Energy Conservation Code 2006
International Fire Code 2006
International Fuel Gas Code 2006
International Mechanical Code 2006
International Plumbing Code 2006
ADA Accessibility Guidelines for Buildings and Facilities
ANSI/ASME A17.1 Safety Code for elevators and Escalators, as adopted by the Commonwealth of Pennsylvania's, Department of Labor and industry, Division of Elevators

Zoning
Doylestown Borough O District zoning (O District is designated for Office use)

Historical
A portion of an armory that was built on the site in 1909 was incorporated into the building. The portion is located along Shewell Avenue and consists of two exterior walls and an interior fireplace. Figure 3 below details the portion of the existing building that was incorporated into the new building.

Figure 3 - Existing Structure to Remain

Building Enclosure

Exterior Wall Materials

For the first two above grade exterior walls, the primary finish material is brick (with a running bond) clad precast concrete panels with decorative profiled precast concrete below the windows and acid etched precast concrete panels for the window sills. See Figure 4 below. The rest of the above grade exterior walls use terracotta clad precast panels as the primary finish material and continue the typical use of decorative profiled precast concrete below the windows. On some of the walls with smaller windows a single course of soldier bricks on precast concrete is added at each floor.

Figure 4 – Exterior Render

Windows

The windows are a curtainwall system with several types of exterior glazing in order to achieve a uniform exterior façade while not impeding on the interior uses of the building. The glazing types include vision glass, translucent glass, spandrel glass, and fritted glass. All of the glazing types have a low-E coating on one of the surfaces.

Roofing

The main roofing type for this project is an inverted roof membrane assembly (IRMA) with a stone ballast and four inches of rigid insulation as shown in Figure 5 on the next page.

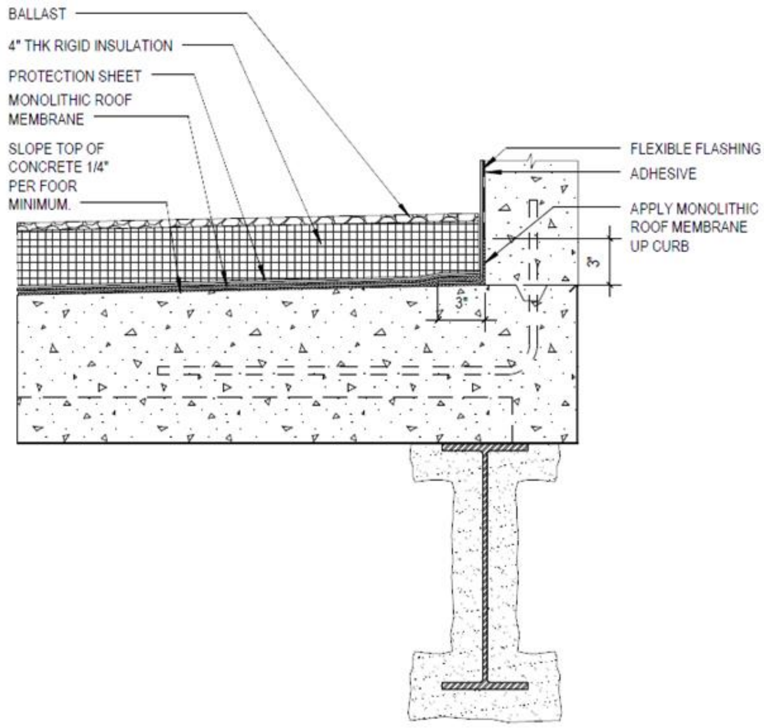


Figure 5 – Roof Detail

Sustainability

The project did not pursue LEED certification. However, the design still incorporates various features to increase efficiency. The design includes networked automated control of the mechanical systems and selected lighting systems in order to maximize efficiency. In order to minimize solar gains while still allowing for daylighting glazing with a low E coating, low SHGC and a fairly high VLT were used. Additionally, high efficiency plumbing fixtures were used throughout the building. Including dual flush water closets, ultra-low flow (1 pint per flush) urinals, 0.5 GPM sinks with aerators, and 2.0 GPM showerheads.

Primary Engineering Systems

Construction Management

The delivery method for the project was design-bid-build. The primary designer and general contractor are HOK and Ernest Bock & Sons, Inc. respectively. The project has a cost of approximately $84 million and a construction duration of about 3.5 years. Access to the site is somewhat constrained by surrounding buildings, but there is substantial frontage for access to the site. The main site entrance was from Union Street with alternate entrances from North Main Street and North Broad Street. After the existing parking garage was demolished in the early stages of construction there was a large amount of future parking lot that provided space for construction staging. The integration of the wall from the existing building was a significant logistical challenge.

Electrical/Lighting

The main electrical system utilizes a 3200 A unit substation that is fed by a 2000 KVA building transformer with a 34.5 KV primary and a 277/480 secondary. Four 800 A 277/480 V vertical busses distribute normal power throughout the building. In general, each floor has two electrical rooms with a 277/480 V and a 120/208 V panel. The 277/480 V panel feeds the 120/208 V panel through a transformer.

A 1000 KW generator provides the emergency and backup power. There are four sets of loads on the generator; fire pump, life safety, emergency, and critical. The fire pump, life safety, and emergency are all code required loads. The critical loads are optional backup loads. The generator directly feeds the ATS for the fire pump and the remaining ATS's are fed from a 1600 A 480/277 V distribution switchboard. All of the optional backup loads except for the heat pumps are fed from a 160 KVA/144 KW UPS.

Interior lighting is predominantly linear fluorescent luminaires with LED accent lighting. Recessed indirect linear florescent luminaires are used for the private offices, conference rooms, and corridors. Direct/indirect linear florescent pendants are used in the open office areas. Various luminaires including CFL downlights and linear florescent wall washers and strip lights are utilized in the courtrooms. For lighting control, there are various types of low voltage push button stations, occupancy sensors, and daylight sensors that are networked with control units. For the courtrooms there are central dimming panels located on every other floor. For the conference rooms, offices, and other spaces control packs with four zones are utilized. All of the lighting controls are tied into the central lighting management system.

Mechanical

There are nine water based AHU's for the building. Seven are located in the penthouse and two are located on level B2. Two of the AHU's are fixed volume dedicated outdoor air units and the rest are variable volume. The AHU's range in size from 5,500 CFM to 40,000 CFM. Five of the AHU's include energy recovery wheels. Chilled water is supplied by two 330 ton air cooled chillers that interface with two 615 GPM cooling towers. Hot water is supplied by five gas boilers each with a 2000 MBH input.

18 water source heat pumps intended for 24/7 cooling are provided for the telecom/data closets, server rooms, and some mechanical rooms. These units are served by a dedicated water/glycol loop.

A CO monitoring system with exhaust fan control is provided for the parking area on level B2. Makeup air is provided by a 16,000 CFM makeup air unit with hot water heating.

Pressurization fans are provided for each stair tower and the elevators. The fans are all around 19,000 CFM.

Variable volume boxes are utilized for the various heating and cooling zones

Structural

The building is a steel framed structure supported by spread footings and strip footings. The spread footings range in size from 4'-0" x 4'-0" x 2'-0" to 9'-0" x 9'-0" x 3'-6" with the most common size for interior supports being 7'-6" x 7'-6" x 3'-1" and the most common size for exterior supports being 4'-0" x 4'-0" x 2'-0". The strip footings are typically 3'-0" deep.

The vast majority of the columns are wide flange, but there are also some hollow structural section columns and standard steel pipe columns. The wide flange steel columns range in size from W14x43 to W14x455. The hollow structural section columns range in size from HSS8.625x0.375 to HSS14x0.625. The standard steel pipe columns are PIPE8"STD.

The floor framing is wide flange beams and wide flange girders. A typical floor bay utilizes 40'-0" W18x40 beams with 24 shear studs and a 1 ½" camber and 30'-0" W21x62 girders with 38 shear studs. However, there are numerous non typical bays that utilize a wide range of beam sizes.

The floor system is 3" composite deck with composite beam framing. The typical floor thickness is 6 ¼" and utilizes welded wire reinforcing. A 7 ½" slab is used to support the equipment in the penthouse. A 5" thick slab on grade is used for B2.

Lateral loads are resisted by braced frames and moment frames. There are eight braced frames distributed throughout the building. Wide flange beams are used in both diagonal and chevron bracing. The bases of the braced frames are anchored by either 74" or 78" deep mat foundations.

Additional Engineering and Engineering Support Services

Fire Protection

The fire protection system includes a fire command center, full building sprinklering, motor operated dampers, pressurized stair towers, and a fire pump. Stand pipes are provided in every stairwell. An automatic wet sprinkler system is used everywhere accept the parking garage and sally port which use a dry system.

Transportation

Vertical circulation is handled by four stair cases and nine elevators. The elevators are dedicated for the following uses: four for general purpose circulation are located in the main elevator lobby, three for prisoner transport are distributed throughout the building, one is dedicated for the judges to use, and one is for service.

Telecommunications

There is sufficient telecommunications equipment to meet the VOIP and data needs of the various offices throughout the building. There are telecommunications rooms centrally located on each floor which are used as hubs for each floor. The backbone cabling is typically 25 strand CAT 3 cable, 12 strand single mode fiber cable and 6 strand multimode fiber cable.

Audio/Visual

All of the courtrooms have an A/V system that includes cameras, microphones, speakers, amplifiers, input stations, touch panel control stations, an assistive listening system, and a projector.

Security

Access control

Both exterior and interior doors utilize electronic locks and card swipes to limit access to secure areas. In general, each door has a 120 V circuit supplied to the control pack which feeds the equipment 24 V, but for doors in close proximity a central power pack is used.

Surveillance

A thorough surveillance system is utilized throughout the building. There are glass break sensors for the windows that are accessible from the outside, door contacts on doors for sensitive areas, and video cameras for the majority of the building. The surveillance devices are fed to security servers located in the telecom rooms. There are various displays and controls for the security system located in the control rooms on level B2. For the internal and external building mounted surveillance cameras CAT 6 UTP cable is used for video and CL3 cable is used to provide low voltage power. Fiber optic cable is used for exterior surveillance cameras that are mounted away from the building.

1. Part 1 – Lighting Depth
1.1 Introduction

The lighting of four unique spaces in the BCJC was redesigned. The designs were based on the criteria that were developed in Tech Report 2. These criteria include qualitative functional aspects such as way finding and security and quantitative aspects such as illuminance levels from the IES Handbook and power density requirements from ASHRAE 90.1 2013. The completed designs are documented with lighting plans, lighting schedules, illuminance calculations, and rendered images. The four spaces are as follows:

Outdoor Space: Main Plaza
Circulation Space: Main Lobby 1000
Large Workspace: Open Office 2520
Special Purpose Space: Ceremonial Courtroom 4100

Figure 6 through Figure 9 on the following pages show the locations of the spaces.

Figure 6 – Main Plaza Location

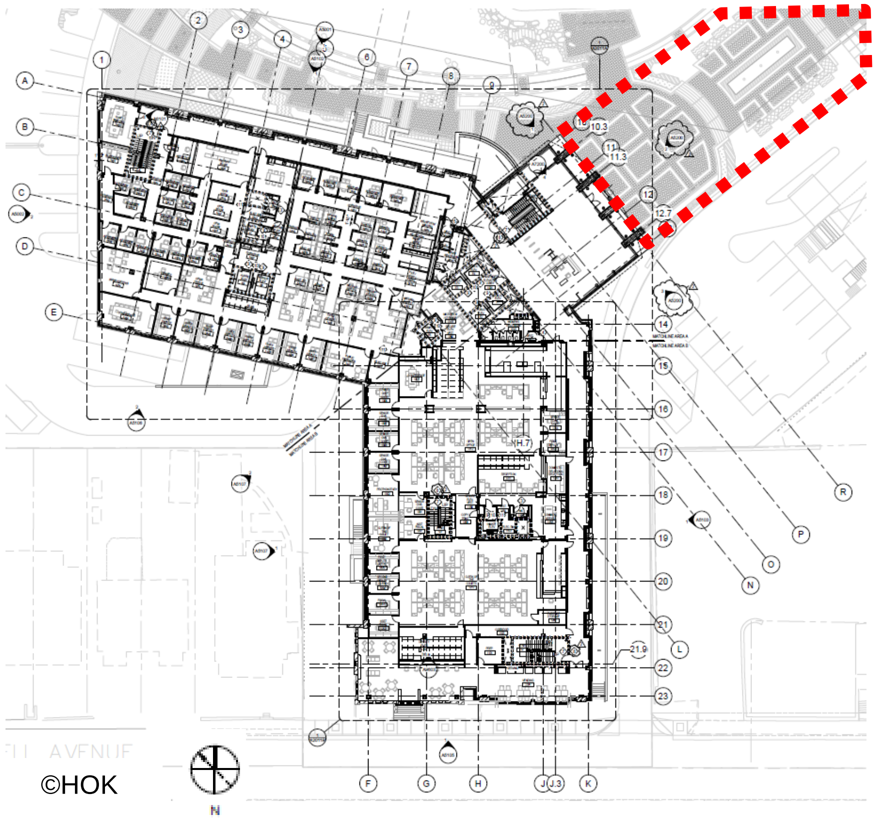


Figure 7 – Main Lobby 1000 Location

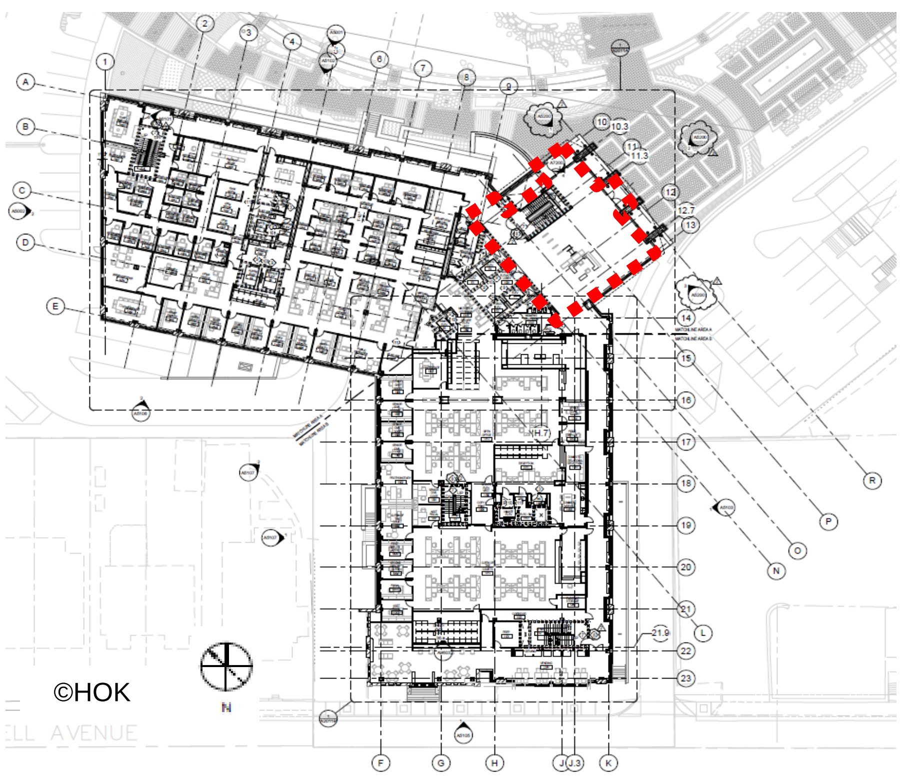


Figure 8 – Open Office 2520 Location

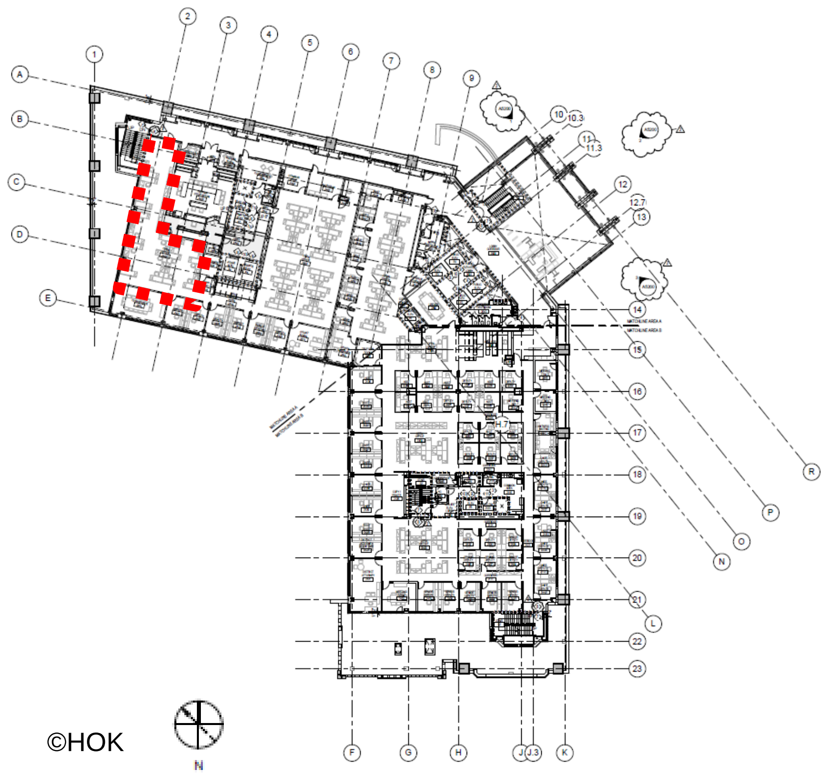
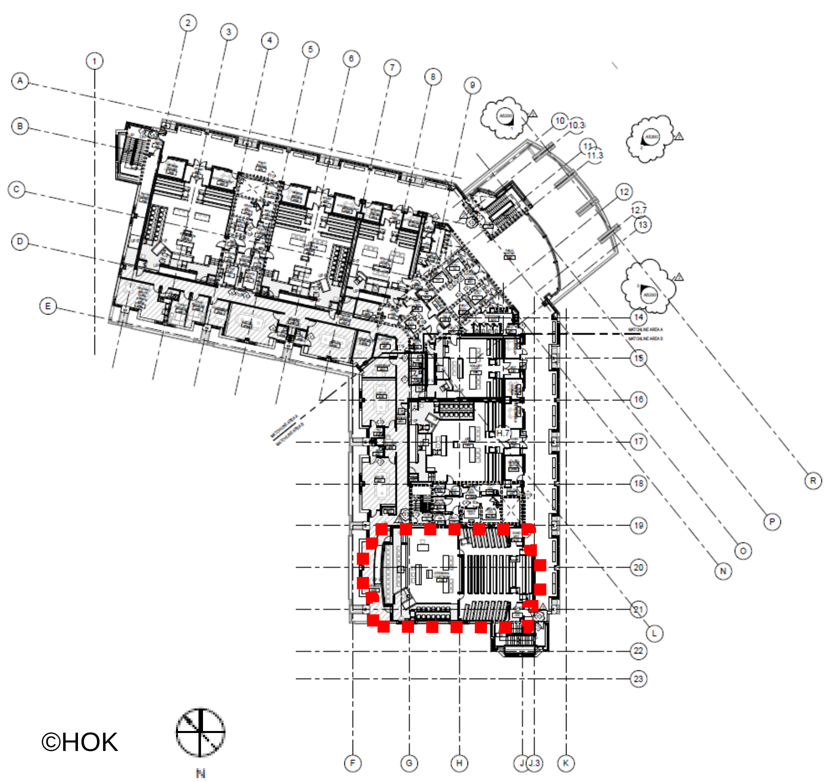


Figure 9 – Ceremonial Courtroom 4100 Location



In addition to the individual criteria that are used for each space the following are criteria for all of the spaces.

CCT of 3500K: A CCT of 3500K was chosen to help with daylight mixing because of the significant amount of daylight that will penetrate many of the spaces. This CCT was used in all of the spaces to help bring uniformity to the building.

20% reduction from ASHRAE LPD requirements: In order to create an efficient design a target reduction was set.

All luminaires have LED light sources. A light loss factor of 0.70 was used for all maintained illuminance calculations. All of the LED's have a minimum L_{70} of 50,000 hours and some have an L_{80} of 50,000 hours. This means that with an average luminaire use of 10 hours per day 5 days a week the 0.7 LLD would not occur for over 19 years. Even with a LLF of 0.7 the illuminance will most likely be significantly higher than the target for at least 10 years. However, for the completeness of this report full LLF calculations for each luminaire type are given in Appendix A-1 – Light Loss Factor Calculations.

All illuminance calculations were performed in AGI32 with a 2'-0" X 2'-0" grid unless noted otherwise.

1.2 Main Plaza

1.2.1 Introduction

The main plaza located outside of Main Lobby 1000 connects the main entrance of the BCJC with the administration building that is located across the street. The majority of this space is hardscape.

1.2.2 Criteria

Way finding: This space leads up to the main entrance of the building and therefore providing a clear path to the entrance is important.

Safety: Ample light must be provided to discourage criminal activity and provide a sense of safety.

Both the illuminance level and illuminance ratio targets shown in Table 1 below are based on recommendations in the IES Handbook.

Table 1 – Main Plaza Illuminance Recommendations

Eh (lux)	Elevation Eh	Ev (lux)	Elevation Ev	Max:Avg	Avg:Min
4	0'-0"	2	5'-0"	4:1	5:1

Control and LPD requirements are based on ASHRAE 90.1 2013 and are as follows:

- The allowed lighting power for Main Plaza (including the plaza area and ADA ramp) was calculated to be **976 watts**. See Table 2 below for calculation.

Table 2 – Allowed Watts Calculation for Plaza and Ramp

Plaza Areas		
Allowance (W/SF)	**Area (SF)**	**Total (W)**
0.14	6171	864

Walkway <10 FT wide		
Allowance (W/lin FT)	**Length (FT)**	**Total (W)**
0.7	160	112

- Photosensor control

- Façade and landscape lighting shutoff between midnight or business closing (whichever is later) and 6 a.m. or business opening (whichever comes first)

- Non façade and landscape lighting shall have automatic control to reduce power by 30% for either the period from midnight or within 1 hour of closing (whichever comes later) and 6 a.m. or opening (whichever comes first) or during any period when no activity has been detected for a time no longer than 15 minutes

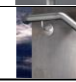
In order to limit light trespass and sky glow the requirements given in the Model Lighting Ordinance (MLO) will be considered. Lighting Zone 2 was selected for this project. The MLO requirements include a total site lumen limit of 22,428, a maximum of 15% of the site lumens making it to the property line, and a maximum single point illuminance at the property line of 3.0 Lux. See Table 3 below for the site lumen calculation.

Table 3 – MLO Site Lumen Calculation

Site area (SF):	6171	
Allowed Lumens Per SF	2.5	15428
Allowed Base Lumens		7000
Total Allowed Lumens:		**22428**

1.2.3 Design

Table 4 – Main Plaza Luminaire Schedule

Type	Description	Manufacturer	Model	Lamp	CCT (K)	CRI	Life (Hours)	Ballast	Input (Watts)	Voltage	Fixture Image
X1	EXTERIOR POLE MOUNTED TYPE 3 DOWN LIGHT TWELVE FOOT POLE, 1635 LUMEN	COOPER LIGHTING	MSA-C01-LED-E1-T3-GM	INTEGRAL	4000	70	60,000+ >90%	INTEGRAL	27	277	
X2	EXTERIOR IN RAIL LIGHT THREE FOOT, 83 LMS/FT	COOPER LIGHTING	0.06.SSS.1.PMC.NR.ASYM.35K.GB3.4	INTEGRAL	3500	80	50,000 L70	INTEGRAL	4.14	277	

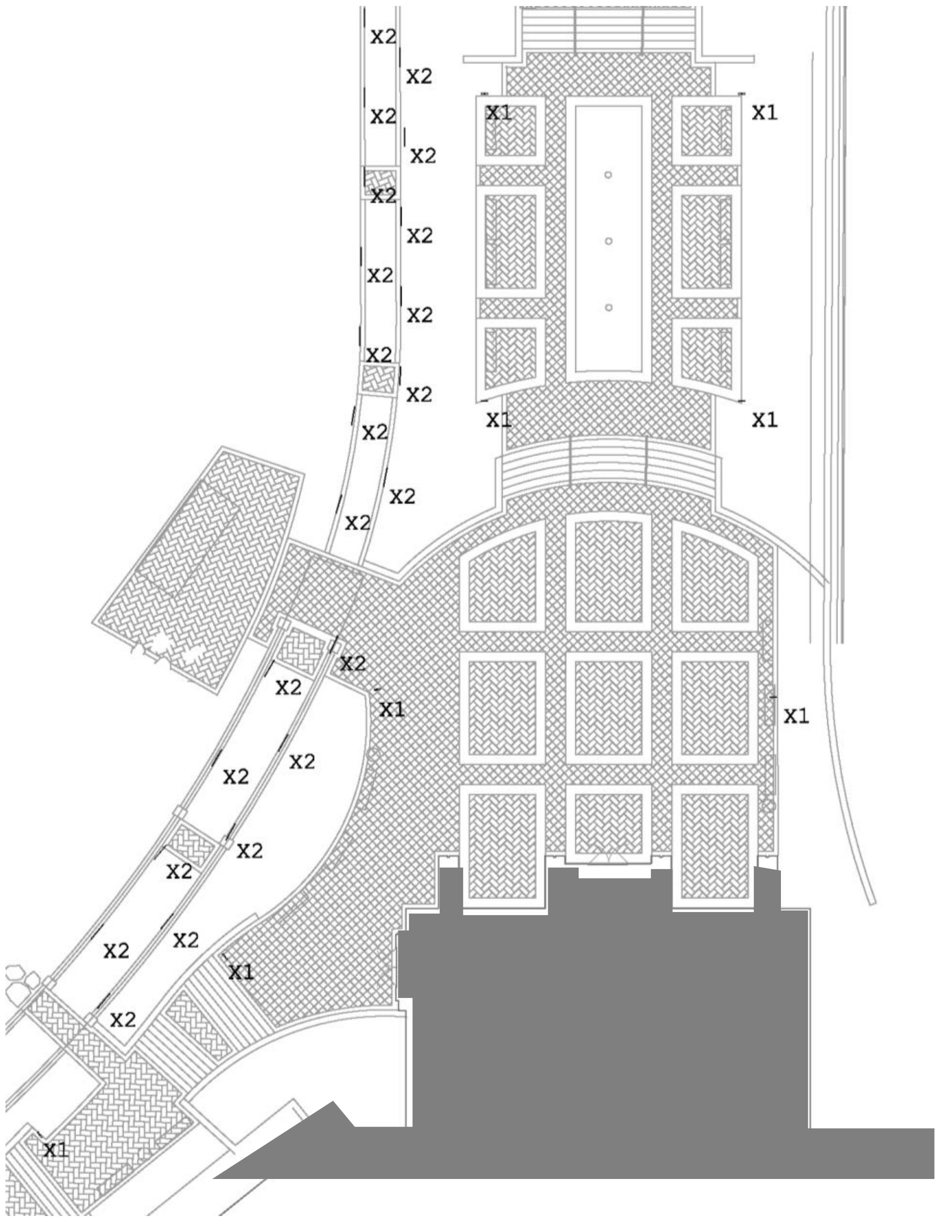


Figure 10 – Main Plaza Lighting Plan

Luminaire X1 is mounted 12 feet above the ground. Luminaire X2 is a 3'-0" long section that is incorporated into the handrail spaced 9'-0" O.C. with the luminaires in the opposite handrail offset as to be in the center of the space that does not have a luminaire.

Table 5 – Main Plaza Target Vs Design Illuminance

Location		Eh (lux)	Height Eh	Max:Avg	Avg:Min
Outdoor Plaza and Ramp	Target	4	0'-0"	4:1	5:1
	Ramp	12	0'-0"	5.5:1	12.4:1
	Plaza	7	0'-0"	2.1:1	7.3:1

The design average illuminance and illuminance ratios are not very close to the target values, but the design provides ample illuminance for the tasks that must be performed. The majority of the plaza area is very uniform; it is just some outlying points that are causing the average to minimum ratio to be so high.

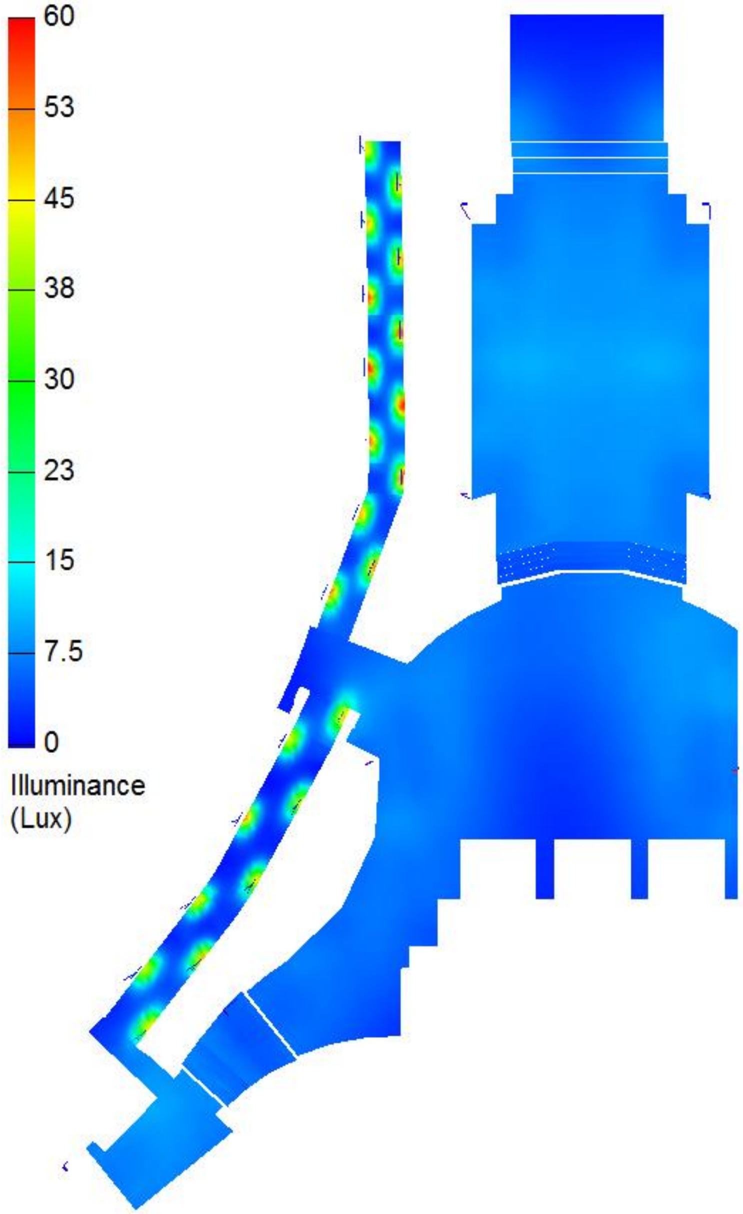


Figure 11 – Main Plaza Pseudo Color

ASHRAE control requirements were addressed as follows:

- A photosensor is used to turn off the site lighting when daylight is present
- There is no façade of landscape lighting present in the design
- A portion of the exterior site lighting accounting for more than 30% of the power is programmed to turn off between midnight and 6 a.m.

The LPD for the site is 68% below the max allowed by ASHRAE. See Appendix A-2 – Lighting Power Density Calculations for the calculations.

MLO Considerations

The total installed lumens is 32% below the max allowed lumens. See Table 6 below for the total site lumen calculation. The total lumens hitting the bounding box is below 12% of the site lumens. The design exceeds the max allowed single point illuminance at a point on the property line. This occurs because the task plane goes right up to the property line so it is impossible to light the task plane and not the property line.

Table 6 – Installed Site Lumens

Luminaire	Lumens per fixture	Quantity	Total Lumens
Pole Light (C1 T3)	1635	8	13080
Rail Light	98	22	2156
		Total Installed Lumens:	**15236**

1.3 Main Lobby 1000

1.3.1 Introduction

Main Lobby 1000 is approximately 3000 SF and is located on the east side of the building at the intersection of the two wings. It is double height with a second floor balcony overlooking it. The east façade is primarily glass which provides extensive daylight exposure. below shows the layout ad dimensions of Main Lobby 1000

Figure 12 – Main Lobby 1000 Layout and Dimensions

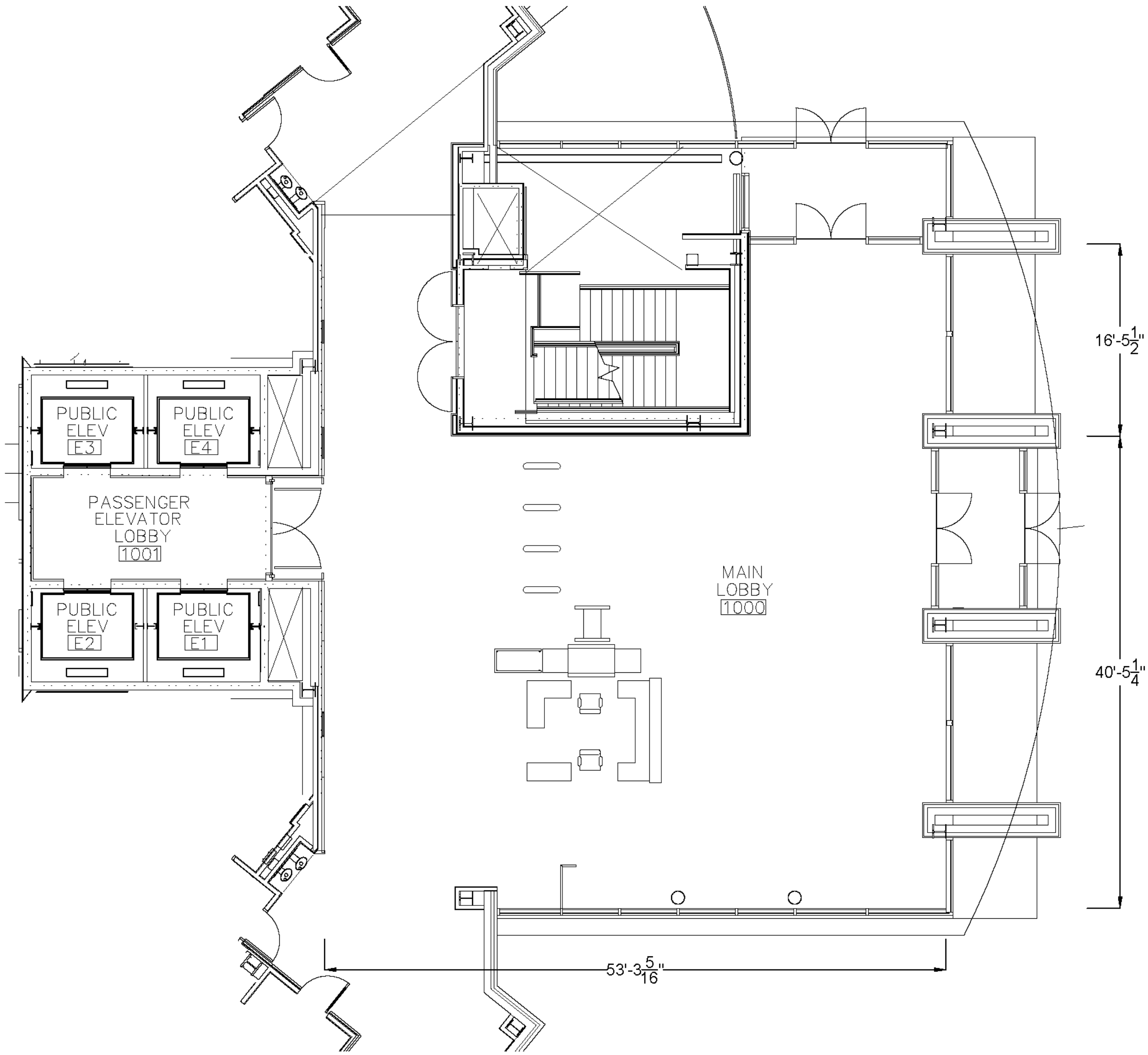


Table 7 and Table 8 below give the finish materials for Main Lobby 1000

Table 7 – Main Lobby 1000 Finish Schedule

Surface	Description	Color	Reflectance
Ceiling	Acoustical Metal ceiling 24” x 24”	-	>0.60
	Acoustical Metal ceiling 6” wide	-	>0.60
Floor	Handset Granite	Mountain Green	0.22*
Wall	Paint	White	0.85
	Terracotta Wall Tile	-	-

*denotes reflectances that were calculated by AGI32 based on the manufacturers image

Table 8 – Main Lobby 1000 Glazing Types

Surface	Description	ρ_{EXT}	ρ_{INT}	ρ_{SOL}	VLT
Windows	Vision glass	0.12	0.12	0.24	.78

1.3.2 Design Criteria

Spaciousness: This space is the main entrance of the building and should be designed in such a way as to instill a sense of awe and grandeur

Safety: This space houses the main security screening for the building and therefore the lighting must be designed to not hinder the screening process

Both the illuminance level and ratio targets given in Table 9 below are based on the recommendations in the IES Handbook.

Table 9 – Main Lobby 1000 Illuminance Recommendations

Location	Eh (lux)	Elevation Eh	Ev (lux)	Elevation Ev	Avg:Min
Security Screening	200	3'-0"	200	5'-0"	2:1
Lobbies near entries (day)	100	Floor	30	5'-0"	4:1

The control and LPD requirements given in are based on ASHRAE 90.1 2013

Table 10 – Main Lobby 1000 LPD and Control Requirements

LPD (W/SF)	Local Control	Automatic Daylight Responsive Controls for Sidelighting	Automatic Full OFF	Scheduled Shutoff
0.9	REQ	REQ	ADD2	ADD2

Note: "ADD2" designates a requirement that has an option. i.e. one of the "ADD2" options must be selected.

1.3.3 Final Design

Table 11 – Main Lobby 1000 Luminaire Schedule

Type	Description	Manufacturer	Model	Lamp	CCT (K)	CRI	Life (Hours)	Ballast	Input (Watts)	Voltage	Fixture Image
R3	RECESSED CIRCULAR 6 INCH WIDE BEAM DOWNLIGHT 1500 LUMEN	COOPER LIGHTING	LD6A15DL3 ERW6A15835 6LW1LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	22.4	277	
R4	RECESSED CIRCULAR 6 INCH WIDE BEAM WALL WASH 1000 LUMEN	COOPER LIGHTING	LD6A10DL3 ERM6A10835 6LM111LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	14.1	277	
R7	RECESSED CIRCULAR 8 INCH MEDIUM BEAM DOWNLIGHT 5000 LUMEN	COOPER LIGHTING	LD8A502DL3 ER8A50835 8LMOLI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	62	277	
R8	RECESSED CIRCULAR 8 INCH MEDIUM BEAM DOWNLIGHT 3000 LUMEN	COOPER LIGHTING	LD8A302DL3 ER8A30835 8LW110LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	42	277	
R9	RECESSED CIRCULAR 8 INCH WIDE BEAM DOWNLIGHT 3000 LUMEN	COOPER LIGHTING	LD8A302DL3 ER8A30835 8LW0LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	42	277	
W1	WALL MOUNTED LINEAR UPLIGHT TWO FOOT, 2000 LUMENS	COOPER LIGHTING	A02-SI-A-2-LED-35K-277-S-AK12-D	INTEGRAL	3500	80	50,000 L70	INTEGRAL	22.6	277	

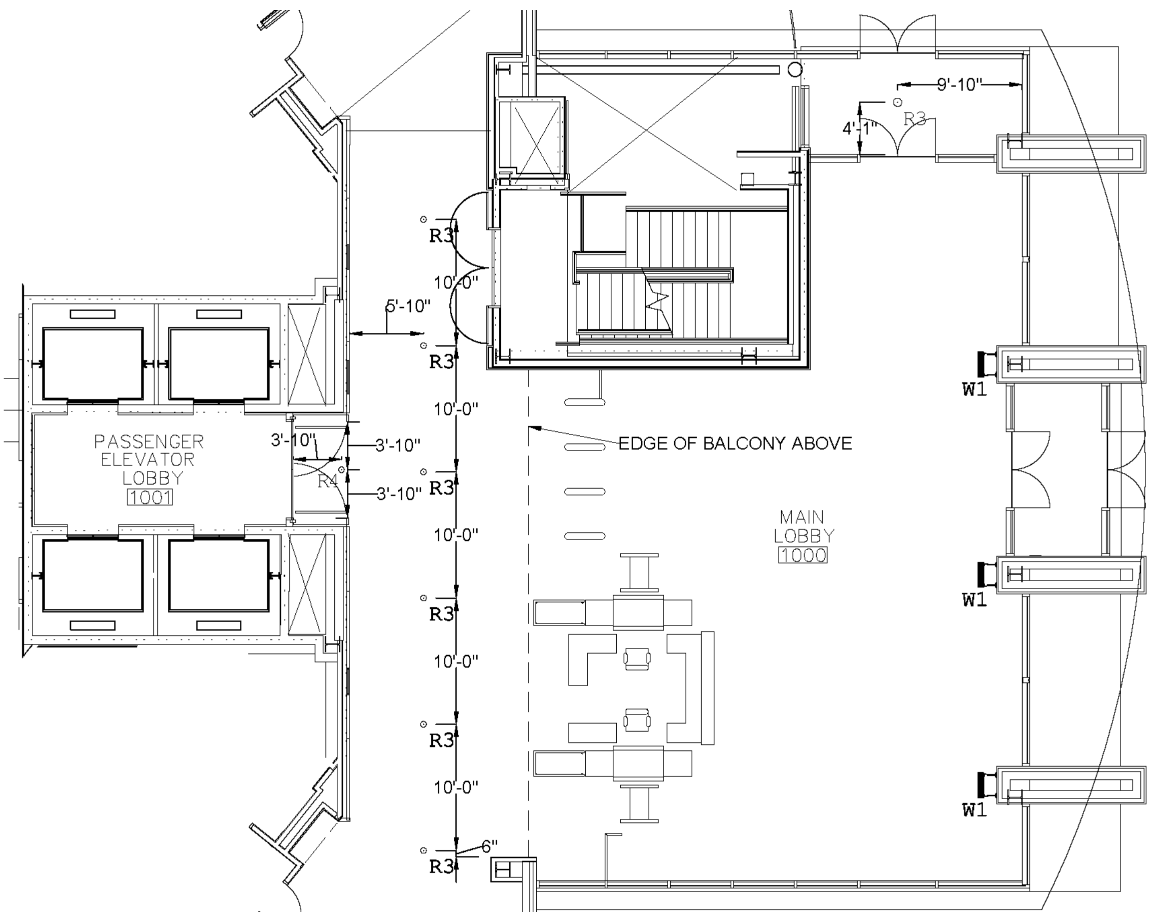


Figure 13 – Main Lobby 1000 Lower Level Reflected Ceiling Plan

Figure 13 on the previous page and Figure 14 below show the luminaire layout for Lobby 1000. All ceiling mounted luminaires are recessed into the drop ceiling. Coordinate the height with the architect. Wall mounted luminaire W1 is to be mounted at the center of the columns 7'-0" AFF.

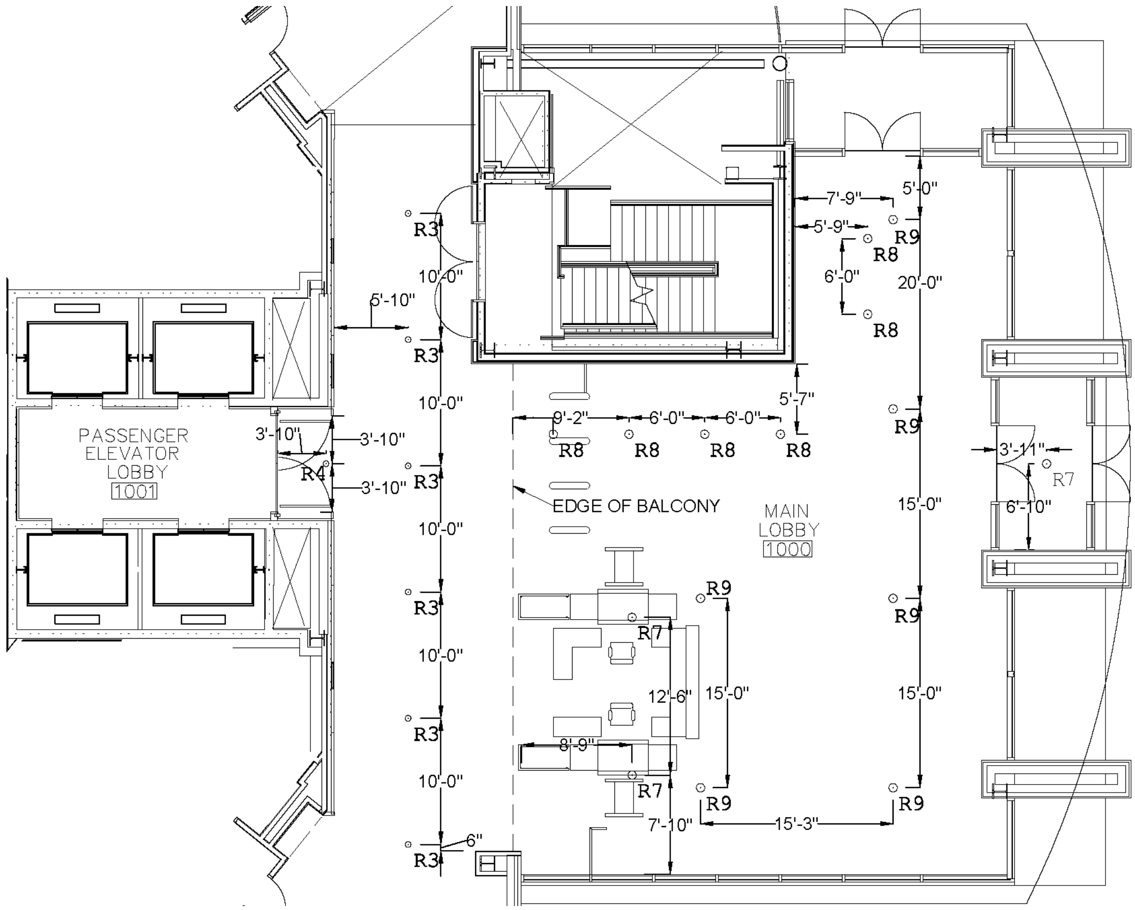


Figure 14 – Main Lobby 1000 Upper Level Reflected Ceiling Plan

Table 12 – Main Lobby 1000 Target Vs Design Illuminance

Location		Eh (lux)	Height Eh	Avg:Min
Security Screening	Target	200	3'0"	2:1
	Design	186	3'-0"	1.7:1
Lobbies near entries (day)	Target	100	Floor	4:1
	Design	139	Floor	3.2:1

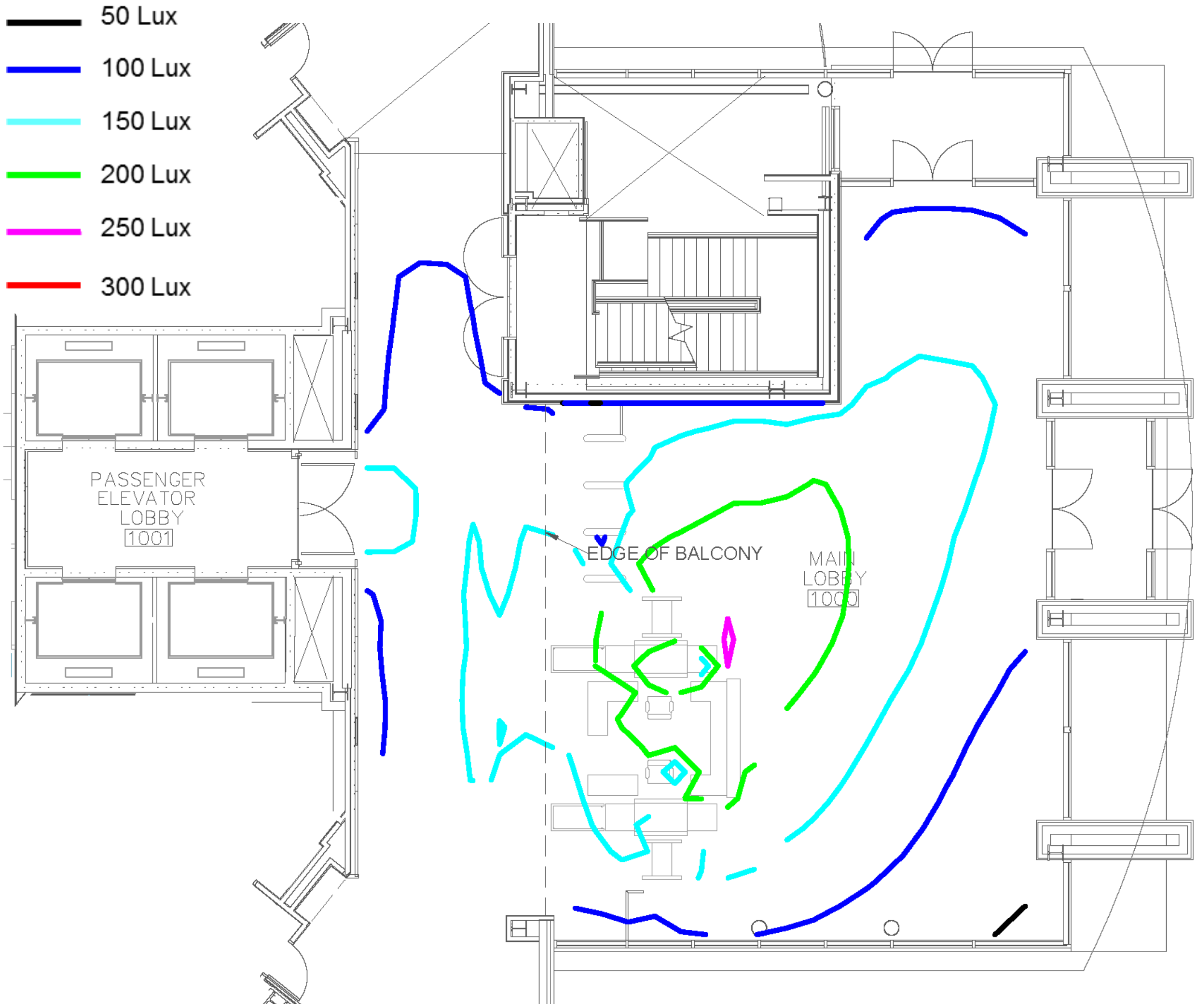


Figure 15 – Main Lobby 1000 Lower Level Isoline

Figure 16 – Main Lobby 1000 Perspective 1

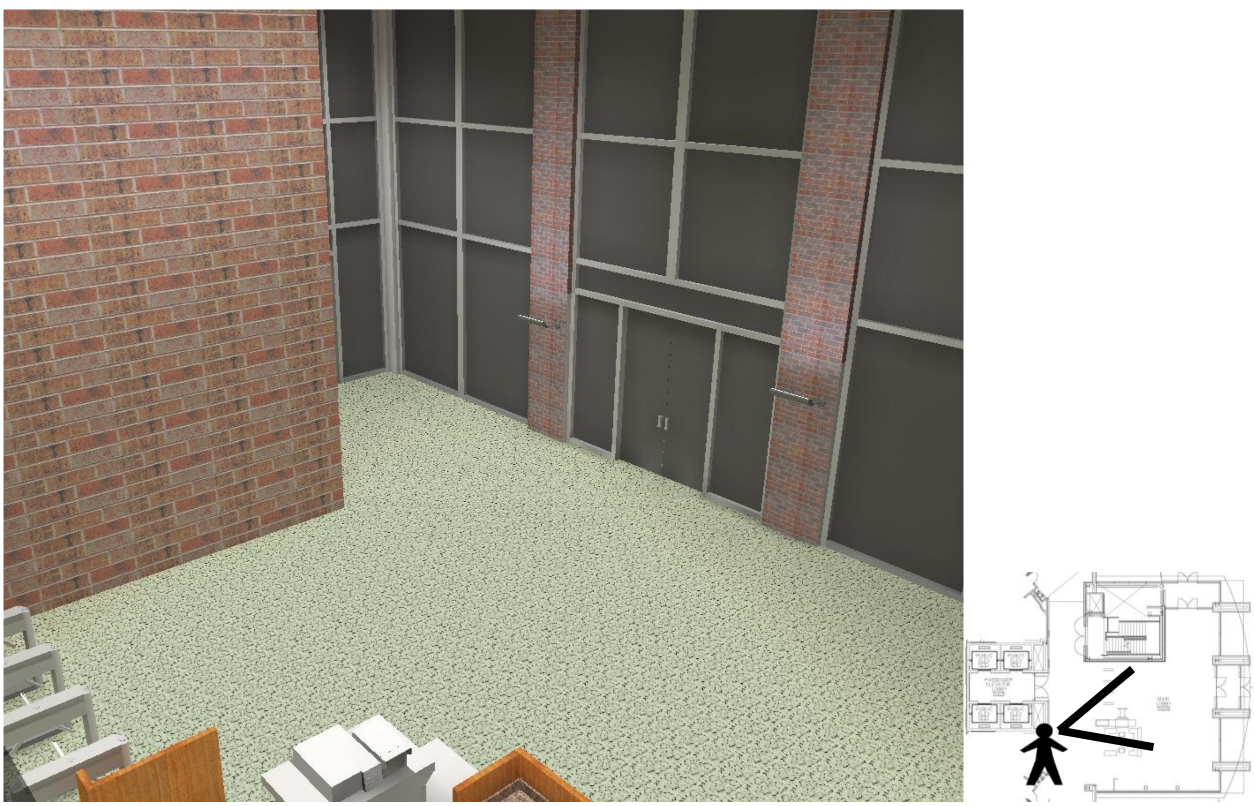


Figure 17 – Main Lobby 1000 Perspective from Balcony

The LPD for this design is 0.33 W/SF which is a 63% reduction from the maximum allowed LPD. See Appendix A-2 – Lighting Power Density Calculations for the calculations.

The ASHRAE controls requirements for this space were addressed as follows:

*Local Control***:** The control station is located at the security station.

Automatic Daylight Responsive Controls for Sidelighting: Nearly the entire room is a primary sidelighted area. As a result photosensor control is provided for all of the general lighting. Continuous dimming will be used for these luminaires. The luminaires for the security screening area are not general lighting and therefore will not be photocontrolled.

Automatic Full OFF: Because this is the main security screening area for the building automatic full off would endanger the safety of the occupants so exception 2 for this requirement will be taken.

Scheduled Shutoff: Because this is the main security screening area for the building scheduled shutoff would endanger the security of the building occupants so exception 3 of this requirement will be taken.

See Figure 18 and Figure 19 on the next page for the lighting controls details.

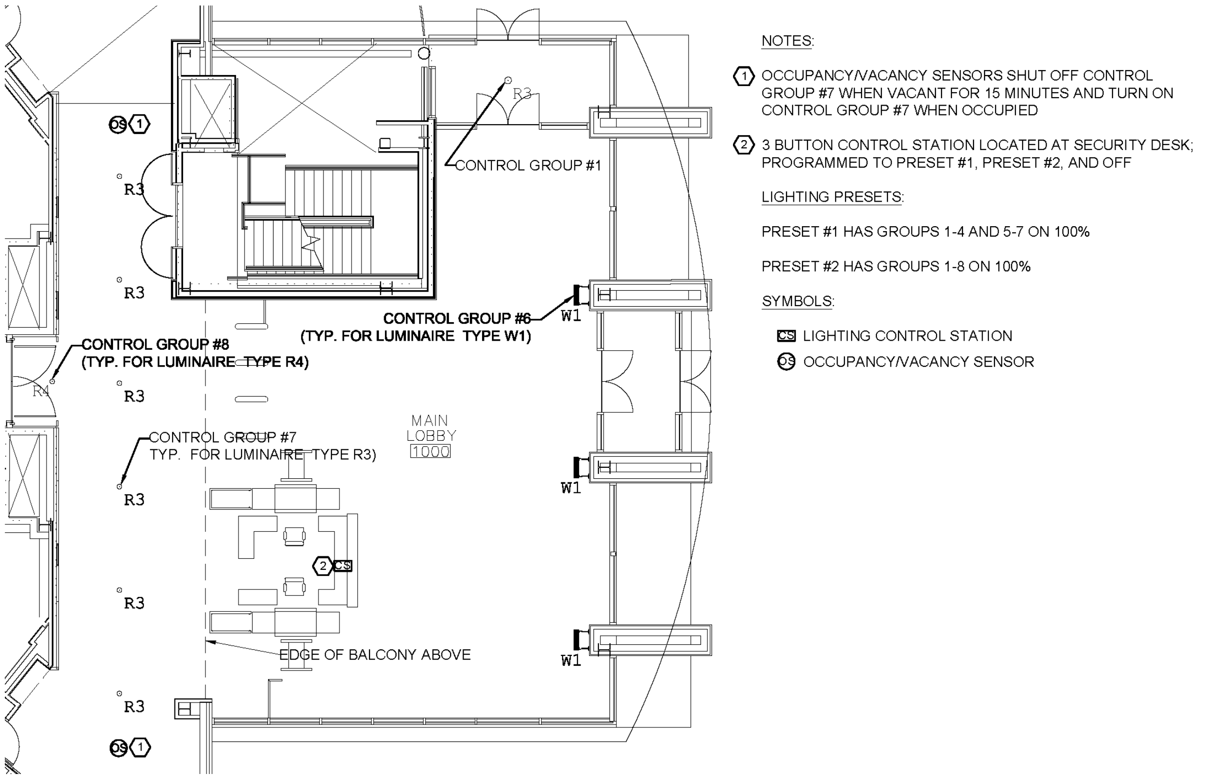


Figure 18 – Main Lobby 1000 Lower Level Lighting Controls

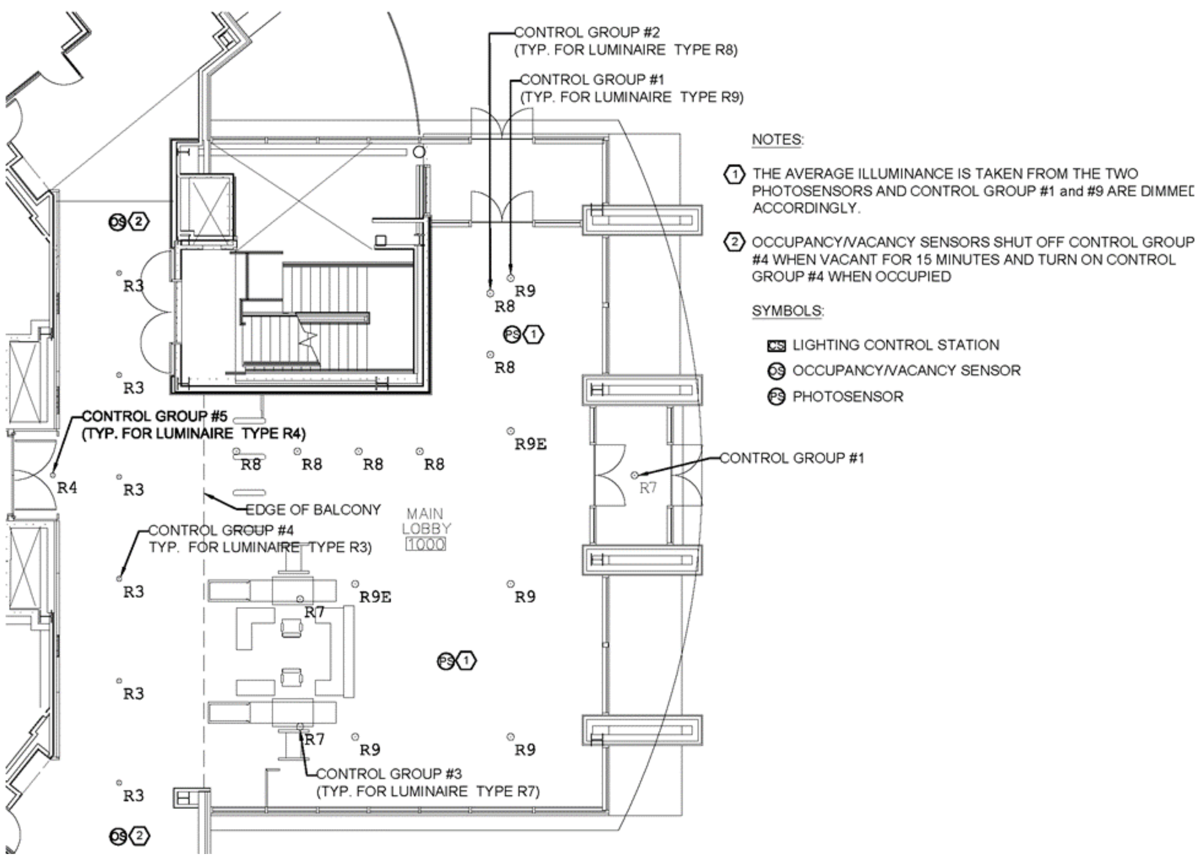


Figure 19 – Main Lobby 1000 Upper Level Lighting Controls

1.4 Open Office 2520

1.4.1 Introduction

Open Office 2520 is a 1600 SF "L" shaped open office located in the southwest corner of the building. This office is typical of the open offices located throughout the building, but has significant exterior exposure on the northwest side. See Figure 20 below for the layout and dimensions of Open Office 2520

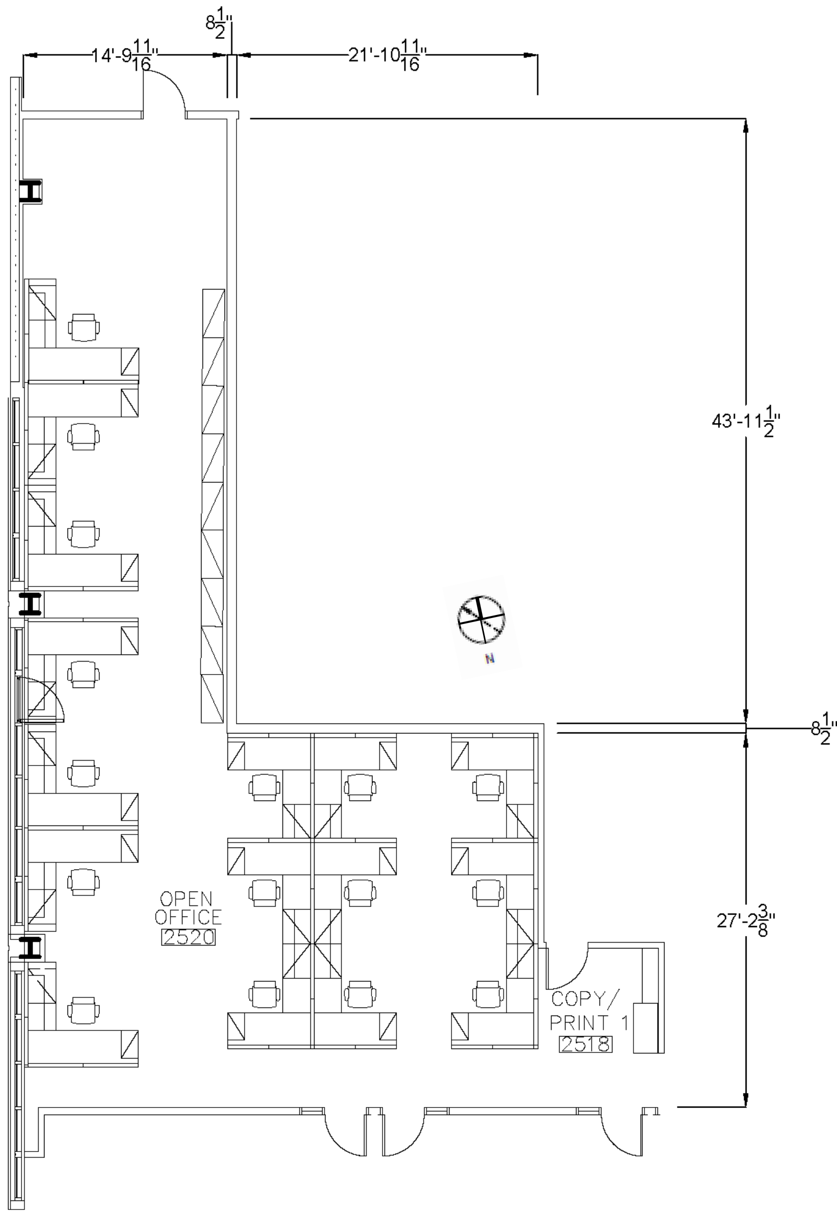


Figure 20 – Open Office 2520 Layout and Dimensions

The finish and glazing properties for Open Office 2520 are given in Table 13 and Table 14 below.

Table 13 – Open Office 2520 Finish Schedule

Surface	Description	Color	Reflectance
Ceiling	Acoustical panel ceiling 24" x 24"	White	0.90
Floor	Carpet Tile 24" x 24"	Opening Night (403674)	0.04*
Wall	Paint	Pure White (7005)	0.85

*denotes reflectances that were calculated by AGI32 based on the manufacturers image

Table 14 – Open Office 2520 Glazing Types

Surface	Description	ρ_{EXT}	ρ_{INT}	ρ_{SOL}	VLT
Windows	Vision glass	0.11	0.11	0.26	0.49

1.4.2 Design Criteria

Views/Daylight: In order to create a friendly working environment, views and daylighting should be utilized as much as possible while keeping glare to a minimum.

Community/Unity: The lighting design of this space should create a sense of community and not cause the space to feel segmented.

Both the illuminance level and illuminance ratios are based on the recommendations in the IES Handbook and are listed in Table 15 below.

Table 15 – Open Office 2520 Illuminance Recommendations

Eh (lux)	Elevation Eh	Ev (lux)	Elevation Ev	Avg:Min
300	2'-6"	50	4'-0"	1.5:1*

*From Table 12.6

The control and LPD requirements from ASHRAE 90.1 2013 are given in Table 16 below.

Table 16 – Open Office 2520 LPD and Control Requirements

LPD (W/SF)	Local Control	Manual ON	Restricted to Partial Automatic ON	Bilevel Lighting Control	Automatic Daylight Responsive Controls for Sidelighting	Automatic Full OFF	Scheduled Shutoff
0.98	REQ	ADD1	ADD1	REQ	REQ	ADD2	ADD2

Note: "ADD1" and "ADD2" designates requirements that have an option. i.e. one of the "ADD1" options and one of the "ADD2" options must be selected.

1.4.3 Final Design

Table 17 – Open Office 2520 Luminaire Schedule

Type	Description	Manufacturer	Model	Lamp	Input Watts	Voltage	Fixture Image
P1	CYLINDRICAL LED DIRECT/INDIRECT PENDANT	PEERLESS	RD4M4 W20/20 8FT R8 277 EZB SCT LP835 F1/24 C110	INTEGRAL	40	277	
P1E	EMERGENCY CYLINDRICAL LED DIRECT/INDIRECT PENDANT	PEERLESS	RD4M4 W20/20 8FT R8 277 EZB 1 EC SCT LP835 F1/24 C110	INTEGRAL	40	277	
P2	CYLINDRICAL LED WALL WASHER PENDANT	PEERLESS	RD4MW W20 40FT R8 277 EZB SCT LP835 F1/24 C110	INTEGRAL	20	277	
P3	CYLINDRICAL LED DIRECT/INDIRECT PENDANT	PEERLESS	RD4M4 W40/20 4FT R4 277 EZB SCT LP835 F1/24 C110	INTEGRAL	60	277	

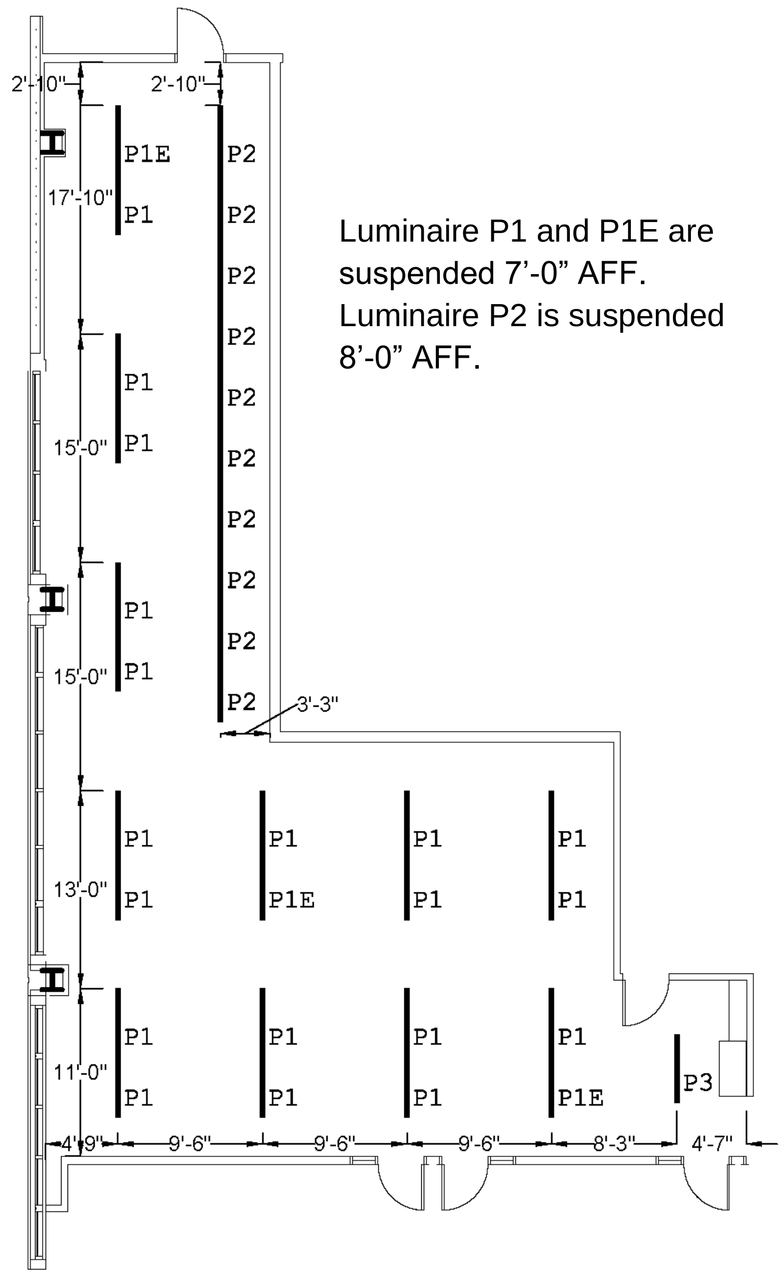


Figure 21 – Open Office 2520 RCP

Table 18 – Open Office 2520 Target Vs Design Illuminance

	Eh (lux)	Height Eh	Avg:Min
Target	300	2'6"	1.5:1
Design	329	2'6"	1.98:1

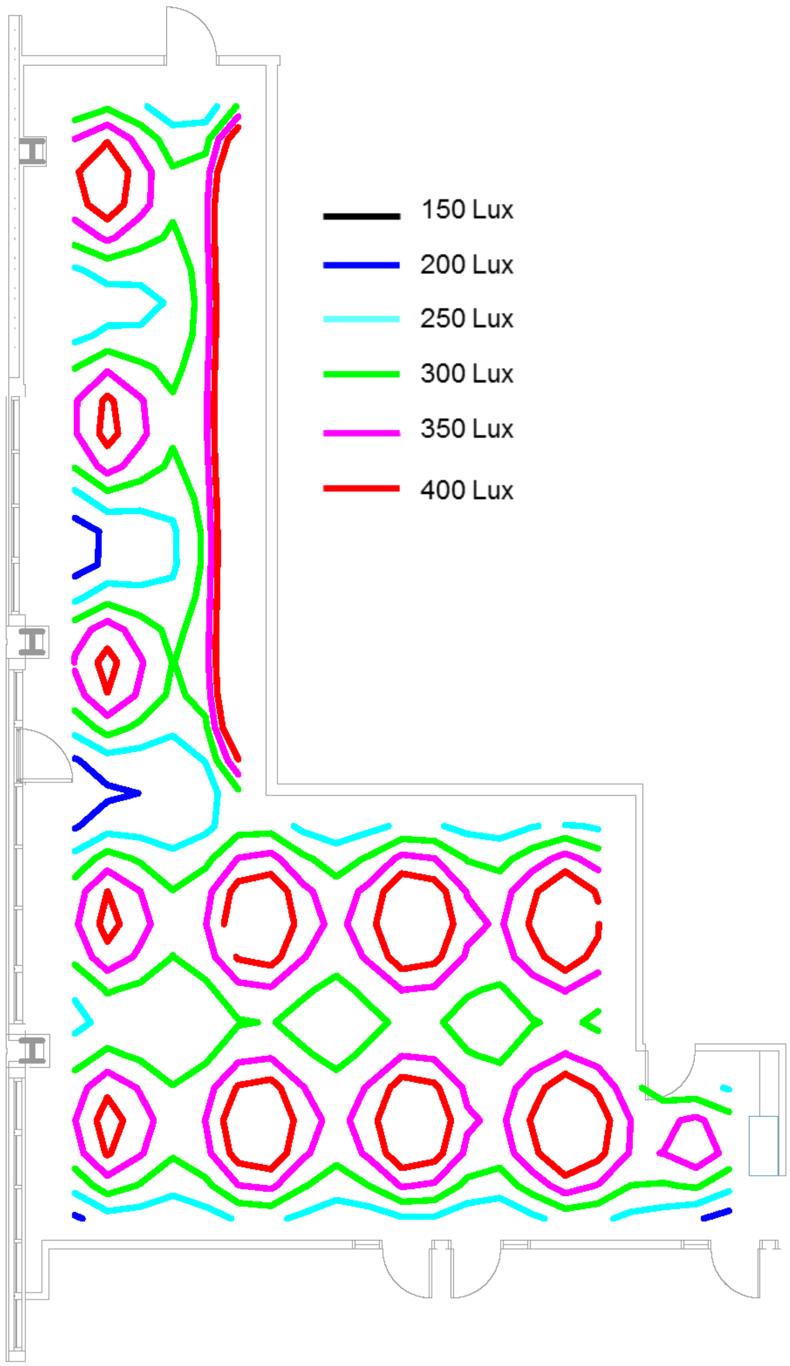


Figure 22 – Open Office 2520 Isolines

Figure 23 – Open Office 2520 Perspective

Figure 24 – Open Office 2520 Perspective

The LPD for this design is 0.71 W/SF which is a 28% reduction from the maximum allowed LPD. See Appendix A-2 – Lighting Power Density Calculations for the calculations.

The ASHRAE control requirements were addressed as follows:

Local Control: There are control stations located at each door.

Manual ON: This is not required because the lighting is restricted to partial automatic on.

Restricted to Partial Automatic ON: The occupancy sensors are only able to turn on a portion of the lighting for this space.

Bilevel Lighting Control: The lighting control stations allow for various luminaire combinations to be turned on including a setting that is between 30% and 70% of the total lighting power.

Automatic Daylight Responsive Controls for Sidelighting: A large portion of the room is a primary sidelighted area. As a result photo sensor control is provided for all of the luminaires in this area. Continuous dimming will be used for these luminaires.

Automatic Full OFF: The lighting control system is equipped with vacancy sensors that will turn off all of the lighting for the space.

Scheduled Shutoff: This is not required because automatic full off is being utilized.

See Figure 25 on the next page for lighting control details.

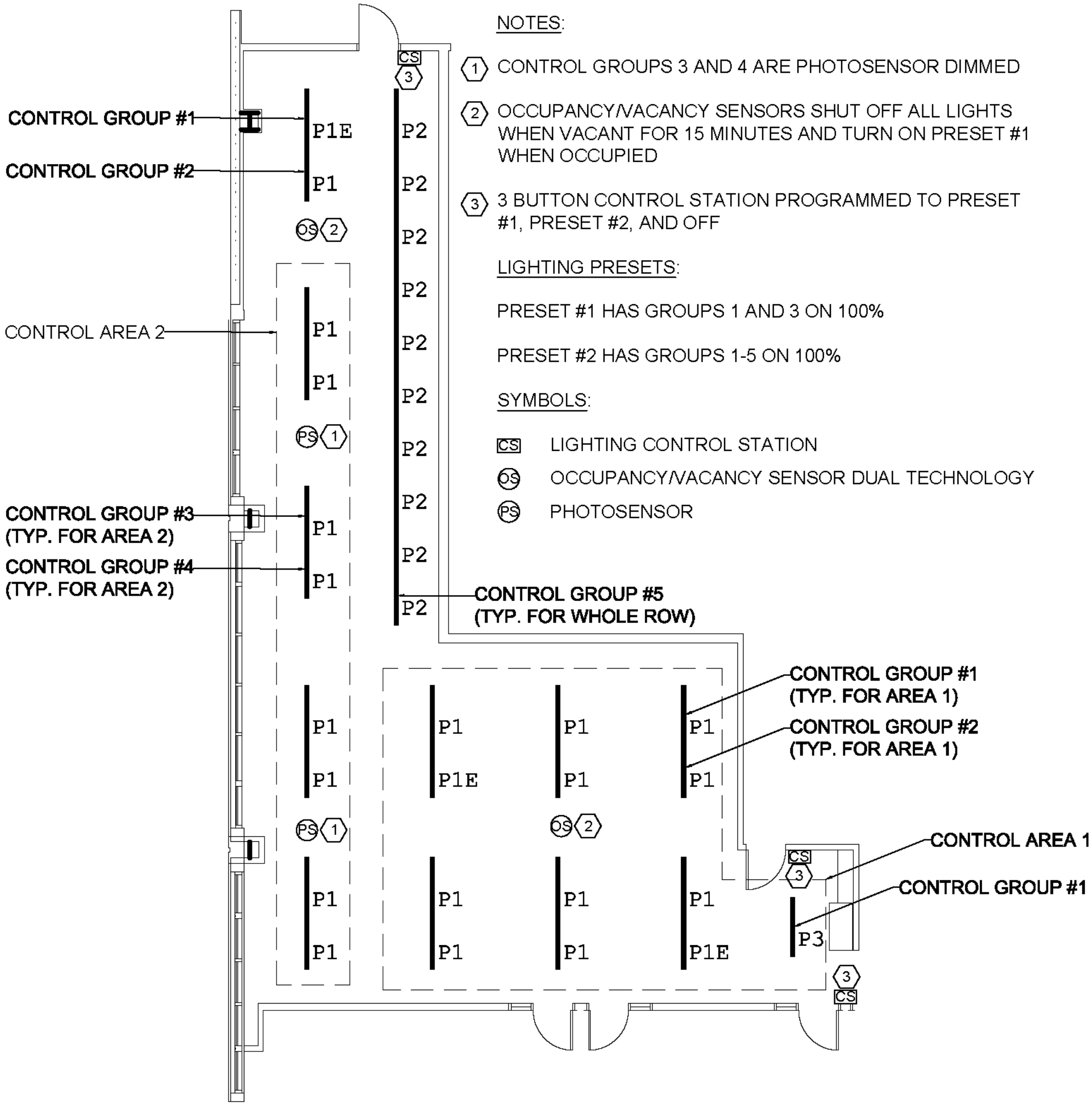


Figure 25 – Open Office 2520 Lighting Control

1.5 Ceremonial Courtroom 4100

1.5.1 Introduction

Ceremonial Courtroom 4100 is located in the southeast end of the building and is the largest of the courtrooms. This courtroom has an area of 2900 SF with 222 public seats and a large area for proceedings that includes the typical items (attorney's tables, evidence table, jury seating, etc.) and seating for a panel of judges. There are various activities that take place in the courtroom that require very different illuminance levels. Figure 26 below gives the layout and dimensions of Ceremonial Courtroom 4100.

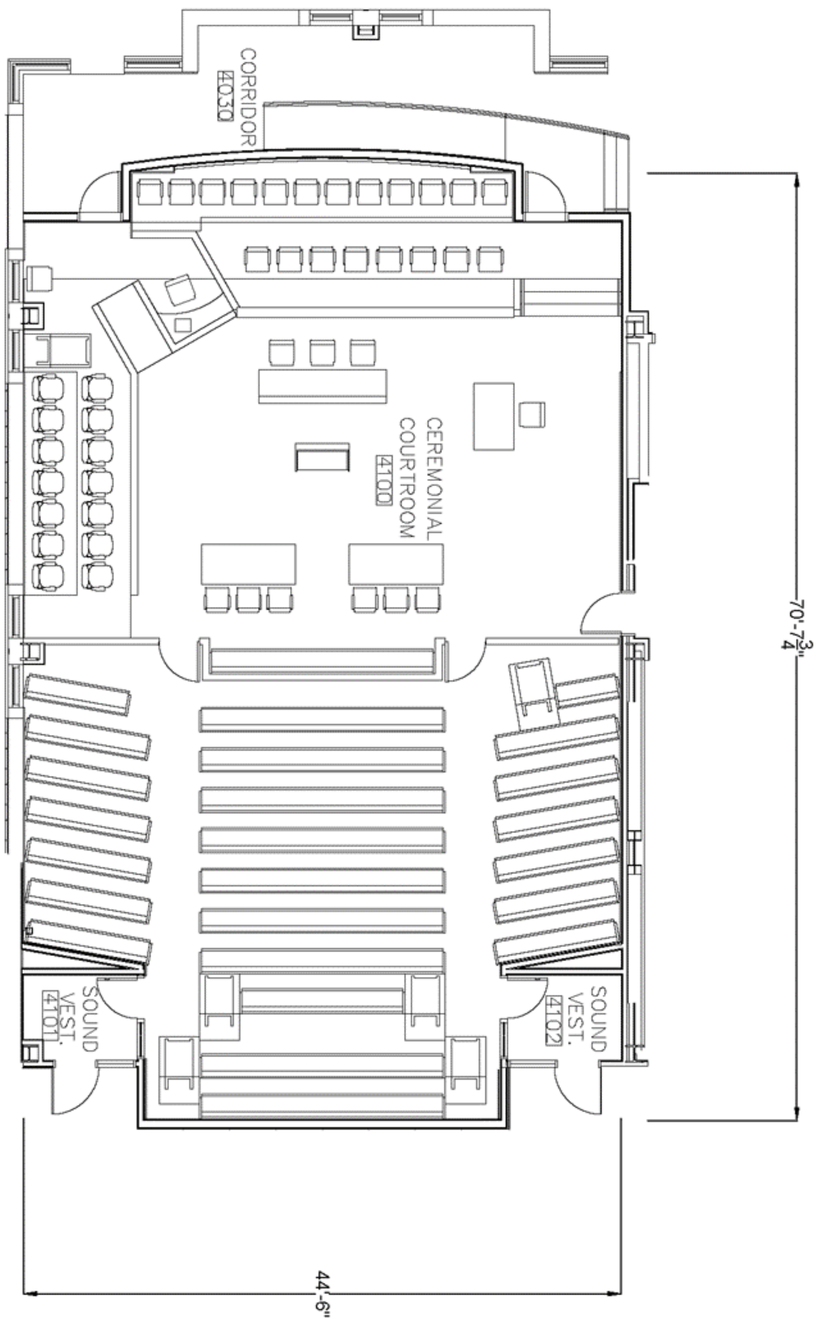


Figure 26 – Ceremonial Courtroom 4100 Layout and Dimensions

The finish materials and their properties for Ceremonial Courtroom 4100 are listed in Table 19 and Table 20 below.

Table 19 - Ceremonial Courtroom 4100 Finish Schedule

Surface	Description	Color	Reflectance
Ceiling	Acoustical panel ceiling 24" x 48"	White	0.83
	Painted gypsum	Pure White (7005)	0.85
Wall	Acoustic Fabric Panel	Designtex 4139 102 Clay	0.72*
	Handset Stone	Mountain Green	0.22*
	Paint	Natural Choice (7011)	0.73
	Hardwood veneer	Black Walnut	0.30*
Floor	Broadloom Carpet	Dusk (921)	0.03*

*denotes reflectances that were calculated by AGI32 based on the manufacturers image

Table 20 - Ceremonial Courtroom 4100 Glazing Types

Surface	Description	ρ_{EXT}	ρ_{INT}	ρ_{SOL}	VLT
Exterior windows	Vision glass	0.11	0.11	0.26	.49
Interior windows	Acoustic Glazing	0.11*	0.11*		.49

*denotes assumed value

1.5.2 Design Criteria

Flexibility: in order to accommodate the various activities that will take place in the courtroom the lighting solution must have various scenes

Respect: the lighting design of this space should convey a sense of honor and respect

Both the illuminance level and illuminance ratios are based on the recommendations in the IES Handbook and are listed in Table 21 below.

Table 21 – Ceremonial Courtroom 4100 Illuminance Recommendations

Location	Eh (lux)	Height Eh	Ev (lux)	Height Ev	Max:Avg	Avg:Min	Notes
Attorneys' Tables	500	2'-6"	200	4'-0"		2:1	
AV Presentation Screen			50		2:1		Max value
Bench and Clerks	500	2'-6"	200	4'-0"		2:1	
Jury Box	300	2'-6"	150	4'-0"		2:1	
Public Seating	100	2'-6"	50	4'-0"		2:1	
Witness Stand	300	2'-6"	150	4'-0"		2:1	

The control and LPD requirements from ASHRAE 90.1 2013 are given in Table 22 below.

Table 22 – Ceremonial Courtroom 4100 LPD and Control Requirements

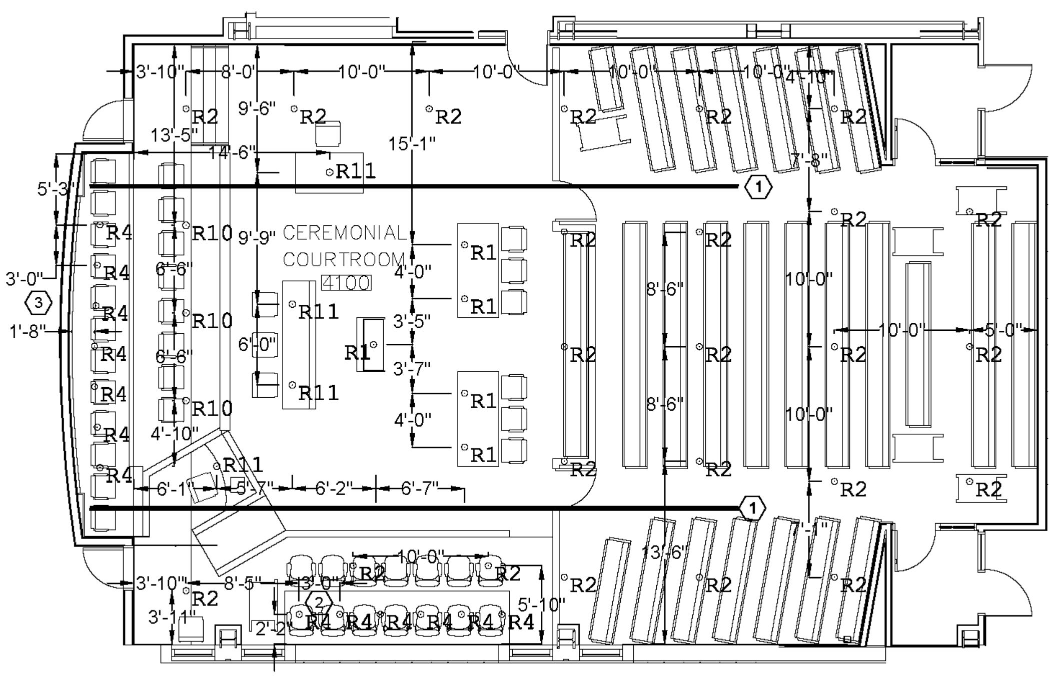
LPD (W/SF)	Local Control	Manual ON	Restricted to Partial Automatic ON	Bilevel Lighting Control	Automatic Daylight Responsive Controls for Sidelighting	Automatic Full OFF	Scheduled Shutoff
1.72	REQ	ADD1	ADD1	REQ	REQ	ADD2	ADD2

Note: "ADD1" and "ADD2" designates requirements that have an option. i.e. one of the "ADD1" options and one of the "ADD2" options must be selected.

1.5.3 Final Design

Table 23 – Ceremonial Courtroom 4100 Luminaire Schedule

Type	Description	Manufacturer	Model	Lamp	CCT (K)	CRI	Life (Hours)	Ballast	Input (Watts)	Voltage	Fixture Image
R1	RECESSED CIRCULAR 6 INCH NARROW BEAM DOWNLIGHT 1500 LUMEN	COOPER LIGHTING	LD6A15DL3 ERN6A10835 6LN1LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	22.4	277	
R2	RECESSED CIRCULAR 6 INCH WIDE BEAM DOWNLIGHT 1000 LUMEN	COOPER LIGHTING	LD6A10DL3 ERW6A10835 6LW1LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	14.1	277	
R4	RECESSED CIRCULAR 6 INCH WIDE BEAM WALL WASH 1000 LUMEN	COOPER LIGHTING	LD6A10DL3 ERM6A10835 6LM111LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	14.1	277	
R10	RECESSED CIRCULAR 6 INCH WIDE BEAM DOWNLIGHT 3000 LUMEN	COOPER LIGHTING	LD6A30DL3 ERW6A30835 6LW1LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	43.6	277	
R11	RECESSED CIRCULAR 6 INCH MEDIUM BEAM DOWNLIGHT 2000 LUMEN	COOPER LIGHTING	LD6A20DL3 ERN6A20835 6LM1LI	INTEGRAL	3500	80	50,000 L70	INTEGRAL	31.5	277	
S1E	SURFACE MOUNTED LINEAR CEILING WASH	IO LIGHITNG	0 -08-35KV2HO-1-72-L	INTEGRAL	3500	80+	50,000 L70	INTEGRAL	63.4	277	



NOTES:

1. EACH COVE LIGHT CONSISTS OF 8 S1 LUMINAIRES. SEE THE DETAIL FOR THE LUMINAIRE LOCATION AND COVE DIMENSIONS
2. ALL LUMINAIRE TYPE R4 IN THIS ROW HAVE EQUIVALENT SPACING
3. ALL LUMINAIRE TYPE R4 IN THIS AREA ARE MOUNTED IN AN ARC THAT MATCHES THE CURVATURE OF THE WALL. THE CENTER OF THE LUMINAIRES ARE TO BE 1'-8" FROM THE WALL. THE LUMINAIRES ARE SPACED 3'-8" FROM CENTER TO CENTER.

Figure 27 – Ceremonial Courtroom 4100 Reflected Ceiling Plan

All luminaires except S1 are recessed in the ceiling. Coordinate the mounting heights with the architect. See Figure 28 on the next page for the cove dimensions.

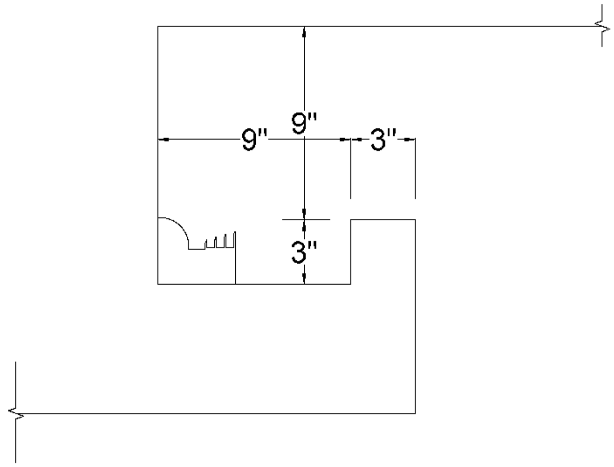


Figure 28 – Cove Detail

Table 24 – Ceremonial Courtroom 4100 Target Vs Design Illuminance

Location		Eh (lux)	Height Eh	Avg:Min
Attorneys' Tables	Target	500	2'-6"	2:1
	Table 1	454	2'-6"	1.1:1
	Table 2	457	2'-6"	1.1:1
Bench and Clerks	Target	500	2'-6"	2:1
	Design (Bench Upper)	434	2'-6"	1.9:1
	Design (Bench Lower)	460	2'-6"	1.7:1
	Design (Clerks)	500	2'-6"	1.2:1
Jury Box	Target	300	2'-6"	2:1
	Design	325	2'-6"	2.0:1
Podium	Target	500	2'-6"	2:1
	Design	456	2'-6"	1.1:1
Public Seating	Target	100	2'-6"	2:1
	Design	123	2'-6"	2.1:1
Witness Stand	Target	300	2'-6"	2:1
	Design	384	2'-6"	1.1:1

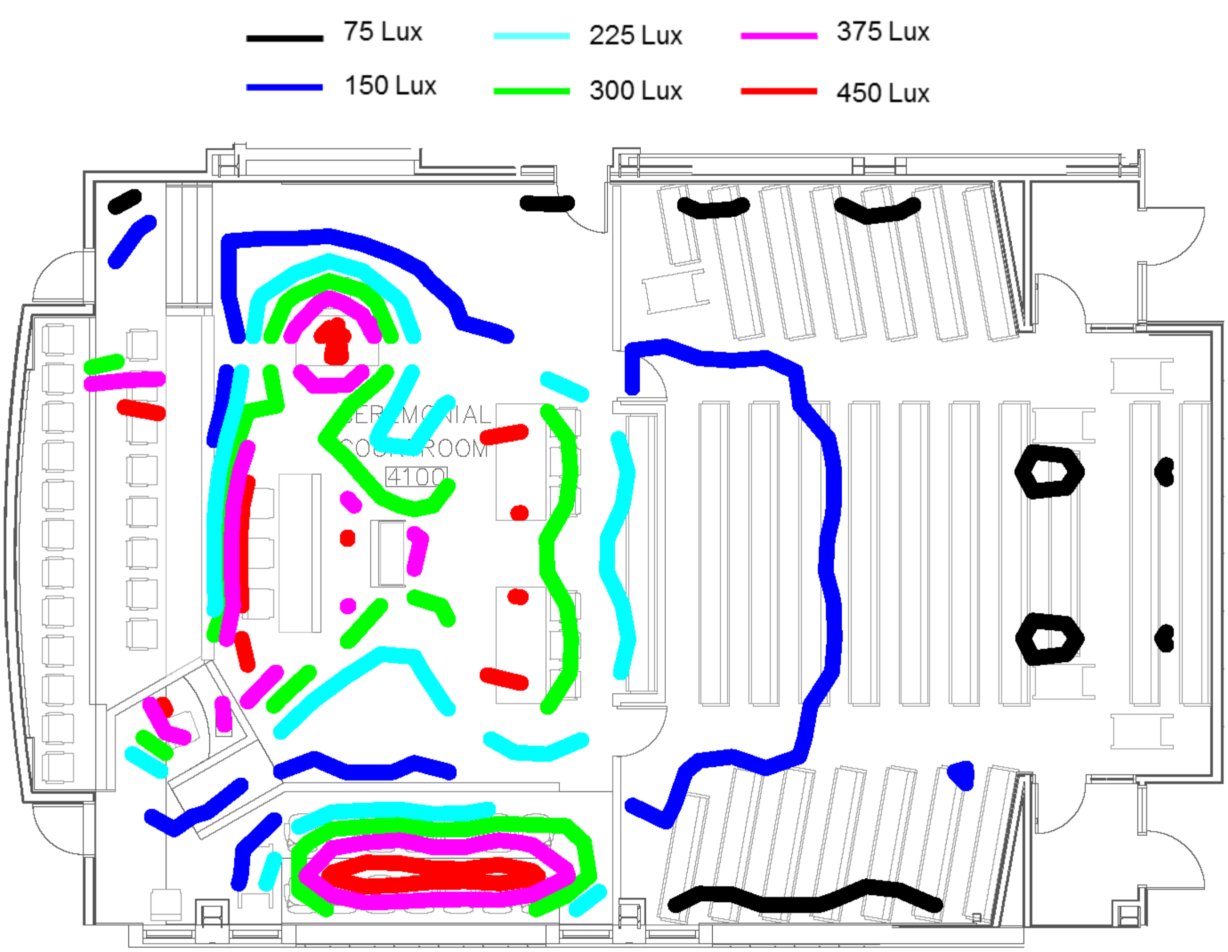


Figure 29 – Ceremonial Courtroom 4100 Isoline

Figure 30 – Ceremonial Courtroom 4100 Perspective from Public Seating

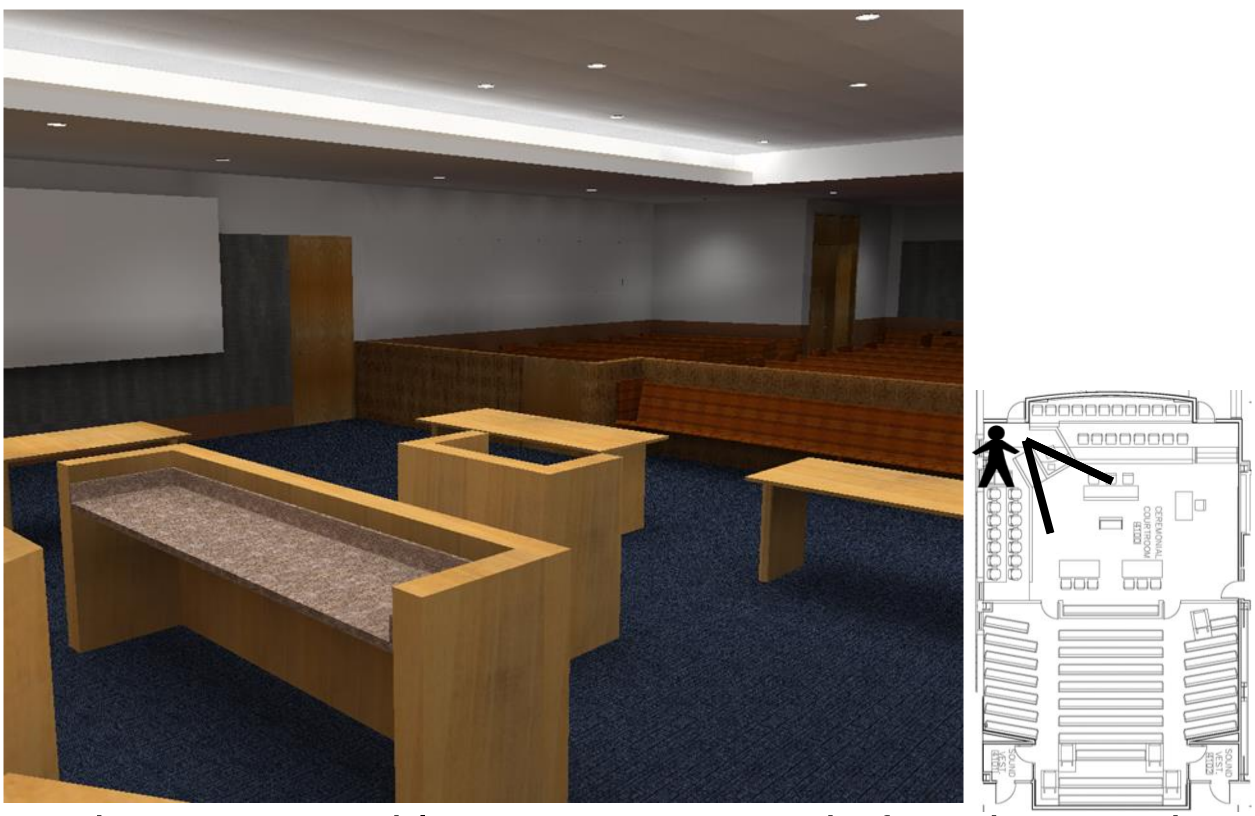


Figure 31 – Ceremonial Courtroom 4100 Perspective from Witness Stand

The LPD for this design is 0.66 W/SF which is a 64% reduction from the maximum allowed LPD. See Appendix A-2 – Lighting Power Density Calculations for the calculations.

The ASHRAE control requirements were addressed as follows:

Local Control: There are control stations located at the two doors at the front of the room and at the bench.

Manual ON: The lighting system is restricted to manual on.

Restricted to Partial Automatic ON: This is not required because the system is restricted to manual on.

Bilevel Lighting Control: The lighting control stations allow for various Luminaire combinations to be turned on including a setting that is between 30% and 70% of the total lighting power.

Automatic Daylight Responsive Controls for Sidelighting: A small portion of the room is primary sidelighted area, but this portion and the associated installed lighting power is enough to make dimming a code requirement. As a result photosensor control is provided for all of the luminaires in this area. Continuous dimming will be used for these luminaires.

Automatic Full OFF: The lighting control system is equipped with vacancy sensors that will turn off all of the lighting for the space.

Scheduled Shutoff: This is not required because automatic full off is being utilized.

See Figure 32 on the next page for lighting control details.

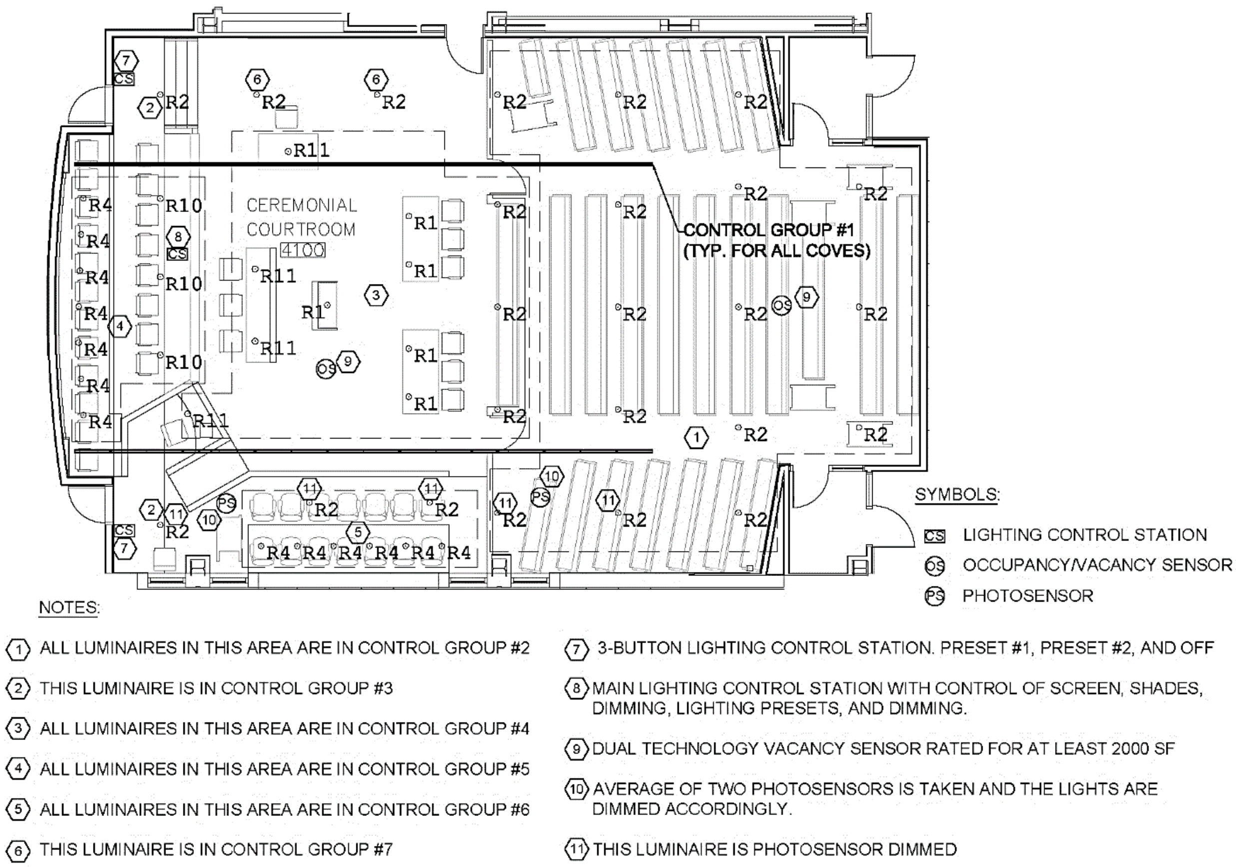


Figure 32 – Ceremonial Courtroom 4100 Lighting Control

The presets will be as follows:

Preset #1 (Entry): control group #1 at 100%

Preset #2 (General Proceedings): control group #1 – control group #7 at 100%

Preset #3 (Projection Screen Use): control group #1 – control group #6 and control group #8 at 100% and control group #7 at 25%

Preset #4 (No Jury): control group #1 – control group #5 and control group #7-control group #8 at 100%

Table 25 below gives the illuminance on the screen for two different presets. Preset #2 and preset #3. For preset #3 the average illuminance at the clerk is 383 Lux which is significantly below the target, but this scene should only be used in rare situations that demand the highest image quality.

Table 25 – Presentation Screen Illuminance Values

Location		Ev (lux)	Max:Avg	Notes
AV Presentation Screen	Target	50	2:01	Max value
	Design (normal)	66	1.6:1	
	Design (A/V mode)	40	1.2:1	

The luminaire drivers for this space have two different types of control. The drivers for the cove lights use Lutron Hi-Lume and the drivers for the recessed luminaires use Lutron Ecosystem. One option for a control system for this space is a Lutron GRAFIK Eye QS with EcoSystem. This system would be able to accommodate the seven lighting control zones and the two other zones (one for shades and one for the screen).

A Sivoia QS could be used for shade control and is capable of controlling up to ten shades from one control box. This room only has four shades so this box could provide control for another adjacent room as well.

Sensors

Occupancy/vacancy sensing could be handled by two ceiling mount LOS-CDT-2000-WH Dual tech which are rated for 2000 SF.

A daylight sensor that is compatible with the EcoSystem ballasts is the C-SR-M1-WH

A QS Contact closure interface QSE-IO could be used to interface the lighting control system with the projection screen.

User Controls

There are 3 user control stations located within this space. The main unit is located at the bench and two 3-button seeTouch QS keypads are located at the front doors. The main control allows for control of multiple lighting scenes as well as control of the window shades and projection screen. The 3-button control stations allow for preset #1 or preset #2 to be turned on and for all the lights to be turned off.

2. Part 2 – Electrical Depth

2.1 Introduction

The BCJC's electrical system utilizes a 3200 A unit substation that is fed by a 2000 KVA building transformer with a 34.5 KV primary and a 277/480 secondary. The building utilizes a dual voltage AC distribution system of 277/480 V and 120/208 V. A 1000 KW generator and a 100 KW UPS serve the emergency power distribution system. There are various low voltage systems throughout the building including audio visual, telecommunications, fire alarm, and an expansive security system. For this report the changes made in the lighting equipment were reflected in the electrical distribution system, a breaker coordination study was performed, a short circuit study was performed and finally research was performed into the feasibility of a DC distribution system.

2.2 Distribution System Analysis/Redesign

In order to accommodate the changes made in the Lighting Depth all of the circuits were updated to reflect the changes in the luminaire type, quantity, and layout for the four spaces that were redesigned. The conductors, conduit, circuit breakers, and panelboards were resized as required.

The changes in the lighting load for Lobby 1000 and Open Office 2520 did not have a significant impact on the panel loads because the amount of load from these two spaces is just a small fraction of the load that is on the entire panel.

The original design for Courtroom 4100 had all of the luminaires run through a single 84 circuit dimmer panel that served a total of six courtrooms. With the redesign dimming is handled by the luminaire ballasts so the dimming panel is no longer required. The total original lighting load for Ceremonial Courtroom 4100 is shown in Table 26 below and the lighting load for the redesigned system is shown in Table 27 below.

Table 26 - Original Lighting Loads for Ceremonial Courtroom 4100

DIMMING PANEL SCHEDULE			DIM4		
MAINS:	100A MCB	**SERVING :** FOURTH FLOOR		**AIC**: 25,000	
VOLTAGE	480/277	**MOUNTING:**	SURFACE		
CIRCUIT	AREA/ROOM	CIRCUIT BREAKER	VOLTAGE	REMARKS	LOAD (W)
26	JURY COURTROOM 4100	20/1	277	DIMMED	676
27	JURY COURTROOM 4100	20/1	277	DIMMED	232
28	JURY COURTROOM 4100	20/1	277	DIMMED	174
29	JURY COURTROOM 4100	20/1	277	DIMMED	232
30	JURY COURTROOM 4100	20/1	277	DIMMED	690
59	JURY COURTROOM 4100	20/1	277	DIMMED / EMERGENCY	840
60	JURY COURTROOM 4100	20/1	277	DIMMED / EMERGENCY	116
81	JURY COURTROOM 4100	20/1	277	DIMMED	58
82	JURY COURTROOM 4100	20/1	277	DIMMED	116
83	JURY COURTROOM 4100	20/1	277	DIMMED	29
84	JURY COURTROOM 4100	20/1	277	DIMMED	29
				Total:	**3192**

Table 27 – Revised Lighting Loads for Ceremonial Courtroom 4100

CIRCUIT	AREA	CIRCUIT BREAKER	VOLTAGE	REMARKS	LOAD (W)
1	Public Seating, Area of Proceedings (includes witness)	20/1	277	Normal Power	491.8
2	Jury and Judges	20/1	277	Normal Power	342.3
3	Cove	20/1	277	Emergency Power	1014.4
4	Screen, Stairs, and ramp	20/1	277	Normal Power	56.4
				Total:	**1904.9**

The revised load is about 2/3 of the original load. Assuming that each of the six courtrooms served by Dim 4 would have the same load as Ceremonial Courtroom 4100 (which is a conservative estimate because 4100 is much larger than most of the courtrooms) the total lighting load would be approximately 11,400 watts with approximately 6,000 watts of this load being emergency/backup lighting. 6000 watts gives a load of about 6 KVA. This is a very small load and requires a very small panelboard. However, to accommodate any future needs the new panel to replace DIM 4 could be a 30 circuit panelboard with a 50 amp main breaker.

2.3 Short Circuit Analysis

A short circuit analysis is an important step in electrical system design in order to make sure that equipment with an appropriate AIC rating is selected. The maximum current let through for each transformer in the building was calculated by assuming infinite current available at the primary. Table 28 below gives the specifications and calculations for transformers that are representative of all the transformers in the BCJC. The associated equations are also given.

Table 28 – Calculated Maximum Transformer Let Through Current

Designation	KVA	Primary Voltage	Secondary Voltage	Phase	Type	%Z*	Mounting	I_{FLA}	I_{SC}
T1	2000	34,500	480Y/277	3	Dry	5.75	Floor	7,217	125,511
T2	30	480	208Y/120	3	Dry	1.8	Hung	250	13,879
T4	45	480	208Y/120	3	Dry	1.8	Hung	375	20,818
T29	15	480	208Y/120	3	Dry	1.9	Hung	125	6,574
T31	75	480	208Y/120	3	Dry	1.7	Hung	625	36,738

*for T1 %Z was taken from Eaton pad mounted transformer typical design impedance for all others %Z was taken from Eaton Type EPT minimum impedance

Equation 1 – Maximum Secondary Full Load Amps

$$I_{FLA} = \frac{(kVA)(1000)}{(V_{LL})\sqrt{3}}$$

Equation 2 – Secondary Short Circuit Current

$$I_{SC} = (I_{FLA})\left(\frac{100}{\%Z}\right)$$

The maximum fault current available at each floor was calculated taking into account the let through of the main transformer (assuming infinite current from the utility) and the impedance from the main cable and busway. The calculations are based on the Bussmann Short Circuit Calculation Guide. Table 29 on the next page shows the details of each calculation. The associated equations are also given.

Table 29 – Calculated Available Fault Current for Each Busway at Each Floor

Location	Conductor Type	Length (Feet)	Table 5 C	$I_{3\emptyset}$	Conductors per phase	V_{LL}	f 3Ø	M	I_{SC}	Notes
Bus #1	3 Sets 300 KCMIL	125	18177	125,511	3	480	1.04	0.49	61,580	Approximate length of conductor from main panel to bus
Level 6	800A Bus	16	49300	61,580	1	480	0.07	0.93	57,438	Length of bus to electrical room based on floor to floor height
Level 5	800A Bus	32	49300	61,580	1	480	0.14	0.87	53,818	
Level 4	800A Bus	48	49300	61,580	1	480	0.22	0.82	50,627	
Level 3	800A Bus	64	49300	61,580	1	480	0.29	0.78	47,793	
Level 2	800A Bus	80	49300	61,580	1	480	0.36	0.73	45,260	
Level 1	800A Bus	96	49300	61,580	1	480	0.43	0.70	42,982	
Bus #2	3 Sets 300 KCMIL	30	18177	125,511	3	480	0.25	0.80	100,476	Approximate length of conductor from main panel to bus
Level 6	800A Bus	16	49300	100,476	1	480	0.12	0.89	89,898	Length of bus to electrical room based on floor to floor height
Level 5	800A Bus	32	49300	100,476	1	480	0.24	0.81	81,335	
Level 4	800A Bus	48	49300	100,476	1	480	0.35	0.74	74,262	
Level 3	800A Bus	64	49300	100,476	1	480	0.47	0.68	68,320	
Level 2	800A Bus	80	49300	100,476	1	480	0.59	0.63	63,259	
Level 1	800A Bus	96	49300	100,476	1	480	0.71	0.59	58,896	
Bus #3	3 Sets 300 KCMIL	35	18177	125,511	3	480	0.29	0.77	97,244	Approximate length of conductor from main panel to bus
Level 6	800A Bus	16	49300	97,244	1	480	0.11	0.90	87,301	Length of bus to electrical room based on floor to floor height
Level 5	800A Bus	32	49300	97,244	1	480	0.23	0.81	79,204	
Level 4	800A Bus	48	49300	97,244	1	480	0.34	0.75	72,481	
Level 3	800A Bus	64	49300	97,244	1	480	0.46	0.69	66,810	
Level 2	800A Bus	80	49300	97,244	1	480	0.57	0.64	61,962	
Level 1	800A Bus	96	49300	97,244	1	480	0.68	0.59	57,770	
Bus #4	3 Sets 300 KCMIL	55	18177	125,511	3	480	0.46	0.69	86,156	Approximate length of conductor from main panel to bus
Level 6	800A Bus	16	49300	86,156	1	480	0.10	0.91	78,259	Length of bus to electrical room based on floor to floor height
Level 5	800A Bus	32	49300	86,156	1	480	0.20	0.83	71,689	
Level 4	800A Bus	48	49300	86,156	1	480	0.30	0.77	66,137	
Level 3	800A Bus	64	49300	86,156	1	480	0.40	0.71	61,382	
Level 2	800A Bus	80	49300	86,156	1	480	0.50	0.66	57,266	
Level 1	800A Bus	96	49300	86,156	1	480	0.61	0.62	53,667	

Equation 3 – f Calculation for 3 Phase Faults

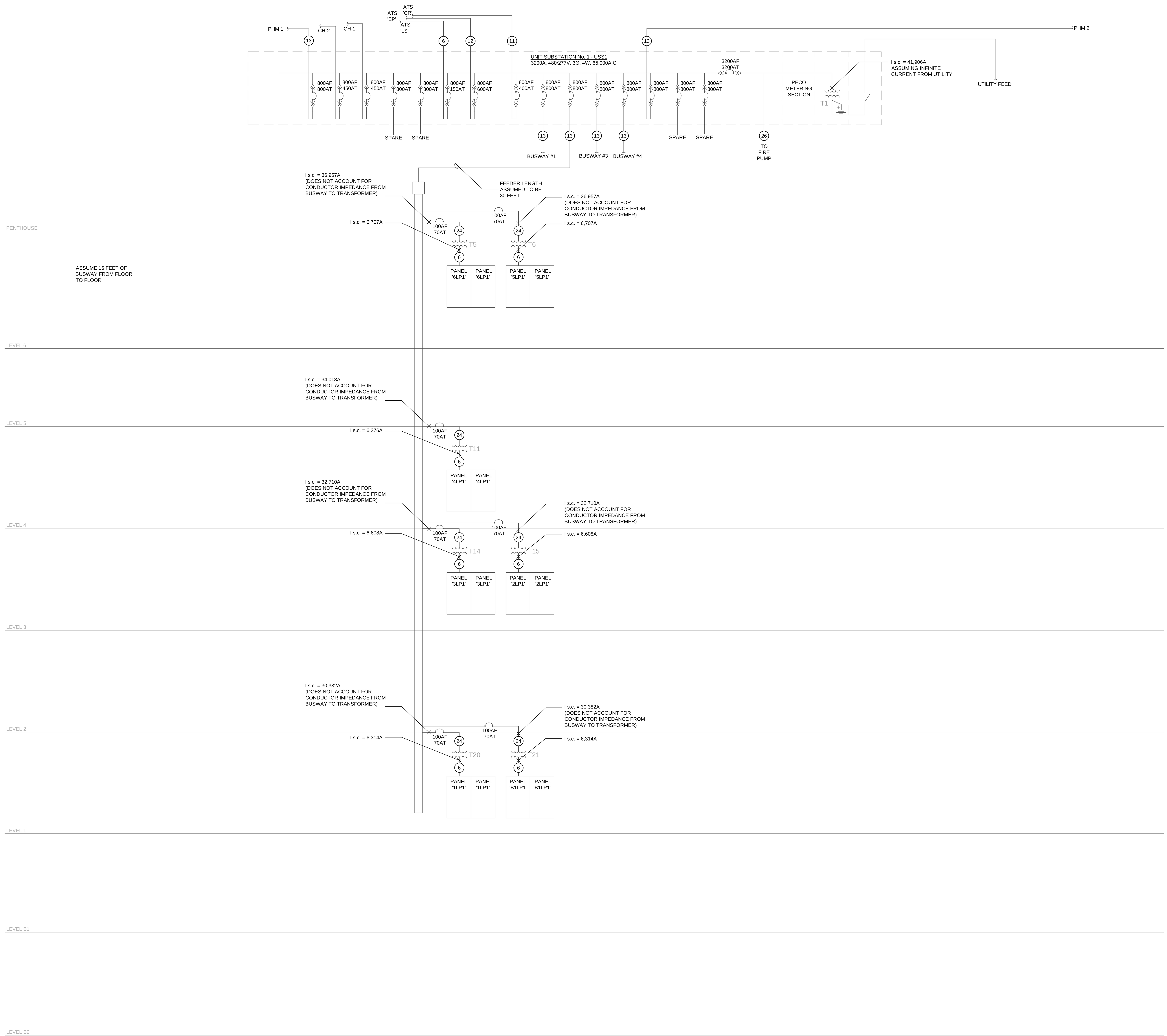
$$3\emptyset\ faults{:}\ f = \frac{\sqrt{3}(L)(I_{3\emptyset})}{(C)(n)(V_{LL})}$$

Equation 4 – M Calculation

$$M = \frac{1}{1+f}$$

A single circuit was selected to calculate the available fault current available at each panelboard. The results of this calculation are shown on the next page.

An AIC rating of 10,000 is sufficient for all of the sub panels, but the sub transformers and breakers that protect them need AIC ratings of up to 40,000.



1 SHORT CIRCUIT STUDY CRCUIT
NOT TO SCALE

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2.4 DC Distribution

Throughout my time at Penn State I have heard it mentioned several times by several different sources that there is significant potential for increasing electrical efficiency by utilizing a DC distribution system for equipment that can utilize DC power. This equipment includes motors, servers, UPS systems, and LED lighting. The increase in efficiency would come from reducing the use of inverters ad rectifiers. I felt that this would be an excellent topic for the electrical depth of my thesis. My initial research into this topic found reports that claimed a significant savings potential of nearly 25%. If these claims were true it seemed that surely the industry would quickly adopt this new method of electrical distribution, but there seems to be no large scale adoption of this method. Upon further research I found a report[1] that compared the results of several of the previous studies and discussed the errors in the methodology of the studies and misconceptions of the data in the reports that were spread by mainstream media. The main misconception comes from the reports comparing the efficiency of a new DC distribution system to the efficiency of existing AC systems that were installed around the 1980's. This is a fair comparison if this is what is actually going to occur, but is pretty much useless when designing a system for a new building using new equipment because it neglects the fact that the efficiency of AC distribution systems and equipment has greatly improved over the last 30 years. The largest discrepancy between the reports was in the efficiency of the UPS. The reports that claimed the highest increase in efficiency by utilizing DC distribution used 10% loss for AC based UPS systems. These values were accurate for the equipment they used, but they used equipment that was a couple of generations old or that operated at a lower voltage. Currently there are currently UPS systems available that operate in bypass mode when power quality is acceptable. This leads to an efficiency of about 98.6%. Another area where there was a large discrepancy was in the area of transformer efficiency. The reports with large efficiency improvements for DC systems also utilized low efficiency transformers for the AC distribution systems.

In conclusion, DC distribution and AC distribution systems have very similar efficiencies; there is not an appreciable difference between the two. In general, it is not practical to use a DC distribution system due to the utility providing AC and the prevalence of AC loads in the building. However, one area where DC distribution could yield savings is for situations where there is onsite DC generation like photovoltaic or wind. In these cases the DC generated by the sources could be distributed directly to DC loads and thus avoiding any inverter or rectifier losses.

(Rasmussen, 2012)[1]

3. Part 3 – Acoustical Breadth/MAE Depth
3.1 Introduction

Speech intelligibility is an important part of court proceedings and Ceremonial Courtroom 4100 is of a size where conditions that are unfavorable for speech intelligibility could easily exist. The large size of this space also makes the application of a sound reinforcement system potentially very beneficial to speech intelligibility. The original design for Ceremonial Courtroom 4100 includes acoustical treatment and a sound reinforcement system. The influence of these systems on speech intelligibility was evaluated through a reverberation time (RT) analysis and a sound distribution analysis.

3.2 Acoustical Breadth: Reverberation Time (RT) Analysis

3.2.1 Introduction

For the acoustical breadth, an analysis was performed of the RT of the space. This analysis involved deciding what range of RT is acceptable for a courtroom, modeling the space as currently designed (including geometry and materials), calculating the RT of the space, and making recommendations to bring the RT into closer agreement with the criteria that were developed.

3.2.2 Original Design

The original design included acoustical panel ceiling for almost the entire ceiling, large sections of seamless acoustical system, and large sections of fabric wrapped acoustical panels. A "worst case scenario" was assumed for the RT calculation by assuming that there would be no jury, only one judge, and only 10% of the public seating area occupied. See the next page for the details of the RT calculation for the original design. The resulting RT's for the 125 Hz to 4000 Hz octave bands are shown in Figure 6Figure 33 below.

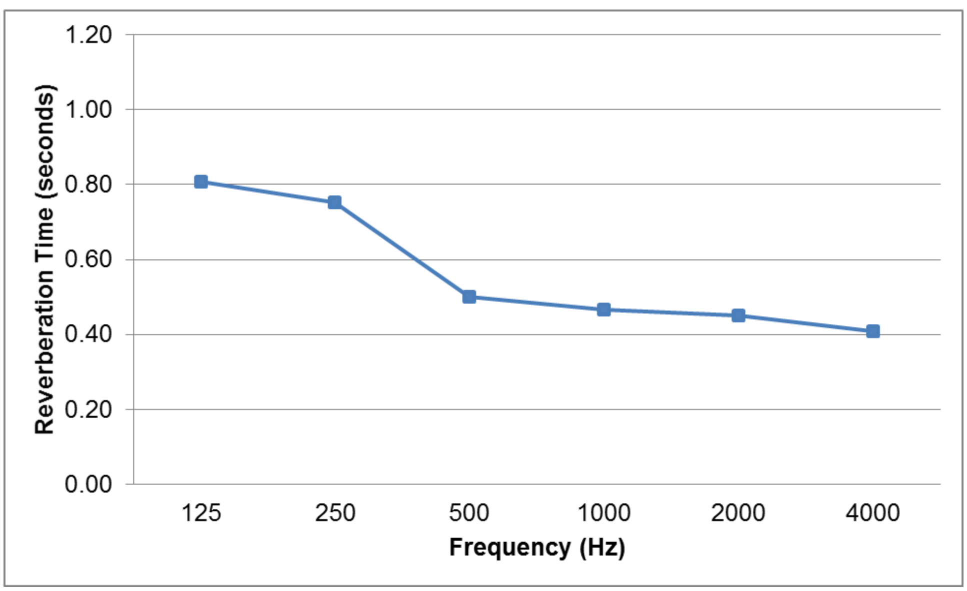


Figure 33 – Ceremonial Courtroom 4100 Original Design RT

Original Reverberation Time Calculations
(English Units)

Volume: (ft^3) V = 31,394

Total Surface Area: (ft^2) S_{tot}= 8,062

Floor Area (ft^2)	2,854.0
Avg. Height (ft)	11.0

Surface Description	Surface Area, S (ft^2)	Material/ Partition Type	Material Description	Sound Absorption Coefficient, α						S*α (sabins)					
				Frequency (Hz)						Frequency (Hz)					
				125	250	500	1000	2000	4000	125	250	500	1000	2000	4000
North Wall															
Door	48		Fenestration 700: 701: 44mm flush door (Absorption Data - University of Hartford)	0.25	0.15	0.10	0.08	0.08	0.08	12	7	5	4	4	4
Fabric Panel 1 Non-acoustical	127	FP-1	StretchWall Prefabricated MagniRoc (StretchWall Data Sheet)	0.05	0.02	0.03	0.03	0.06	0.04	6	3	4	4	8	5
Fabric Panel 1 Acoustical	76	FP-1	Fabric Wrapped FG Panel, 1", over 400mm air space (Decoustics Tests)	0.67	0.97	0.76	0.99	0.99	0.99	51	74	58	76	76	76
Gypsum	201	G4C	Gypsum board, 2 layers 5/8" on studs 16"oc w/batt (Egan)	0.28	0.12	0.10	0.07	0.13	0.09	56	24	20	14	26	18
Wood Paneling	128	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	13	14	13	10	10	14
Glass	28		Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	10	7	5	3	2	1
West Wall															
Stone	209	ST-1	Marble or glazed tile (Mehta Pg. 407)	0.01	0.01	0.01	0.01	0.02	0.02	2	2	2	2	4	4
Doors	48		Fenestration 700: 701: 44mm flush door (Absorption Data - University of Hartford)	0.25	0.15	0.10	0.08	0.08	0.08	12	7	5	4	4	4
Wood Paneling	144	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	14	16	14	12	12	16
East Wall															
Seamless Acoustical Finish	131	SAF	BASWA acoustic BASWAphon 30mm Classic Fine Finish (BASWA Data Sheet)	0.32	0.34	0.86	0.98	0.89	0.72	42	45	113	128	117	94
Wood Paneling	157	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	16	17	16	13	13	17
Fabric Panel 1 Acoustical	120	FP-1	Fabric Wrapped FG Panel, 1", over 400mm air space (Decoustics Tests)	0.67	0.97	0.76	0.99	0.99	0.99	80	116	91	119	119	119
Glazing	54	GL-12	Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	19	13	10	6	4	2
Gypsum	10	N4DY	Two 5/8" gyp. Bd. On each side of 3-5/8" studs + Fiberglass (Mehta pg. 407)	0.10	0.07	0.05	0.05	0.04	0.04	1	1	1	1	0	0
South Wall															
Window	112		Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	39	28	20	13	8	4
Fabric Panel 1 Non-acoustical	127	FP-1	StretchWall Prefabricated MagniRoc (StretchWall Data Sheet)	0.05	0.02	0.03	0.03	0.06	0.04	6	3	4	4	8	5
Fabric Panel 1 Acoustical	76	FP-1	Fabric Wrapped FG Panel, 1", over 400mm air space (Decoustics Tests)	0.67	0.97	0.76	0.99	0.99	0.99	51	74	58	76	76	76
Glass	28		Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	10	7	5	3	2	1
Gypsum	204	GYP-1	Gypsum board, 2 layers 5/8" on studs 16"oc w/batt (Egan)	0.28	0.12	0.10	0.07	0.13	0.09	57	24	20	14	27	18
Wood Paneling	130	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	13	14	13	10	10	14
Door	24		Fenestration 700: 701: 44mm flush door (Absorption Data - University of Hartford)	0.25	0.15	0.10	0.08	0.08	0.08	6	4	2	2	2	2
Floor															
Public Seating (occupied)	105		Pews, wood occupied (Mehta Pg. 408)	0.57	0.61	0.75	0.86	0.91	0.86	60	64	79	90	96	90
Public Seating (unoccupied)	945		Unoccupied pews, wood (Mehta Pg. 408)	0.10	0.10	0.09	0.08	0.08	0.08	95	95	85	76	76	76
Circulation	300		Carpet glued to floor (Mehta Pg. 407)	0.02	0.03	0.06	0.10	0.26	0.47	6	9	18	30	78	141
Jury (Unoccupied)	128		Unoccupied medium upholstered seats (Mehta Pg. 408)	0.56	0.64	0.70	0.72	0.68	0.62	72	82	90	92	87	79
Judges (Unoccupied)	246		Unoccupied medium upholstered seats (Mehta Pg. 408)	0.56	0.64	0.70	0.72	0.68	0.62	138	157	172	177	167	153
Area of Proceedings	1,130		Carpet glued to floor (Mehta Pg. 407)	0.02	0.03	0.06	0.10	0.26	0.47	23	34	68	113	294	531
Ceilling															
Acoustical Panel Ceiling	844	APC-4	Armstrong Ultima (Armstrong Data Sheet)	0.32	0.34	0.76	0.87	0.86	0.84	270	287	641	734	726	709
Acoustical Panel Ceiling	1,208	APC-7	Armstrong Dune Second Look (Armstrong Data Sheet)	0.34	0.39	0.71	0.66	0.52	0.40	411	471	858	798	628	483
Gypsum Ceiling	973	GYP-1	1/2" gyp. Bd. Ceiling (Mehta Pg. 407)	0.11	0.11	0.05	0.06	0.04	0.05	107	107	49	58	39	49

	125	250	500	1000	2000	4000
∑Sα	1,698	1,807	2,538	2,687	2,720	2,807
Avg. α	0.21	0.22	0.31	0.33	0.34	0.35
Air absorption constant for 20 °C and 40% RH, m (ft^{-1})	0	0	1.83E-04	3.26E-04	7.86E-04	2.56E-03
Sabine Reverb Time: (s) RT =	0.91	0.85	0.60	0.56	0.55	0.49
Norris-Eyring Reverb Time: (s) RT =	0.81	0.75	0.50	0.46	0.45	0.41
Calculated RT (s)	0.81	0.75	0.50	0.46	0.45	0.41
Target RT (s)	0.98	0.86	0.75	0.75	0.75	0.75

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S\alpha}{S_{tot}}$$

$$\bar{\alpha} < 0.2 \qquad RT_{Sabine} = \frac{0.049V}{S_{tot}\bar{\alpha} + 4mV}$$

$$\bar{\alpha} \geq 0.2 \qquad RT_{Norris-Eyring} = \frac{0.049V}{-S_{tot}\ln(1-\bar{\alpha}) + 4mV}$$

3.2.3 Design Criteria

A target reverberation time was set based on the volume of Ceremonial Courtroom 4100 and the type of activity that was expected to occur in it. The volume was calculated to be approximately 31,000 cubic feet and the anticipated activity is speech. Based on this information the target RT for the 500 Hz octave band was found by using Figure 17.10 from an architectural acoustics text book[2]. See Figure 34 below. To determine the RT targets for the other octave bands the recommendations in another architectural acoustics text book[3] were used; increasing the RT at 125 Hz by 30% and the RT at 250 Hz by 15%. See Table 30 below for the target RT's.

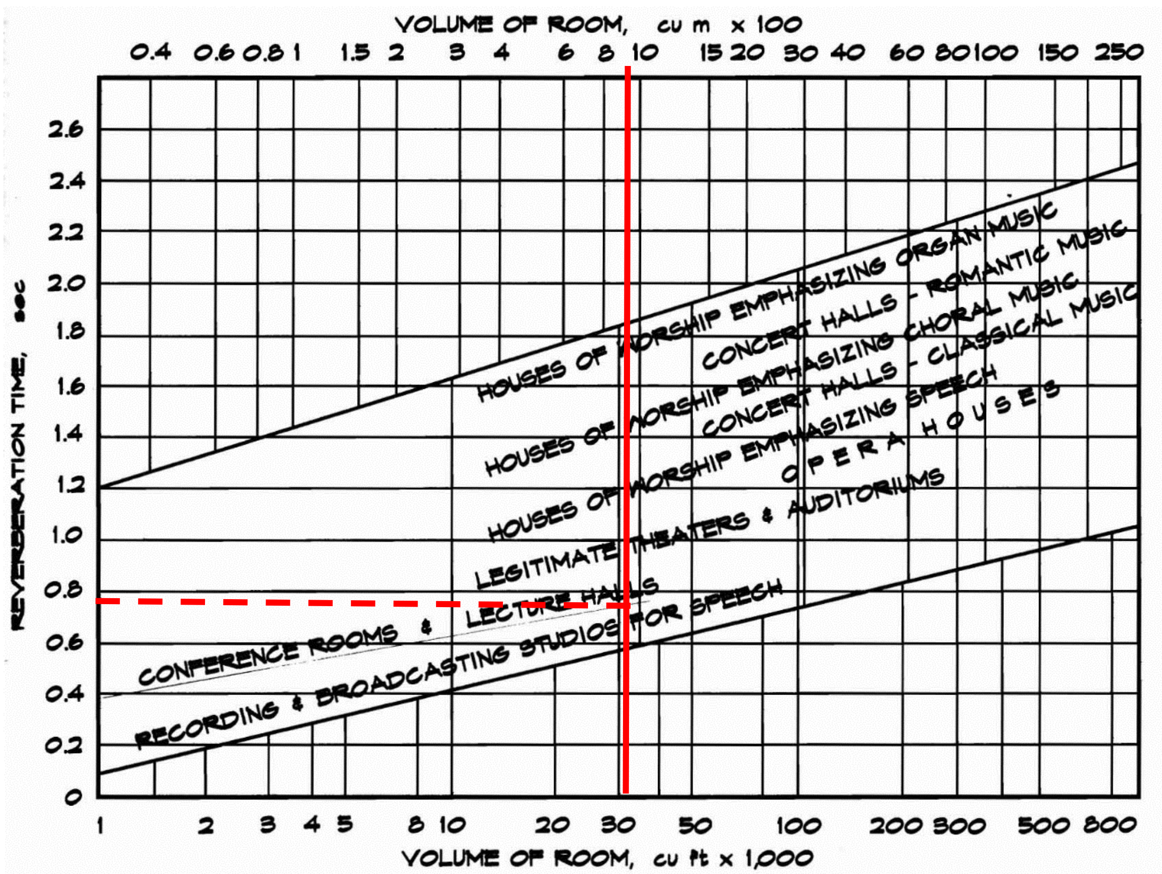


Figure 34 – Figure 17.10 With Annotations to Find the Target RT for Ceremonial Courtroom 4100

Table 30 – Target RT for Ceremonial Courtroom 4100

	Frequency (Hz)					
	125	**250**	**500**	**1000**	**2000**	**4000**
Target RT (s)	0.98	0.86	0.75	0.75	0.75	0.75

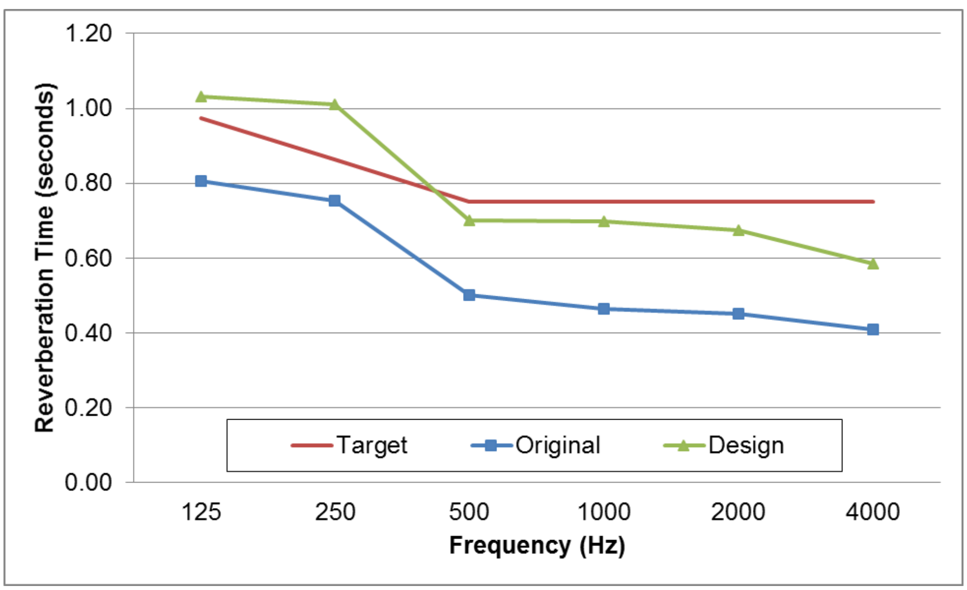
[2] (Long, 2014)

[3] (Mehta, Johnson, & Rocafort, 1999)

3.2.4 Final Design

The original RT was significantly lower than the target RT for all octave bands and particularly for the high frequencies. This was with the assumption that the public seating area was only at 10% occupancy. A higher occupancy would further reduce the RT time. In order to bring the RT into closer alignment with the target RT many modifications were made to the finish materials of the room including changing large sections of the acoustical panel ceiling to gypsum, changing fabric wrapped acoustical panels to fabric wrapped non-acoustical panels, and removing all of the seamless acoustical treatment. See Appendix B – Supporting Material for Acoustical Breadth for elevations detailing the locations of materials that were changed. The detailed calculations for the new design are given on the next page. Figure 35 below compares the target, original, and design RT's. The design RT is much closer to the target, but is still low at the 4000 Hz octave band and is a bit high at the 250 Hz band. The curve could be brought into closer alignment if specialized materials were used. However, this addition would add considerable cost and complexity to the project with only minimal benefit.

Figure 35 – Target, Original, and Design RT for Ceremonial Courtroom 4100



Final Reverberation Time Calculations
(English Units)

Volume: (ft^3) $V =$ 31,394

Total Surface Area: (ft^2) $S_{tot}=$ 8,053

Floor Area (ft^2)	2,854.0
Avg. Height (ft)	11.0

Surface Description	Surface Area, S (ft^2)	Material/ Partition Type	Material Description	Sound Absorption Coefficient, α — Frequency (Hz) 125	250	500	1000	2000	4000	S*α (sabins) — Frequency (Hz) 125	250	500	1000	2000	4000
North Wall															
Door	48		Fenestration 700: 701: 44mm flush door (Absorption Data - University of Hartford)	0.25	0.15	0.10	0.08	0.08	0.08	12	7	5	4	4	4
Fabric Panel 1 Non-acoustical	70	FP-1	StretchWall Prefabricated MagniRoc (StretchWall Data Sheet)	0.05	0.02	0.03	0.03	0.06	0.04	4	1	2	2	4	3
Fabric Panel 1 Acoustical	43	FP-1	StretchWall Prefabricated MagniRoc (StretchWall Data Sheet)	0.05	0.02	0.03	0.03	0.06	0.04	2	1	1	1	3	2
Gypsum	291	G4C	Gypsum board, 2 layers 5/8" on studs 16"oc w/batt (Egan)	0.28	0.12	0.10	0.07	0.13	0.09	81	35	29	20	38	26
Wood Paneling	128	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	13	14	13	10	10	14
Glass	28		Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	10	7	5	3	2	1
West Wall															
Stone	209	ST-1	Marble or glazed tile (Mehta Pg. 407)	0.01	0.01	0.01	0.01	0.02	0.02	2	2	2	2	4	4
Doors	48		Fenestration 700: 701: 44mm flush door (Absorption Data - University of Hartford)	0.25	0.15	0.10	0.08	0.08	0.08	12	7	5	4	4	4
Wood Paneling	144	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	14	16	14	12	12	16
East Wall															
Gypsum	131	N4DY	Two 5/8" gyp. Bd. On each side of 3-5/8" studs + Fiberglass (Mehta pg. 407)	0.10	0.07	0.05	0.05	0.04	0.04	13	9	7	7	5	5
Wood Paneling	157	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	16	17	16	13	13	17
Fabric Panel 1 Acoustical	120	FP-1	Fabric Wrapped FG Panel, 1", over 400mm air space (Decoustics Tests)	0.67	0.97	0.76	0.99	0.99	0.99	80	116	91	119	119	119
Glazing	54	GL-12	Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	19	13	10	6	4	2
Gypsum	10	N4DY	Two 5/8" gyp. Bd. On each side of 3-5/8" studs + Fiberglass (Mehta pg. 407)	0.10	0.07	0.05	0.05	0.04	0.04	1	1	1	1	0	0
South Wall															
Window	112		Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	39	28	20	13	8	4
Fabric Panel 1 Non-acoustical	96	FP-1	StretchWall Prefabricated MagniRoc (StretchWall Data Sheet)	0.05	0.02	0.03	0.03	0.06	0.04	5	2	3	3	6	4
Fabric Panel 1 Acoustical	34	FP-1	StretchWall Prefabricated MagniRoc (StretchWall Data Sheet)	0.05	0.02	0.03	0.03	0.06	0.04	2	1	1	1	2	1
Glass	28		Glass Window (Mehta Pg. 408)	0.35	0.25	0.18	0.12	0.07	0.04	10	7	5	3	2	1
Gypsum	268	GYP-1	Gypsum board, 2 layers 5/8" on studs 16"oc w/batt (Egan)	0.28	0.12	0.10	0.07	0.13	0.09	75	32	27	19	35	24
Wood Paneling	130	WD-1	Wood (pine) sheathing (Mehta Pg. 407)	0.10	0.11	0.10	0.08	0.08	0.11	13	14	13	10	10	14
Door	24		Fenestration 700: 701: 44mm flush door (Absorption Data - University of Hartford)	0.25	0.15	0.10	0.08	0.08	0.08	6	4	2	2	2	2
Floor															
Public Seating (occupied)	105		Pews, wood occupied (Mehta Pg. 408)	0.57	0.61	0.75	0.86	0.91	0.86	60	64	79	90	96	90
Public Seating (unoccupied)	945		Unoccupied pews, wood (Mehta Pg. 408)	0.10	0.10	0.09	0.08	0.08	0.08	95	95	85	76	76	76
Circulation	300	CP-1	Carpet glued to floor (Mehta Pg. 407)	0.02	0.03	0.06	0.10	0.26	0.47	6	9	18	30	78	141
Jury (Unoccupied)	128		Unoccupied medium upholstered seats (Mehta Pg. 408)	0.56	0.64	0.70	0.72	0.68	0.62	72	82	90	92	87	79
Judges (Unoccupied)	246		Unoccupied medium upholstered seats (Mehta Pg. 408)	0.56	0.64	0.70	0.72	0.68	0.62	138	157	172	177	167	153
Area of Proceedings	1,130	CP-1	Carpet glued to floor (Mehta Pg. 407)	0.02	0.03	0.06	0.10	0.26	0.47	23	34	68	113	294	531
Ceilling															
Gypsum Ceiling	580	GYP-1	1/2" gyp. Bd. Ceiling (Mehta Pg. 407)	0.11	0.11	0.05	0.06	0.04	0.05	64	64	29	35	23	29
Acoustical Panel Ceiling	264	APC-7	Armstrong Dune Second Look (Armstrong Data Sheet)	0.34	0.39	0.71	0.66	0.52	0.40	90	103	187	174	137	106
Acoustical Panel Ceiling**	1,208	APC-7	Armstrong Dune Second Look (Armstrong Data Sheet)	0.34	0.39	0.71	0.66	0.52	0.40	411	471	858	798	628	483
Gypsum Ceiling	973	GYP-1	1/2" gyp. Bd. Ceiling (Mehta Pg. 407)	0.11	0.11	0.05	0.06	0.04	0.05	107	107	49	58	39	49
									∑Sα	1,493	1,521	1,906	1,899	1,911	2,005

	125	250	500	1000	2000	4000
Avg. α	0.19	0.19	0.24	0.24	0.24	0.25
Air absorption constant for 20 °C and 40% RH, m (ft^{-1})	0	0	1.83E-04	3.26E-04	7.86E-04	2.56E-03
Sabine Reverb Time: (s) RT =	1.03	1.01	0.80	0.79	0.77	0.66
Norris-Eyring Reverb Time: (s) RT =	0.93	0.91	0.70	0.70	0.67	0.59
Calculated RT (s)	1.03	1.01	0.70	0.70	0.67	0.59
Target RT (s)	0.98	0.86	0.75	0.75	0.75	0.75

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S\alpha}{S_{tot}}$$

$$\bar{\alpha} < 0.2 \qquad RT_{Sabine} = \frac{0.049V}{S_{tot}\bar{\alpha} + 4mV}$$

$$\bar{\alpha} \geq 0.2 \qquad RT_{Norris-Eyring} = \frac{0.049V}{-S_{tot}\ln(1-\bar{\alpha}) + 4mV}$$

*Replace BASWAphon with gypsum
**Replace APC-7 with APC-4

3.3 Acoustical MAE Depth: Sound Reinforcement System Analysis

3.3.1 Introduction

The design for Ceremonial Courtroom 4100 has a distributed audio amplification system. The influence that this system has on speech intelligibility and distribution was studied using EASE. This study involved creating a geometric model of the space, assigning material properties, selecting appropriate files for the sources, and receivers, and running simulations. The metrics selected to measure system performance were sound pressure level (SPL) and speech transmission index (STI). Auralizations were created to simulate what would be heard from two different locations in the audience when the sound reinforcement system was and was not in use.

3.3.2 Model

Figure 36 below shows the layout for the model. There are 21 recessed ceiling mounted speakers. For this analysis, 6 audience areas were used: Audience 1, Audience 2, and Audience 3 comprise the public seating area, Jury is the jury box, and Judge 1 and Judge 2 make up the judge's box. Two seat locations were used for auralizations one at the front right and one at the back center of the audience area. Figure 37 below is a 3D perspective of the space.

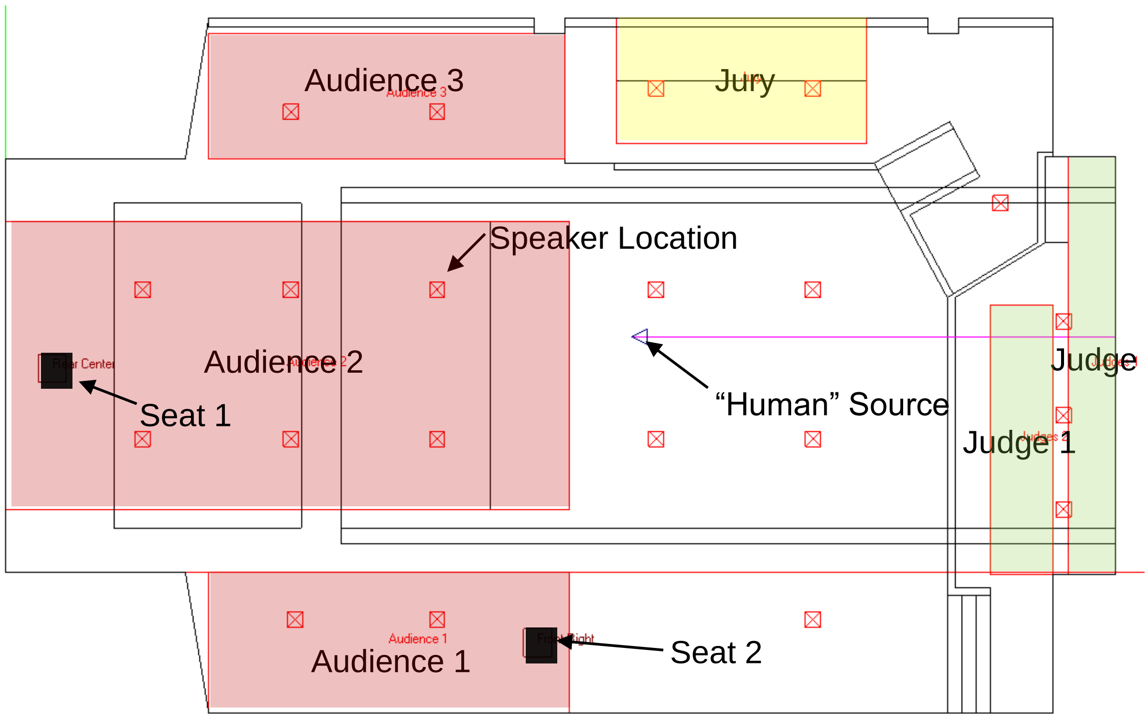


Figure 36 – Ceremonial Courtroom 4100 Plan

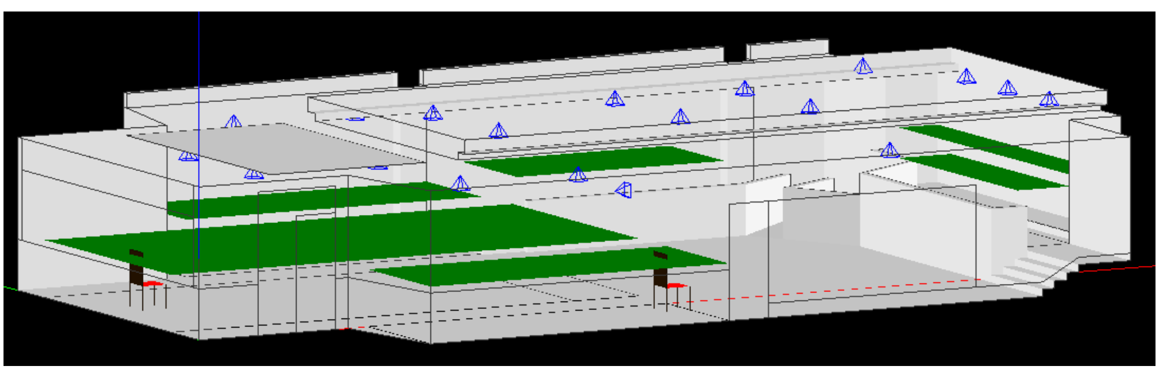


Figure 37 – Ceremonial Courtroom 4100 Perspective

3.3.3 Results

Figure 38 below shows the SPL distribution without sound reinforcement and Figure 39 below shows the SPL distribution with sound reinforcement. The sound distribution with the sound reinforcement system is at a higher level and is much more consistent than the unamplified speech distribution. This would help to improve speech intelligibility.

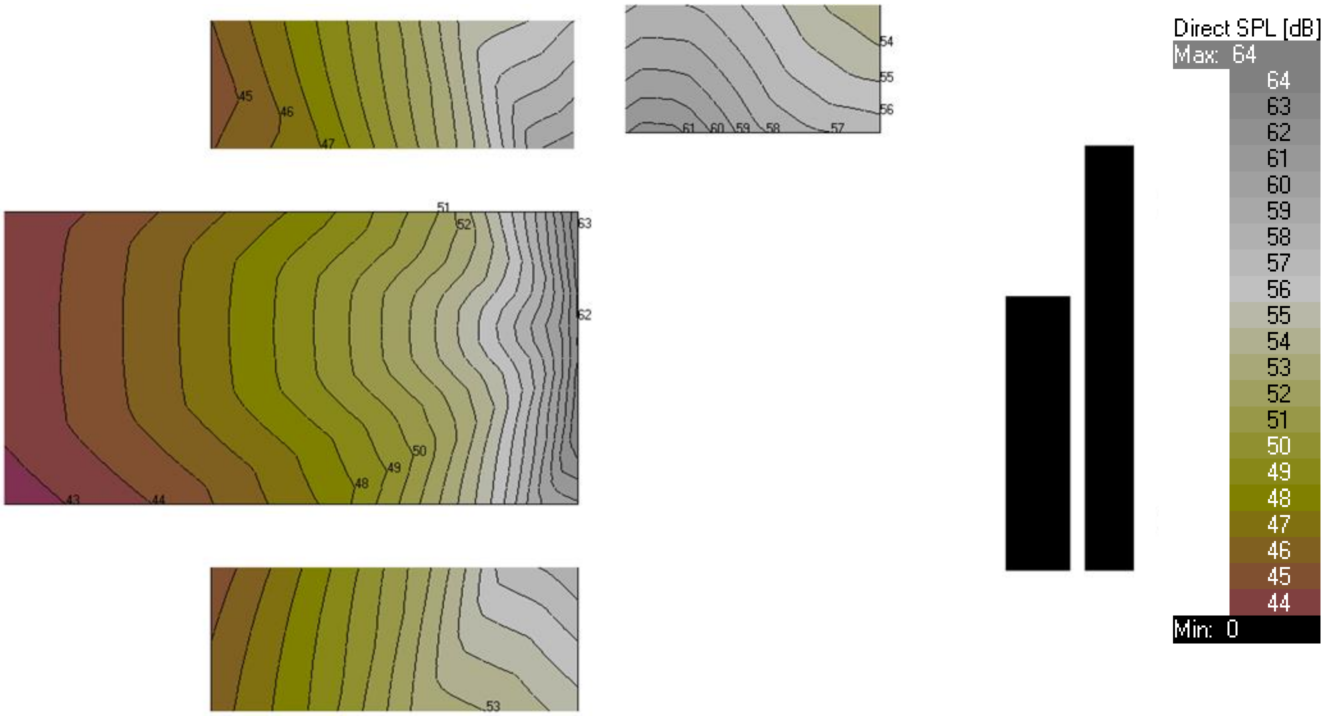


Figure 38 – Direct SPL Without Sound Reinforcement

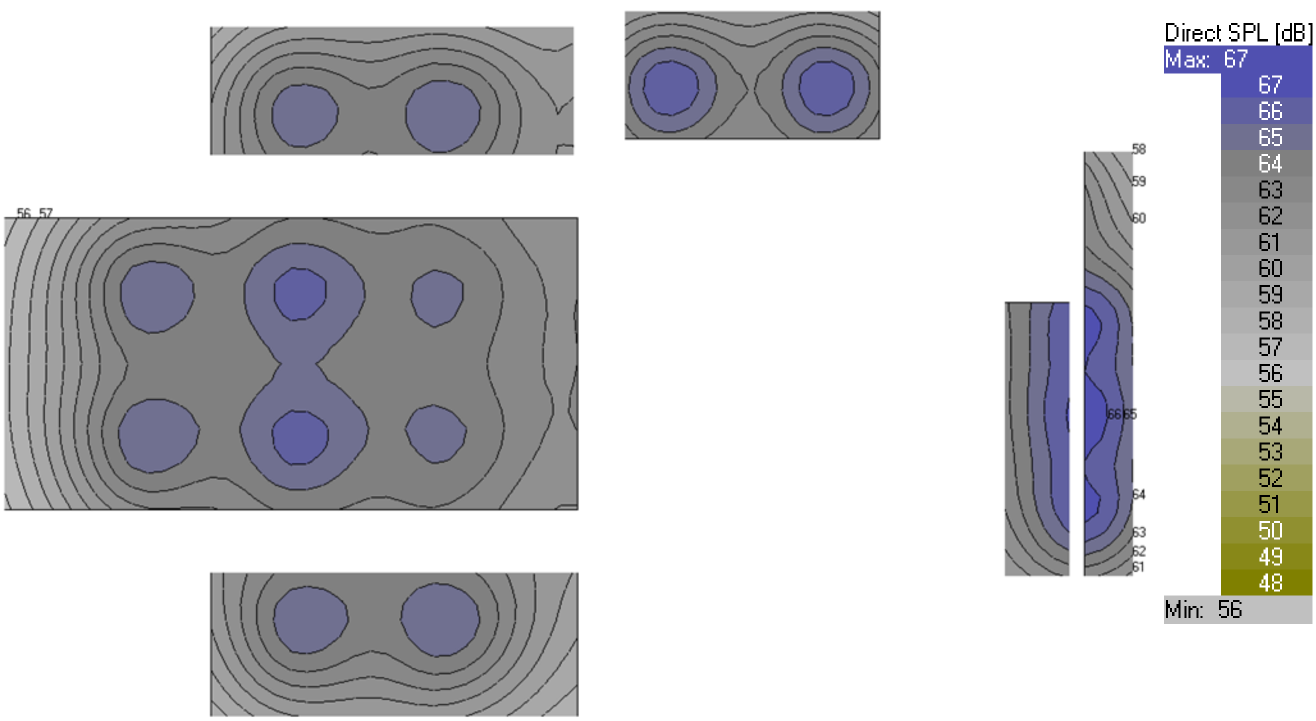


Figure 39 – Direct SPL With Audio Reinforcement

Figure 40 below shows the STI map without sound reinforcement and Figure 41 below shows the STI map with sound reinforcement. The STI with sound reinforcement is much higher and more consistent especially in the public seating areas than that of the unreinforced system.

Figure 40 – STI Without Sound Reinforcement

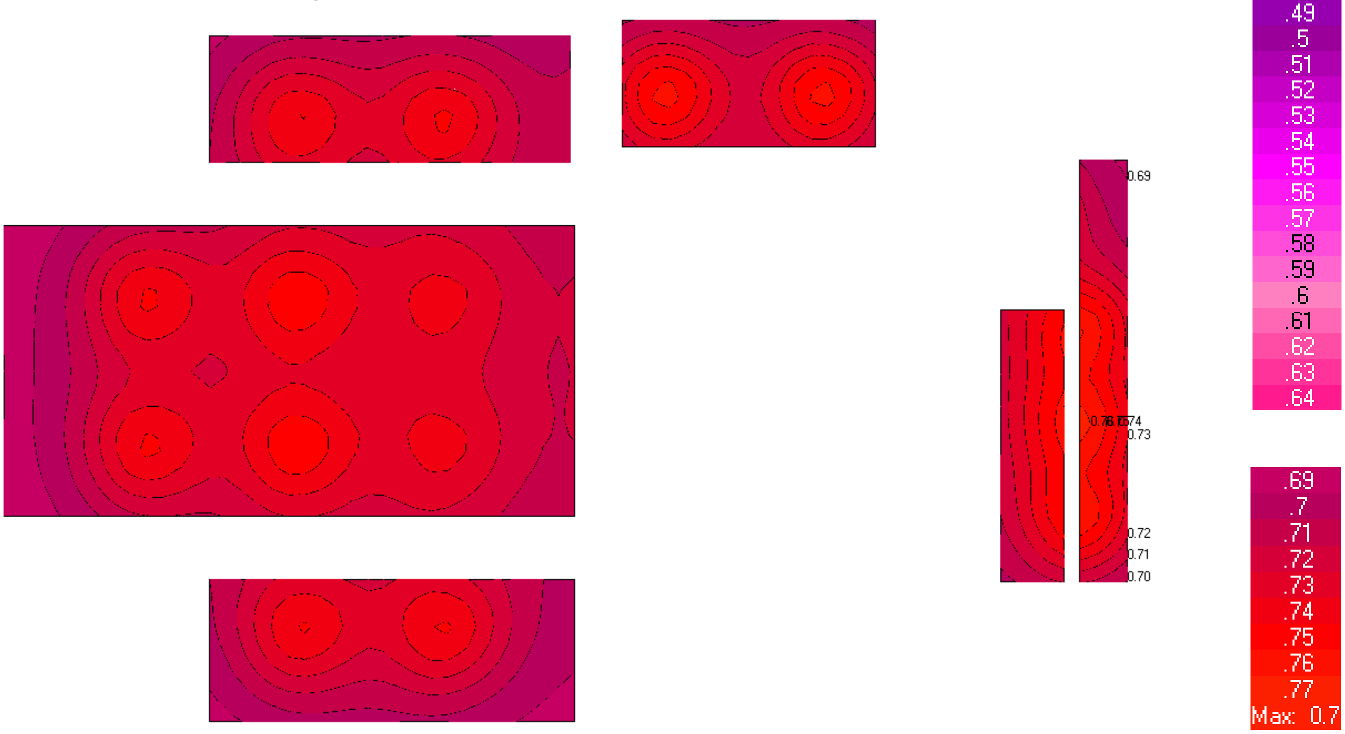


Figure 41 – STI With Sound Reinforcement

A background noise level (BNL) of 30 dB was used in the STI calculations.
The speaker used in the simulations was an Atlas FAP62T at an output level that was about 20dB below its output at 1W. For the simulation of unreinforced speech the “Man Loud” file provided in EASE was used at an unadjusted level.

Four auralizations were created to demonstrate how the room would sound with and without the sound reinforcement system. These auralizations were created by convolving the impulse response generated by the Aura module of EASE. The auralizations are described in Table 31 below and can be found at Y:\Lange_Thesis\Report_Files\Auralizations.

Table 31 - Auralizations

Source:	**Receiver Locations**	
Lawyer	Seat 1	Seat 2
Sound Reinforcement System	Seat 1	Seat 2

3.3.4 Conclusion

The analysis demonstrated that the sound reinforcement system greatly increased the level and uniformity of SPL throughout the listener areas. The analysis also showed a large improvement in STI for the listener areas when the sound reinforcement system was used. However, a value of 0.7 is considered a ‘good’ STI, but even with the sound reinforcement system the max STI is only 0.7. Further still, this value is achieved only directly below the speakers and for listeners further from the speaker STI is significantly lower. The STI could be improved by selecting a speaker with a wider distribution pattern.

4. Part 4 – Mechanical Breadth: Combined Heat and Power (CHP) Analysis

4.1 Introduction

A CHP system has the potential to greatly improve the primary energy efficiency of a building, reduce energy costs, and significantly reduce emissions associated with generation. An analysis was performed to evaluate the suitability of the BCJC for a CHP system. There was limited project specific data available so many design decisions were made based on existing data from similar projects and average values from similar buildings. The analysis included finding appropriate thermal and electric demands for the BCJC, checking the suitability of the loads for CHP, and calculating the simple payback period of a CHP system.

4.2 Analysis

The heating and cooling loads were extracted from a Trane Trace model. The model provided average hourly loads for Saturday, Sunday, Monday, and the average weekday for each month. The monthly loads were calculated by assuming there are 4.345 of each day per month. See Equation 5 below.

Equation 5 – Heating and Cooling Loads

$$Total\ monthly\ load = 4.345(Saturday + Sunday + Monday + 4 \times Average\ Weekday)$$

The electric demand was calculated based on data from the United States Energy Information Administration (EIA). EIA provided system separated annual electric use data for 25 office buildings that are in the Mid-Atlantic region, were constructed from 1990-1999, are between 200,001 and 500,000 SF, and use non-electric heat. The total annual electric usage for each subsystem was reported in mBTU. This consumption was averaged over the entire year and converted to watts and used to find the average electric demand per square foot. The average electric demand for the 25 buildings was found to be 2.41W/SF. By using the electric cooling subsystem data from EIA the average percentage of electricity used for cooling was found to be 11%. See Table 32 below for the electric demand data used in the analysis.

Table 32 – Annual Electric Use

Annual Electric Usage					
Annual Avg. (W/SF)	Hours per year	Building Area (SF)	Total Usage (KWh)	Cooling (KWh)	Other (KWh)
2.41	8,760	275,000	5,805,690	638,626	5,167,064

The electric used for cooling was distributed by month proportionally to the cooling loads for that month. The remaining electric use was distributed evenly across the months. See Table 33 below.

Table 33 – Monthly Loads

Month	Thermal Load (MMBTU)	Cooling Load (Tons)	Percentage of Cooling	Electric (KWh)
Jan	2,966	0	0%	430,589
Feb	2,936	0	0%	430,589
Mar	2,656	124	0%	430,753
Apr	2,396	5,758	1%	438,202
May	1,907	52,884	11%	500,513
Jun	1,568	92,296	19%	552,624
Jul	1,224	137,726	29%	612,692
Aug	1,573	121,058	25%	590,653
Sep	1,856	56,014	12%	504,651
Oct	2,288	12,761	3%	447,461
Nov	2,488	4,375	1%	436,374
Dec	2,758	0	0%	430,589
Total	**26,615**	**482,996**		**5,805,690**

The base electric load was found by taking the average electric use for the winter (December, January, and February) and the base thermal load was found by taking the average thermal demand for the summer months (June, July, and August). See Table 34 below.

Table 34 – Summer and Winter Average Demand and Seasonal Based Loads

Summer Average (June, July, August)	
Thermal (MMBTU/hr)	1.99
Electric (KW)	802

Winter Average (December, January, February)	
Electric (KW)	590
Thermal (MMBTU/hr)	3.95

Average Weather Demand	
Cooling Electric (KW)	212
Heating Thermal (MMBTU/hr)	1.96

A typical boiler efficiency of 80% was assumed for the calculations.

The 2013 average electric and natural gas costs for commercial customers in Pennsylvania were used to calculate spark spread and simple payback see Table 35 on the next page for fuel costs.

Table 35 – 2013 Average Fuel Costs

Fuel Cost	
Gas $/1000CF	10.15
Gas $/MMBTU	9.90
Electric $/KWh	0.11
Electric $/MMBTU	31.88

The difference between the cost of one MMBTU of electricity and one MMBTU of gas (known as spark spread) was calculated to be 21.98. The ratio of annual thermal energy demand to annual electric energy demand for the site (known as $\lambda_{D)}$ was calculated to be 1.34. Figure 42 and Table 36 on the next page show the monthly thermal and electric demand of the site as well as the monthly $\lambda_{D.}$

The United States Department of Energy (DOE) CHP Qualification Tool was used to calculate the simple payback period for an appropriately sized CHP system. The result of this calculation was 16.3 years. Which is significantly longer than most clients are willing to accept.

Figure 42 – Average Monthly Thermal and Electric Demand and Lambda D

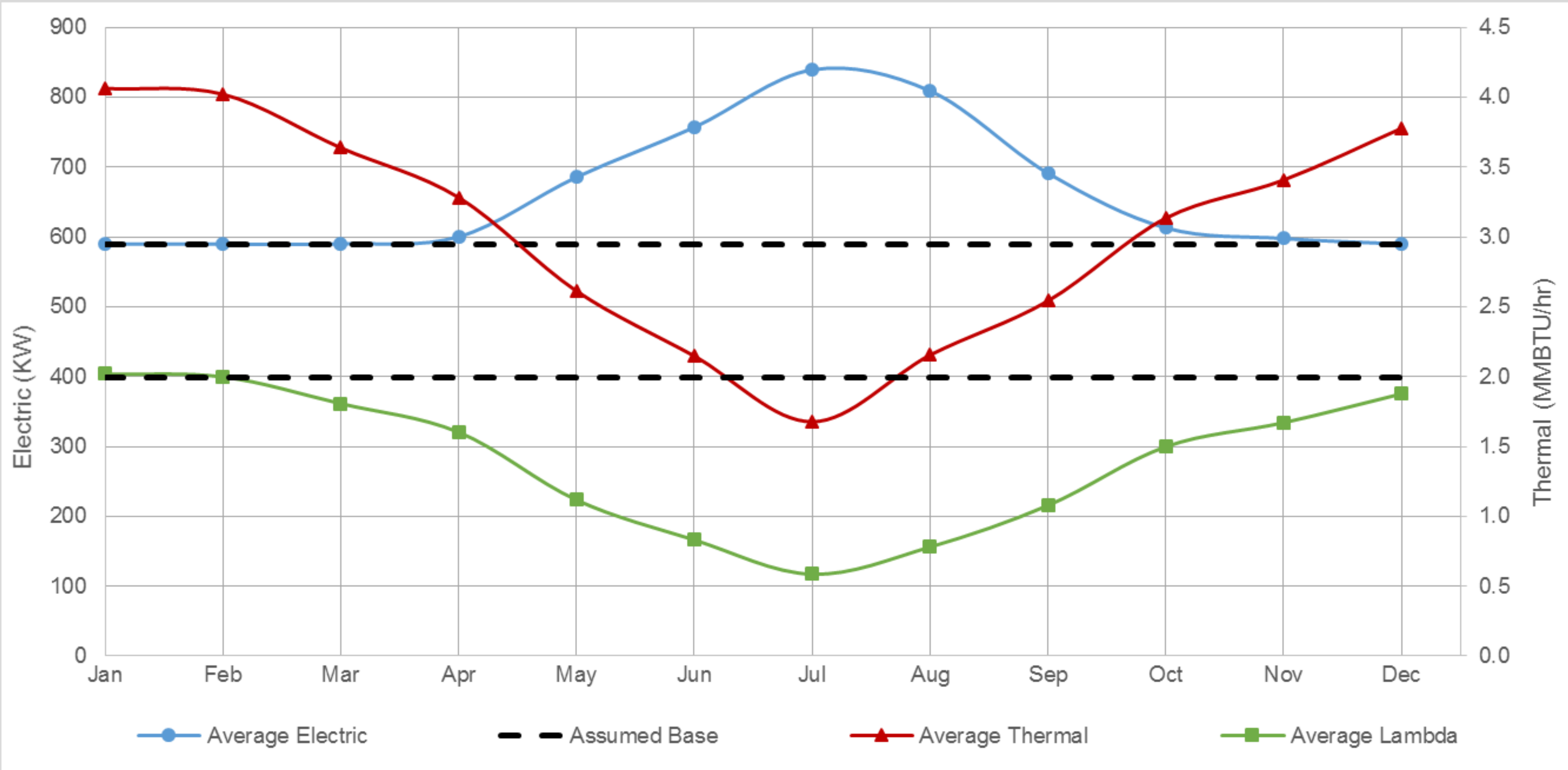


Table 36 –Thermal and Electric Demand and Lambda D

Month	January	February	March	April	May	June	July	August	September	October	November	December	Total
Heating Load	2,966	2,936	2,656	2,396	1,907	1,568	1,224	1,573	1,856	2,288	2,488	2,758	**26,615**
Monthly Electric	430,589	430,589	430,753	438,202	500,513	552,624	612,692	590,653	504,651	447,461	436,374	430,589	**5,805,690**
Days per month (Days)	30	30	30	30	30	30	30	30	30	30	30	30	**365**
Monthly Hourly average electric demand (KW)	589.85	589.85	590.07	600.28	685.64	757.02	839.31	809.12	691.30	612.96	597.77	589.85	**7,953**
Monthly Hourly average thermal demand (MMBTU/hr)	4.06	4.02	3.64	3.28	2.61	2.15	1.68	2.15	2.54	3.13	3.41	3.78	**36**
Monthly Hourly average λD	2.02	2.00	1.81	1.60	1.12	0.83	0.59	0.78	1.08	1.50	1.67	1.88	**0**
Electrical 'baseload' (KW)	590	590	590	590	590	590	590	590	590	590	590	590	**7,078**
Thermal 'baseload' (MMBTU/hr)	2	2	2	2	2	2	2	2	2	2	2	2	**24**

4.3 Conclusion

Despite the relatively high spark spread, which should have resulted in a short payback period, the payback period of a CHP system for this project was found to be 16.3 years. This is well beyond the range that most owners consider acceptable for an energy saving investment. A CHP system is not appropriate for this project due to the very low λ_D which is a result of there not being any system that requires thermal energy other than the heating system. If the site had a higher thermal demand then a larger system could be selected which would mean that the savings from a reduction in purchasing electric rom he utility company would be greater and thus there would be a shorter payback period.

Summary and Conclusion

The lighting depth of this report detailed the lighting redesign for four unique spaces in the BCJC. The goal of the designs was to meet the criteria that were established. The criteria included qualitative criteria as well as illuminance values and ratios from the IES Handbook and control and LPD requirements from ASHRAE. All of the spaces met the control requirements. All of the spaces had LPD's that were significantly below the maximum as shown in Table 37 below.

Table 37 – LPD Reduction from Maximum

Space	% LPD Reduction
Main Plaza	68
Main Lobby 1000	63
Open Office 2520	28
Ceremonial Courtroom 4100	64

The design illuminance values and ratios are generally in compliance with the targets, but there are some spaces that are not as close to the targets as was desired. This is mostly due to outlying analysis points being in locations that do not conform to the majority of the space. The illuminance targets not being exactly met was accepted because of the other design factors such as luminaire spacing/arrangement that would have been compromised by further adjustment.

The electrical depth of this report looked at the effects of the lighting breadth on the electrical distribution system and made the required changes. A short circuit study was performed to check that appropriately rated electrical equipment was selected. Finally, an investigation was performed into the potential of an increase in efficiency from the use of a DC distribution system. This revealed that there are not significant savings from a DC distribution system and that the added complexity of having a dual distribution system is not worth it.

For the acoustical breadth an analysis of the RT of Ceremonial Courtroom 4100 was performed. This analysis revealed that the RT of the original design was significantly below the target that was set for this project. As a result many material changes were made until the RT was in closer alignment with the criteria. However, the design RT was not in perfect agreement with the target especially in the 250 Hz octave and the 4000 Hz octave bands. This could have been resolved through the use of specialized construction materials, but this would have added significant cost and complexity to the project.

For the MAE breadth an analysis was performed on the influence of the sound reinforcement system in Ceremonial Courtroom 4100 on speech intelligibility. This analysis was performed using EASE. It was found that the sound reinforcement system greatly increases the SPL of the room and makes the SPL significantly more even as compared to an unamplified speaker. Additionally, the system also greatly improved STI, but was still in the low end of “good” values. This could be improved by using loudspeakers with a wider distribution.

The mechanical breadth of this report looked at the applicability of using a CHP system at the BCJC. Because data for this project was not available this analysis used average data from past similar projects for calculations. This analysis revealed that this project does not have a high enough thermal demand to make a CHP system economical and thus the payback period of the system was well beyond what is acceptable to most owners.

Overall, this project provided a wide range of opportunities for analysis and enabled me to sharpen a wide range of skills that will hopefully be used throughout my career in the construction industry.

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