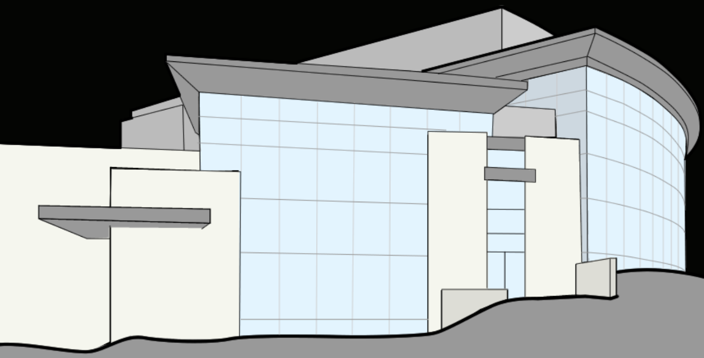
# Wentz Concert Hall and Fine Arts Center

North Central College
Naperville, Illinois

Advisors: Dr. R. Mistrick, Prof. T. Dannerth

AE 472 / 897G - Final Report

**Will Lesieutre**



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## and Fine Arts Center

North Central College, Naperville IL

Will Lesieutre - Lighting/Electrical

http://www.engr.psu.edu/ae/thesis/portfolios/2012/WWL5031

| | |
|---|---|
| Architecture | Total size: 57,000 $ft^2$<br>3 stories above grade / 1 partially below grade<br>Precast concrete and curtain wall exterior, with aluminum cornice<br>Centrally featured lobby flanked by two entrances<br>Concert hall (13,000 $ft^2$) seats 605<br>Black box theater (2,500 $ft^2$) designed for flexible layout<br>Art gallery (1,400 $ft^2$) for showcasing both student and professional work<br>Design, bid, build: Constructed July 2006 - September 2008<br>Total cost: $30.6 million |
| Lighting and Electrical | Power supplied by the Naperville Department of Public Utilities<br>Utility owned main transformer, pad mounted on northwest of site<br>Emergency power by 200kW/w50 KVA, 480Y/277 3Φ diesel generator<br>Power conditioning used for audiovisual loads<br>Primarily incandescent lighting in theater area and fluorescent in offices |
| Structural | Steel structural system with connections to exterior embedded in precast panels by manufacturer<br>Maximum design loads of 30 PSF SDL and 125 PSF LL<br>Due to the unusually shaped spaces, there is no standard bay design<br>Column sizes range from W10x54 to W14x283<br>Beam sizes range from W10x19 to W24x104 |
| Mechanical | Floor plenum system designed for silent air conditioning in concert hall<br>Ceiling diffusers and air returns used in the majority of other spaces<br>System is supplied by 8 RTUs and 5 air cooled condensing units<br>Heaters include both electric baseboards and cabinet units |
| Project Team | *Owner*<br>North Central College<br>*Architect*<br>Loebl Schlossman & Hackl<br>*Landscape Architect*<br>Hitchcock Design Group<br>*Structural Engineer*<br>Campbell & Associates<br>*MEP and Fire Protection*<br>WMA Consulting Engineers<br>*Theater Planner*<br>Schuler Shook<br>*Lighting Designer*<br>Schuler Shook<br>*Acoustics & Audio Consultant*<br>Talaske<br>*General Contractor*<br>Gilbane<br>*Construction Manager*<br>Gilbane |

# Executive Summary

The Wentz Concert Hall and Fine Arts Center is an exhibitional and educational facility constructed at North Central College in 2008. Located in Naperville, Illinois, the building is approximately 30 miles west of Chicago. It was designed to meet the needs of the college's educational programs, as well as to promote the arts in the wider Naperville community. This report will examine several aspects of the building and propose alternative design options.

The main focus of this study is a lighting and power redesign of four parts of the building: the main lobby, the concert hall, the music rehearsal room, and the façade. For the concert hall, it also includes studies of the space's architectural and acoustical aspects. For the lighting designs, an overarching theme is developed to help unify the spaces with each other and the overall architectural style. In the main lobby, I've performed a computer rendering using Radiance techniques learned in Flux Transfer Theory. The designs are performed with a focus on energy efficiency in what is traditionally an energy intensive building type.

Additionally, this report considers the alternative of a reduced number of transformers to serve its 120/208 V electrical loads, and the addition of a roof mounted solar array. A short circuit study of the electrical system is included, as is a protective device coordination study for a portion of the building.

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# Project Background

The Wentz Concert Hall and Fine Arts Center is owned and operated by North Central College, in Naperville, Illinois. It is the college's second fine arts facility, the first being Pfeiffer Hall, with 1,050 seats. The Wentz, completed in 2008, seeks to provide a smaller concert hall, seating 605, with greatly improved acoustics.

In addition to the concert hall, the facility has Naperville's first art gallery, as well as a black box theater. It also includes music practice rooms, offices, a computer lab, and a large rehearsal space.

# Existing Building Information

## Project Summary

- Building Name: Wentz Concert Hall and Fine Arts Center
- Location: North Central College, Naperville Illinois
- Function: Concert hall, art gallery, education
- Size: 57,000 $ft^2$
- Levels Above Grade: 2 (and catwalks)
- Total Levels : 3

## Design Team

- Architect: Loebl Schlossman and Hackl
- Landscape Architect: Hitchcock Design Group
- Structural Engineer: Campbell and Associates
- MEP and Fire Protection: WMA Consulting Engineers
- Theater Planner: Schuler Shook
- Lighting Designer: Schuler Shook
- Acoustics and Audio Consultant: Talaske
- General Contractor: Gilbane
- Construction Manager: Gilbane

## Lighting

Being a fine arts center, lighting systems are a critical aspect of the experience. The font of house areas, including the lobby, the art gallery, and the concert hall, are lit primarily by incandescent and halogen lighting. These provide a smooth spectrum of light, giving good and consistent color rendition through all of the spaces.

Restrooms, classrooms, offices, storage areas, the computer lab, and all of the other spaces that aren't likely to be a part of a visitor's experience to the fine arts center. In these spaces, lamp life and source efficacy outweigh the concerns in more public areas, and predominantly fluorescent lighting is used.

Fluorescent lamp types include 32W T8s, 31W U shaped T8s, 21W T5s, and 26W quad tube CFLs. A high pressure sodium lamp is used on the exterior at the loading dock.

Because of the nature of the facility, lighting controls are more complicated than what you'd see in a typical project. Two dimmer racks in the dimmer room are used by the concert hall lighting control system. Lighting in the public areas can be controlled by preset wall panels, with optional lockable covers. Smaller spaces, such as restrooms, offices, practice rooms, and storage, have occupancy sensors.

## Electrical

The power distribution system is laid out radially, a single point of entrance branching out through a small network panels before reaching the branch circuits. The utility serves the building at 480Y/120 volts through a pad mounted transformer outside the electrical room. From the main switchboard in the electrical room, large equipment (primarily HVAC) is served directly at 480 volts. Smaller loads (lighting, receptacles, and AV) are served through five smaller transformers throughout the building. All lighting loads are operated at 120V; there are no lights directly on the 480/277V system.

While the bulk of the electrical equipment is in the main electrical room and its neighboring emergency electrical room, the dimmer room on the first floor holds three of the five 120/277V transformers, as well as the two dimmer racks and several branch panelboards. One of these transformers (T1-DCTP-1) is an isolation transformer, serves the clean technical power system. Clean technical power is used for audio processing racks, amplifier racks, the control booth, and orange CTP receptacles throughout the concert hall's back of house spaces. The CTP loads are connected to an isolated ground. An additional three dimmer racks serve the black box theater's lighting. The remainder of the panelboards are housed in small electrical closets.

## Mechanical

The building has eight RTUs, six constant air volume and two variable air volume. The CAV units serve the concert hall, stage, black box theater, main lobby, and black box lobby. The VAV units serve the first floor and the lower level. Ventilation in the concert hall is provided through vaults under the floor, divided by CMU walls to direct airflow and reduce noise. The ductwork beneath the concert hall is plastic coated and buried in a concrete enclosure. As a result, the concert hall is almost completely silent.

Electric cabinet heaters are used in the vestibules by the main entrances. A number of spaces, particularly offices and theater support along the exterior walls, also include electric baseboard heaters.

## Structural

The structural system is a combination of structural steel and precast concrete. The load bearing precast wall runs around the entire concert hall area, up through the lower roof level. The wall behind the stage continues to the upper roof level. A smaller number of walls, directly adjacent to the concert hall, are load bearing CMU.

There isn't an overall column and beam grid that extends through the whole building; instead, it reacts to the shapes of the spaces. This is especially in the concert hall, where beams wrap around the edge of the balcony, and are cantilevered out from the lower columns. The office corridor's longest span is supported by a W18x75, while shorter spans are as small as W10x33.

## Fire Protection

The fire protection system is supplied by water entering the plumbing room on the north end of the building. The plumbing room contains the fire pump, as well as the fire pump control center and transfer switch to allow it to run on emergency power from the generator. The vast majority of sprinklerheads are recessed to preserve the architecturally clean spaces. The exception to this is areas without appropriately finished ceilings, including the black box theater.

## Transportation

There are two hydraulic elevators, one in the lobby for handicap access between the first floor and balcony level, and a second on the office corridor between the lower level and first floor. These floors are also accessible by stairs, with the main public stairs being between the lower black box theater lobby and main lobby, and at each end of the main lobby between the first floor and balcony level. There is also a stairway at each end of the office corridor, and back of house stairways into the balcony level reverb chambers, for access to the choral balcony. The catwalk level can be reached by a spiral staircase in the north reverb chamber.

## Audiovisual

Most of the facility is wired to the audiovisual system, at least to some degree. The back of house rooms (office, etc) on the lower level have ceiling speakers, as do the art gallery, main lobby restrooms, lobby balcony corridor, and others. The first floor of the lobby uses wall mounted speakers, due to the high ceiling.

The rehearsal room is outfitted with loudspeakers, a video projector, and a plug box for recording microphones. The concert hall includes several loudspeakers, and has plugboxes throughout the stage and catwalks with connections for microphones, tie lines, intercoms, speakers, video, data, and fiber. The main audio control center is at the back of the concert hall, on the first floor under the balcony.

# Lighting Redesign

# Main Lobby

## Space description

Important both as a gathering space and for providing access to the concert hall, the main lobby is long and relatively narrow. On one side, it has a high curtain wall, and on the other a wood paneled wall and balcony level corridor.

The north end of the lobby, by the main entrance, has a lower ceiling and contains the box office and coat check. Patrons enter through this area, and proceed through the main lobby space to enter the concert hall either on the first floor, or at the balcony level by means of stairs at each end. The southern end stairs wind around an elevator, while the northern end's instead house a small seating area.

### *Materials*

| Type | Reflectance/transmittance (approx) |
|---|---|
| Carpet | 20% |
| Wood | 15% |
| Paint – Columns | 80% |
| Paint – Ceiling | 60% |
| Paint – Upper Wall | 40% |
| Glazing | 50% |

## Design Criteria

The lobby serves two main purposes: it is a main circulation path between the main entry, black box theater lobby, and concert hall, as well as a gathering area before performances and during intermissions. Lighting levels must be designed to suit both of these uses.

### *Illuminance (High priority)*

A prefunction area outside a concert hall may adjust its lighting levels during events to allow easier transitions between spaces. Since the lobby here is also used as a central circulation space, lighting levels during events may need to be maintained at higher than the IES recommendation.

- Horizontal (average at floor)
    - 5 fc during production
    - 15 fc pre/post production and during intermissions
    - Avg:Min = 3:1
- Vertical (average at 5 ft. AFF)
    - 3 fc during production
    - 7.5 fc pre/post production and during intermissions
    - Avg:Min = 3:1

### *Glare (High priority)*

Since the lobby is used as a transition area from the concert hall, direct glare from light sources should be avoided. Exiting the concert hall during a performance into the brighter lobby will require some adaptation, and additional glare could be blinding.

### *Color Rendition*

Because of the rich materials used in the lobby, color rendering will be particularly important for lights illuminating the wooden walls.

### *Color Temperature*

As discussed above, warmer color temperatures are preferred in the concert hall. As this space is directly adjacent, it will be desirable to use the same color temperature here.

### *Sound*

While the vestibule between the lobby and concert hall helps to block light and sound, source sound emission should still be considered. In this case, quiet noises will not be problematic, but the buzz emitted by many magnetic ballasts would be undesirable.

### *ASHRAE 90.1 2010*

*Power Allowance (Mandatory)*

Lobby for performing arts theatre

- Lighting Power Density: 2.00 W/ft$^2$

- An additional allowance of up to 1.0 $W/ft^2$ is available for decorative lighting

*Automatic Shutoff (Mandatory)*

An automatic control device is required to control lighting in all spaces. It must be based on either a preset schedule, occupancy sensors, or information from another control system that indicates a space is not occupied.

*Display/Accent Lighting (Mandatory)*

Display or accent lighting must be controlled separately from general lighting.

*Automatic Daylighting Controls for Primary Sidelighted Areas (Mandatory)*

In sidelighted spaces over 250 $ft^2$, lamps for general lighting must be separately controlled by a multilevel photocontrol dimming system.

## Design Overview

Traditionally, the lobby of a concert hall or theater is lit with incandescent fixtures. As electricity prices rise and energy code become more strict, this strategy may become inappropriate. For the Wentz Concert Hall's lobby, I've designed it to reduce energy use by transitioning to CFL fixtures, which trade the optical control and color rendition of incandescent reflector lamps for much reduced energy use.

I've also modified the *Wentz Concert Hall* signage to be edge lit with LEDs instead of using spotlight to illuminate the entire wall. This lower amount of light and strong contrasts from the edge lighting fit the overall scheme I've used for the new lighting designs.

Figure 1: Main Lobby – First Floor North Lighting Plan

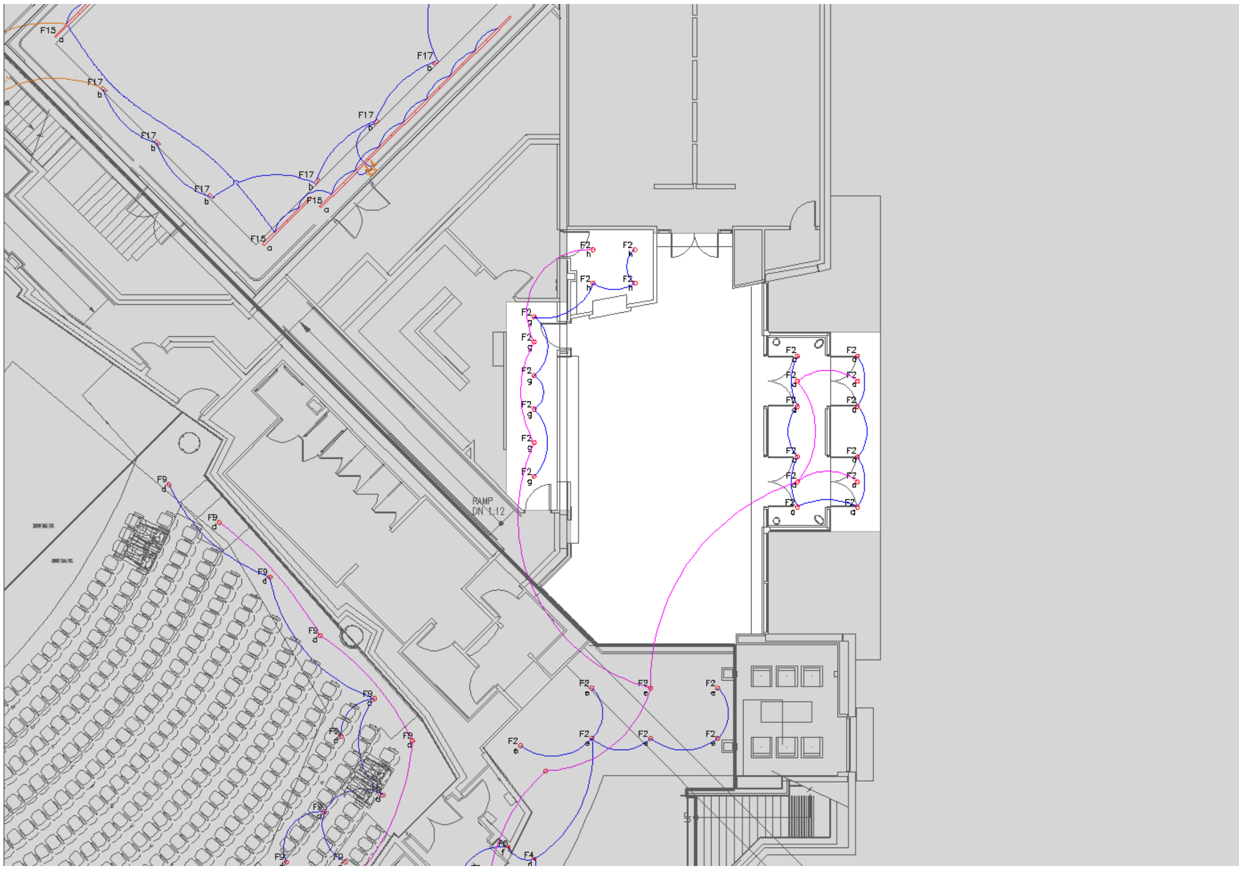


Figure 2: Main Lobby – First Floor South Lighting Plan

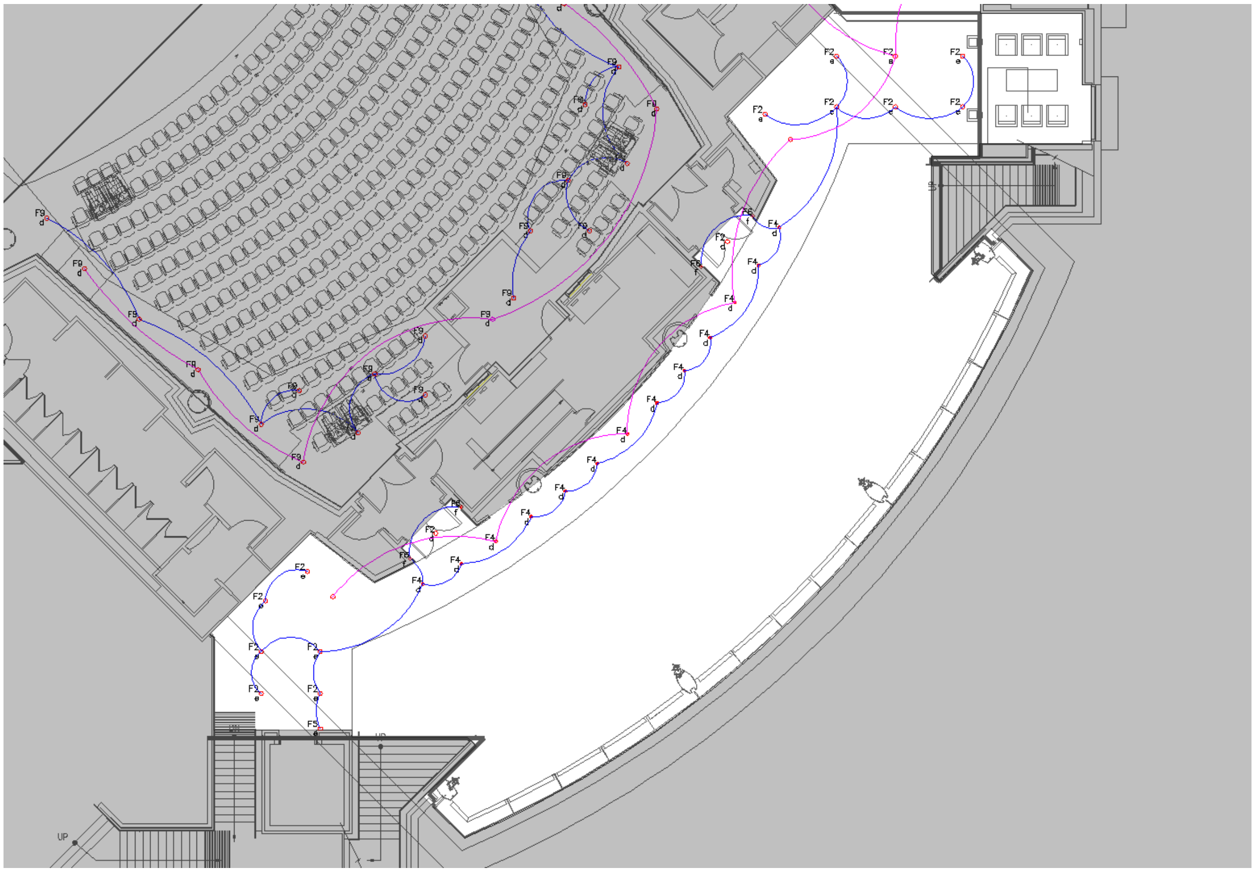


Figure 3: Main Lobby – Balcony Level North Lighting Plan

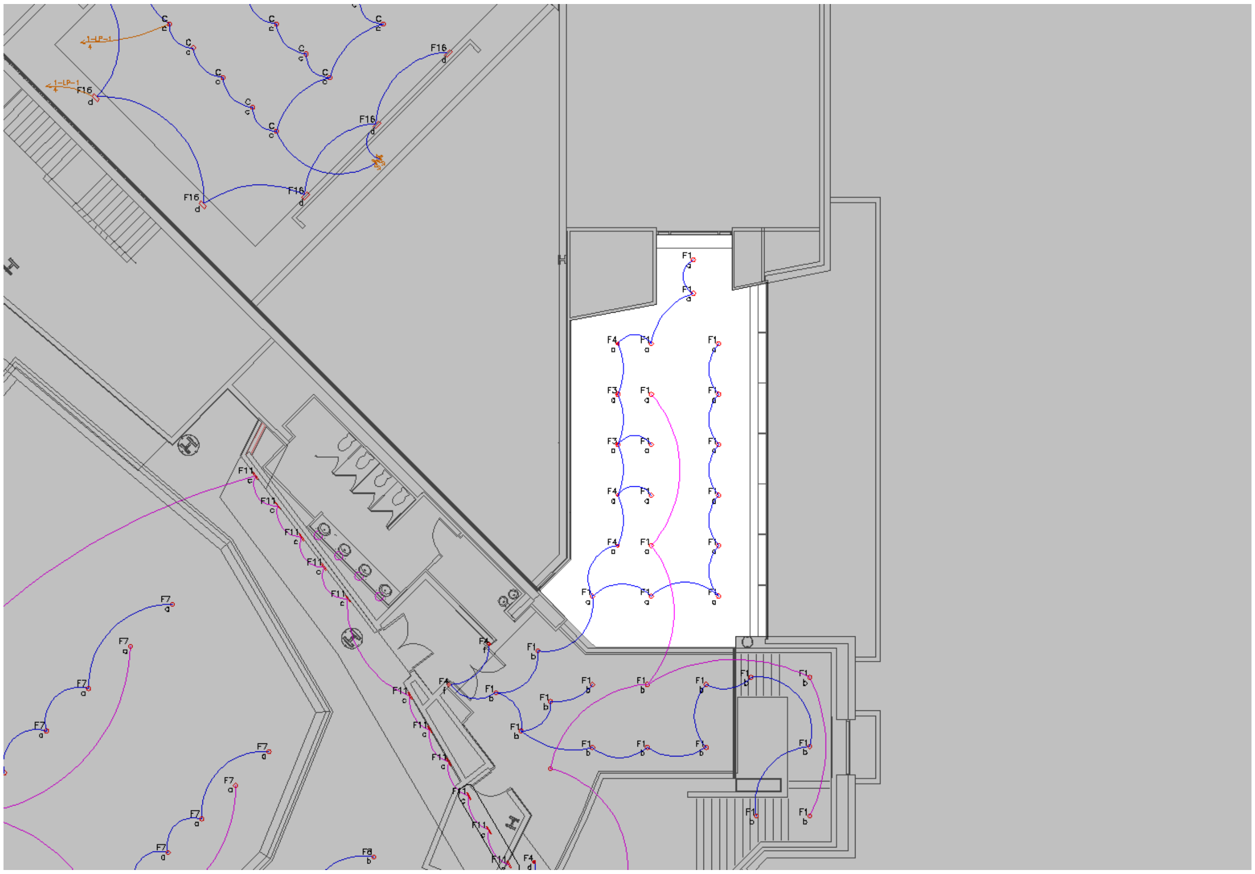
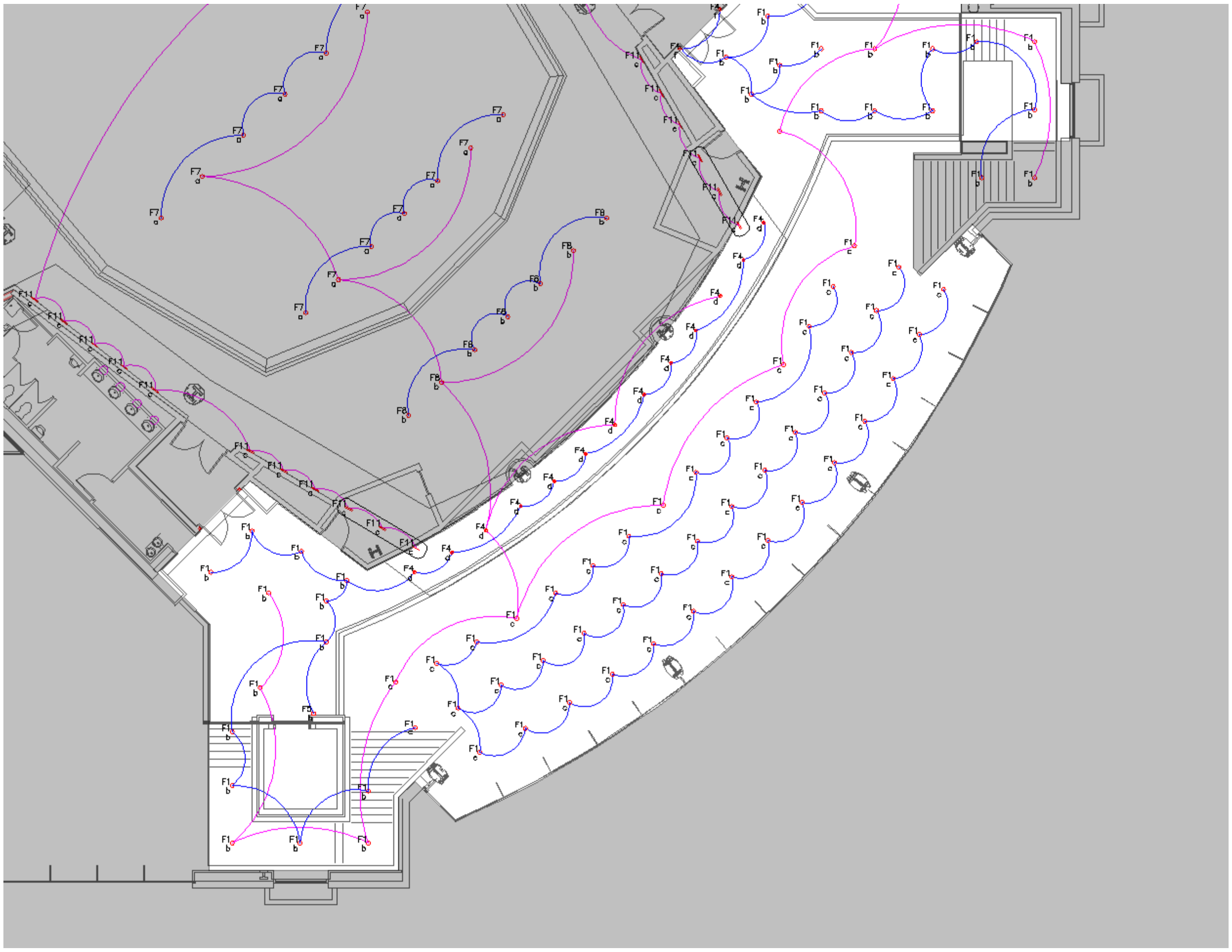


Figure 4: Main Lobby – Balcony Level South Lighting Plan



## *Lamp/Luminaire Selection*

Most of the space uses a standard CFL downlight in various wattages to account for the high and low ceilings. The wood walls are washed using a CFL wall washer, which have a color rendering index of 82. While this won't be as ideal for the warm materials, it's consistent with the rest of the space, and is much more efficient than incandescent alternatives.

Two wall sconces are used to mark the elevator and provide a visual connection between the floors. The seating area under the north stairs will be lit with a floor and table lamp to create a more appropriate scale.

## *Fixture Schedule*

| Type | Description | Manufacturer | Catalog Number | Lamp(s) | Input Watts |
|---|---|---|---|---|---|
| F1 | Unlensed 42W compact fluorescent downlight with 6" nominal aperture, white trim, and wheat reflector | Kurt Versen | P927DM-120-W-WT | (1) F42TBX/827/A/ECO by GE | 43.2 |
| F2 | Unlensed 26W compact fluorescent downlight with 6" nominal aperture, white trim, and wheat reflector | Kurt Versen | P626DM-120-W-WT | (1) F26DBX/827/ECO4P by GE | 26.4 |
| F3 | Unlensed 42W compact fluorescent wall washer with 6" nominal aperture, white trim, and wheat reflector | Kurt Versen | P953DM-120-W-WT | (1) F42TBX/827/A/ECO by GE | 43.2 |
| F4 | Unlensed 18W compact fluorescent wall washer with 4" nominal aperture, white trim, and wheat reflector | Kurt Versen | P919DM-120-W-WT | (1) F18TBX/827/A/ECO by GE | 21.3 |
| F5 | Shielded 3' T5 wall sconce with diffuse white acrylic panel | Lightolier | 48022ALU-21W-120 | (1) F21W/T5/830/ECO by GE | 25 |
| F6 | Continuous diffuse LED strip light with dimmable driver | Birchwood Lighting | JAKE-325-TR-1-HF2N-H-30-CRx-120-CU | 54 3000K LEDs per 10" section | 5 W/ft |

## *Light Loss Factors*

Type F1

- LLD = 2690/3200 = 0.84
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.76

Type F2

- LLD = 1530/1800 = 0.85
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.77

Type F3

- LLD = 2690/3200 = 0.84
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0

- Total = 0.76

Type F4

- LLD = 1010/1200 = 0.84
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.77

Type F5

- LLD = 1930/2100 = 0.92
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.83

Type F6

- LLD = 0.8 (estimated)
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- Total = 0.73

## Control System

Lobby control zones:

a) Entry lobby downlights and wall washers
b) Balcony level downlights
c) Main lobby downlights
d) First floor and balcony wall washers
e) First floor downlights
f) Concert hall entry LEDs
g) Coat check
h) Box office

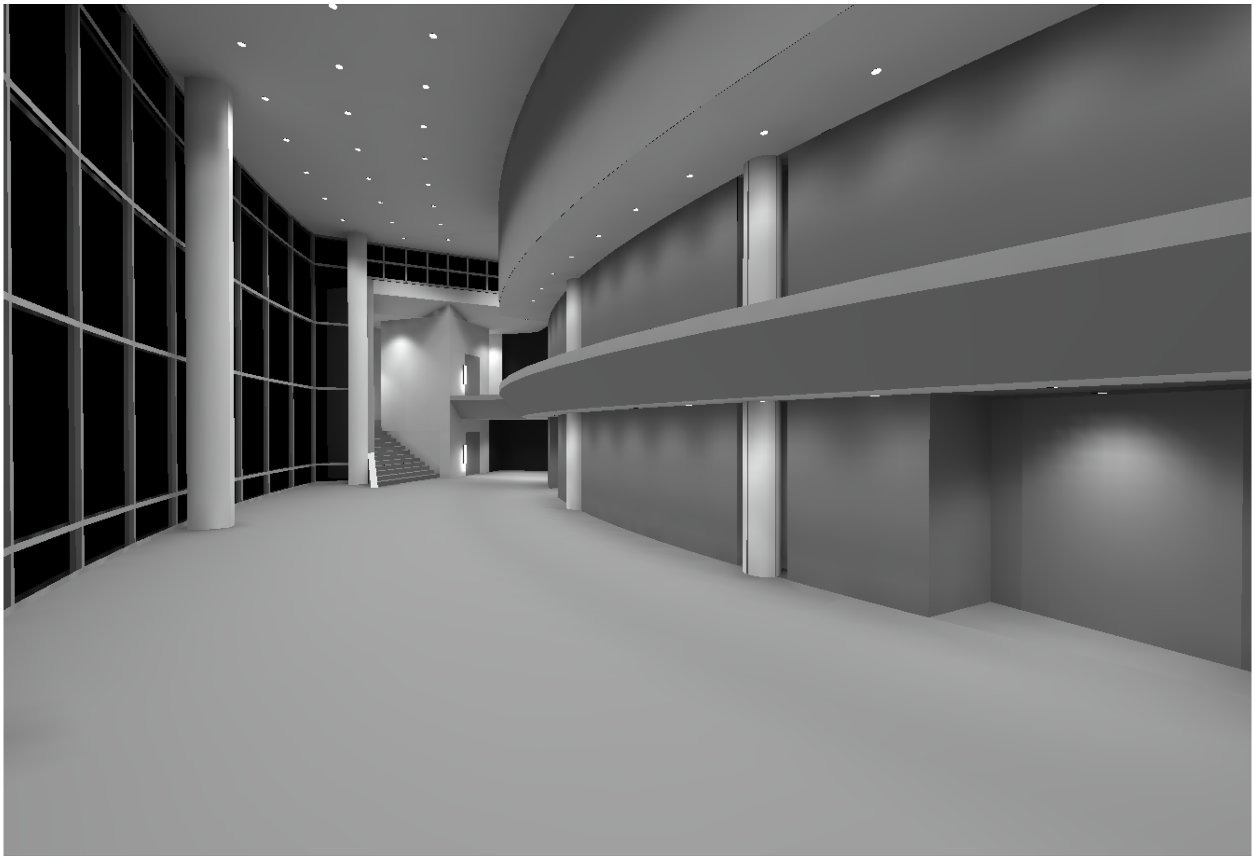
Controlled by Grafik Eye 4000. See electrical section for details of control system.

## Design Performance

Figure 5: Main Lobby Rendering (north)

The large dark area in this rendering represents a transition to the art gallery, which is out of the scope of this project. As you can see, the downlights illuminate the space evenly, and wall washers highlight the wood wall on the left, as well as providing additional vertical illuminance at the coat check and box office counters.

Figure 6: Main Lobby Rendering (south)

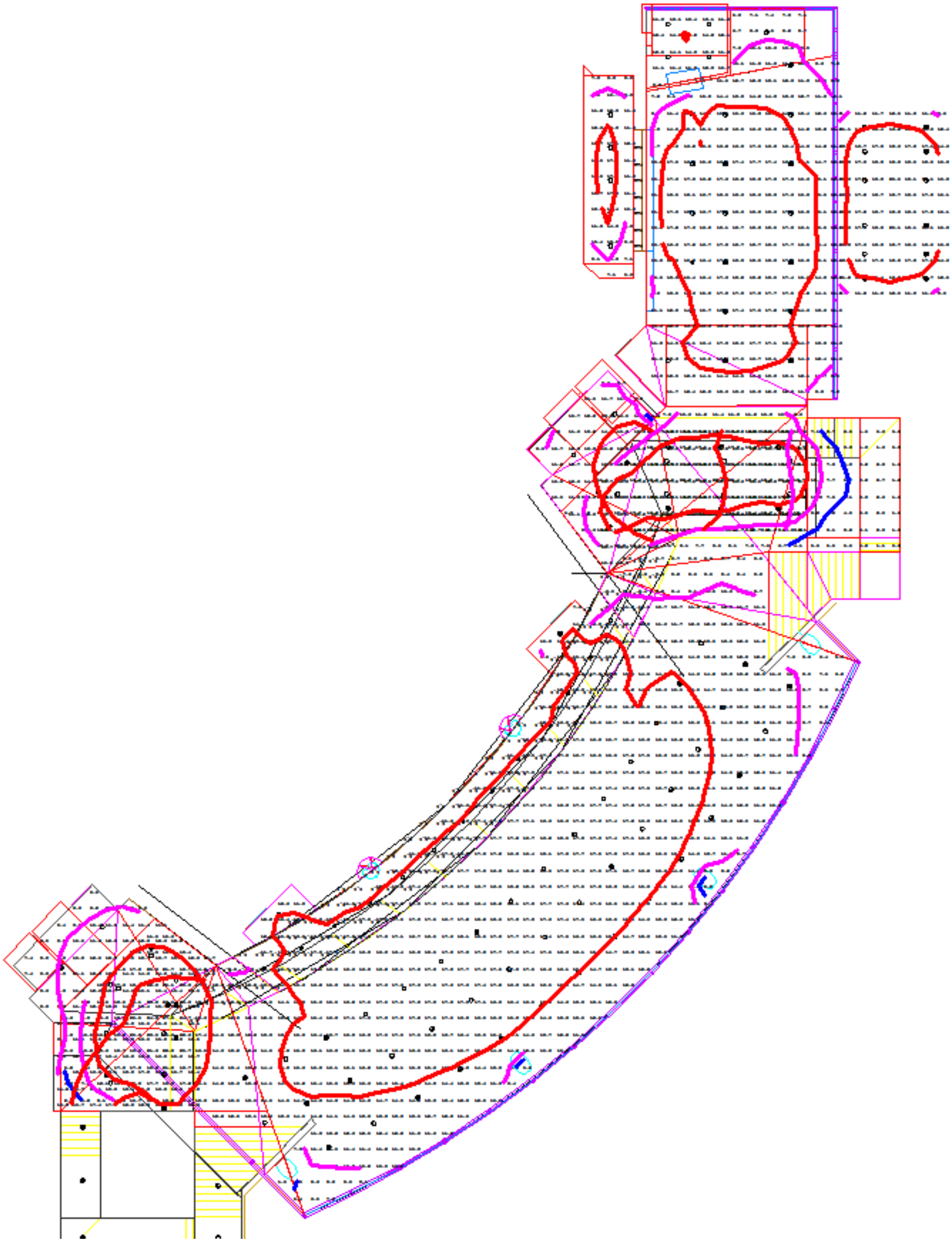


This rendering shows the larger portion of the main lobby, with one of the doors to the concert hall on the right hand side. Not illustrated are the linear seemless LED fixtures that are mounted in an arch around the door, and used to draw attention to the circulation destination. This fixture also helps tie the design of the lobby into the linear fixtures used prominently in the concert hall.

Also not included in the calculation is the large Wentz Concert Hall lettering on the upper right wall. This signage is to be lit using a flexible LED edge lighting strip, providing it with higher contrast, and avoiding shadows that would be cast by spotlights. This signage is visible from the outside, through the large curtain wall.

Circulation destinations are clearly visible: the scallop and LED arch mark the concert hall doors, a bright downlight illuminates the wall over the stairs, and a tall linear sconce visually connects the two elevator doors.

Figure 7: Main Lobby Isoilluminance Lines



Red: 15 fc Magenta: 10 fc Blue: 5 fc

The blue contour line under the north stairway is a seating area which will be illuminated by a table and floor lamp. These are not included in the calculation. All other areas are satisfactory.

### *Lighting Power Density*

| | |
|---|---|
| Area | 7,167 $ft^2$ |
| Max Power Density | 2 $W/ft^2$ |
| Lighting power allowance | 14.334 kW |
| Decorative allowance | 7.167 kW |

| Type | Quantity | Watts/Fixture | Type total | |
|---|---|---|---|---|
| F1 | 83 | 43.2 | 3585.6 W | |
| F2 | 40 | 26.4 | 1056 W | |
| F3 | 2 | 43.2 | 86.4 W | |
| F4 | 29 | 21.3 | 617.7 W | |
| F5 | 2 | 25 | 50 W | |
| F6 | 72.666 ft | 5 W/ft | 363.33 W | (Decorative) |

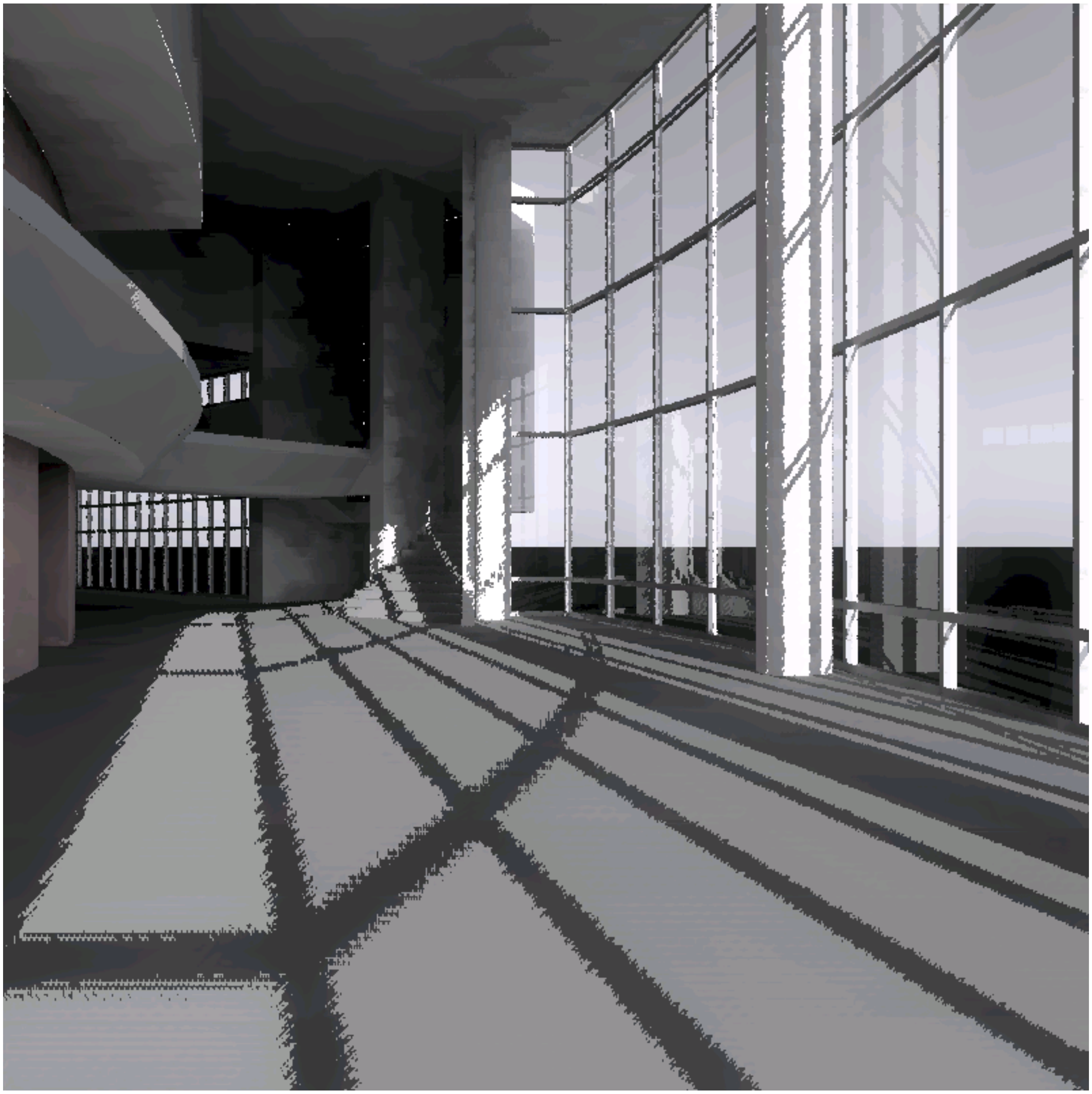
| | |
|---|---|
| Total lighting power | 5.3957 kW |
| Space power allowance | 14.334 kW |
| Total decorative power | 0.363 kW |
| Space decorative allowance | 7.167 kW |

Lobby meets ASHRAE 90.1 2010's lighting power density requirements for a building lobby.

## Radiance Rendering (MAE Breadth)

Based on the discussions of Radiance from Flux Transfer Theory and Daylighting, I've produced a rendering of the main lobby.

Figure 8: Lobby Radiance Rendering



# Concert Hall

## Space description

The Wentz Concert Hall, named after Dr. Myron Wentz, is the focal point of the Wentz Concert Hall and Fine Arts Center, and the space's design plainly shows this. Spanning the first floor and balcony level, warm finishes and upholstery make the space intimate and comfortable, despite its relatively large size.

The balcony level protrudes only slightly over the back of the first floor seating, and the faceted edge of the balcony is mirrored at the perimeter below the ceiling, giving both levels a similar scale despite the wide open spaces. Curtains on the balcony level walls and behind the stage on the first floor add texture to the space, and allow for the concert hall's acoustics to be adjusted.

The walls on the first floor are finished with a textured wood panel, consisting of narrow horizontal strips, in sections that protrude various distances from the wall. The strip element is carried through the rest of the concert hall with an element on the balcony, and another series of them on the upper side walls.

### *Materials*

| Type | Reflectance (approximate) |
|---|---|
| Carpet | 30% |
| Wood | 30% |
| Curtains | 50% |
| Paint – Walls | 60% |
| Paint – Ceiling | 80% |
| Paint – Balcony | 40% |

## Design Criteria

### *Illuminance*

*Audience seating*

The main tasks performed in the audience area are wayfinding, facial recognition, and reading programs. Lighting must be sufficient for patrons to easily and safely find their seats, and must smoothly dim to the low levels required during a performance.

- Horizontal (average at floor)
  - 0.2 fc during production
  - 10 fc pre/post production and during intermissions
  - Avg:Min = 2:1
- Vertical (average at 5 ft. AFF)
  - 0.1 fc during production
  - 3 fc pre/post production and during intermissions
  - Avg:Min = 2:1

*Aisles*

Used for circulation by large crowds, the aisle lighting is critical for ensuring that patrons can quickly and safely navigate the concert hall. As with other lighting in the concert hall, it must also be smoothly dimmable to very low levels.

- Horizontal (average at floor)
  - 0.2 fc during production
  - 10 fc pre/post show and during intermissions
  - Avg:Min = 5:1
- Vertical (average at 5 ft. AFF)
  - 0.1 fc during production
  - 3 fc pre/post production and during intermissions
  - Avg:Min = 2:1

*Control Booths*

Control of light and sound is crucial to the success of an event, but it must be done without lighting that would be distracting to the audience. To this end, control panels are frequently backlit to alleviate the need for supplemental lighting.

- Horizontal (average at floor)
  - 0.2 fc during production
  - 20 fc pre/post production and during intermissions
  - Avg:Min = 2:1

### Isolation (High priority)
Given the importance of a dark environment in the concert hall during productions, care must be taken to prevent light from external sources into the space.

### Glare (High priority)
Direct glare from light sources should be avoided, since it could interfere with adaptation to the low light levels. Bright light sources detract attention from the intended focus on the stage.

### Color Rendition
Good color rendering is important for stage lighting, and using sources with similar color rendering throughout the space will maintain uniform appearance of room finishes.

### Color Temperature
Warm materials are used throughout the space, and a similarly warm color temperature should be selected for light sources.

### Sound
As the concert hall is an acoustically sensitive environment, sources should be selected to avoid background noise generation.

### ASHRAE 90.1 2010
*Power Allowance (Mandatory)*

Permanent audience / seating area for performing arts theatre

- Lighting Power Density: 2.43 W/ft$^2$
- Theatrical lighting equipment is exempt from this allowance, the full amount is available for architectural lighting purposes
- An additional allowance of up to 1.0 W/ft$^2$ is available for decorative lighting

*Automatic Shutoff (Mandatory)*

An automatic control device is required to control lighting in all spaces. It must be based on either a preset schedule, occupancy sensors, or information from another control system that indicates a space is not occupied.

*Display/Accent Lighting (Mandatory)*

Display or accent lighting must be controlled separately from general lighting.

## Design Overview

The concert hall's architecture is strongly linear, with horizontal elements throughout. These include the wood paneling on the walls, wooden strips across the reverberation chamber's screen, matching strips on the balcony level walls, and a number of architectural shelves designed to match the angular profile of the balcony level's edge.

My lighting solution seeks to reduce energy usage by using glowing linear fixtures to accent these features, rather than illuminating the walls with energy-intensive incandescent wall washers or grazers. To this end, I've selected two LED fixtures: a 3.5" continuous linear fixture with a diffuse lens, and an architectural neon replacement that can be easily surface mounted for smaller accents. These two fixtures are integrated into horizontal elements, defining the space while directing audience attention forward to the stage, where walls are brightly lit.

Figure 9: Concert Hall – First Floor Lighting Plan

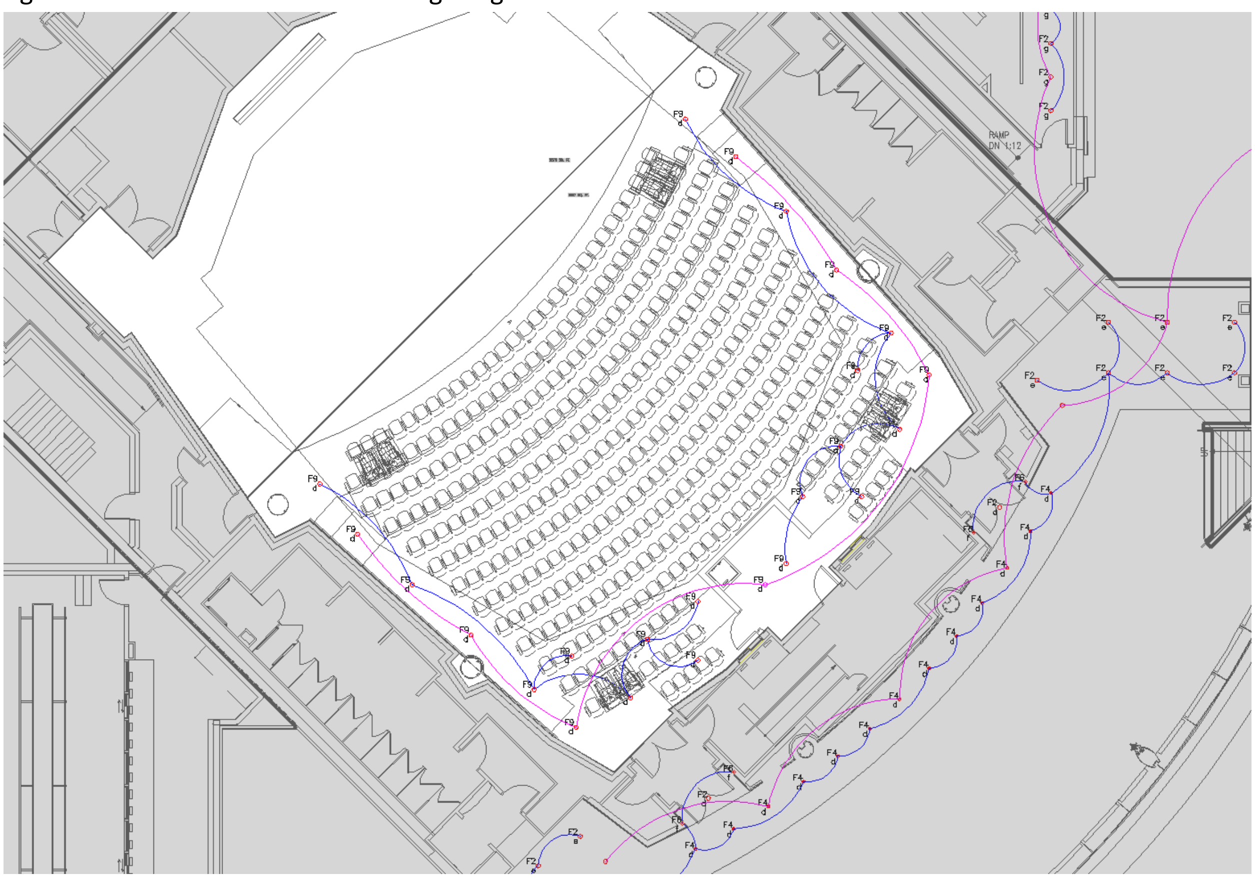


Figure 10: Concert Hall – Balcony Level Lighting Plan

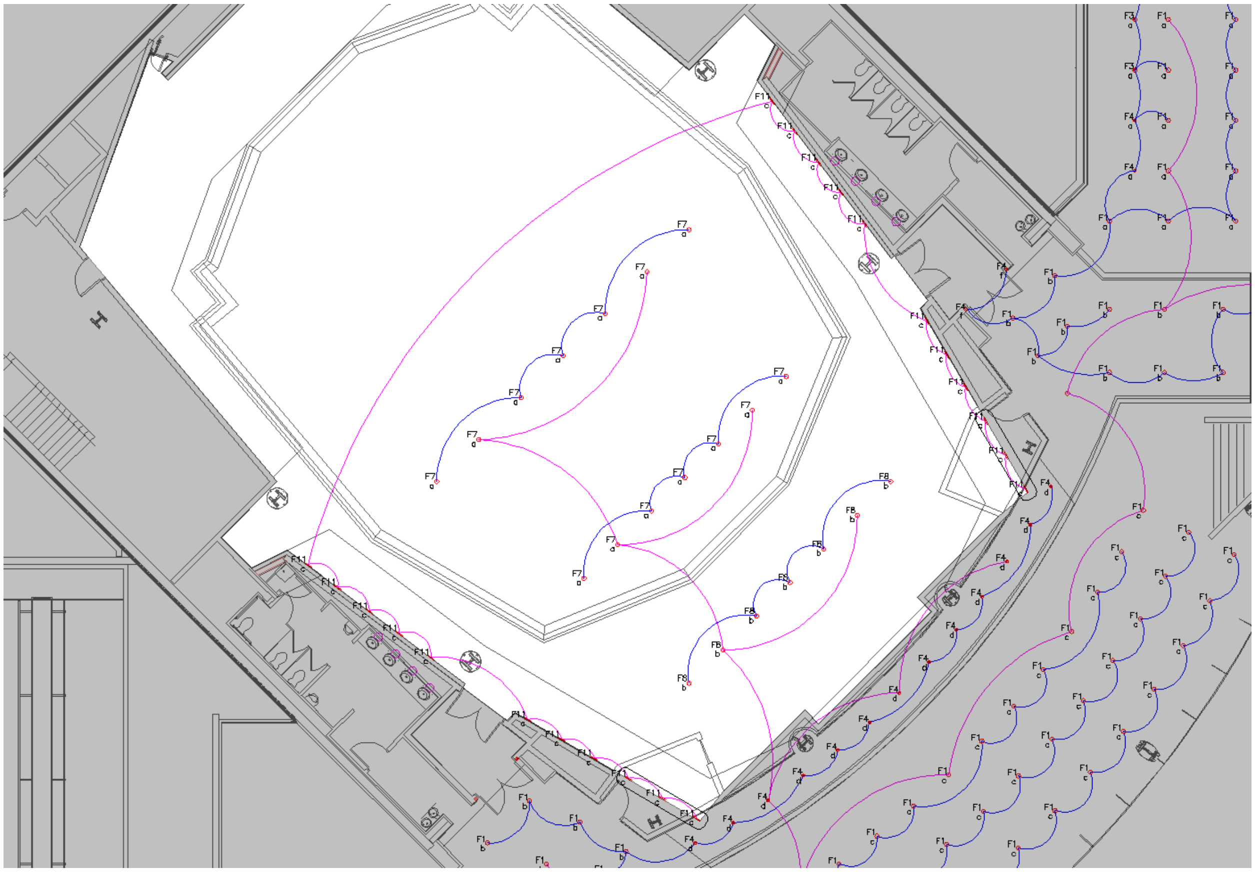
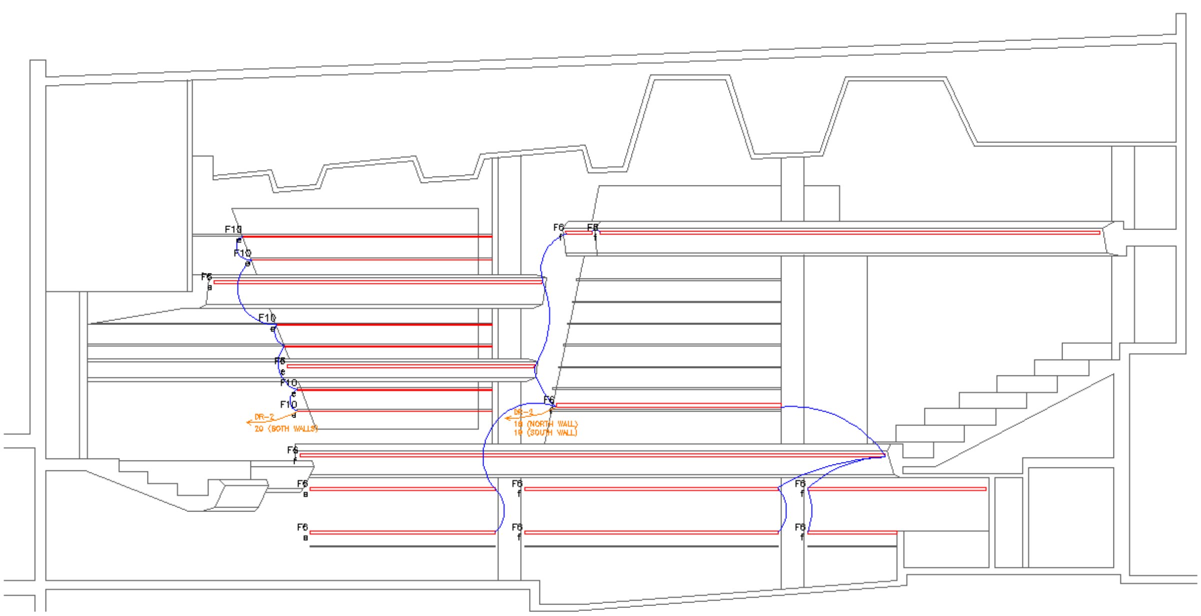


Figure 11: Concert Hall – Wall Lighting Plan



## *Lamp/Luminaire Selection*

The primary source of light in the space is halogen incandescent downlights with PAR38 and PAR30 lamps in the upper ceiling and below the balcony. These are selected to provide light with the same color temperature and spectral distribution as the stage lights so that the room's materials will be rendered uniformly throughout.

Additional lights are LED based, including steplights for the balcony aisle where the catwalks above wouldn't allow for maintenance access to downlights. A 3.5" linear strip with a continuous diffuse lens is used as a primary architectural accent light, with smaller accents provided by an LED neon-replacement fixture. This allows for easier installation, while providing a similar linear glow.

## *Fixture Schedule*

| Type | Description | Manufacturer | Catalog Number | Lamp(s) | Input Watts |
|---|---|---|---|---|---|
| F7 | Top relampable 250W PAR38 halogen downlight with white trim | Kurt Versen | C7302-W-WT | 250PAR38HALFL30 by Sylvania | 250 |
| F8 | Top relampable 90W PAR38 halogen downlight with white trim | Kurt Versen | C7302-W-WT | 90PAR/FL25XL-EG by GE | 90 |
| F9 | Top relampable 75W PAR30 halogen downlight with white trim | Kurt Versen | C7301-W-WT | 75PAR30/H/FL35 by GE | 75 |
| F6 | Continuous diffuse LED strip light with dimmable driver | Birchwood Lighting | JAKE-325-TR-1-HF2N-H-30-CRx-120-CU | 54 3000K LEDs per 10" section | 5 W/ft |
| F10 | Linear LED neon-replacement with diffuse white light guide and dimmable driver | GE | GEWWXNLE1-30K-A | 3000K LEDs | 3.39 W/ft |
| F11 | LED steplight with black front-plate, fully shielded aperture, and dimmable driver | Cole Lighting | L-2158-BLK | 6W 3000K integrated LED | 8 |

## *Light Loss Factors*

Type F7

- 0.8 (estimated)

Type F8

- 0.8 (estimated)

Type F9

- 0.8 (estimated)

Type F6

- LLD = 0.8 (estimated)
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- Total = 0.73

Type F10

- 0.8 (estimated)

Type F11

- 0.8 (estimated)

### *Control System*

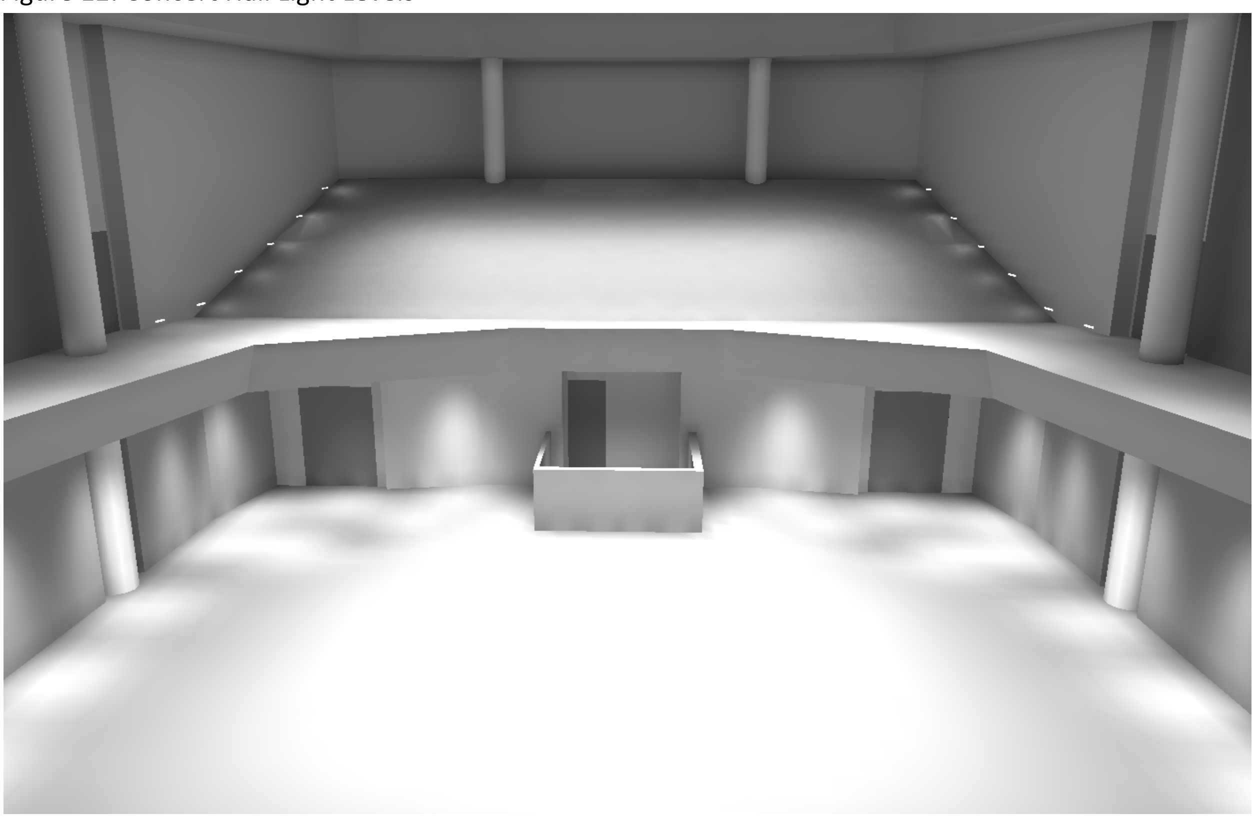
Concert hall control zones:

a) Upper downlights (for first floor seating)
b) Upper downlights (for balcony seating)
c) Balcony steplights
d) First floor downlights
e) Front linear LEDs
f) Other linear LEDs

Controlled by Grafik Eye 4000. See electrical section for details of control system.

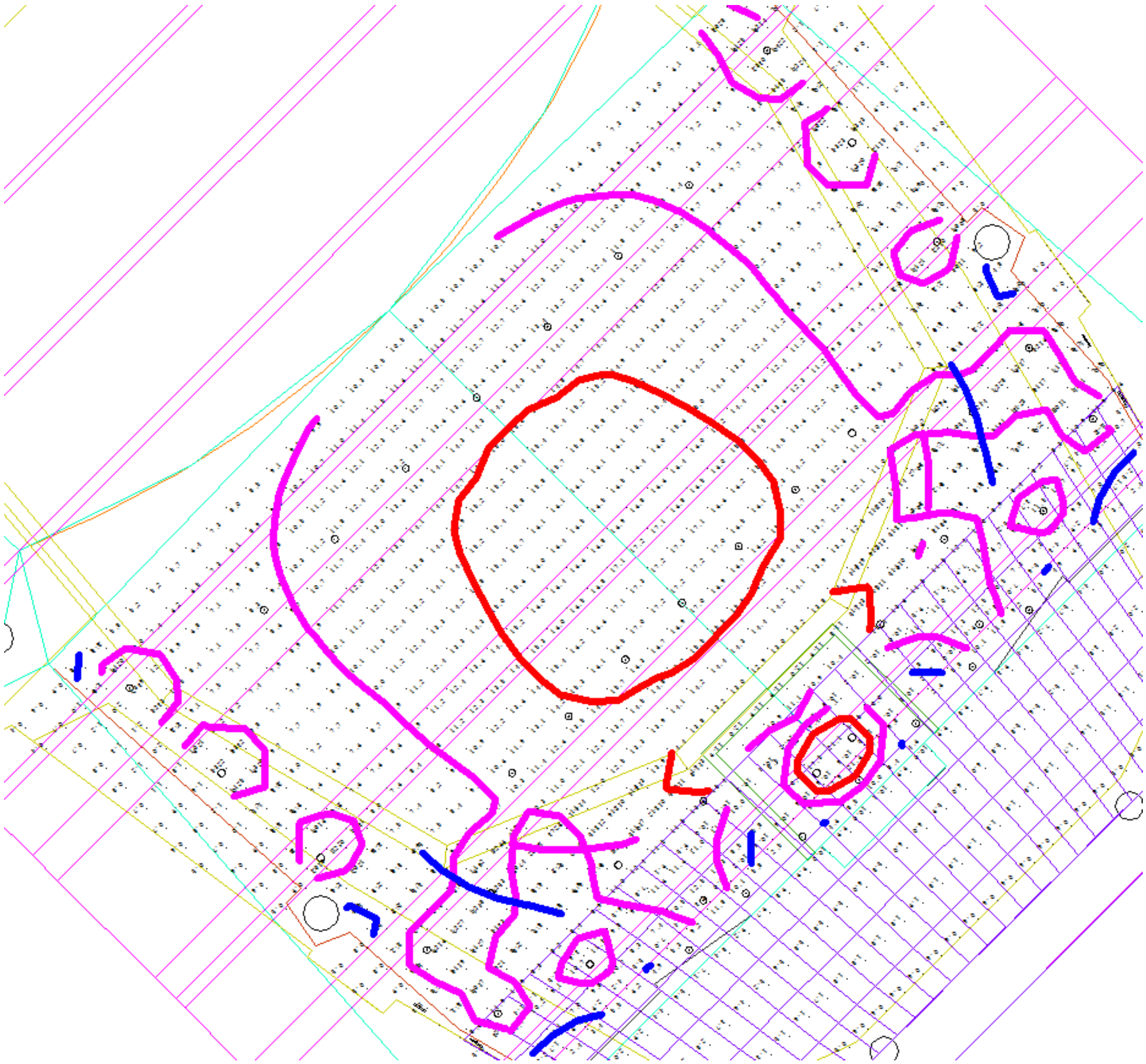
## Design Performance

Figure 12: Concert Hall Light Levels



As you can see in the above rendering, the first floor is brightly illuminated. The balcony relies on steplights for the aisles because the ceiling isn't accessible from catwalks at the edge to relamp downlights. Note that the light level calculation only includes the general illumination, decorative linear fixtures were not calculated because photometry information was not available.

Figure 13: Concert Hall Isoilluminance Lines



Red: 15 fc Magenta: 10 fc Blue: 5 fc

The concert hall's audience seating area targets 10 fc, marked by the magenta lines, and it achieves that out to almost the edge of the seating area. In the center it reaches 15 fc because the catwalk's limited accessible ceiling area restricts lighting at the edges of the space. The illuminance averages 11 fc, and drops to 6 fc at some points at the edge of the seating area, within the target 2:1 average:minimum ratio.

It peaks in the rear at the control booth, with light levels in the range of 15-20 fc, as desired at full output.

### Lighting Power Density

| | |
|---|---|
| Area (audience only) | 5,921 $ft^2$ |
| Max Power Density | 2.43 $W/ft^2$ |
| Lighting power allowance | 14.388 kW |
| Decorative allowance | 5.921 kW |

| Type | Quantity | Watts/Fixture | Type total | |
|---|---|---|---|---|
| F7 | 14 | 250 | 3500 W | |
| F8 | 7 | 90 | 630 W | |
| F9 | 24 | 75 | 1800 W | |
| F6 | 654 | 5 W/ft | 3270 W | (Decorative) |
| F10 | 280 | 3.39 W/ft | 949.2 W | (Decorative) |
| F11 | 22 | 8 | 176 W | |

| | |
|---|---|
| Total lighting power | 6.106 kW |
| Space power allowance | 14.388 kW |
| Total decorative power | 4.219 kW |
| Space decorative allowance | 5.921 kW |

The concert hall meets ASRAE 90.1 2010’s power density requirements for an audience seating area.

## Acoustical Breadth

The existing design uses adjustable curtains for acoustical control, allowing it to achieve a range of sound qualities to suit different types of performances. But the concert hall has a very linear architectural style, and everything else in the space is designed with hard edges. What adjustable acoustical control options could be used as an alternative?

The reverberation time, a simple metric used to summarize the acoustical performance of a space, depends on the room’s volume and its total sound absorption. With the current system, absorption is modified by moving the curtains out from compartments at the back, allowing them to absorb sound that would have been reflected by the walls behind them. Can a comparable range of reverb times be achieved by changing the room’s volume?

The best way to do this is by using reverberation chambers with movable wall panels. The concert hall has two reverberation chambers at the front on the balcony level. Their acoustics are adjusted by curtains across their back walls, but the volume can’t be closed off from the rest of the concert hall.

The ideal reverberation time for a concert hall of this size is approximately 2 seconds at middle frequencies (500-1000 Hz). I will perform my calculations for sound at 500 Hz.

$a_{\text{total room absorption}} = \Sigma(S\alpha)$, where S = surface area and $\alpha$ = surface absorption coefficient

$T_{60}$, the time for a sound to decay by 60 decibels, is calculated by $T_{60} = 0.05V/a$.

**Room volume:** 369500 $ft^3$ with reverberation chambers
310026 $ft^3$ without reverberation chambers

### *Base Case (Chambers open, curtains hidden)*

| | Area ($ft^2$) | Material | Absorption Coefficient |
|---|---|---|---|
| 1st floor Walls | 4,095 | 1/2" Gyp. Board on 2x4s | 0.05 |
| 2nd Floor Walls | 15,032 | 1/2" Gyp. Board on 2x4s | 0.05 |
| Ceiling | 7,289 | 1/2" Gyp. Board | 0.05 |
| Stage | 2,373 | Wood | 0.10 |
| Audience | 2,412 | Audience in upholstered seats | 0.80 |
| Floor | 1,284 | Heavy carpet on concrete | 0.14 |
| | | Σ(Area x Absorption) | 3667 Sabins |
| | | Reverberation Time | 5.03 seconds |

### *Reverberation Chambers Closed*

| | Area ($ft^2$) | Material | Absorption Coefficient |
|---|---|---|---|
| 1st floor Walls | 4,095 | 1/2" Gyp. Board on 2x4s | 0.05 |
| 2nd Floor Walls | 11,856 | 1/2" Gyp. Board on 2x4s | 0.05 |
| Ceiling | 7,289 | 1/2" Gyp. Board | 0.05 |
| Stage | 2,373 | Wood | 0.1 |
| Audience | 2,412 | Audience in upholstered seats | 0.8 |
| Floor | 1,284 | Heavy carpet on concrete | 0.14 |
| | | Σ(Area x Absorption) | 3508 Sabins |
| | | Reverberation Time | 4.41 seconds |

### *Curtains Exposed*

| | Area (ft2) | Material | Absorption Coefficient |
|---|---|---|---|
| 1st floor Walls | 3,695 | 1/2" Gyp. Board on 2x4s | 0.05 |
| 2nd Floor Walls | 14,232 | 1/2" Gyp. Board on 2x4s | 0.05 |
| Ceiling | 7,289 | 1/2" Gyp. Board | 0.05 |
| Stage | 2,373 | Wood | 0.1 |
| Audience | 2,412 | Audience in upholstered seats | 0.8 |
| Floor | 1,284 | Heavy carpet on concrete | 0.14 |
| Curtains | 1,200 | Mediumweight drapery | 0.49 |
| | | Σ(Area x Absorption) | 4195 Sabins |
| | | Reverberation Time | 4.40 seconds |

As you can see, closing off the additional reverberation volume has almost the exact same effect as adding 1,200 $ft^2$ of mediumweight drapery. The calculated reverberation times are higher than expected, probably due to poor approximations of the materials in my calculation. If the walls were more absorptive that I've estimated, the relative effect of the curtains would actually be decreased.

Regardless, this demonstrates that the volume of reverberation chamber in the Wentz Concert Hall is sufficient to be useful in adjusting its acoustical properties. A reflective panel placed behind the screen would let changes be made with no visible distraction from the architecture.

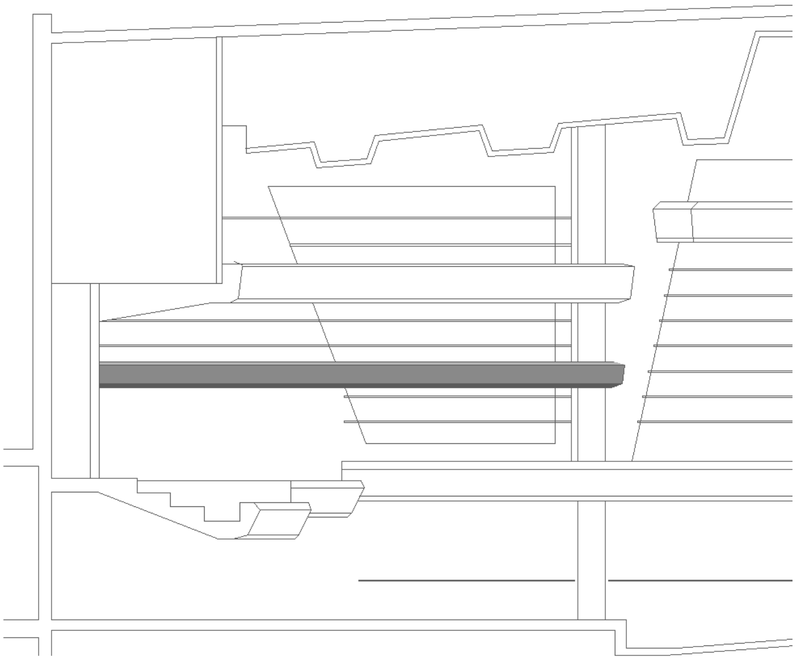
## Architectural Breadth

As has been mentioned before, the concert hall has many horizontal lines. These help to direct attention toward the stage at the front, but they also mean there isn't a strong definition of the boundary between the stage and audience. For my architectural breadth, I've attempted to give this transition more spatial definition, without disrupting the room as a whole.

Figure 14: Original Concert Hall Design

You can see in the figure above that the beginning of the stage is marked by a column, which is followed by the screen into the reverberation chamber. The strong vertical of the column is a disruption of the flow of attention toward the front of the room.

Figure 15: Revised Elevation



My solution to this is to add a third shelf level, smaller than the balcony's edge and the upper shelf, above head level of a person walking along the balcony. This visually breaks up the column so that it no longer dominates the view from the audience, and creates a visual arch form using the three shelf levels and the ceiling. This arch over the stage visually separates it from the rest of the space, while avoiding a sharp transition, and ties the concert hall together more strongly than the original design.

The new shelf also serves as location to integrate wide LED strip, as seen in the concert hall lighting elevation.

# Facade

## Space description

The building's façade is primarily finished with architectural precast concrete in a warm yellow. It's mostly smooth with a pattern of horizontal lines, but is broken by several wide rusticated strips. At night, most of the façade's appearance comes from the inside, with light shining out from its two large lobbies.

Cornices around the two lobby masses protrude several feet at a45° angle, and are finished with aluminum panels.

## Design Criteria

### *Illuminance (High Priority)*

Façade illuminance criteria are as recommended for an area of medium night activity and LZ3 lighting zone.

*Facade*

- Vertical
  - 7.5 fc maximum, to highlight façade details or features
    - Apply to <20% of façade
  - 3 fc average for large illuminated areas

*Entry*

- Horizontal (average at grade)
  - 1.5 fc
  - Avg:Min = 2:1
- Vertical (average at 5 ft. above grade)
  - 0.8 fc
  - Avg:Min = 4:1

### *Wayfinding*

The main entry is the primary destination for most people entering the building, though some will also be entering at the black box theater lobby. Since many visitors may not be familiar with the building, lighting can be used as a wayfinding aid.

### *Landmark Appearance (High Priority)*

The bright lobby with its Wentz Concert Hall lettering makes a powerful landmark, which will help patrons recognize the building even if they have never seen it before. Exterior lighting should avoid overpowering this effect.

### Light Pollution/Trespass

Exterior lighting should minimize light trespass to adjacent properties and light emitted upward.

### ASHRAE 90.1 2010

*Power Allowance (Mandatory)*

Lighting Zone 3:

- Tradable allowances
  - 30 W/ft of main entrance width
  - 20 W/ft of other door width
  - 0.4 W/ft$^2$ of entry canopies
- Non-tradable allowances
  - 3.5 W/ft of illuminated facade

## Design Overview

The façade’s most attention-grabbing features are the large main lobby and the Madden Theater lobby, both of which have large curtain walls, and are visible from outside the building at night. Lighting the walls adjacent to these spaces would reduce their visual impact, so the walls on the lower floors are left dark.

Instead, color changing LED strips illuminate the high wall above the concert hall. This makes it instantly recognizable as a landmark from a large distance. Narrow beam LED fixtures near the entrances give more form to the building without floodlighting the walls, and they allude to the linear lighting designs of the interior.

Figure 16: Façade lighting plan


## *Lamp/Luminaire Selection*

The upper wall is lit using a linear 4' RGB LED fixture, which will have a long operating life and allow the color to be cycled much more easily than with permanently colored filters. Since these mix light by adding the wavelengths they need instead of filtering out unwanted colors, they're also much more energy efficient.

For additional accent near the entries, a small LED up/downlight with symmetrical 10° degree beams mimics the impression from the linear fixtures used inside, but without requiring large penetrations and large wet-rated enclosures. Downlighting under the canopy is performed with standard fluorescent fixtures.

## Fixture Schedule

| Type | Description | Manufacturer | Catalog Number | Lamp(s) | Input Watts |
|---|---|---|---|---|---|
| F12 | Color changing linear LED fixture with 30x60 degree beam distribution in 2' nominal lengths. IP66 rated for outdoor use | Color Kinetics | 123-000030-03 | RGB LEDs | 35 |
| F2 | Unlensed 26W compact fluorescent downlight with 6" nominal aperture, white trim, and wheat reflector | Kurt Versen | P626DM-120-W-WT | (1) F26DBX/827/ECO4P by GE | 26.4 |
| F13 | Wall mounted LED grazer with 10° up and down beams | Beta-Calco | 66-2201 | (2) 3800K white LEDs | 4.5 |
| F14 | Wet rated cylindrical up/downlight, wall mounted with convex lens | Delray Lighting | 242-BM-CUV8242.1E-WL | (2) F42TBX/830/A/ECO by GE | 43.2 |

## Light Loss Factors

Type F12
- Total = 0.8 (estimated)

Type F2
- LLD = 1530/1800 = 0.85
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.77

Type F13
- Total = 0.8 (estimated)

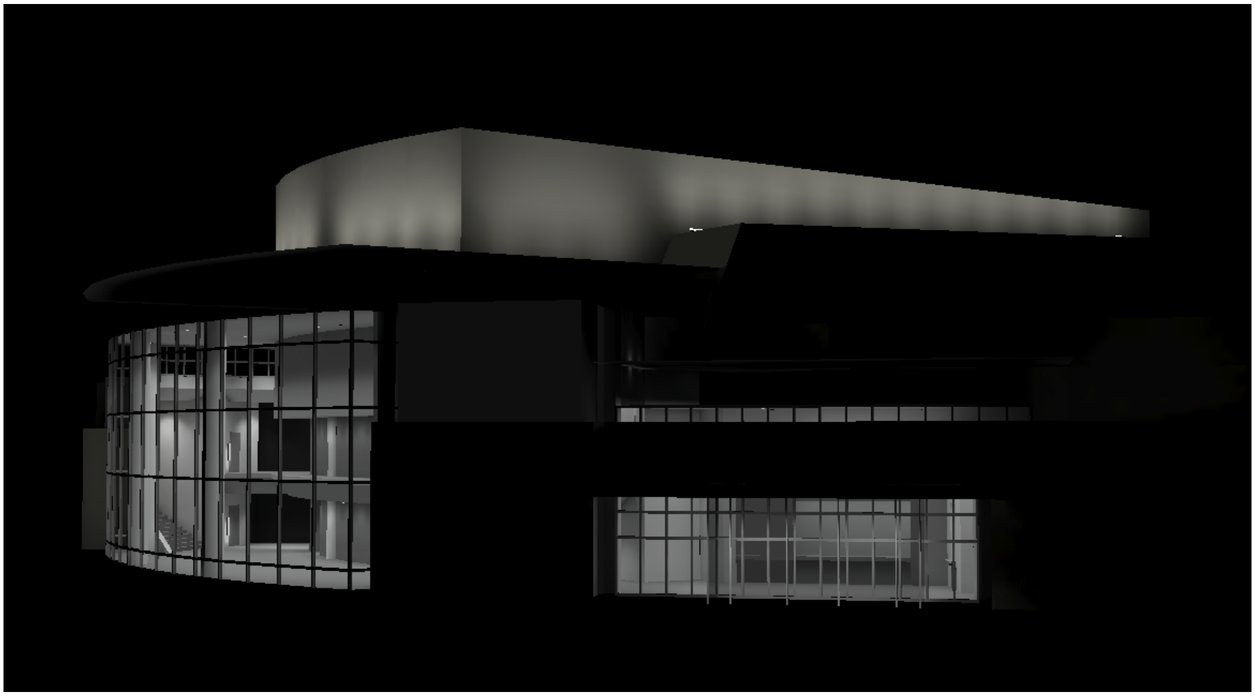
Type F14
- LLD = 2690/3200 = 0.84
- LDD = 0.79 (24 month cleaning cycle, moderate dirt level)
- BF = 1.0
- Total = 0.66

## Control System

The exterior lighting at the entrances are controlled with the vestibule lighting from the lobbies. Color changing LED fixtures are tied to the Grafik 4000 controls, and are managed using preset scenes.

## CFL side Design Performance

Figure 17: Façade Rendering



The exterior lighting doesn't meet the IES recommended illuminance, coming in at 1.5 fc rather than the 3 fc target for large illuminated areas. This is due in part to the way the energy code is structured, where façade power allowance is based only on the illuminated walls. No additional power is freed for use by choosing to leave the majority of the building unilluminated, because the façade lighting allowance is untradeable.

The entry downlights, which are calculated in conjunction with the main lobby (north portion), can exceed the IES recommended 1.5 fc, but are on a dimming system and can be reduced. This will allow it to be brightly lit to welcome guests to a performance, but turned down as people are leaving with their eyes adjusted to the performance's lowered light levels.

### *Lighting Power Density*

*Tradable Allowances*

| | |
|---|---|
| Main entrance width | 24 ft |
| Allowance | 30 W/ft |
| Total other door width | 72 ft |
| Allowance | 20 W/ft |
| Entry canopy area | 333 $ft^2$ |
| Allowance | 0.4 $W/ft^2$ |
| Façade power allowance | 2.293 kW |

| **Type** | **Quantity** | **Watts/Fixture** | **Type total** |
|---|---|---|---|
| F2 | 6 | 90 | 540 W |
| F13 | 4 | 75 | 300 W |
| F14 | 2 | 86.4 | 172.8 W |

*Non-tradable Allowances*

| | |
|---|---|
| Illuminated façade length | 403 ft |
| Allowance | 3.75 W/ft |
| Façade power allowance | 1.511 kW |

| **Type** | **Quantity** | **Watts/Fixture** | **Type total** |
|---|---|---|---|
| F12 | 37 | 35 | 1.295 kW |

The façade lighting design meets ASHRAE 90.1 2010's power density requirements for a building façade in zone 3.

# Rehearsal Room

Space description

The rehearsal room is a high ceilinged open space, used for both music practice and teaching. Halfway up the wall, it has a technical shelf used to house AV systems, HVAC equipment, and curtain track for the lower walls. The profile of this shelf mirrors the design used repeatedly in the concert hall.

## Design Criteria

### *Illuminance (High Priority)*

*Music Classroom*

- Horizontal (average at 4 ft. AFF)
  - 30 fc
  - Avg:Min = 2:1
- Vertical (average at 4 ft. AFF)
  - 20 fc
  - Avg:Min = 2:1

### Uniformity

Without fixed furniture, people can be seated at a chair anywhere in the room. It's important to avoid creating dark spots where music stands can't be read.

### Color Temperature

Color temperature should generally be selected to match other sources in an architectural project, avoiding transitions between areas of different CCT. While there are fewer direct reasons to select a warm color temperature here, they would be consistent with the other spaces. On the other hand, some research suggests that higher color temperatures can increase focus and productivity, which could be desired in an office space.

### Color Rendition

The tasks performed in these spaces do not require highly accurate color rendition, but consistency with other spaces may be a consideration.

### ASHRAE 90.1 2010

*Power Allowance (Mandatory)*

Classroom

- Lighting Power Density: 1.24 W/ft$^2$
- An additional allowance of up to 1.0 W/ft$^2$ is available for decorative lighting

*Automatic Shutoff (Mandatory)*

An automatic control device is required to control lighting in all spaces. It must be based on either a preset schedule, occupancy sensors, or information from another control system that indicates a space is not occupied.

*Display/Accent Lighting (Mandatory)*

Display or accent lighting must be controlled separately from general lighting.

## Design Overview

As with the lobby, much of the horizontal illuminance here is provided by downlights in high ceiling. Vertical illuminance is essential for reading music on slanted music stands, and must be high in all directions. This is achieved using a linear wallwasher along two sides of the room to bounce light off of the lower walls and curtains, as well as with an asymmetric CFL fixture on the side of the technical shelf. Horizontal illuminance is provided by downlights in the upper ceiling, and asymmetric uplights shine from the top of the technical shelf to illuminate parts of the walls and ceiling.

Figure 18: Rehearsal Room – Balcony Level Lighting Plan

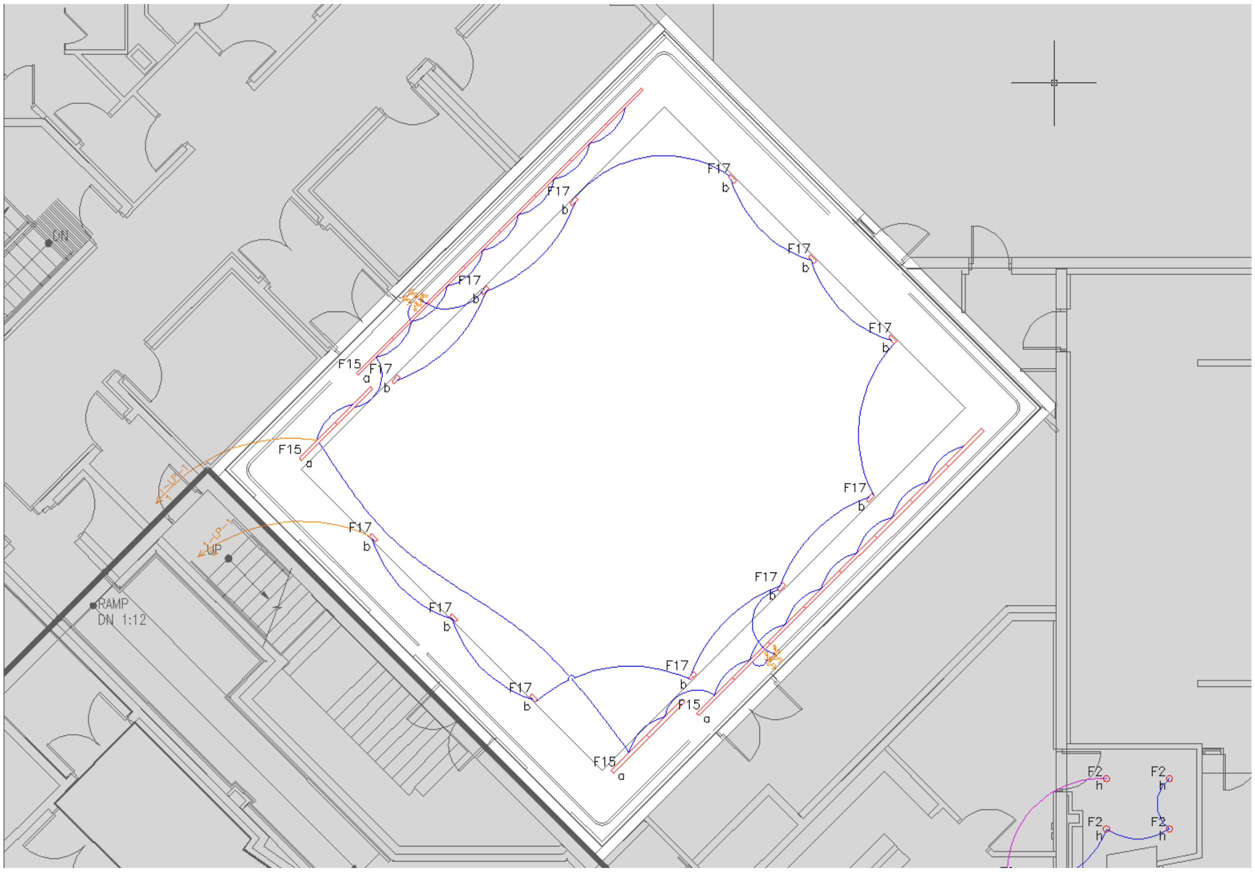
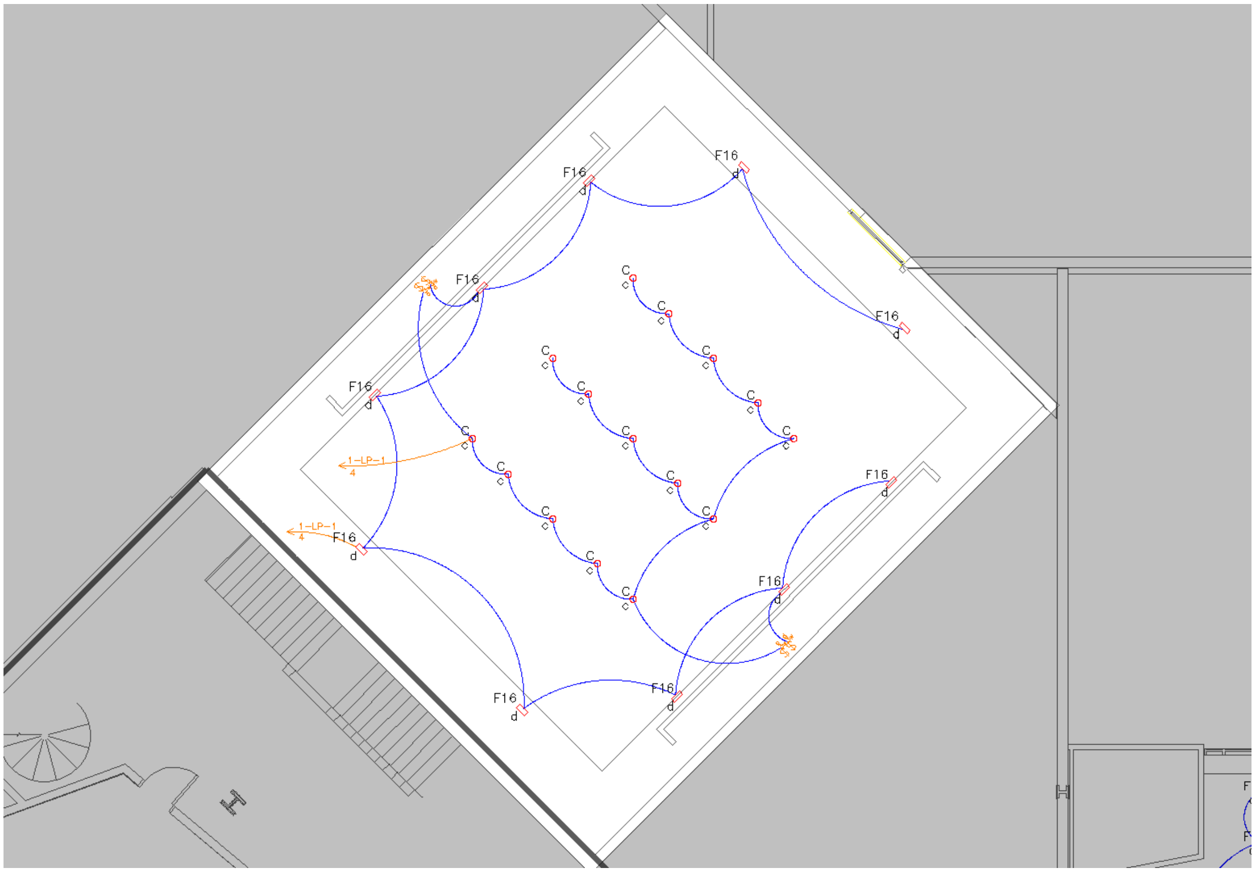


Figure 19: Rehearsal Room – Balcony Level Lighting Plan



## *Lamp/Luminaire Selection*

In keeping with the low energy goals for the project, the space uses fluorescent fixtures. Downlights have wheat reflectors for a warmer feel, and all lamps are 3000K. This is slightly cooler than what was used in the lobby, but the rehearsal room is relatively farm removed from the warm red woods of the lobby and concert hall, and 3000K is sufficiently warm for a classroom. The linear wall washers use a standard output T5 lamp.

## Fixture Schedule

| Type | Description | Manufacturer | Catalog Number | Lamp(s) | Input Watts |
|---|---|---|---|---|---|
| F15 | Recessed linear T5 fixture in 4' lengths with low iridescent louver | Peerless Lighting | LAR9-28T5-LDL-U4-120-C200 | (1) F28W/T5/830/ECO by GE | 26.8 |
| F16 | Adjustable asymmetric CFL wall washer with lockable angle and semi gloss white finish | Winona Lighting | LS8-CFM142-120-P1-SGW-X-STD | (1) F42TBX/830/A/ECO by GE | 43.2 |
| F17 | Semi-recessed asymmetric CFL with semi gloss white finish | Winona Lighting | LSRU-LR-CFM142-120-P1-SGW-X-STD | (1) F42TBX/830/A/ECO by GE | 43.2 |
| F18 | Unlensed 42W compact fluorescent downlight with 6" nominal aperture, white trim, and wheat reflector | Kurt Versen | P927-120-W-WT | (1) F42TBX/830/A/ECO by GE | 43.2 |

## Light Loss Factors

Type F15

- LLD = 2660/2900 = 0.92
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.83

Type F16

- LLD = 2690/3200 = 0.84
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.76

Type F17

- LLD = 2690/3200 = 0.84
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.76

Type F18

- LLD = 2690/3200 = 0.84
- LDD = 0.91 (24 month cleaning cycle, open/unvented)
- BF = 1.0
- Total = 0.76

## Control System

The four types of lights are set up in four separate switching groups so that they can be used independently and turned off to reduce energy use when they aren't needed.

a) Linear wall washers
b) CFL side lights
c) Upper ceiling downlights
d) CFL uplights

Controlled by Grafik Eye 4000. See electrical section for details of control system.

## Design Performance

Figure 20: Rehearsal Room Rendering

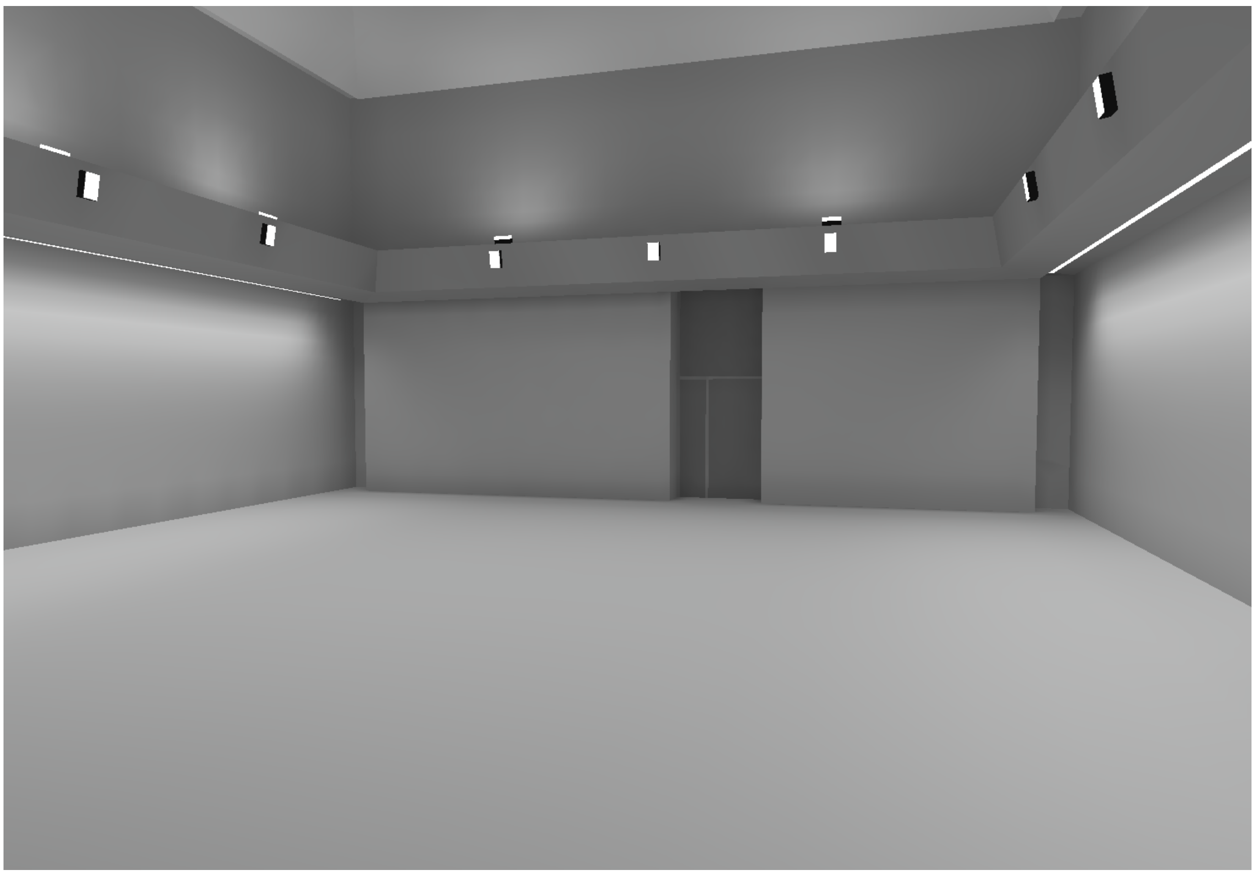
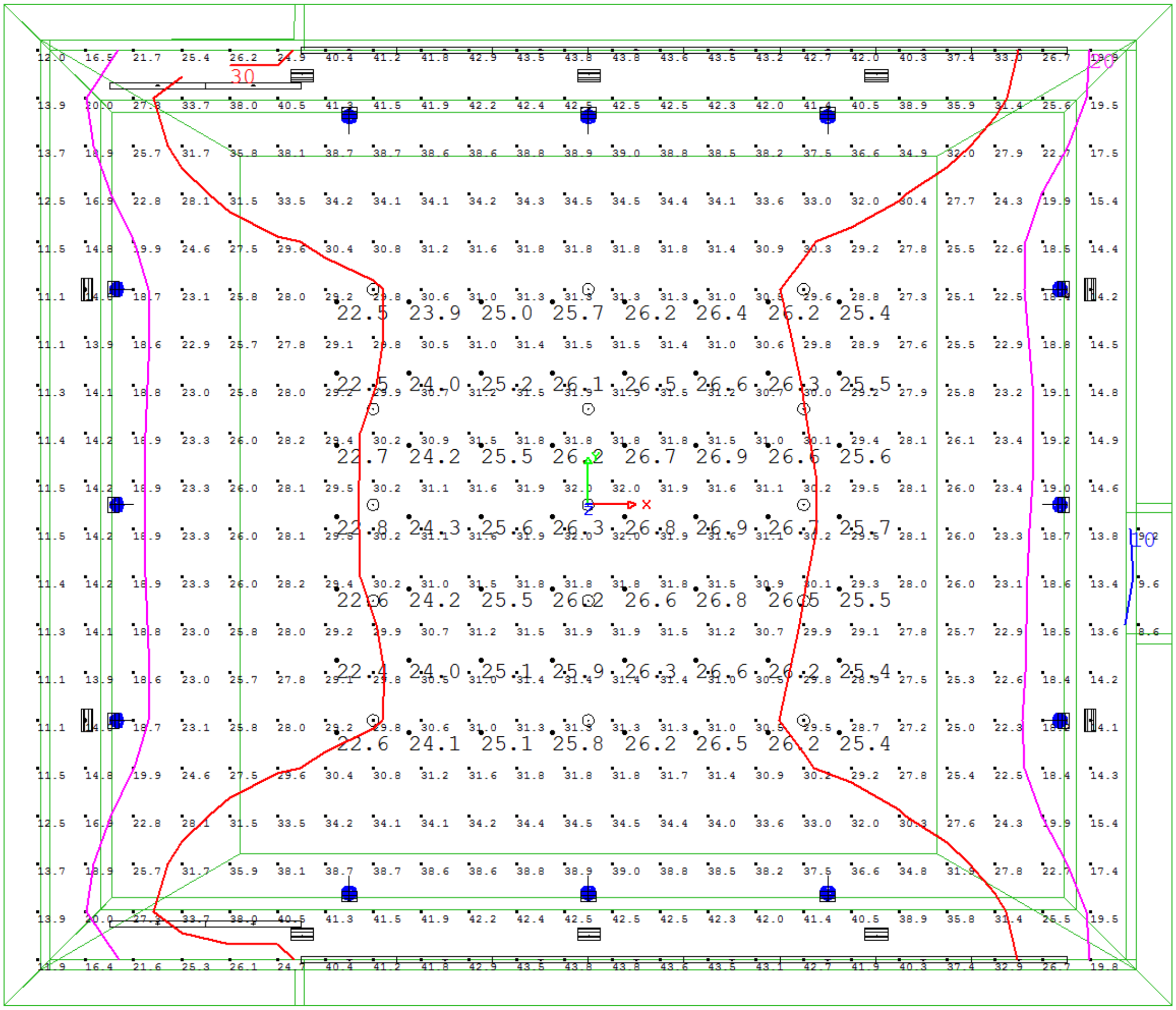


Figure 21: Rehearsal Room Isoilluminance Lines




Red: 30 fc    Magenta: 20 fc    Blue: 10 fc

The room is brightly illuminated, and meets the target of 30 fc in the center area and toward the sides with linear fixtures. Toward the front and back, it drops off to 20 fc, but only reaches 10 at a few points between the curtain pockets. The average to minimum ratio is 1.13:1, well below the recommended 2:1

Vertical illuminances are also as targeted, with points aimed at 45 degrees (to simulate a music stand) still receiving above 25 fc in the central area.

## *Lighting Power Density*

| | |
|---|---|
| Area | 2,041 $ft^2$ |
| Max Power Density | 1.24 $W/ft^2$ |
| Lighting power allowance | 2.530 kW |
| Decorative allowance | 2.041 kW |

| Type | Quantity | Watts/Fixture | Type total | |
|---|---|---|---|---|
| F15 | 15 | 26.8 | 402 W | |
| F16 | 10 | 43.2 | 432 W | (Decorative) |
| F17 | 12 | 43.2 | 518.4 W | |
| F18 | 20 | 43.2 | 864 W | |

| | |
|---|---|
| Total lighting power (kW) | 1.784 kW |
| Space power allowance (kW) | 2.041 kW |
| Total decorative power | 0.432 kW |
| Space decorative allowance | 2.041 kW |

Rehearsal room meets ASHRAE 90.1 2010 power density requirements for a classroom space.

# Electrical Redesign

The four redesigned spaces are the main lobby, concert hall, façade, and rehearsal room. Each of these spaces span the first floor and balcony levels. The rehearsal room and lobby are designed to use predominantly CFL sources, while the concert hall uses incandescent downlights with linear LEDs as an efficient architectural accent. The façade's main focus is the upper exterior wall of the concert hall, which is lit by color changing LEDs.

| Panelboards | | | | | | |
|---|---|---|---|---|---|---|
| **Panel Tag** | **Voltage** | **System** | **Rehearsal Room** | **Main Lobby** | **Concert Hall** | **Façade** |
| DR1 | 208Y/120V, 3P 4W | N | | X | X | X |
| DR2 | 208Y/120V, 3P 4W | N | | | X | X |
| EM-XFR-1 | 208Y/120V, 3P 4W | N/E | | X | X | X |
| 1-ELP-1 | 208Y/120V, 3P 4W | N/E | X | | | |
| 1-LL-1 | 208Y/120V, 3P 4W | N | X | | | |

# Control Systems

The rehearsal room, as a back of house area, uses a simple switching system, with luminaires grouped by type. There are two entrances on opposite sides of the room, and three way switching is used so that all lighting can be controlled from either one.

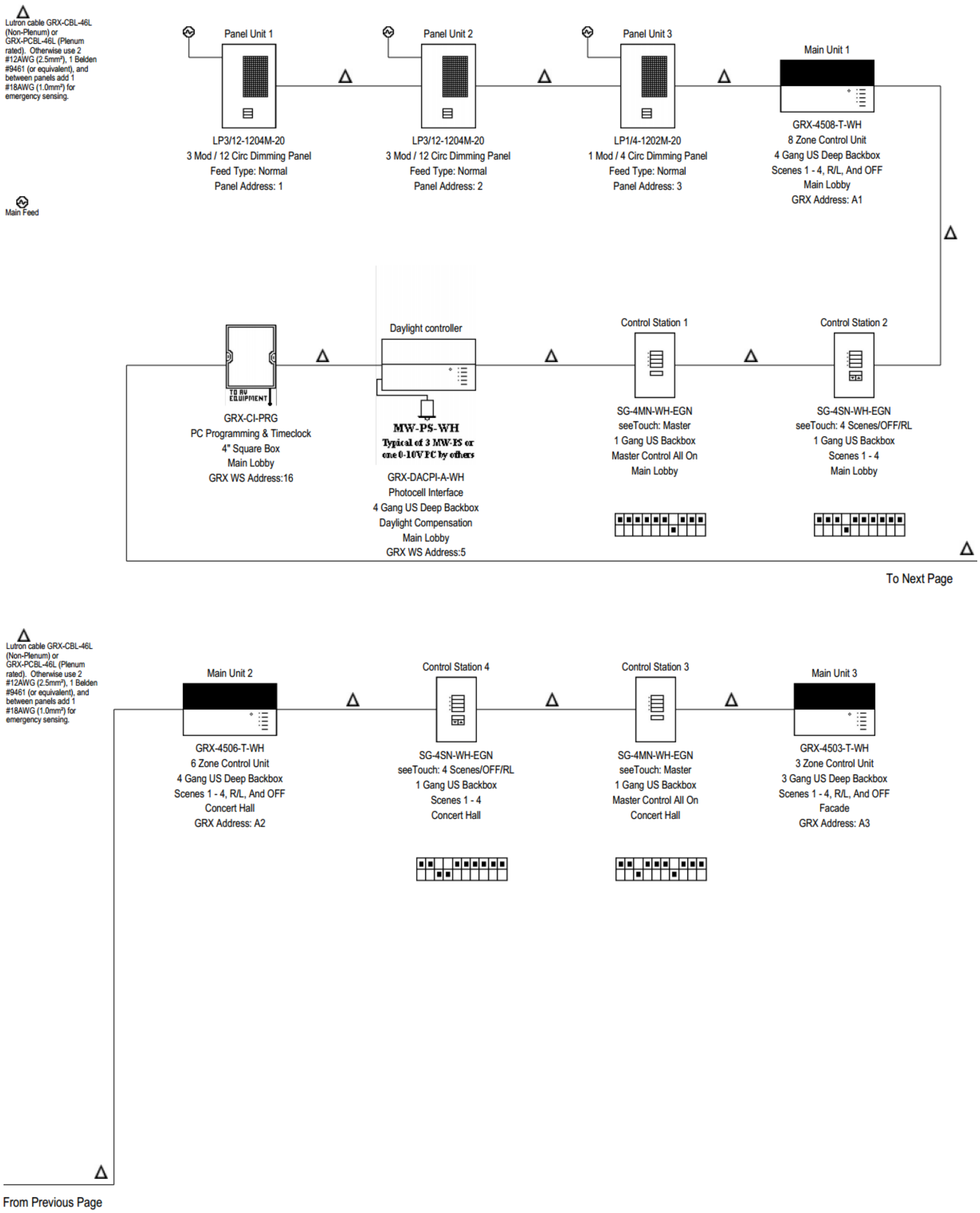
The main lobby, concert hall, and façade are operated by a Lutron Grafik Eye 4000 multi-space dimming system. This product was selected for its ability to control multiple light sources, instead of a standard dimmer rack system for incandescents only, as well as the ability to integrated with a theatrical lighting console. The Grafik Eye 4000 also allows for photosensor controlled dimming (required by ASHRAE 90.1 in the main lobby), and allows emergency lighting to be controlled along with normal lighting circuits using a dimming level override in case of normal power failure.

Table 1: Control Equipment Schedule

| Grafik 4000 | | | |
|---|---|---|---|
| **Item** | **Lutron Model No.** | **Description** | **Qty** |
| 1) | LP3/12-1204M-20 | 120V Branch Breakers LP Dimming Panel containing 3 20A-1Pole branch breakers rated at 10,000AIC for 3 modules (12 switch legs). 4 dimming outputs per module. Max input feed = 20A (3Ø-4 Wire), 40A (1Ø-3 Wire), 60A (1Ø-2 Wire) | 2 |
| 2) | LP1/4-1202M-20 | 120V Branch Breakers LP Dimming Panel containing 1 20A-1Pole branch breaker rated at 10,000AIC for 1 module (4 switch legs). 4 dimming outputs per module. Max input feed = 20A | 1 |
| 3) | PHPM-3F-120-WH | 120V Fluorescent Power Module. Enables a control to dim Lutron Hi-Lume or Eco-10 Dimming Ballasts. Module requires a neutral wire. Maximum 16A output. 2 Gang US Backbox. | 16 |
| 4) | SG-4SN-WH-EGN | seeTouch series GRAFIK Eye wallstation. Recalls preset light levels for up to 4 scenes plus off. Fine-tuning of light levels with master raise/lower. Noninsert Version; Optional Backlighting. 1 Gang US Backbox. | 2 |
| 5) | SG-4MN-WH-EGN | seeTouch series GRAFIK Eye wallstation. Allows Master Control of any GRAFIK Eye on a button-by button basis. Noninsert Version; Optional Backlighting. 1 Gang US Backbox. | 2 |
| 6) | GRX-DACPI-A-WH | Automatically selects preset scenes on a GRAFIK Eye Control Unit in response to ambient daylight. Opaque Top Cover. Works with either 1 0-10V photocell or up to 3 Lutron MW-PS photocells. 4 Gang US Backbox. | 1 |
| 7) | MW-PS-WH | Ceiling mounted daylight photosensor. Low voltage class 2, 24V DC. | 1 |
| 8) | GRX-CI-PRG | RS232 and Ethernet Interface. Allows for PC Programming with GRX-3500 and GRX-4500 Control Units. Can also be used as an astronomic timeclock for any GRAFIK Eye system. Surface mount. | 1 |
| 9) | GRX-4508-T-WH | 8 Zone GRAFIK Eye 4000 Control Unit with PC Setup Capability and Translucent Top Cover. For use with Lutron GP, LP, and XP Power Panels. 4 Gang US Backbox. | 1 |
| 10) | GRX-4506-T-WH | 6 Zone GRAFIK Eye 4000 Control Unit with PC Setup Capability and Translucent Top Cover. For use with Lutron GP, LP, and XP Power Panels. 4 Gang US Backbox. | 1 |
| 11) | GRX-4503-T-WH | 3 Zone GRAFIK Eye 4000 Control Unit with PC Setup Capability and Translucent Top Cover. For use with Lutron GP, LP, and XP Power Panels. 3 Gang US Backbox. | 1 |
| All electrical devices should match system controls. Use Lutron NovaT* dimmers, switches, receptacles, jacks and faceplates as required. | | | |

Panels are Lutron LP series, which use 20A modules to supply different load types. LED loads are to be dimmed using Lutron Hi-Lume drivers for 1% minimum dimming level, and CFLs below 42W also use Hi-Lume ballasts. Fixtures with 42W triple tube CFLs These two load types can be served by the same LP dimming module. Each dimming module supports up to 4 dimming zones.

Figure 22: Control System Single-Line



# Existing Panelboards

The drawing set for the project does not include existing branch panelboard schedules. These are estimated based on information from the electrical and lighting design drawings to approximate loads given in the distribution panel schedules.

**PANELBOARD SCHEDULE**

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | 1-LP-1 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 225A | PANEL LOCATION: | 173 - Electrical Closet | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 225A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lighting | Rehearsal | 1320 | 20A/1P | 1 | * | | | 2 | 20A/1P | 1000 | Rehearsal | Lighting |
| Lighting | Rehearsal | 1000 | 20A/1P | 3 | | * | | 4 | 20A/1P | 915 | Rehearsal | Lighting |
| Existing Load | Misc | 1200 | 20A/1P | 5 | | | * | 6 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 7 | * | | | 8 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 9 | | * | | 10 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 11 | | | * | 12 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 15 | | * | | 16 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 17 | | | * | 18 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 19 | * | | | 20 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 21 | | * | | 22 | 20A/1P | 1200 | Misc | Existing Load |
| | | 0 | 20A/1P | 23 | | | * | 24 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 25 | * | | | 26 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 27 | | * | | 28 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 29 | | | * | 30 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 9.52 | TOTAL DESIGN LOAD (KW) | 31.00 |
| CONNECTED LOAD (KW) - B Ph. | 9.12 | POWER FACTOR | 0.91 |
| CONNECTED LOAD (KW) - C Ph. | 7.20 | TOTAL DESIGN LOAD (AMPS) | 95 |

# PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | 1-ELP-1 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 100A | PANEL LOCATION: | 173 - Electrical Closet | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 15A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EM Lighting | Rehearsal | 458 | 20A/1P | 1 | * | | | 2 | 20A/1P | 600 | | Existing Load |
| Existing Load | | 600 | 20A/1P | 3 | | * | | 4 | 20A/1P | 600 | | Existing Load |
| Existing Load | | 600 | 20A/1P | 5 | | | * | 6 | 20A/1P | 600 | | Existing Load |
| Existing Load | | 600 | 20A/1P | 7 | * | | | 8 | 20A/1P | 600 | | Existing Load |
| Existing Load | | 600 | 20A/1P | 9 | | * | | 10 | 20A/1P | 600 | | Existing Load |
| Existing Load | | 600 | 20A/1P | 11 | | | * | 12 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 13 | * | | | 14 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 15 | | * | | 16 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 17 | | | * | 18 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 19 | * | | | 20 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 21 | | * | | 22 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 23 | | | * | 24 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 25 | * | | | 26 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 27 | | * | | 28 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 29 | | | * | 30 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 2.26 | TOTAL DESIGN LOAD (KW) | 7.75 |
| CONNECTED LOAD (KW) - B Ph. | 2.40 | POWER FACTOR | 0.90 |
| CONNECTED LOAD (KW) - C Ph. | 1.80 | TOTAL DESIGN LOAD (AMPS) | 10 |

# PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | DR-1 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 225A | PANEL LOCATION: | 139 - Dimmer Room | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 225A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choral terrace R2 ce | Concert Hall | 1250 | 20A/1P | 1 | * | | | 2 | 20A/1P | 1250 | Concert Hall | Choral terrace R1 cen |
| Choral terrace SL | Concert Hall | 1500 | 20A/1P | 3 | | * | | 4 | 20A/1P | 1500 | Concert Hall | Choral terrace SR |
| Row 1 HR | Concert Hall | 1725 | 20A/1P | 5 | | | * | 6 | 20A/1P | 1725 | Concert Hall | Row 1 center |
| Row 2 HR | Concert Hall | 1725 | 20A/1P | 7 | * | | | 8 | 20A/1P | 1725 | Concert Hall | Row 2 CR |
| Row 2 CL | Concert Hall | 1725 | 20A/1P | 9 | | * | | 10 | 20A/1P | 1725 | Concert Hall | Row 2 HL |
| Row 3 HR | Concert Hall | 1725 | 20A/1P | 11 | | | * | 12 | 20A/1P | 1725 | Concert Hall | Row 3 CR |
| Row 3 CL | Concert Hall | 1725 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1725 | Concert Hall | Row 3 HL |
| Row 4 HR | Concert Hall | 1725 | 20A/1P | 15 | | * | | 16 | 20A/1P | 1725 | Concert Hall | Row 4 CR |
| Row 5 HR | Concert Hall | 1725 | 20A/1P | 17 | | | * | 18 | 20A/1P | 1725 | Concert Hall | Row 5 CR |
| Row 5 C | Concert Hall | 1725 | 20A/1P | 19 | * | | | 20 | 20A/1P | 1725 | Concert Hall | Row 5 CL |
| Row 5 HL | Concert Hall | 1725 | 20A/1P | 21 | | * | | 22 | 20A/1P | 1725 | Concert Hall | Catwalk #4 HR |
| Catwalk #4 CR | Concert Hall | 1725 | 20A/1P | 23 | | | * | 24 | 20A/1P | 1725 | Concert Hall | Catwalk #4 CL |
| Catwalk #4 HL | Concert Hall | 1725 | 20A/1P | 25 | * | | | 26 | 20A/1P | 308 | Main Lobby | Column backlight |
| Seating sconces | Main Lobby | 46 | 20A/1P | 27 | | * | | 28 | 20A/1P | 300 | Main Lobby | Column light |
| Column light | Main Lobby | 300 | 20A/1P | 29 | | | * | 30 | 20A/1P | 300 | Main Lobby | Column light |
| Column light | Main Lobby | 300 | 20A/1P | 31 | * | | | 32 | 20A/1P | 1575 | Main Lobby | Wood washers |
| Bridge downlights | Main Lobby | 1500 | 20A/1P | 33 | | * | | 34 | 20A/1P | 1500 | Main Lobby | Coat check |
| Coat check | Main Lobby | 700 | 20A/1P | 35 | | | * | 36 | 20A/1P | 600 | Main Lobby | Main entrance |
| Concert entry | Main Lobby | 200 | 20A/1P | 37 | * | | | 38 | 20A/1P | 1125 | Main Lobby | Upper wall wash |
| North lobby track | Main Lobby | 1100 | 20A/1P | 39 | | * | | 40 | 20A/1P | 1400 | Main Lobby | North lobby accent |
| Ceiling uplight | Main Lobby | 1500 | 20A/1P | 41 | | | * | 42 | 20A/1P | 1500 | Main Lobby | Ceiling uplight |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 18.08 | TOTAL DESIGN LOAD (KW) | 67.18 |
| CONNECTED LOAD (KW) - B Ph. | 19.20 | POWER FACTOR | 1.00 |
| CONNECTED LOAD (KW) - C Ph. | 18.70 | TOTAL DESIGN LOAD (AMPS) | 187 |

**P A N E L B O A R D   S C H E D U L E**

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | DR-2 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 225A | PANEL LOCATION: | 139 - Dimmer Room | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 225A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry vestibules | Lobby | 1000 | 20A/1P | 1 | * | | | 2 | 20A/1P | 1000 | Concert Hall | ownlights - Row 1 out |
| ownlights - Row 1 inn | Concert Hall | 1250 | 20A/1P | 3 | | * | | 4 | 20A/1P | 1000 | Concert Hall | ownlights - Row 2 out |
| ownlights - Row 2 inn | Concert Hall | 1250 | 20A/1P | 5 | | | * | 6 | 20A/1P | 400 | Concert Hall | ownlights - Row 3 out |
| ownlights - Row 3 inn | Concert Hall | 500 | 20A/1P | 7 | * | | | 8 | 20A/1P | 1200 | Concert Hall | wnlights - Under balco |
| ghts - Under balcony | Concert Hall | 200 | 20A/1P | 9 | | * | | 10 | 20A/1P | 600 | Concert Hall | Rear wallwashers |
| House rear wall | Concert Hall | 1080 | 20A/1P | 11 | | | * | 12 | 20A/1P | 1080 | Concert Hall | House rear wall |
| House side wall | Concert Hall | 1320 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1320 | Concert Hall | House side wall |
| Platform lower wall | Concert Hall | 980 | 20A/1P | 15 | | * | | 16 | 20A/1P | 980 | Concert Hall | Platform lower wall |
| latform rear lower wa | Concert Hall | 1400 | 20A/1P | 17 | | | * | 18 | 20A/1P | 720 | Concert Hall | atform center lower wa |
| cony rear wall wash | Concert Hall | 1900 | 20A/1P | 19 | * | | | 20 | 20A/1P | 1440 | Concert Hall | Balcony side wall |
| Balcony side wall | Concert Hall | 1440 | 20A/1P | 21 | | * | | 22 | 20A/1P | 1440 | Concert Hall | Chour terrace sidewall |
| Chour terrace sidewa | Concert Hall | 1440 | 20A/1P | 23 | | | * | 24 | 20A/1P | 1200 | Concert Hall | Chour terace rear wall |
| Chour terrace rear ct | Concert Hall | 1080 | 20A/1P | 25 | * | | | 26 | 20A/1P | 2400 | Concert Hall | Upper sidewall |
| Upper sidewall | Concert Hall | 2400 | 20A/1P | 27 | | * | | 28 | 20A/1P | 1080 | Concert Hall | Upper rear wall |
| Balcony rail sconces | Concert Hall | 400 | 20A/1P | 29 | | | * | 30 | 20A/1P | 480 | Concert Hall | Balcony rail sconces |
| Balcony rail sconces | Concert Hall | 600 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | Main Lobby | Signage spot |
| Signage spot | Main Lobby | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | Main Lobby | Main lobby track |
| Main lobby track | Main Lobby | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | Main Lobby | Main lobby track |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 13.76 | TOTAL DESIGN LOAD (KW) | 41.50 |
| CONNECTED LOAD (KW) - B Ph. | 11.37 | POWER FACTOR | 1.00 |
| CONNECTED LOAD (KW) - C Ph. | 9.45 | TOTAL DESIGN LOAD (AMPS) | 115 |

# Revised Panelboards

**P A N E L B O A R D   S C H E D U L E**

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | 1-LP-1 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 225A | PANEL LOCATION: | 173 - Electrical Closet | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 225A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rehearsal lighting | Rehearsal Room | 921 | 20A/1P | 1 | * | | | 2 | 20A/1P | 950 | Rehearsal Room | Rehearsal lighting |
| Existing Load | Misc | 1200 | 20A/1P | 3 | | * | | 4 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 5 | | | * | 6 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 7 | * | | | 8 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 9 | | * | | 10 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 11 | | | * | 12 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 15 | | * | | 16 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 17 | | | * | 18 | 20A/1P | 1200 | Misc | Existing Load |
| Existing Load | Misc | 1200 | 20A/1P | 19 | * | | | 20 | 20A/1P | 1200 | Misc | Existing Load |
| | | 0 | 20A/1P | 21 | | * | | 22 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 23 | | | * | 24 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 25 | * | | | 26 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 27 | | * | | 28 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 29 | | | * | 30 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 9.07 | TOTAL DESIGN LOAD (KW) | 28.17 |
| CONNECTED LOAD (KW) - B Ph. | 7.20 | POWER FACTOR | 0.90 |
| CONNECTED LOAD (KW) - C Ph. | 7.20 | TOTAL DESIGN LOAD (AMPS) | 87 |

# PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | 1-ELP-1 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 100A | PANEL LOCATION: | 173 - Electrical Closet | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 100A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EM Lighting | Rehearsal room | 130 | 20A/1P | 1 | * | | | 2 | 20A/1P | 600 | Misc | Existing Load |
| Existing Load | Misc | 600 | 20A/1P | 3 | | * | | 4 | 20A/1P | 600 | Misc | Existing Load |
| Existing Load | Misc | 600 | 20A/1P | 5 | | | * | 6 | 20A/1P | 600 | Misc | Existing Load |
| Existing Load | Misc | 600 | 20A/1P | 7 | * | | | 8 | 20A/1P | 600 | Misc | Existing Load |
| Existing Load | Misc | 600 | 20A/1P | 9 | | * | | 10 | 20A/1P | 600 | Misc | Existing Load |
| Existing Load | Misc | 600 | 20A/1P | 11 | | | * | 12 | 20A/1P | 525 | Concert Hall | EM Lighting |
| EM Lighting | Concert Hall | 176 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1270 | Concert Hall | EM Lighting |
| EM Lighting | Main Lobby | 333 | 20A/1P | 15 | | * | | 16 | 20A/1P | 712 | Main Lobby | EM Lighting |
| | | 0 | 20A/1P | 17 | | | * | 18 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 19 | * | | | 20 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 21 | | * | | 22 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 23 | | | * | 24 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 25 | * | | | 26 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 27 | | * | | 28 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 29 | | | * | 30 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 3.38 | TOTAL DESIGN LOAD (KW) | 10.97 |
| CONNECTED LOAD (KW) - B Ph. | 3.45 | POWER FACTOR | 0.90 |
| CONNECTED LOAD (KW) - C Ph. | 2.33 | TOTAL DESIGN LOAD (AMPS) | 34 |

# PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | DR-1 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 225A | PANEL LOCATION: | 139 - Dimmer Room | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 225A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choral terrace R2 ce | Concert Hall | 1250 | 20A/1P | 1 | * | | | 2 | 20A/1P | 1250 | Concert Hall | Choral terrace R1 cen |
| Choral terrace SL | Concert Hall | 1500 | 20A/1P | 3 | | * | | 4 | 20A/1P | 1500 | Concert Hall | Choral terrace SR |
| Row 1 HR | Concert Hall | 1725 | 20A/1P | 5 | | | * | 6 | 20A/1P | 1725 | Concert Hall | Row 1 center |
| Row 2 HR | Concert Hall | 1725 | 20A/1P | 7 | * | | | 8 | 20A/1P | 1725 | Concert Hall | Row 2 CR |
| Row 2 CL | Concert Hall | 1725 | 20A/1P | 9 | | * | | 10 | 20A/1P | 1725 | Concert Hall | Row 2 HL |
| Row 3 HR | Concert Hall | 1725 | 20A/1P | 11 | | | * | 12 | 20A/1P | 1725 | Concert Hall | Row 3 CR |
| Row 3 CL | Concert Hall | 1725 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1725 | Concert Hall | Row 3 HL |
| Row 4 HR | Concert Hall | 1725 | 20A/1P | 15 | | * | | 16 | 20A/1P | 1725 | Concert Hall | Row 4 CR |
| Row 5 HR | Concert Hall | 1725 | 20A/1P | 17 | | | * | 18 | 20A/1P | 1725 | Concert Hall | Row 5 CR |
| Row 5 C | Concert Hall | 1725 | 20A/1P | 19 | * | | | 20 | 20A/1P | 1725 | Concert Hall | Row 5 CL |
| Row 5 HL | Concert Hall | 1725 | 20A/1P | 21 | | * | | 22 | 20A/1P | 1725 | Concert Hall | Catwalk #4 HR |
| Catwalk #4 CR | Concert Hall | 1725 | 20A/1P | 23 | | | * | 24 | 20A/1P | 1725 | Concert Hall | Catwalk #4 CL |
| Catwalk #4 HL | Concert Hall | 1725 | 20A/1P | 25 | * | | | 26 | 20A/1P | 1359 | Lobby | 1st floor lighting |
| Main downlights | Lobby | 1685 | 20A/1P | 27 | | * | | 28 | 20A/1P | 1296 | Lobby | North lighting |
| South lighting | Lobby | 732 | 20A/1P | 29 | | | * | 30 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 15.93 | TOTAL DESIGN LOAD (KW) | 56.16 |
| CONNECTED LOAD (KW) - B Ph. | 16.33 | POWER FACTOR | 0.99 |
| CONNECTED LOAD (KW) - C Ph. | 14.53 | TOTAL DESIGN LOAD (AMPS) | 158 |

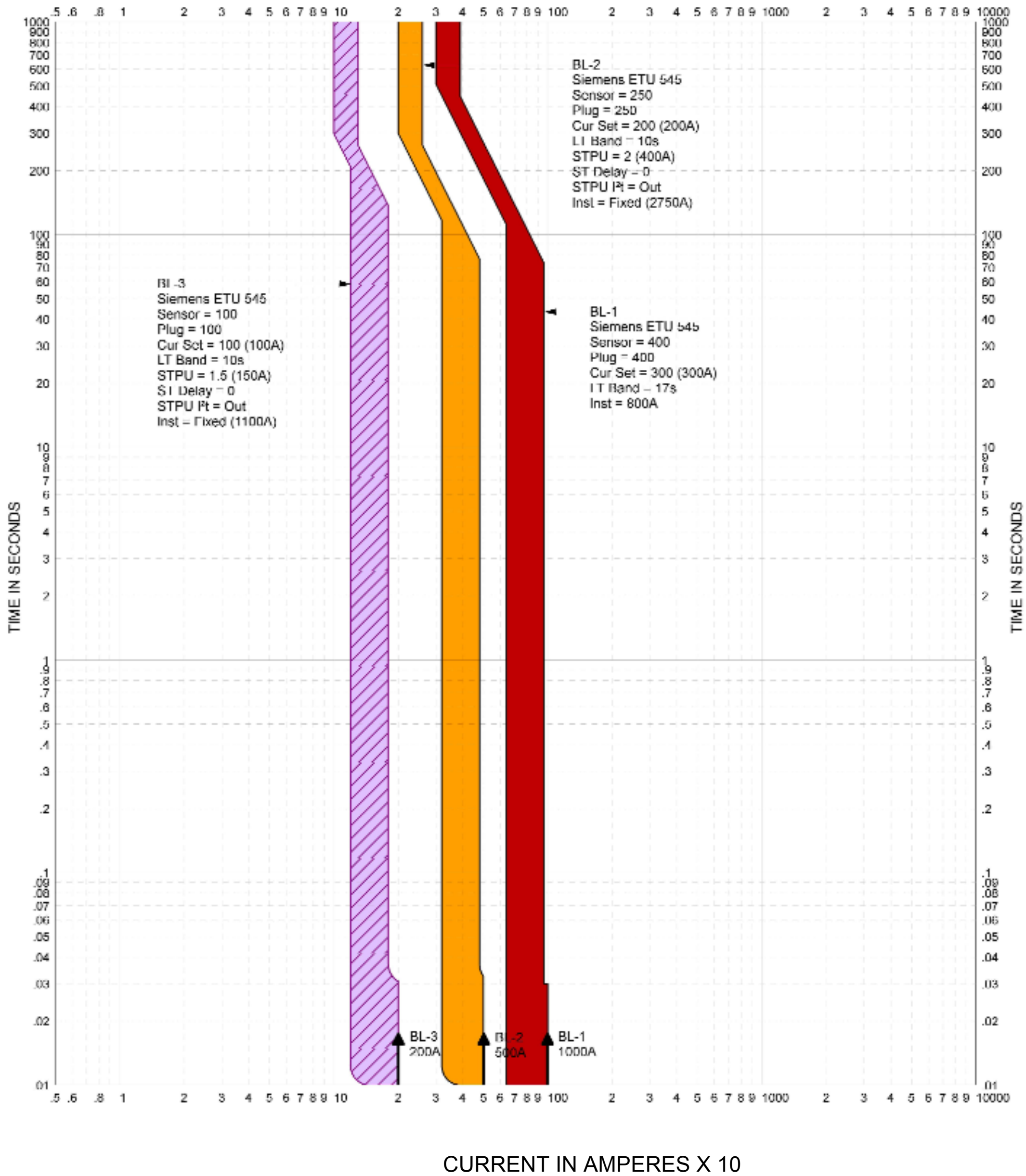
# PANELBOARD SCHEDULE

| | | | | | |
|---|---|---|---|---|---|
| VOLTAGE: | 208Y/120V,3PH,4W | PANEL TAG: | DR-2 | MIN. C/B AIC: | 10K |
| SIZE/TYPE BUS: | 225A | PANEL LOCATION: | 139 - Dimmer Room | OPTIONS: | PROVIDE FEED THROUGH LUGS |
| SIZE/TYPE MAIN: | 225A/3P C/B | PANEL MOUNTING: | SURFACE | | FOR PANELBOARD 1L1B |

| DESCRIPTION | LOCATION | LOAD (WATTS) | C/B SIZE | POS. NO. | A | B | C | POS. NO. | C/B SIZE | LOAD (WATTS) | LOCATION | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry vestibules | Lobby | 1000 | 20A/1P | 1 | * | | | 2 | 20A/1P | 600 | Concert Hall | Rear wallwashers |
| Platform lower wall | Concert Hall | 980 | 20A/1P | 3 | | * | | 4 | 20A/1P | 980 | Concert Hall | Platform lower wall |
| latform rear lower wa | Concert Hall | 1400 | 20A/1P | 5 | | | * | 6 | 20A/1P | 720 | Concert Hall | atform center lower wa |
| Chour terrace sidewa | Concert Hall | 1440 | 20A/1P | 7 | * | | | 8 | 20A/1P | 1440 | Concert Hall | Chour terrace sidewall |
| Chour terace rear wa | Concert Hall | 1200 | 20A/1P | 9 | | * | | 10 | 20A/1P | 1080 | Concert Hall | Chour terrace rear ctr |
| Upper sidewall | Concert Hall | 2400 | 20A/1P | 11 | | | * | 12 | 20A/1P | 2400 | Concert Hall | Upper sidewall |
| Upper rear wall | Concert Hall | 1080 | 20A/1P | 13 | * | | | 14 | 20A/1P | 1200 | Concert Hall | First floor downlights |
| Upper downlights 1 | Concert Hall | 1250 | 20A/1P | 15 | | * | | 16 | 20A/1P | 1250 | Concert Hall | Upper downlights 2 |
| Upper downlights 3 | Concert Hall | 450 | 20A/1P | 17 | | | * | 18 | 20A/1P | 1600 | Concert Hall | Wide LED strips 1 |
| Wide LED strips 2 | Concert Hall | 1600 | 20A/1P | 19 | * | | | 20 | 20A/1P | 949 | Concert Hall | Narrow LED strips |
| Façade lighting | Façade | 1644 | 20A/1P | 21 | | * | | 22 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 23 | | | * | 24 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 25 | * | | | 26 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 27 | | * | | 28 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 29 | | | * | 30 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 31 | * | | | 32 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 33 | | * | | 34 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 35 | | | * | 36 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 37 | * | | | 38 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 39 | | * | | 40 | 20A/1P | 0 | | |
| | | 0 | 20A/1P | 41 | | | * | 42 | 20A/1P | 0 | | |

| | | | |
|---|---|---|---|
| CONNECTED LOAD (KW) - A Ph. | 9.31 | TOTAL DESIGN LOAD (KW) | 32.00 |
| CONNECTED LOAD (KW) - B Ph. | 8.38 | POWER FACTOR | 0.98 |
| CONNECTED LOAD (KW) - C Ph. | 8.97 | TOTAL DESIGN LOAD (AMPS) | 91 |

# Protective Device Coordination




In the above diagram, the three protective devices are shown to be coordinated, because the time/current curves do not overlap. When a current exceeds the designed level, the breaker farthest into the system will trip first. This prevents power loss in a larger portion of the building, as well as making it easier to locate the source of the overcurrent.

**Note**: Overcurrent device specifications were not available; the characteristics used here are assumed values.

# Short Circuit Analysis

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Utility S.C. | 1,000,000 | kVA | | | | | |
| Base kVA | 1,000 | kVA | | ΣX | ΣR | ΣZ | Isc (A) |
| **Utility Transformer Primary** | | | | | | | |
| | | X = Base kVA/Utility Contribution = | 0.001 | 0.001 | 0 | 0.001 | |
| **Utility Transformer Secondary** | | | | | | | |
| %Z = | 5.175 | $X = \%X*kVA_{base}/(100*kVA_{transformer})$ = | 0.02445 | | | | |
| Avg. X/R = | 2.9 | $R = \%R*kVA_{base}/(100*kVA_{transformer})$ = | 0.0084 | | | | |
| %X = | 4.89 | | | 0.02545 | 0.0084 | 0.02680 | **103,570** |
| %R = | 1.68 | | | | | | |
| kVA = | 2,000 | | | | | | |
| **Switchboard 1-SWBD-1** | | | | | | | |
| Wire size = | 500 kcmil | $X = (L/1000)*X_L*(1/\#\ sets)$ = | 0.00052425 | | | | |
| # of Sets = | 8 | $R = (L/1000)*R_L*(1/\#\ sets)$ = | 0.00052425 | | | | |
| Length = | 90 | | | 0.02597 | 0.00892 | 0.02746 | **101,065** |
| $X_L$ = | 0.0466 | | | | | | |
| $R_L$ = | 0.0294 | | | | | | |
| **Tranformer T1-TLDP-1 Primary** | | | | | | | |
| Wire size = | 350 kcmil | $X = (L/1000)*X_L*(1/\#\ sets)$ = | 0.0066285 | | | | |
| # of Sets = | 1 | $R = (L/1000)*R_L*(1/\#\ sets)$ = | 0.005103 | | | | |
| Length = | 135 | | | 0.03260 | 0.01403 | 0.03549 | **78,206** |
| $X_L$ = | 0.0491 | | | | | | |
| $R_L$ = | 0.0378 | | | | | | |
| **Transformer T1-TLDP-1 Secondary** | | | | | | | |
| %Z = | 5.175 | $X = \%X*kVA_{base}/(100*kVA_{transformer})$ = | 0.02934 | | | | |
| Avg. X/R = | 2.9 | $R = \%R*kVA_{base}/(100*kVA_{transformer})$ = | 0.01008 | | | | |
| %X = | 4.89 | | | 0.06194 | 0.02411 | 0.06647 | **41,760** |
| %R = | 1.68 | | | | | | |
| kVA = | 225 | | | | | | |
| **Panelboard 1-TLDP-1** | | | | | | | |
| Wire size = | 500 kcmil | $X = (L/1000)*X_L*(1/\#\ sets)$ = | 0.0066285 | | | | |
| # of Sets = | 2 | $R = (L/1000)*R_L*(1/\#\ sets)$ = | 0.005103 | | | | |
| Length = | 10 | | | 0.06857 | 0.02921 | 0.07453 | **37,241** |
| $X_L$ = | 0.0466 | | | | | | |
| $R_L$ = | 0.0294 | | | | | | |
| **Isc at SP-1 (Panel)** | | | | | | | |
| Wire size = | 3/0 AWG | $X = (L/1000)*X_L*(1/\#\ sets)$ = | 0.0066285 | | | | |
| # of Sets = | 1 | $R = (L/1000)*R_L*(1/\#\ sets)$ = | 0.005103 | | | | |
| Length = | 35 | | | 0.07520 | 0.03431 | 0.08266 | **33,581** |
| $X_L$ = | 0.0519 | | | | | | |
| $R_L$ = | 0.0805 | | | | | | |

**Note:** Transformer specifications were not available; the characteristics used here are assumed values used for the purposes of completing the calculation.

# Transformer Consolidation  Electrical Depth 1

As designed, the Wentz Concert Hall and Fine Arts Center has five transformers to serve its 120/208V systems. How many of these could be consolidated into a single transformer, and what would the effect of fewer but larger transformers on the overall cost of the electrical system?

One of the transformers, TLL-LDP-1, serves the kitchen and miscellaneous lighting and power loads throughout the building. Others are dedicated to more specific purposes: T1-TLDP-1 serves the concert hall, T1-TLDP-2 serves the black box theater, T1-DCTP-1 is a power conditioner for the audiovisual system, and TLL-ELP-1 receives power from an emergency transfer switch to serve most of the emergency loads.

These transformers can't all be consolidated to a central device; the clean technical power needs to remain on an isolated system with its own power conditioner. The other four can be, provided that the generator and fire pump are switched to 208/120V so that the emergency panel no longer needs a transformer.

The central transformer will be located in the main electrical room on the lower level (LL49), where TLL-LDP-1 is currently sited. To accommodate a larger transformer, the wall shared with the emergency electrical room (LL50) can be moved several feet, which no longer needs space for TLL-ELP-1.

Several changes must be made to accommodate the proposed system. Feeders directly to the 208/120V panelboards are sized up from what originally served the transformers. The generator, firepump, and emergency transfer switches are replaced to operate at 208/120V. And, of course, four of the transformers are replaced by a single large unit. The new transformer will be fed directly from the main switchboard.

Cost estimates used are total prices including materials, labor, overhead, and profit, and are based on data from Q1 2012.

## Panelboards

The distribution panel LL-HDP-1 serves, T1-DCTP-1, LL-ELP-1 (via ATS-1), and TLL-LDP-1. The second and third of these transformers will be removed, and LL-HDP-1 can be removed (and replaced with a 208/120 V panel), as it would now only be serving the clean technical power transformer.

The new transformer will require a panel (located in the space left by LL-HDP-1), to distribute power to the panels originally served by their own transformers. This panel, LL-LDP, will include the following loads:

| Panel | Demand Load (KVA) |
|---|---|
| 1-TLDP-1 | 116.2 |
| 1-TLDP-2 | 100.3 |
| LL-ELP-1 | 38 |
| LL-LDP-1 | 206.9 |
| **Total** | **461.4** |

This gives a demand ampacity of 3841A, which can't be met with a 4000A bus switchboard.

Table 2: Original Distribution Panel Costs

| | Original Design | |
|---|---|---|
| Tag | Panel Size | Cost |
| 1-TLDP-1 | 800 A | $ 4,375.00 |
| 1-TLDP-2 | 1400 A | $ 5,625.00 |
| LL-ELP-1 | 400 A | $ 2,860.00 |
| LL-LDP-1 | 1200 A | $ 5,275.00 |
| Total | | $ 18,135.00 |

Table 3: Redesigned Distribution Panel Costs

| | Proposed Centralized Design | |
|---|---|---|
| Tag | Panel Size | Cost |
| LL-LDP | 4000 A | $12,200 |

## Transformer

The new transformer, TLL-LDP is sized at 500 kVA to supply the LL-LDP panelboard described above.

It replaces T1-TLDP-1, T1-TLDP-2, TLL-ELP-1, and TLL-LDP-1.

Table 4: Original Transformer Costs

| Tag | Original Design<br>Transformer Size | Cost |
|---|---|---|
| 1-TLDP-1 | 225 kVA | $8,624 |
| 1-TLDP-2 | 225 kVA | $8,624 |
| LL-ELP-1 | 30 kVA | $2,800 |
| LL-LDP-1 | 300 kVA | $10,690.00 |
| Total | | $30,738.00 |

Table 5: Redesigned Transformer Costs

| Tag | Proposed Centralized Design<br>Transformer Size | Cost |
|---|---|---|
| TLL-LDP | 500 kVA | $16,325 |

## Feeders

One effect of a centralized transformer is that larger wires are required to distribute power out to the 208/120V panelboards, increasing wiring cost.

Table 6: Original Feeder Costs

| Load | Original Design<br>Type | Phase/N | Ground | Raceway | Length (ft) | Feeder cost / ft | Raceway cost / ft | Total cost |
|---|---|---|---|---|---|---|---|---|
| T1-TLDP-1 | THHN | (3) 350 | 3 | 2 1/2" | 135 | 16.705 | 28.5 | $ 6,102.68 |
| T1-TLDP-2 | THHN | (3) 350 | 3 | 2 1/2" | 165 | 15.03 | 28.5 | $ 7,182.45 |
| LL-ELP-2 | THHN | (3) 8 | 10 | 3/4" | 15 | 4.28 | 10.25 | $ 217.95 |
| LL-LDP-1 | THHN | (3) 500 | 3 | 3" | 30 | 20.72 | 36.2 | $ 1,707.60 |
| FPC-ATS | THHN | (4) 1 | n/a | 1 1/4" | 25 | 8.48 | 14.85 | $ 583.25 |
| LL-HDP-1 | THHN | 2x (4) 500 | 1/0 | 3 1/2" | 15 | 50.8 | 44.9 | $ 1,435.50 |
| T1-DCTP-1 | THHN | (3) 1 | 8 | 1 1/4" | 155 | 7.515 | 14.85 | $ 3,466.58 |
| Total: | | | | | | | | $ 20,696.00 |

Table 7: Redesigned Feeder Costs

| | Proposed Centralized Design | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Load | Design KVA | Design A | Type | Phase/N | Ground | Raceway | Length (ft) | Feeder cost / ft | Raceway cost / ft | Total cost |
| 1-TLDP-1 | 133 | 369 | THHN | (4) 400 | 3 | 3" | 135 | 24.235 | 36.2 | $ 8,158.73 |
| 1-TLDP-2 | 146 | 405 | THHN | (4) 500 | 2 | 3" | 165 | 27.075 | 36.2 | $10,440.38 |
| LL-ELP-1 | 30 | 83 | THHN | (4) 5 | 8 | 1" | 15 | 9.7 | 12.21 | $ 328.65 |
| LL-LDP-1 | 244 | 677 | THHN | 2x (4) 350 | 2x 3 | 3 1/2" | 30 | 43.43 | 44.9 | $ 2,649.90 |
| FPC-ATS | 80 | 222 | THHN | (4) 3/0 | 4 | 2" | 25 | 14.13 | 20.15 | $ 857.00 |
| LL-LDP | 462 | 1282 | THHN | 3x (4) 500 | 3 | (3) 2 1/2" | 15 | 81.225 | 85.5 | $ 2,500.88 |
| T1-DCTP-1 | 75 | 90 | THHN | (3) 1 | 8 | 1 1/4" | 165 | 7.515 | 14.85 | $ 3,690.23 |
| Total: | | | | | | | | | | $28,625.75 |

## Overall cost

Table 8: Original and Redesign Cost Comparison

| Category | Original Cost ($) | Centralized Cost ($) |
|---|---|---|
| Panels | $ 18,135.00 | $ 12,200.00 |
| Transformers | $ 30,738.00 | $ 16,325.00 |
| Feeders | $ 20,696.00 | $ 28,625.75 |
| Total | $ 69,569.00 | $ 57,150.75 |

As you can see, the cost of the distribution panels and feeders is somewhat lower for a centralized panelboard. But this comes with the cost of slower installation and the possibility of needing to oversize feeders or branch circuits to reduce voltage drop. Additionally, centralizing the transformers introduces a single point of failure to the system. If the transformer has a defect, it would cut off power to the entire 120/208V system.

# Photovoltaic Array  Electrical Depth 2

With the escalating cost of energy, photovoltaic power generation has become more and more popular. In this depth, I'll propose the addition of a solar system on the Wentz Concert Hall's upper roof.

## Equipment

### *Panel*

The system uses a crystalline silicon SunPower SPR-210-BLK solar panel, with an overall efficiency of 16.89%. It produces a maximum power of 210.1 $W_{DC}$ at 40 $V_{DC}$ and 5.25 $A_{DC}$. The open circuit voltage is 47.7 $V_{DC}$ per panel, and short circuit current is 5.75 $A_{DC}$. Each module is composed of 72 cells connected in series.

The panels are 61.4 inches long, 31.4 inches wide, and 1.8 inch thick. They each weigh 33 lbs. Panels are estimated to cost $2.05 per $W_{DC}$.

### *Inverter*

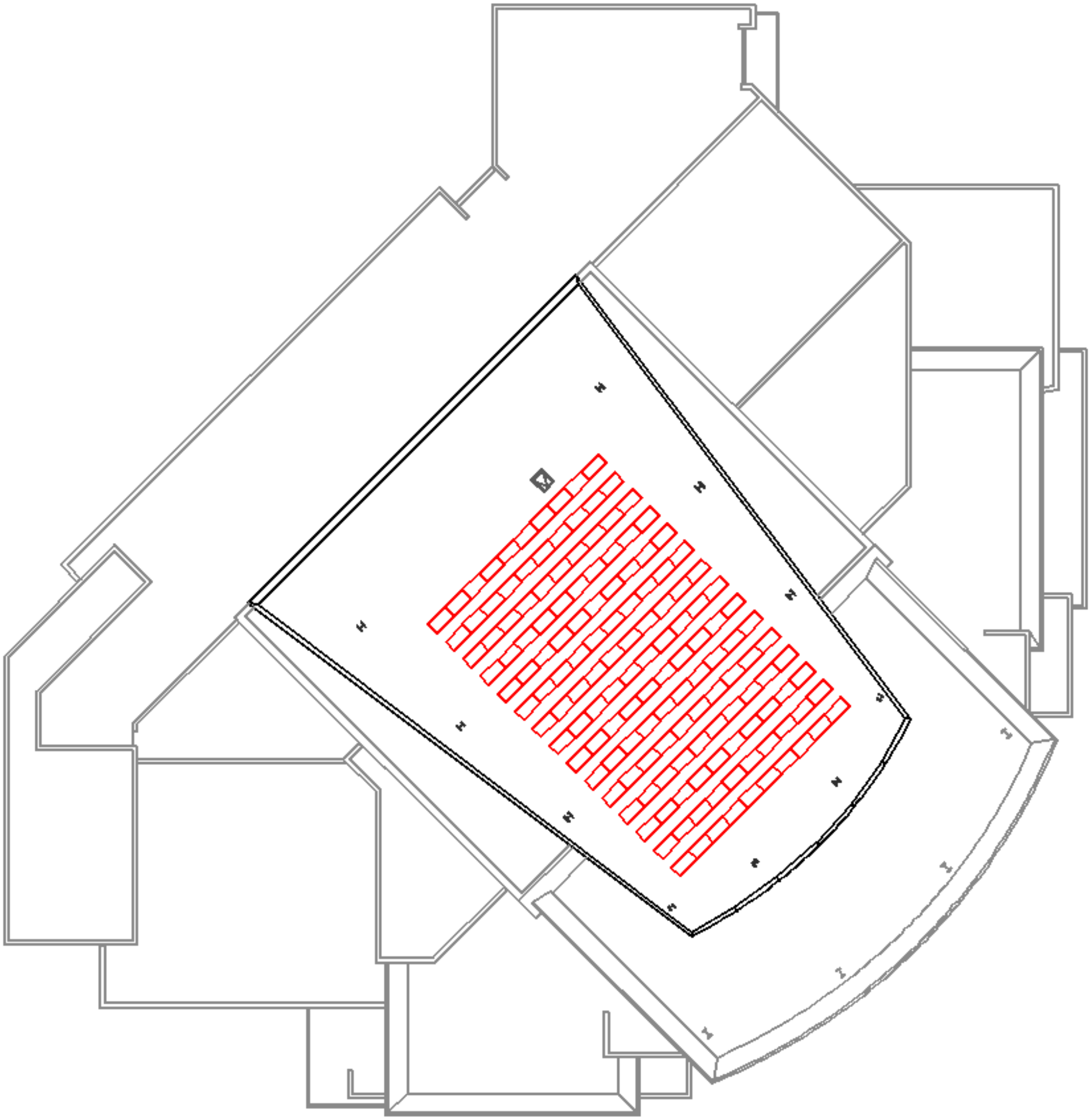
The inverter is a PV Powered PVP35kW-480, which converts from a maximum of 125 A and 600 $V_{DC}$ to AC at 480V. It can convert up to 36.5 $kW_{DC}$ to 35 $kW_{AC}$. The inverter cost is estimated at $0.37 per $W_{DC}$. Additional costs, such as installation and installer margin are estimated to cost $1.72 per $W_{DC}$.

A single inverter is used instead of microinverters because the concert hall is the highest building in the area, and inter-row shading wouldn't differ between strings because of the regular layout.

## Layout

The roof has a very slight north facing slope, from 753 ft. elevation at the southeast edge, to 748 ft. toward the northwest. Modules are sloped at a relatively shallow 15 degrees, to allow tighter spacing without inter-row shading on the space constrained roof. The panels are arranged for 50% cover. They face southeast, to align with the roof and account for the building's heaver use earlier in the day.

Figure 23: Photovoltaic Array Layout



The panels extend to a closest distance of 6 feet from the edge of the roof. They are arranged in 15 rows of 10, for a total of 150 panels. Each row of 10 panels is connected in series to produce a maximum of 470$V_{DC}$.

## Output

With 150 panels at 210.1 $W_{DC}$, the system produces a maximum of 315.2 $kW_{DC}$. According to a simulation run in NREL's System Advisor Model, it has an annual estimated output of 39,440 kWh.

## Electrical Connection

Each string has a short circuit current of 5.75A, and is protected and isolated by a small solar fuse to prevent overcurrent or reverse current in case of a fault in a string. These fuses are sized at 9A (the next size above 150% $I_{SC}$) and are located in a solar combiner box, which collects the DC from each string and combines it into a single DC output, which is sent to the inverter.

The inverted takes the DC current and converts to AC at 480Y/277 V, which is fed into the main switchboard. Its peak output is 35 kW at minimum 0.99 power factor. This gives a current of 73 A, and can be connected with size 3 AWG wires.

## Economics

The economics are analyzed for a 25 year period with a projected inflation of 2%, real discount rate of 5.20%. In accordance with Illinois' Special Assessment for Solar Energy Systems, the property taxes are assessed at the price of a standard electrical system. It uses 5 year accelerated depreciation at the federal and state level.

Illinois doesn't currently have a market for Solar Renewable Energy Credits, but they will beginning in energy year June 2012 to May 2013. It is difficult to predict how this market will perform over the next 25 years, but I have assumed a price of $100 per MWh for 15 years. The SRECs are purchased by utility companies from independent solar operators to count toward minimum renewable generation requirements.

The estimated real levelized cost of energy of the system is 13.43 ¢/kWh. This is higher than the current electric rate, but due to inflation and increasing electric rates, the system should pay off after 22.7 years. Since the system is expected to last 25-30 years, it shouldn't lose money, but it may not be the best investment. It is more justifiable as an effort to reduce dependence on energy produced by fossil fuels than as a long term financial investment.

# Conclusion

The design solutions presented here are aimed largely at reducing the Wentz Concert Hall and Fine Arts Center’s electrical demands, and at creating a lighting design scheme that ties into the architectural style to achieve its effect without requiring large amounts of power. The lobby lighting is both welcoming and efficient, the concert hall has drastically reduced power requirements while giving it an even more memorable appearance, and the façade’s colored top level marks the center as an important building from far away. As a long lasting institution established in 1861, North Central College has an interest looking to the future and reducing its energy dependence. These alternate designs are a good start to moving the college toward that goal.

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