Boston University Arena and Recreation Center

2007 Thesis Final Report

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Lighting and Electrical Emphasis

Technical Advisors: Dr. Mistrick and Ted Dannerth

Boston University Arena and Recreation Center

Boston, MA

Structural

Spread footing foundations;
Pile and lagging earth retention system around site due to close proximity of existing structures.
Cast in place concrete perimeter walls approx. 3 levels below grade.
Arena LL2 floor post-tensioned slab, all other floors slab on metal deck.
Steel columns and beams, as well as roof trusses in Arena

Lighting/Electrical

A wide variety of fluorescent and metal halide lighting fixtures.
13.8kV utility serves 2 Arena substations and 1 Recreation Center substation.
Recreation substation has 2 15kV feeds with step down transformer to 480Y/277V, and a 1600A, 3P, 5W 480Y/277V plug in busway services floors LL2 through UL3.

Mechanical

17 AHUs with total capacity 650,000cfm;
Gas fired pre-heat coils with TUR coils;
and 3 chillers and 3 cooling towers.
Building Automation System to operate all heating/cooling on preset temperatures with the ability to manually change by location.

Project Team

Owner: Trustees of Boston University
Contractor: Barton Malow and Walsh Brothers Sports Partnership
Architect: Cannon Design
Structural Engineering: Cannon Design and LeMessurier Consultants, Inc.
MEP Engineering: Cannon Design
Lighting Consultant: The RETEC Group, Inc.
Civil Engineering: Bryant Associates, Inc.

Special Features

Recreation Center: 18,000sf weight and cardio room, 2 swimming pools, 2 gymnasiums, 1/8 mile elevated jogging track, multipurpose activity/classrooms, and a 35' climbing wall.
Arena: Seating for 6,300, 29 suites and premium seats, ice hockey rink as well as portable basketball floor, exclusive Club Room, and several concession stands.

Project Description

Total Square Footage: 822,000
Levels: 3 below and 3 above grade
Cost: $185,000,000
Dates of Construction: May 2002- April 2005
Project Delivery Method: CM/GMP

Alexis Kreft
Lighting/Electrical Emphasis
http://www.arche.psu.edu/thesis/eportfolio/2007/portfolios/amk316

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Executive Summary

Boston University's Student Village Project design intent was to create a centralized location for active student life on campus. The ten acre site developed a connection between the east and west sides of campus, allowing students, faculty, and alumni to join together in array of activities. Incorporated into the new John Hancock Student Village is an Arena and a Recreation and Fitness Center, which will be the building project examined in my Capstone Project.

This report will include an in-depth study on a proposed light redesign for four major spaces in the building. I will provide recommendations for luminaires, ballasts, controls, and lamp information, as well as suggestions for fixture placement and design. Creating a new lighting scheme for an already well designed space was rather challenging. Be developing entirely new concepts, I was able to develop a plan for each lighting space that was unique but kept in line with the overall building concept.

An electrical depth analysis will also be included in this report. Within this section the four lighting spaces are re-circuited to accommodate the new lighting loads. Each space will also have a resized panelboard, overcurrent protection device, and distribution feeder. Also included in this section of the report, will be a comparison between the advantages and disadvantages of copper and aluminum wire. A study was also conducted analyzing the usage of energy efficient transformers. The research will look at the differences in initial costs, energy savings, payback periods, as well as greenhouse gas reduction. Lastly in this section, an examination of protective device coordination has been carried out.

In order to improve constructability and value engineering during the building construction process, a section of the lobby ceiling has been investigated, which is found in the construction management breadth of this report. The existing ceiling is an aluminum metal, highly reflective drop ceiling cut on a 40ft inner radius. The study will compare the exiting ceiling with a new acoustical ceiling tile. Labor costs, material costs, as well as scheduling will be taken into consideration.

Lastly, this report will include a mechanical breadth analysis. The new lighting design concept for the gymnasium incorporated maximizing daylight and minimizing electric lighting during day time hours. Clerestories were added to the gym roof structure in order to bring more daylight to the space. The addition of many windows will directly affect the heating and cooling loads required for the gymnasium. The analysis shows the difference between the existing and new mechanical loads required for this space.

Introduction

Background

The Boston University Arena and Recreation Center Project is part of a larger campus plan known as the Student Village. The new ten acre hub is designed to be the center of campus life. Included on the site is a state-of-the art fitness, athletic, recreational, and entertainment facility, an exquisite arena as well as, a high-rise dormitory complex. The intent of the John Hancock Student Village was to unify the east and west sides of campus, and create a central location for student life and activity. With this project, Boston University wanted to "bring together students, faculty, alumni, and others through a range of athletic events, fitness programs, university events such as Homecoming and Commencement, academic and professional conferences, intramural sports, social gatherings, concerts, and cultural events" (Boston University Business Affairs, April 6, 2005).

General Building Overview

Project Name: Boston University Arena and Recreation Center
Location: 915 Commonwealth Ave, Boston, MA
Building Occupancy: Boston University
Function: Arena, Fitness Center, Dance Studios, Activity Rooms, Gymnasiums
Size: Arena- 264,635 sq ft
Recreation Center- 267,995 sq ft
Underground Structured Parking- 289,370 sq ft
TOTAL- 822,000 sq ft
Levels: 5 stories
Owner: Boston University http://www.bu.edu
Owner Representative: David Flynn
Construction Managers: Joint venture- Barton Malow Co. http://www.bartonmalow.com/ and Walsh Brothers Partnership
Architects and Engineers: Cannon Design http://cannondesign.com/
Dates of Construction: May 21, 2002 – April 2005
Cost: $185 million GMP price, which covered total building construction, plus CM general conditions and fees. The price went up a little with owner change orders.
Project Delivery Method: CM/GMP

Design Background

Architecture: The entire site is built primarily with brick and pre-cast concrete panels. The facades and walkways are constructed with a rich red brick in creative design patterns. A notable architecture feature found within the Arena and Recreation Center is the use of curved structures. The Recreation Center has a large rotunda located near the front entrance of the building. The curved architecture is not only seen from the outside, but continues on the interior with a 40ft radius. The Arena also has curved features, such as the north and south facades which are completely curved. Another distinguishing feature is the use of glass. Throughout both buildings large floor to ceiling windows were incorporated to maximize daylight. The entire rotunda exterior is made of glass as well as the main entrances for both facilities. The glass also continues to be implemented within the interior. Along the Recreation Center lobby, floor to ceiling glass windows are used in order to see into the competition pool area. The gymnasiums are also equipped with viewing windows so those passing by can peer into the basketball or racquetball courts.

Electrical: The Boston University Arena and Recreation Center electrical system implements a combination of system types for increased reliability and ease of maintenance. The primary feed comes in at 13.8kV where it runs through a 15kV, 600A interrupter fuse before beginning a primary loop system through three different substations (2-Arena substations and 1-Recreation Center substation). Once the primary feed enters each substation there is a 13.8kV primary, 480Y/277V secondary step down transformer, which then services a secondary selective system. Between the two radial layouts there is a normally open tie-breaker, which can close if a primary feeder or transformer is lost on either side. Most of the Recreation Center power is distributed off a 1600A, 3P, 5W plug-in busway which runs vertically through the building and is fed off the main distribution panel.

Lighting: In the Recreation Center, most of the lighting is 277V compact fluorescents, incandescent PAR, or metal halide lamps. The ballasts used are mostly electronic and electronic dimming with a ballast factor greater than or equal to 0.88. On the 120V system there are a small amount of incandescent and halogen lamps. Not many decorative lighting fixtures are used besides some decorative cove illumination. The lighting system is pretty basic and the primary goals are functionality and maintenance friendly.

Mechanical: The mechanical system implements many different types of equipment. There are seventeen air handling units with a total capacity of 650,000cfm; gas fired pre-heat coils with TUR coils; three chillers and three cooling towers. There is a building automation system that operates all heating and cooling on preset temperatures with the ability to manually change by location.

Structural: The site is built on a spread footing foundation with a pile and lagging earth retention system around the site due to close proximity with the existing structures. Cast-in-place concrete perimeter walls are approximately three levels below grade. The Arena lower level two has a post-tension slab floor, but all other floor slabs are metal decking. There are also steel columns and beams throughout the Arena and Recreation Center.

Fire Protection: The system includes many different types of detectors such as smoke, heat, and local automatic. They are all programmed to transmit alarms to BU protective services, faculty, central control devices, sound audible alarms, visual alarms, release hold open fire and smoke doors, release lock on fire command center, and signal local lighting control full brightness.

Telecommunications: All offices, classrooms, activity rooms, and team locker rooms have access to the telecommunication and data systems. BU implements ResNet telecommunication with quads and wireless network quads, as well as high intensity data 4-strand fiber optic ports.

Site

Below is a picture of the John Hancock Student Village as it exists today. The highlighted area is the site for the Student Village construction plan. Within that plan the Agganis Arena and Fitness Center construction project came forth.

Lighting Depth- Redesign Work

Club Room

Lobby & Circulation Space

Four Court Gymnasium

Exterior Pathways

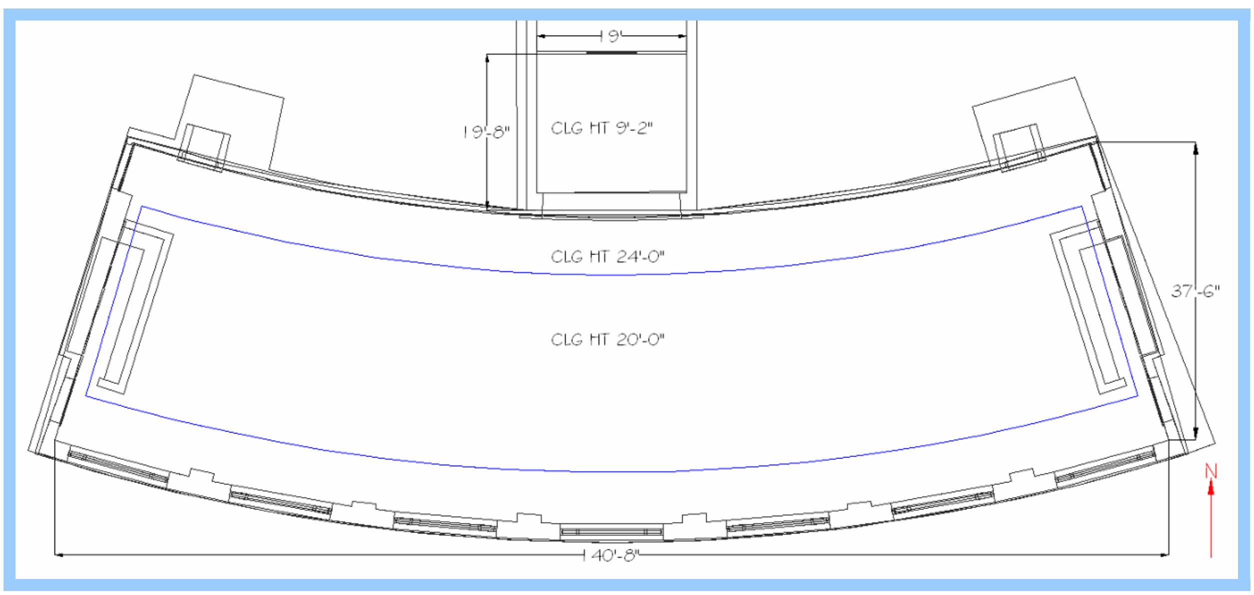
Club Room

Overview

The Club Room is meant specifically for special gatherings of VIPs, special donors, and premium shareholders of Boston University. Located above the main lobby, the Club Room is situated on the south end of the Arena concourse level. The two story room is a multipurpose space designed for luxury, with floor to ceiling windows, elegant furniture, and numerous decorative elements. The expansive 5,600 square-foot area features a bar, video screens, and kitchen support areas with a flexible floor plan that can accommodate up to 400 guests.

Floor Plan

Generally, the Club Room is used as a VIP lounge with no definitive furniture plan. The main entrance to the space is located off the concourse on the North end of the room. Situated on the east and west sides are full cocktail bars with flat screen monitors located directly above the bar, while four other large flat screen televisions are located on the North and South walls. All furniture in the space is more than likely to alter depending on the function; there are couches with coffee tables, high tables with stools, a bar with stools, as well as typical height table and chair sets. The only permanent features within the space are the flat screen monitors and wall hangings in the entrance corridor.



Surface Characteristics

The Club Room is designed with a rich color palette, incorporating warmer earth tones throughout the space. Most of the walls are covered with wood paneling and in the absence of the paneling, the walls and ceiling are painted eggshell white. Tan-grey carpets and terrazzo tiles make up the floor covering. The floor to ceiling windows are clear double-pane insulating glass with a standard low E-coating, and in the case of presentations or events on the television the windows are equipped with black-out roller shades that have an interior color similar to that of the painted walls/ceiling.

$\rho = 0.37$ $\rho = 0.52$ $\rho = 0.23$ $\rho = 0.87$

Left to Right: Un-steamed European Beech wood panel walls, terrazzo floor, grey carpet, soft butter cream walls and ceiling.

The Visible Light Transmittance of the floor to ceiling windows for a typical Low-E is 0.72 and the Solar Heat Gain Coefficient is 0.41. The Visible Light Transmittance of the floor to ceiling windows for a clear double pane is 0.81 and the Solar Heat Gain Coefficient is 0.76.

Design Criteria

Main Goal: To generate a design that creates a comfortable, luxurious feeling for the exclusive guests incorporating several different settings for the different functions. The lighting should not be based on a specific furniture plan except for the main entrance wall hangings and bar area lighting. This system should be very flexible and user friendly.

The appearance of the space and luminaires within the Club Room is an essential aspect of the design. The space is meant for very exclusive members and should have an elegant feel to separate itself from the rest of the Arena. Luminaires should be hidden as best as possible and/or more graceful decorative fixtures should be used for aesthetics, more than purely functional. Another lighting design criterion crucial for the space is system control and flexibility. Because the area is multifunctional without definitive furniture plan, there should be several different lighting scenes to accommodate each usage. In case the function changes often, the control system should be simple and user friendly. Although, hidden from the public eye, the control pad should be in an easily accessible area.

Color appearance is also an important criterion to consider for the lighting design. The space is filled with earth-tone colors such as browns, creams, tans, and grays. The luminaires should have a low color temperature in order to avoid washing out the wood panels and warm colored walls. All general, ambient lighting fixtures should have the similar, if not the same, color temperature to avoid unevenness. Another important factor to consider is the points of interest. Throughout the spaces there are several architectural elements and permanent features such as flat screen televisions, picture frames, and wood paneling that need to be considered when creating a new lighting design. The lighting should either avoid or highlight points of interest. The surface characteristics are also an important feature of the space to think about.

Daylighting integration and control is also an important issue when creating a new lighting layout. The south facing, floor-ceiling windows will bring in copious amounts of sunlight throughout the space. When an event is being viewed on the large flat screen televisions, black out shades will be pulled down, in which case the lighting should accommodate the change. Finally, other important issues to consider for the Club Room lighting design are the target illuminance values. If the space is being used as a lounge the lighting should be adequate enough for reading and working with a horizontal illuminance of about 30-40fc. During social gatherings and formal events in the evening a horizontal illuminance of about 5-10fc is desired. The vertical illuminance throughout the space should be brighter on points of interest and in the case of highlighting architectural or textured elements.

Design Concept

The Club Room is a very versatile space with an elegant touch. The room was designed to give the VIPs, premium shareholders, and special donors of Boston University a space of luxury separated from the general public. Located on the South end of the Arena, the Club Room receives sun throughout the day from the 20 ft floor to ceiling windows that expand the entire south side. Opposite the windows, the wall is covered with beech wood panels. Other decorative elements include large wall hangings in the entrance corridor, large flat screen televisions, cocktail bars, and a drop ceiling.

When beginning the lighting design for this space, the most important features I want to include are flexibility and user friendly controls. Because the space can be used for daily lounging, sport event viewing, nightly formals, and/or informal social gatherings, the lighting needs to accommodate all of these needs as well as make it simple for the users to control. After thorough research the Lutron Grafik Eye 4000 seemed to be the best control system for this space. With a flexible control system, I was ready to begin the lighting design.

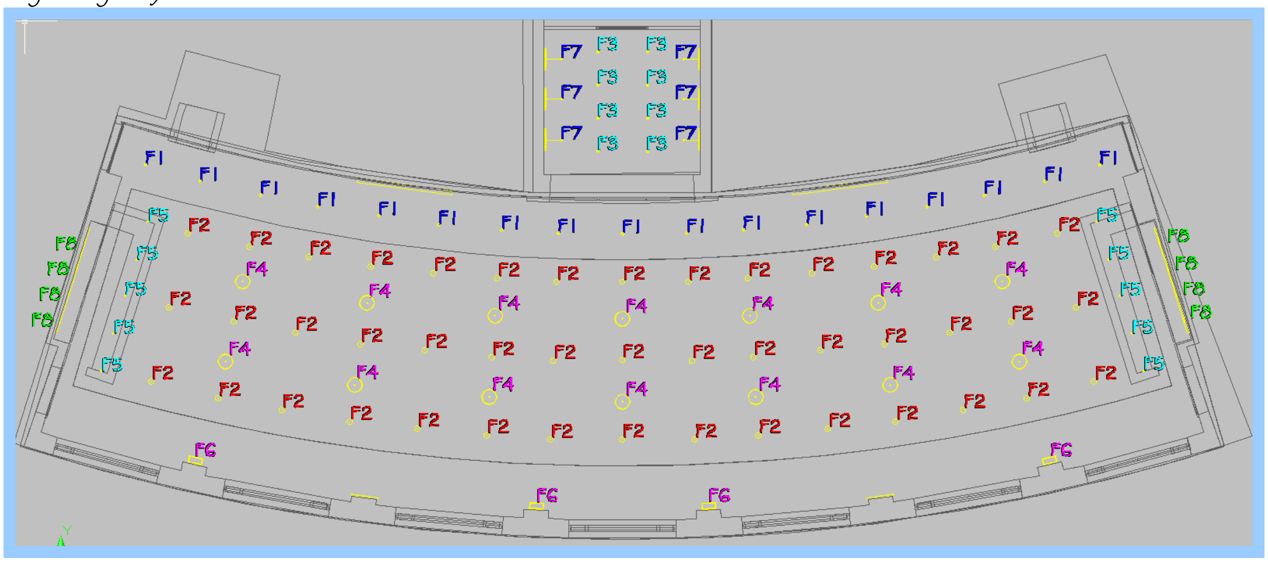
The overall lighting concept is to create a space home-away-from home for the specials guests. This area is "their" space and they should feel welcome and warm at all times. There should also be a touch of elegancy in the fixtures. The lighting should not only provide adequate light levels, but should also provide a decorative element within the space. Since the height of the ceiling is about 20ft, the best way to provide lighting on the workplane for possible reading is through a downlight fixture. Inner-mixed with the downlights could be decorative-indirect, but efficient pendants. In order to highlight and bring out the texture of the wood-panel wall a wall washer may be used that also creates movement itself.

Around the bar area, decorative and more colorful fixtures will be used. Recessed in the shelf behind the bar, a linear-recessed LED fixture will highlight the liquor bottles from below. The fixture will be on a slow color changing sequence that will rotate through the rainbow. Directly above the bar counter itself, decorative pendants will be used.

In the entrance corridor, the main goal is to lead the guests directly to the larger Club Room space. On each side of the corridor, small picture lighting fixtures will highlight the wall hangings. Down the center of the corridor, small downlights that provide just enough light to walk will be used, but the intent is to keep the large room much brighter than the corridor in order to lead people's attention to the more important, larger space. The large windows will be equipped with black out shades in the event the large screen televisions are being used. Daylighting will be an important element within the space but will not directly control the electric lighting.

Luminaire Plan

Lighting Layout



Luminaire Images

Luminaire Schedule

Label	Description	Catalogue NO.	Lamp			Ballast		Voltage	Fixture Qty.
			NO.	Type	Watts	Type	Lamps		
F1	Reccessed wallwash, Low Voltage Halogen	ERCO 22415.023	1	T4 75W 12V GY6.35 2850K Min CRI 82	75	N/A	N/A	120/12	17
F2	Recessed Compact Fluorescent Downlight	ERCO 22227.023	2	CFM 32W GX24q-3 3000K Min CRI 82	32	Electronic Dimming	2	120	45
F3	Recessed Low Voltage Halogen Downlight	ERCO 22403.023	1	T4 50W 12V GY6.35 3000K Min CRI 82	50	N/A	N/A	120/12	8
F4	Compact Fluorescent Pendant with a Natural Spanish Finish	Visa Lighting CP1310-2F39-SA-PB-TL	2	F39BX/SPX30 3000K Min CRI 82	39	Electronic Dimming	2	120	14
F5	Compact Fluorescent Decorative Pendant	Light Concepts 11990-GW	1	CFQ13T35/G24Q 3500K Min CRI 82	13	Electronic Dimming	1	120	10
F6	Compact Fluorescent Decorative Wall Sconce	Visa Lighting CB3616-2F13-SA-PB-TL	2	F13BX/ECO/GX23 3000K Min CRI 82	13	Magnetic	2	120	4
F7	Accent Picture Lights	Halo Lighting LZR800SL	1	20W MR16 12V 2900K Min CRI 82	20	N/A	N/A	120/12	6
F8	Recessed LED Strip Accent Lights	SaVi Accent 300(40.75")	45/ft= 150/fixt.	Red, Green, & Blue LEDs	3.5/ft= 11.67/fixt	N/A	N/A	120	8

Light Loss Factors

Luminaire Label	Maintenance Category	LLD	LDD	RSDD	BF	Total LLF
F1	IV	0.95	0.94	0.98	-	0.875
F2	IV	0.84	0.94	0.98	0.95	0.735
F3	IV	0.96	0.94	0.97	-	0.875
F4	VI	0.88	0.93	0.9	0.95	0.7
F5	II	0.84	0.97	0.94	1	0.766
F6	VI	0.86	0.93	0.9	1.02	0.734
F7	I	0.98	0.96	0.97	-	0.913
F8	V	1	0.93	0.98	-	0.911
Assumptions: 12 month cleaning interval and a very clean environment.						

Power Density

Label	Qty	Watts	Total Watts
F1	17	75	1275
F2	45	67	3015
F3	8	50	400
F4	14	80	1120
F5	10	18	180
F6	4	32	128
F7	6	20	120
F8	8	11.67	93.36
		Total:	6331.4
		Sq Ft:	5600
		Power Density:	1.1306

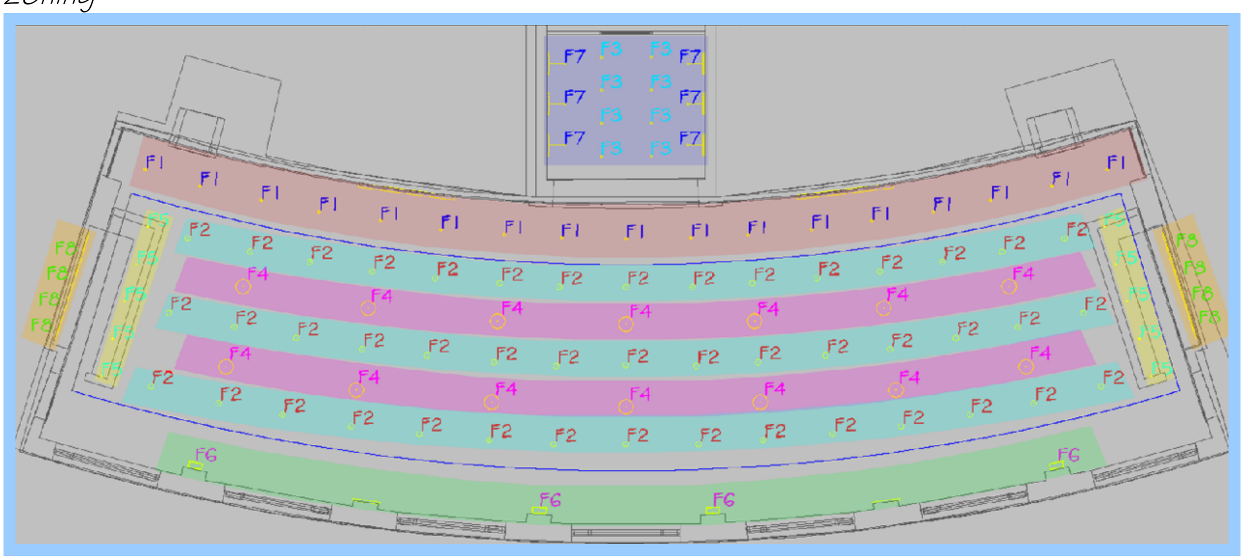
ASHRAE 90.1 Power Density Requirements: Using Table 9.3.1.2, Lighting Power Densities Using the Space-by-Space Method, and classifying the Club Room as a "Conference Meeting/Multipurpose Room" within a Sports Arena, the required power density is 1.5 W/ft^2. Therefore, the achieved power density for this space of 1.13 W/ft^2 is about 24.67% less than the allowed 1.5 W/ft^2.

Control Plan

Control Equipment

The Lutron Grafik Eye 4000 allows the space to have 8 different zones and 4 different scenes. After doing extensive research, daylighting will not be integrated with the electric lighting due to high costs and lack of constant activity within the space. Instead of using a system that utilizes photosensors with dimming electric lighting, a specific scene will coordinate with the black out shades. The black-out shades will have a corresponding lighting scene that will be manually adjusted by the user. The three other scenes include general lounge lighting for reading and gathering, formal event lighting, and a scene for the users to create on their own depending on the needs of the space. All fixtures will be linked to this system as well as emergency, which is also a nice feature of Lutron's Grafik Eye 4000. The LEDs located by the bars (highlighted in orange below) will be connected to the system as well, but will have a separate wall control. Lutron Grafik Eye 4000 model number: GRX-4108, 4 Gang (1) SB4G.

Zoning



Scene Control:

Zone	Color
A	Red
B	Light Blue
C	Dark Blue
D	Magenta
E	Yellow
F	Green
G	Purple
H	Orange

Scene 1- General purpose, lounge lighting

Zone A- Wallwashers 100% output
Zone B- CFL downlights 100% output
Zone C- LV Halogen downlights & track lighting 100% output
Zone D- CFL Pendants 50-75% output
Zone E- CFL Pendants 100% output
Zone F to H- OFF

The above scene will create a comfortable ambient lighting, while allowing enough light levels for reading and working. Most of the decorative fixtures will be turned off besides the picture lighting in the entry corridor.

Scene 2- Event on the television and black-out shades are drawn.

Zone A- Off Zone B- <= 50% output Zone C to E-100% output

(Zone H- LED strip lighting set on slow color changing effect)

This settings for the above lighting scene is designed so the majority of the lighting throughout the space is coming from the decorative fixtures. The scene is meant to create a movie theater atmosphere, with the addition of dimmed ambient lighting.

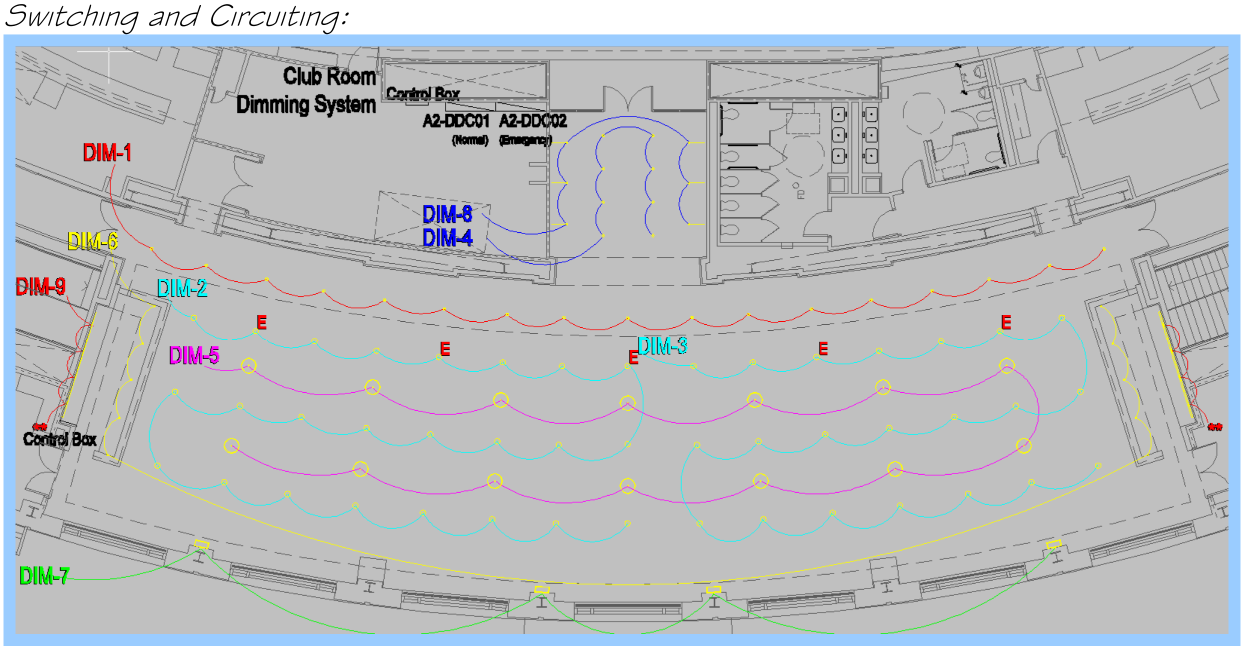
Scene 3- Formal events, social gatherings, evening ambient lighting

Zone A, C to H- 100% output Zone B- 50% or less light output

Scene 3 lighting design is meant for formal evening events. Lutron's Grafik Eye systems allows easy adjustment once a scene is selected, so in the event the scene is set for Zone 2 at 50%, the user can use the slider to turn it down or off and it will reset itself to the original settings once the scene is turned off.

Scene 4- To be determined by the user.

Switching and Circuiting:

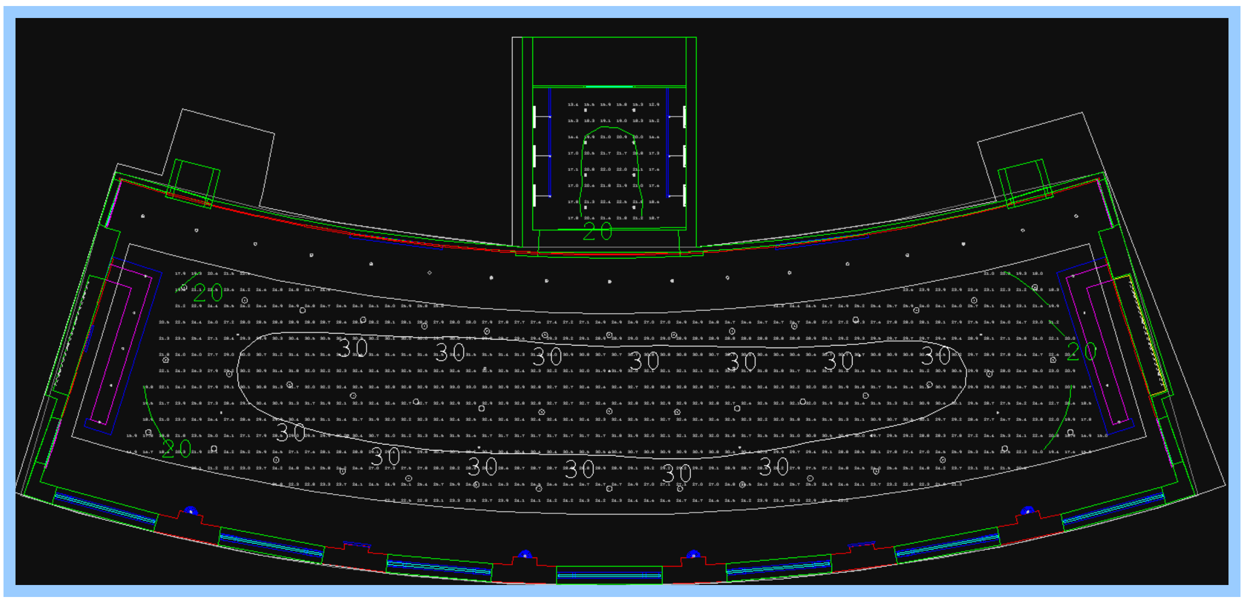


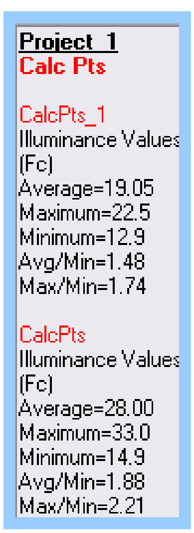
**The dimming panel is found in the Electrical Depth part of this report under Branch Circuit Redesign/ Club Room.*

Software Calculations

Illuminance Levels

Below is a screen shot from an AGI calculation. *Scene 1* was calculated to make sure the desired 30fc was met, which is required for people to read and carry out other visual tasks. The other calculation points represent the levels met in the entrance corridor for passage. The desired illuminance is about 20fc.





Project 1
Calc Pts

CalcPts_1
Illuminance Values (Fc)
Average=19.05
Maximum=22.5
Minimum=12.9
Avg/Min=1.48
Max/Min=1.74

CalcPts
Illuminance Values (Fc)
Average=28.00
Maximum=33.0
Minimum=14.9
Avg/Min=1.88
Max/Min=2.21

To the right shows the calculation point summary. The first set of calculation points refer to the entrance corridor and are located at a workplane height of 2.5ft. The second refers to the main room area and are located at floor level. Both areas have met the desired illuminance levels.

Main space desired: about 30fc
Main space achieved: 28fc average, 30fc around the center of the room
Entrance corridor desired: 15-20fc
Entrance corridor achieved: 19.05fc avg

Renderings

The following renderings are similar to Scene 2 and 3, with Zone B at 0% output.

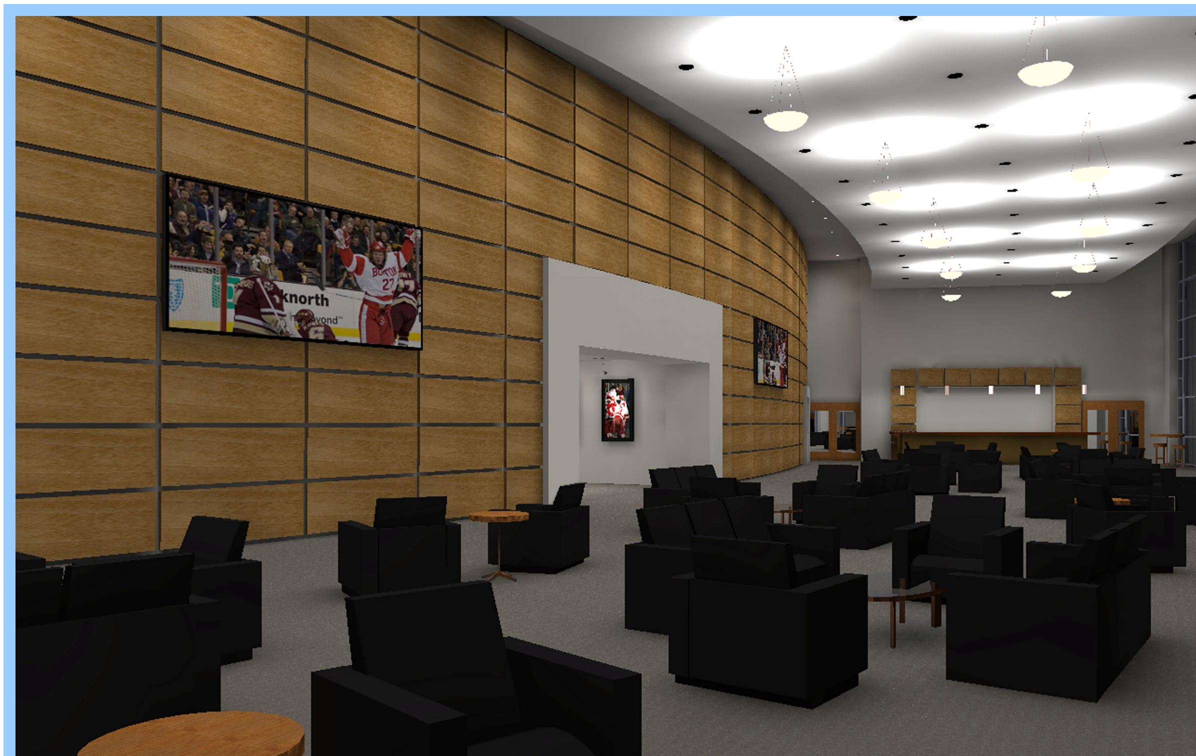
View from the Exterior

View from the East Side Bar

View of the Entrance Corridor

View of West Side from Entrance Corridor

View from West Side Bar



Conclusion

The Executive Club Room is an exquisite space for important guests to feel at home. The unique architecture sets the room apart from the rest of the building, creating an atmosphere exclusively enjoyed by the elite members. The wood panels, the curved shape, and the floor to ceiling windows are elements that should be highlighted and taken into consideration when providing a lighting design. For a more formal event, the compact fluorescent indirect pendants and wall scones are perfect to indirectly light space at different levels. The fixtures along the wood paneled wall bring out the texture as well as create movement in the space with the scalloped distribution. The Grafik Eye control system allows the user to easily create scenes for the many different functions and then change those scenes with a click of a button. If the black out shades are drawn the lighting can quickly go from lounge lighting to dimmed indirect lighting. Providing the proper amount of light on the workplane when the space is used as lounge was a main concern and was accomplished using this layout. Overall, I recommend this system to be a good solution for this exclusive multipurpose space; the luminaires are decorative yet functional, creating a pleasant atmosphere for the special guests.

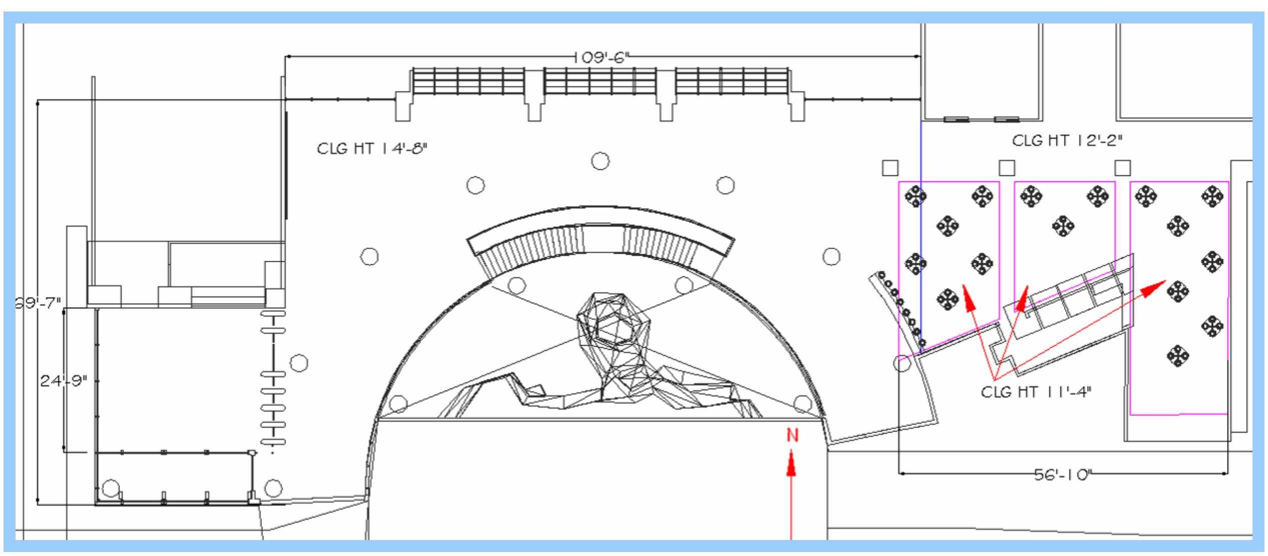
Lobby & Circulation Space

Overview

The main lobby of the Fitness and Recreation Center is situated on the south-west corner of the building. Through this entrance students and gym users must show their gym passes and identification cards. The lobby is heavily used by guest and students alike. Once you move beyond the turnstiles (south-west corner), there is a large rotunda with a 35' climbing wall in the center. Opposite the climbing wall is a two-story window that looks directly into the competition swimming pool. From there you can either head downstairs to the racquetball courts, dance studio, or three court multipurpose gym. You may also enter the fitness center which can be accessed on the right side of the rock wall. Another feature of the lobby on the east side is a Juice Bar with tables and stools for athletes to take a breather and quench their thirst. The Lobby space is frequented often and serves as a central meeting area for the Fitness and Recreation Center.

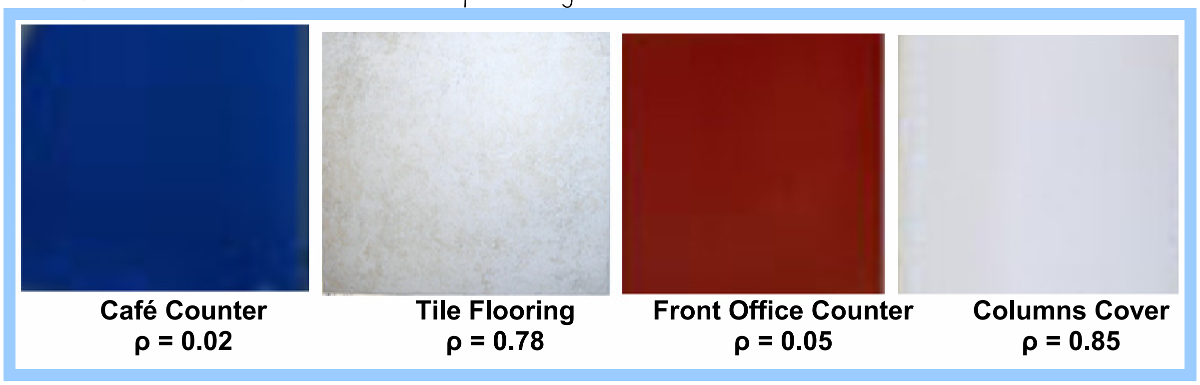
Floor Plan:

At the top of the drawing there are 4 columns and in between them are floor to ceiling windows which look into the competition pool area. The semi-circle around the rock wall is open to below and the bottom left is the main entrance to the Recreation Center. The signage above the main office entrance and columns are points of interest. The Juice Bar on the bottom right has three drop ceilings directly above the seating.



Space Characteristics:

The main entrance and circulation lobby have a glossy tile finished floor. Most of the walls are white with a few elements painted red or blue. The columns scattered around the rotunda have a white paneling finish.



Café Counter $\rho = 0.02$ | **Tile Flooring** $\rho = 0.78$ | **Front Office Counter** $\rho = 0.05$ | **Columns Cover** $\rho = 0.85$

Design Criteria

Main Goal: To generate a design that provides a functional and creative lighting scheme that contributes to the flow of traffic through the space. The lighting should consider the architecture of the space and highlight the unique elements.

A very important design criterion to consider for the Lobby space is the illuminance levels. Because the space is used often and is heavily populated throughout the day, light levels must be adequate enough for people to walk. The horizontal illuminance should reach about 15-10fc throughout and a vertical illuminance of 5fc for facial recognition. Another important design issue to think about is the appearance of the space and luminaires. The Lobby is used by students, teachers, as well as guests from out of town visiting to watch a sporting event. Therefore, the area should look welcoming and nice for all those using the space. The luminaires shouldn't be an eyesore or too industrial looking.

The points of interest are also important issues to regard when creating a lighting design. On the wall next to the main office is a large bulletin board for public and school oriented postings. The Juice Bar is also an area to highlight with a creative lighting design. Color appearance is another criterion to look into. The surfaces around the lobby are generally white with red accents for Boston University's colors. The color temperature of the lamps should stay similar, if not the same, to keep an even look across the space. The luminaires should avoid causing direct glare. Although daylighting enters the space, it will only be regarded with the entry vestibule lighting. The system control should stay clear of the public eye and should only be accessed by Boston University personnel.

Design Concept

The overall design concept of the lobby space is to highlight the spatial characteristics and guide people through the space. The lobby has many unique features that should be acknowledged in the lighting design. The central focus is the circular rotunda on a 40ft radius. In order to bring this characteristic out the lighting will follow this same circle. Circular downlights with white or red rims will be aligned around the rock climbing wall. Red and white will be used in order to bring out Boston University's school colors.

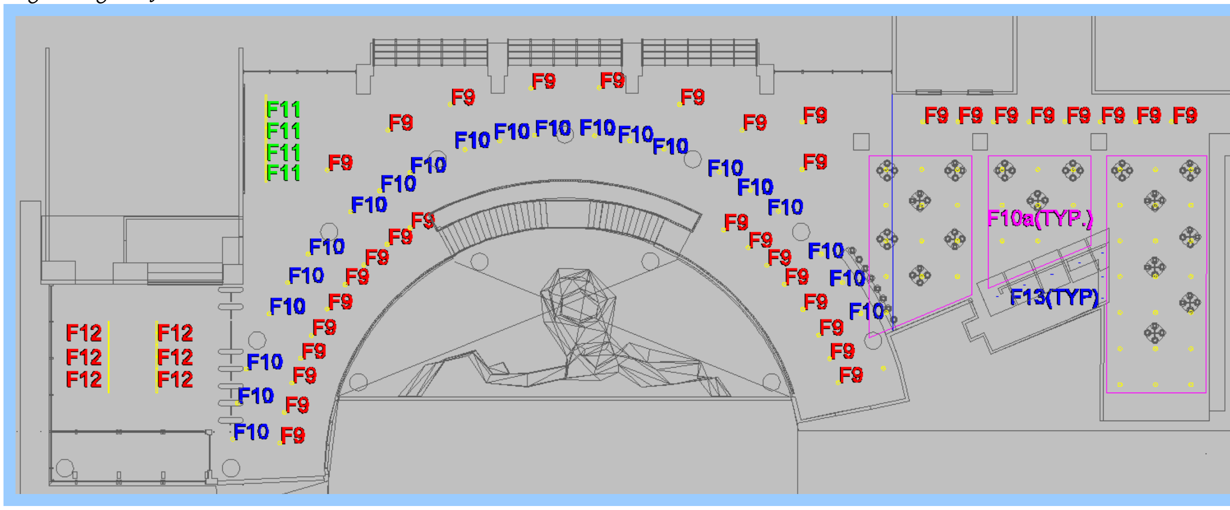
Another lighting design concept will look at the architect's purpose for this space. When entering the lobby one has the ability to watch a swim competition, enjoy a cold fruit drink, watch rock climbers, as well as view into the basketball courts. The lobby is central circulation space but it is also an area that is full of Boston University's activity life. In order to bring out the spirit of Boston University students, I would like to incorporate the school pride, the school colors, in the lighting design. I would also like to add some color to the juice bar to highlight the different colors of fruit.

Lighting will be used to bring out points of interest such as the bulletin board wall, signage, and the entrance to the elevators. To keep a clean look, recessed linear wallwashers will be used to highlight the entire bulletin board. Above the Juice Bar recessed downlights with a color changing LED ring will be implemented to create an interesting lighting effect while provided sufficient light levels about the tables for reading purposes.

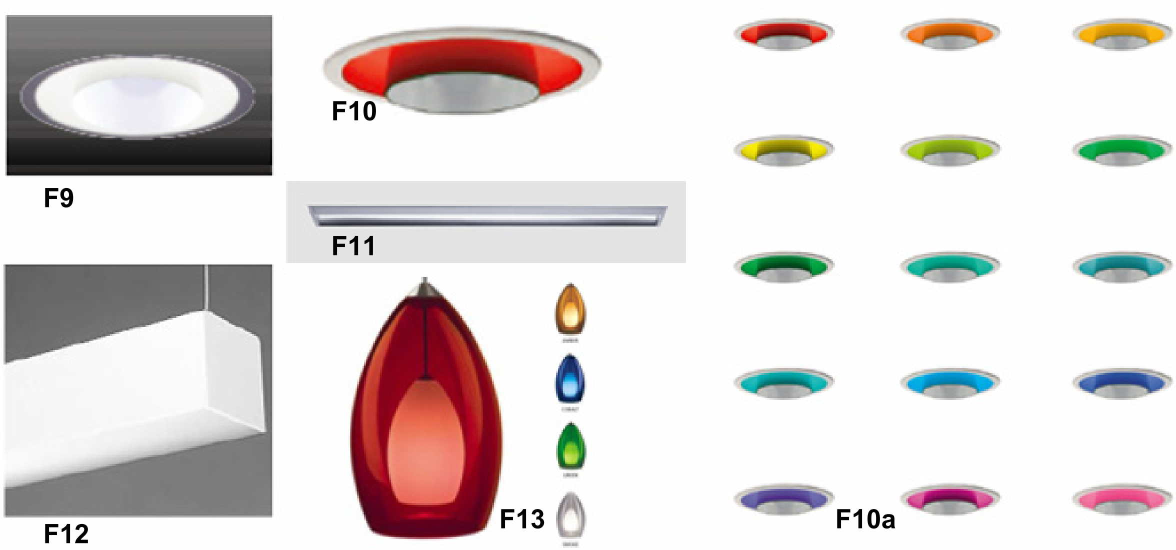
The lobby space is generally very bland in color. The walls, floor, and ceiling are some form of white. The juice bar has some color, but only around the counter. Therefore, adding color for the purpose of the school colors AND for some design aesthetics is also desired. The lighting should also guide people through the space. By following the curve of the columns the lighting will direct one's attention toward the other end of the space where all the activity access points are located.

Lighting Plan

Lighting Layout



Luminaire Images



Luminaire Schedule

Label	Description	Catalogue NO.	Lamp			Ballast		Voltage	Fixture Qty.
			NO.	Type	Watts	Type	Lamps		
F9	Recessed Compact Fluorescent Downlight with Candeo Clear	Gotham Lighting PDGF 1/32TRT 8AR WHT	1	CF32WTRT	32	Electronic	1	277	35
F10	Recessed Compact Fluorescent Downlight with Red LED Ring	Gotham Lighting PDLFV 32TRT 8AR LD	1	CF32WTRT + LEDs	32	Electronic	1	277	22
F10a	Recessed CFL Downlight with Color Changing LED Ring	Gotham Lighting PDLFV 42TRT 8AR LD	1	CF42TRT + LEDs	42	Electronic	1	277	42
F11	Recessed Linear Fluorescent Wallwash	ERCO 65040.023	1	F28T5 Min Bipin	28	Electronic	1	277	4
F12	Linear Fluorescent Indirect Pendant	se'lux M100 1T5HO-C-012-WH	1	F54T5HO	54	Electronic Dimming	1	277	6
F13	Halogen Decorative Pendant	Tech Lighting 700 Color Variation	1	40W T4 G9 Pin Base	40	N/A	N/A	120	6

Light Loss Factors

Luminaire Label	Maintenance Category	LLD	LDD	RSDD	BF	Total LLF
F9	IV	0.84	0.94	0.98	0.98	0.774
F10	IV	0.84	0.94	0.98	0.98	0.774
F10a	IV	0.84	0.94	0.98	0.98	0.774
F11	IV	0.92	0.94	0.98	1.04	0.848
F12	VI	0.92	0.93	0.9	0.99	0.77
F13	II	1	0.97	0.94	-	0.912
Assume: 12 month cleaning interval and a very clean environment.						

Power Density

Label	Qty	Watts	Total Watts
F9	35	36	1260
F10	22	38	836
F10a	42	48	2016
F11	4	33	132
F12	6	62	372
F13	7	40	280
		Total:	4896
		Sq Ft:	6500
		Power Density:	**0.753231**

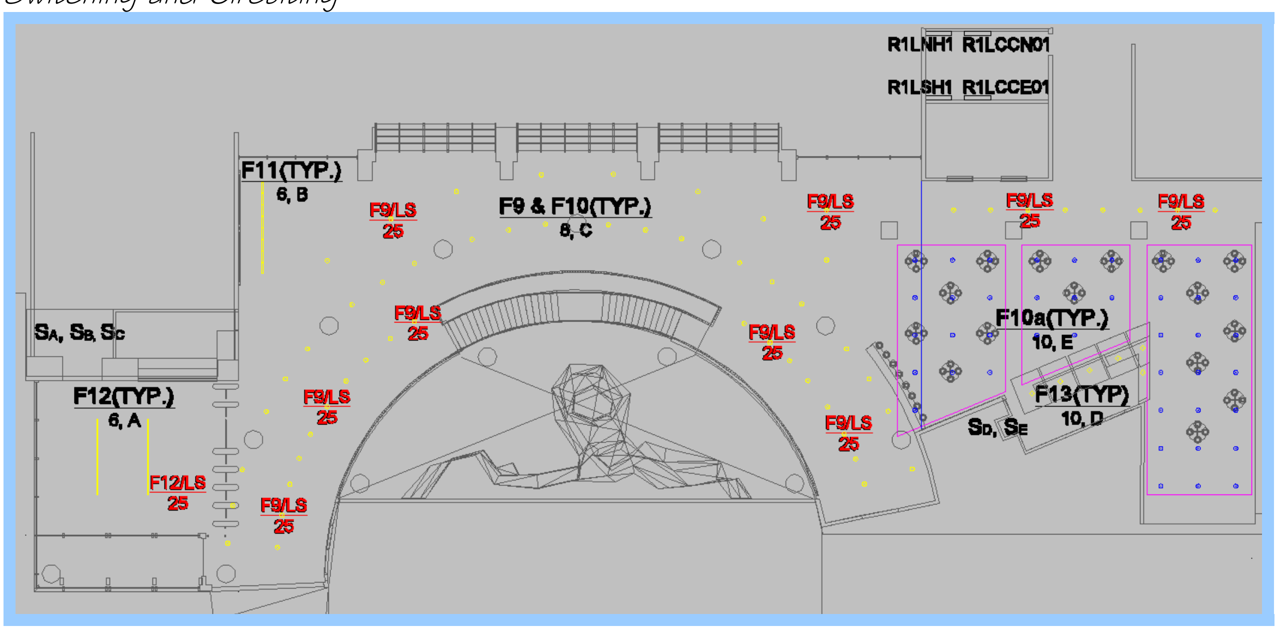
ASHRAE 90.1 Power Density Requirements: Using Table 9.3.1.2, Lighting Power Densities Using the Space-by-Space Method, the gymnasium "lobby" has an allowed maximum power density of 1.8 W/ft^2. Therefore, the lighting layout of this space of 0.75 W/ft^2 is about 58% less than the allowed power density for this type of space.

Control Plan

Control Equipment:

All normal branch circuits are circuited to panelboard R1LNH1, which is a 480/277 panel. Wire all normal lighting fixtures through low voltage lighting control cabinet R1-LCCN01. All life safety branch circuits are circuited to panelboard R1LSH1. Wire all life safety lighting fixtures through low voltage lighting control cabinet R1-LCCE01. The lighting control cabinet will have dimming controls for circuits 6, 8, and 10. Fixture F12 will be on a timing system. The entire space is surrounded by windows and the sun can provide enough lighting for the area. The fluorescent fixtures will turn on at 4pm and off at 7am. There will also be a manual switch to override the timers.

Switching and Circuiting

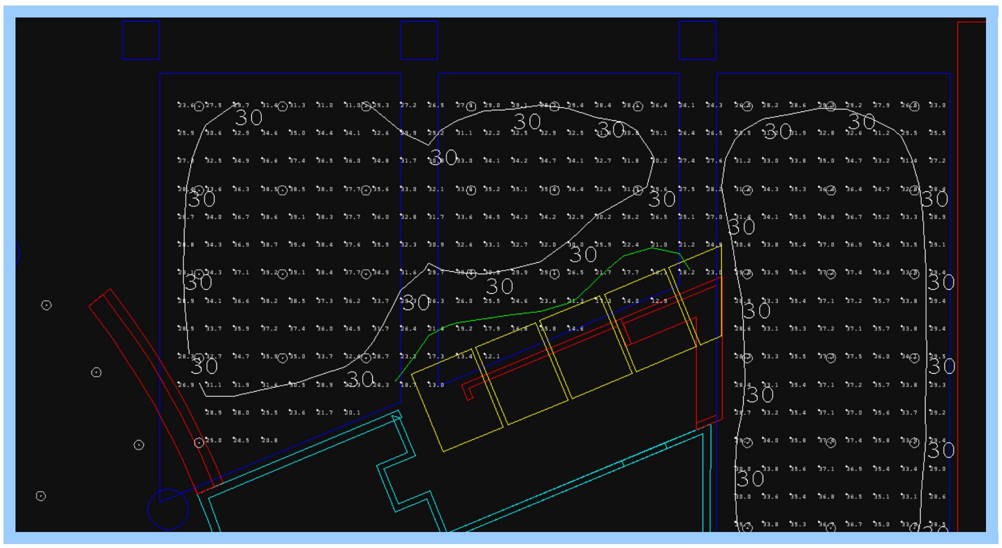


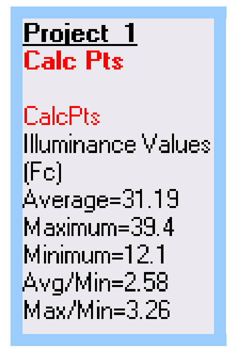
**The panelboard schedule is found in the Electrical Depth part of this report under Branch Circuit Redesign/ Lobby.*

Software Calculations

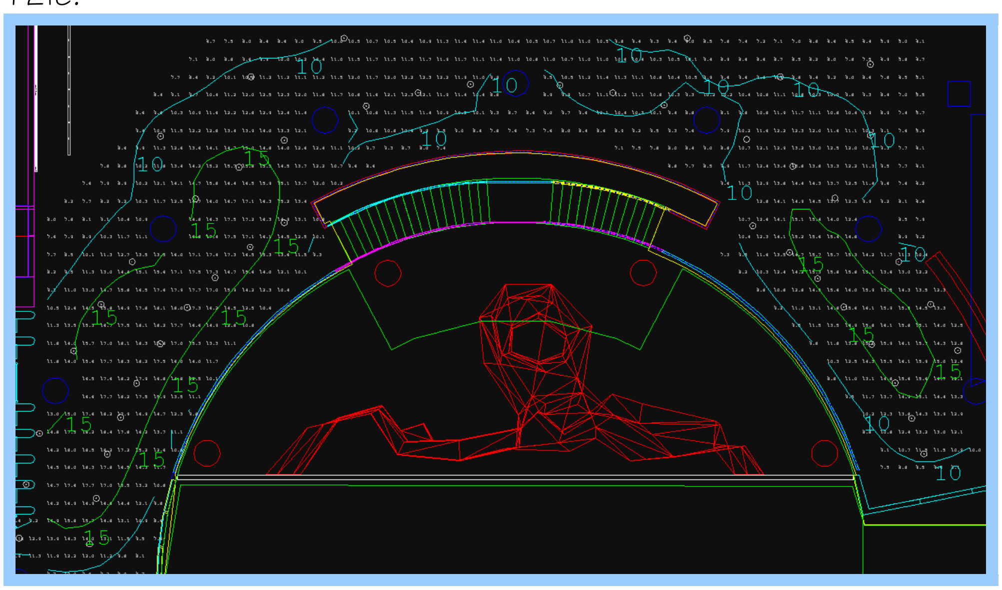
Illuminance levels

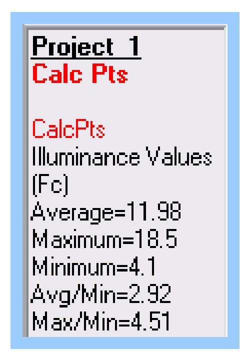
Below is a screen shot from illuminance calculation points of the Juice Bar area. The desired illuminance level at table height (2.5ft) is between 30 and 40fc for students to read and catch up on homework. From the calculation points and calculation summary it is evident this criteria has been met.





Below are calculation points for the lobby circulation area. The desired illuminance is 10-15fc. By looking at the isolines the achieved illuminance is between 10-15fc & avg 12fc.





Renderings

**Fixtures used to light the rock wall are only there for aesthetics; they are not part of the new design.*

View of the Lobby from Entrance Corridor

View of the Entrance Corridor from the Lobby

View of Lobby Just Past Turnstiles

View of Lobby from Juice Bar

View Looking Toward Entrance from Elevators

Close-up View of the Bulletin Boards

View of the Juice Bar

Conclusion

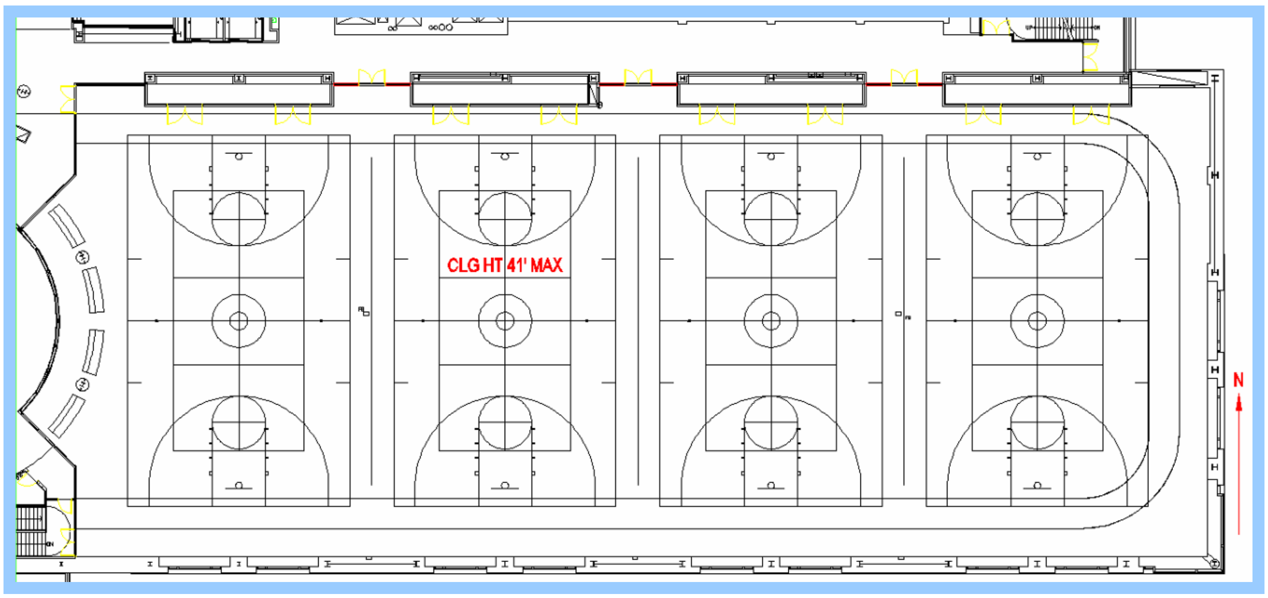
The Recreation Center lobby and circulation area is a very busy intricate space. As you walk into the main entrance, you can see a variety of different activities taking place. The large rock climbing wall is a central focal point, and directly across from it a glass wall stands which enables people to peer into the competition swimming pool. The area boldly states movement, energy, and liveliness which were important concepts for the new lighting scheme. The curved architecture also brings out a sense of movement and uniqueness. The compact fluorescent downlights follow the curved shape in order to emphasize the architecture. The red LEDs highlight BU's school colors, as well as add a touch of color that represents energy to the space. The fixtures over the Juice Bar create a colorful element to a very white space and provide adequate light levels for those who want to read and do work at the tables. The lighting is meant to bring out the architectural uniqueness of the space as well as provide adequate light levels for active pedestrian use. The initial goals for the new lighting design were met, while incorporating a creative solution for the Recreation Center lobby lighting.

Gymnasium

Overview

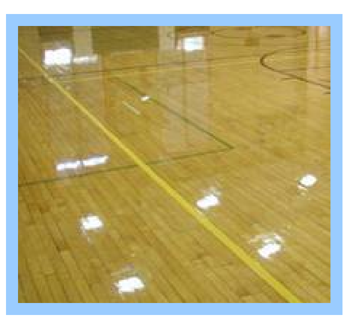
The 4-court multipurpose gym is mostly used for basketball and volleyball sporting events. A 1/8 mile elevated track encompasses the gym floor. Large two story windows are set in the south and east facing wall. Red and white accent colors are used throughout the space in honor of Boston University's school colors.

Floor Plan:



Space Characteristics:

The gym floor is a light, glossy wood paneling. The walls and ceiling are painted white. The windows in the gym are a laminated vision glass, 9/16" thick with a pattern frit in the middle of the two glass layers. The custom stripe frit pattern has a 60% coverage and the stripes are 1/8" thick. The glass is manufactured by Viracon and has a transmittance of 0.74.



Design Criteria

Main Goal: The gymnasium lighting design should incorporate the use of daylighting and durable fixtures, as well as create a brightly lit space for athletic activities.

From Figure 20-1 in the IESNA Handbook the basketball facility is in Class III (No special provision for spectators), and from Figure 20-2 under Basketball/Class III the recommended illuminance levels are listed. The IESNA recommended horizontal illuminance for the gym floor is about 50-80fc and 30fc for the track floor, which is very important to meet.

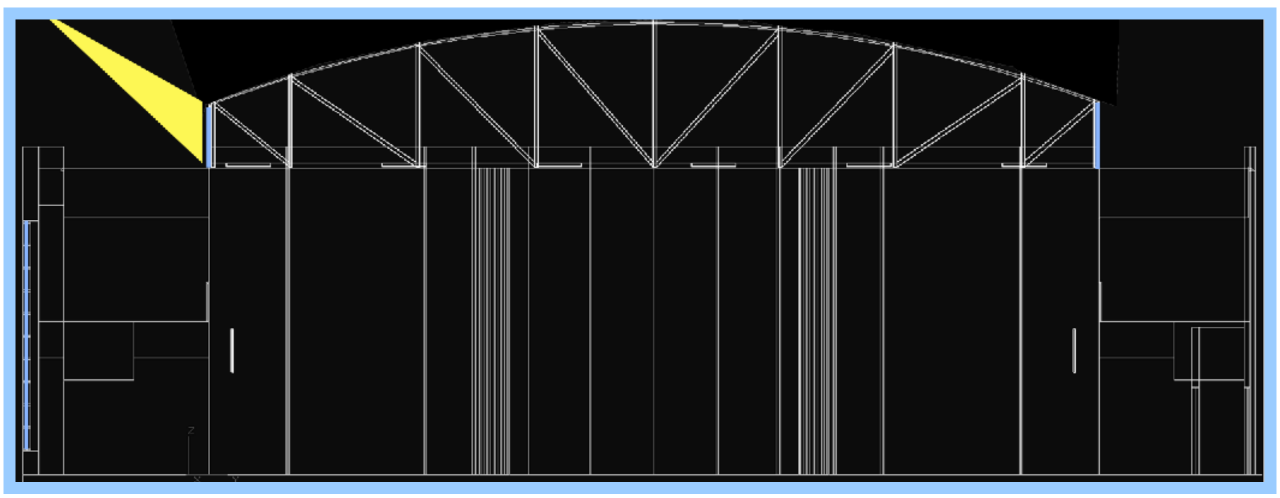
Daylighting integration and control is also a very important design criterion for the gymnasium. The floor to ceiling windows on the south and east sides will bring in an abundant amount of daylight throughout the day, which could be used as an advantage. In order to minimize energy and maximize the advantages of the sun, photosensor control of the electrical lighting may be a solution to the lighting design system. The daylighting and electric lighting should be integrated together to cerate enough illumination on the gym floor, whether dimming or shutting off the electric overhead fixtures.

Direct glare is another important criterion to consider for the gymnasium lighting design. The fixtures should avoid direct glare into the athlete's eyes. No fixtures should be installed directly above the backboard. Currently the glass windows have a custom frit between the two panes which should eliminate direct glare from the sun, or at least make it as minimal as possible.

Another important lighting design aspect to consider is the light distribution on surfaces. There should be an even distribution on the gym floor; the IESNA recommended illuminance ratio max:min is about [1.7-2.5]:1, or less. The walls and ceiling do not need too much attention with light distribution, unless there are display cases and/or posters, in which highlighting these areas may be desirable. There should also be an even light distribution on the elevated track. Although an indoor track is not mentioned in the IESNA, an outdoor track max:min should be about 2.5:1, or less.

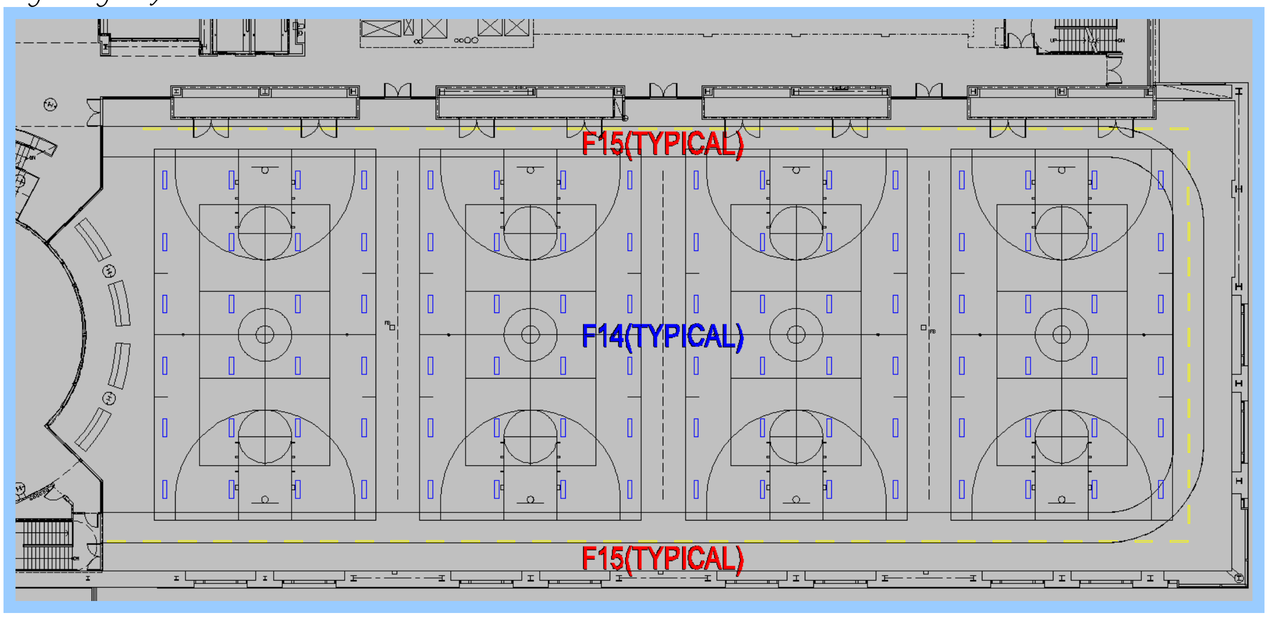
Design Concept

The basic lighting design concept for the gymnasium is to create a feeling of playing basketball outdoors. The sunlight will shine through the south facing windows, while clerestories will be added to the south and north facing structure of the roof. In order to minimize energy usage, dimmable hi-bay fluorescent fixtures will be implemented and controlled by photosensors. A simple section of the clerestory addition is shown below. The blue indicates glass; to the left of the photo is the floor to ceiling, south-facing windows. The shape of the roof-truss system is unaltered, but the north and south sides were solid walls that are now made into windows that run the length of the gym. The clerestory glass will be the same type of glass used in the south facing windows.

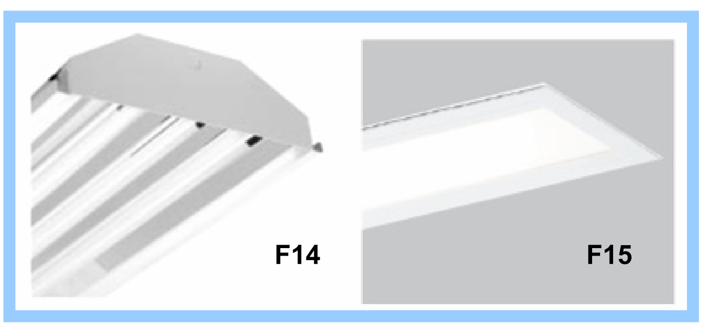


Lighting Plan

Lighting Layout



Luminaires Images



**Although not depicted here, Fixture F14 will have a wireguard accessory for protection from athletic equipment.*

Luminaire Schedule

Label	Description	Catalogue NO.	Lamp			Ballast		Voltage	Fixture Qty.
			NO.	Type	Watts	Type	Lamps		
F14	Suspended Linear Fluorescent High Bay Industrial Fixture	Stonco Industrial Lighting T-Bay Series	4	F54T5HO	54	Electronic Dimming	2	277	90
F15	Recessed Linear Fluorescent	Litecontrol Mod^2 R-D-4400 Series	1	F54T5HO	54	Electronic	1	277	146

Light Loss Factors

Luminaire Label	Maintenance Category	LLD	LDD	RSDD	BF	Total LLF
F14	IV	0.92	0.89	0.97	1	0.794
F15	V	0.92	0.88	0.97	1	0.785
Assume: 24 month cleaning interval and a very clean environment.						

Power Density

Label	Qty	Watts	Total Watts
F14	180	125	22500
F15	73	125	9125
		Total:	31625
		Sq Ft:	25400
		Power Density:	**1.245079**

ASHRAE 90.1 Power Density Requirements: Using Table 9.3.1.2, the gymnasium "playing area" has a maximum power density of 1.9 W/ft^2. **Therefore, the lighting layout of this space of 1.25 W/ft^2 is about 34% less than the allowed power density for this type of space.**

**Power density calculations based on a 2 lamp electronic dimming ballast input watts.*

Control Plan

Control Equipment

The gymnasium is equipped with dimmable fluorescent high bay fixtures in order to install photosensor controls. The fluorescent fixtures at 100% output provide adequate light levels for night time lighting, but during day time hours the sunlight may provide enough light for the fixtures to be dimmed and possibly turned off. A daylighting study was conducted in order to determine the illuminance levels found in the gymnasium throughout the day. The calculation points were placed only around the four-court gymnasium area because it is the most important area in which the critical point(s) that control the photosensors must be determined to keep the required light levels.

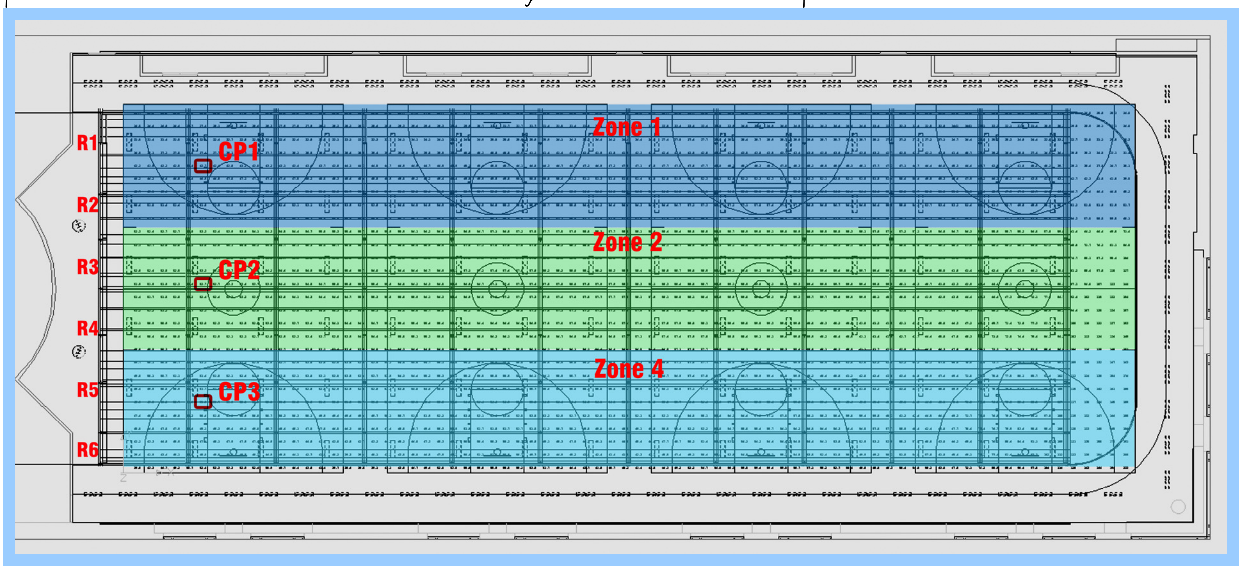
The Daylight Study was conducted during three different days of the year: March 21st 2007, June 21st 2007, and December 1st 2007. The sun during December and June months is at its most extreme angles (the highest sun angles in June and the lowest sun angles in December). This is why those two months were chosen for the daylight study. March is in between the two months and corresponds to September, which are good estimates of the sun levels between the extreme (high and low) sun levels. The calculation points with their corresponding RGB renderings and pseudo colors are found in Appendix B as well as the critical point analysis.

Control Schedule

After analyzing the calculation points for the three different sample days of the year and their corresponding times, the best way to divide the different dimming zones seems to be from north to south. This means that the Zones will run parallel with the south facing window. The calculation points tend to increase gradually from the north

end of the gymnasium to the south end. A Wattstopper LS-301 Dimming Photosensor will be placed directly above three different cricitcal points. Each zone will have a photosensor dimming control, which also means a critical point must be found within each zone. In order to minimize the effect each photosensor has on one another, the critical points must be placed away from one another. After thoroughly analyzing the data, three different critical points were selected one for each zone.

Below is an image of the zoning with the corresponding critical points. The photosensors will be mounted directly above the critical point.

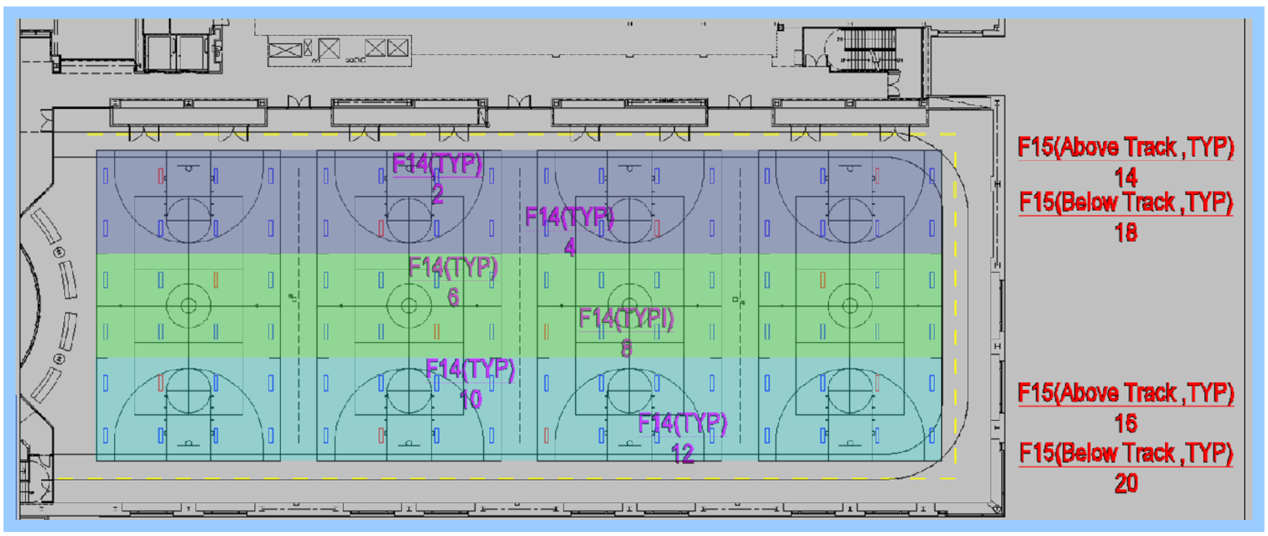


Zone 1: Row 1 and Row 2, CP1, Photosensor 1, Maintain 80fc
Zone 2: Row 3 and Row 4, CP2, Photosensor 2, Maintain 80fc
Zone 3: Row 5 and Row 6, CP3, Photosensor 3, Maintain 80fc

All normal branch circuits are circuited to panelboard R3LNH1, which is a 480/277 panel. Wire all normal lighting fixtures through dimming, low voltage lighting control cabinet R3-LCCN01. All life safety branch circuits are circuited to panelboard R3LSH1. Wire all life safety lighting fixtures through dimming, low voltage lighting control cabinet R3-LCCE01. The lighting control cabinet will have dimming controls for circuits 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20.

Switching and Circuiting

Below is an image of the circuiting plan. In order to make the drawing more clear to see on this page, the labeling was simplified. The recessed fixtures above and below the track, F15, has been circuited by floor level than by side of the gym (north or south). The high bay fixtures, F14, have been circuited first according to zone, then by row. For example, Zone 1/Row 1 (closets to the gym doors on the north end) of fixtures are all on one circuit, circuit 2. The red fixtures are categorized as emergency and are circuited to the emergency panel on circuit 4. The panelboards are located in an electrical room just north of the elevators (top left corner).

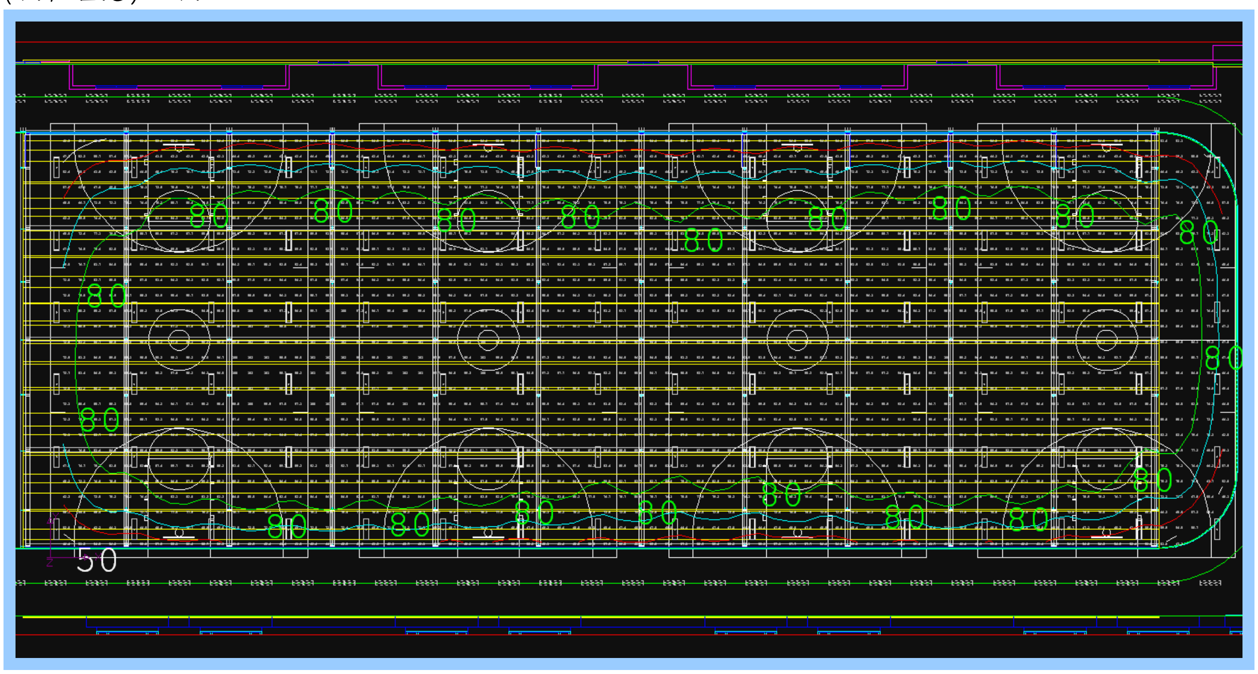


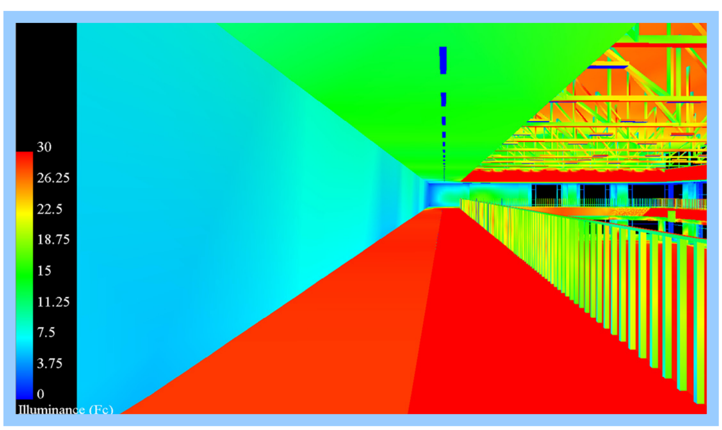
**The panelboard schedule is found in the Electrical Depth part of this report under Branch Circuit Redesign/ Gymnasium.*

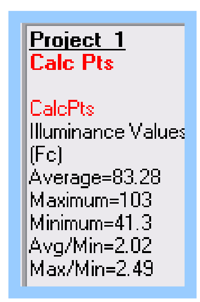
Software Calculations

Illuminance levels

Below is a screen shot from the electric lighting only AGI simulation. The desired average illuminance level is 80fc and the desired illuminance maximum to minimum ratio is (1.7-2.5) : 1.





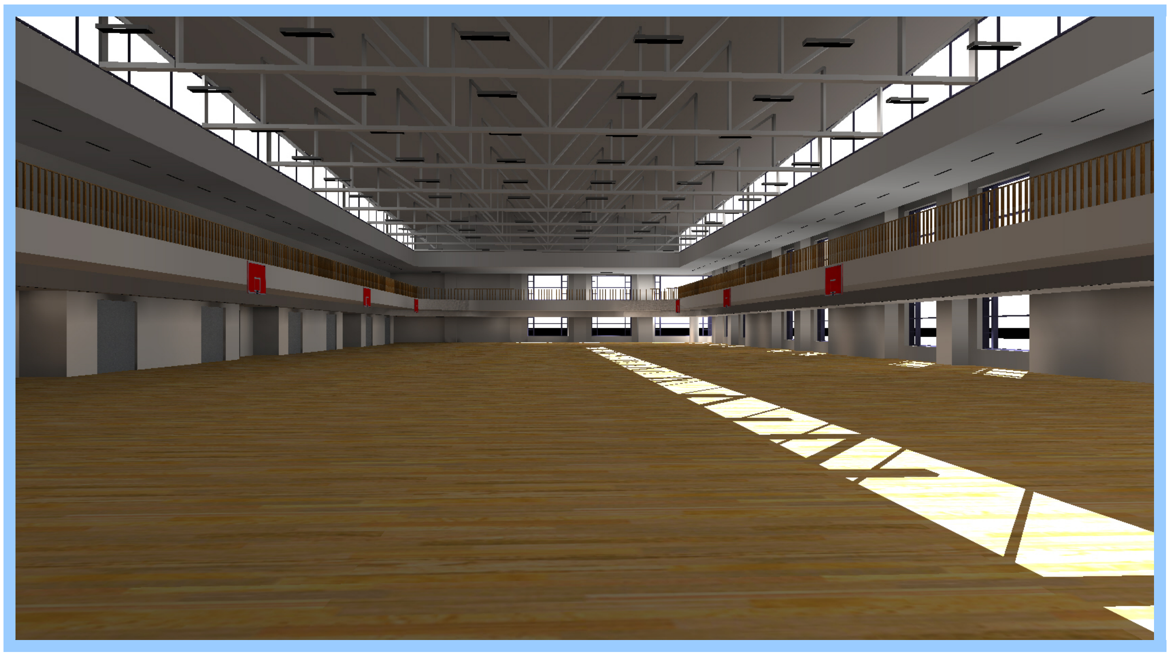


The Figure on the left is a pseudo color representing the illuminance levels on the track floor. The red is 30fc and the blue is 0fc. The recessed fluorescent fixtures adequately light the track floor evenly. The Figure on the left shows the calculation summary from the Gymnasium Floor AGI simulation. The average illuminance levels reached 83fc on the floor, which is above desired and the max:min ratio reached 2.49:1 which meets the desired criteria. The fluorescent lighting reaches the required light levels as well as keeping an even distribution on the gym floor.

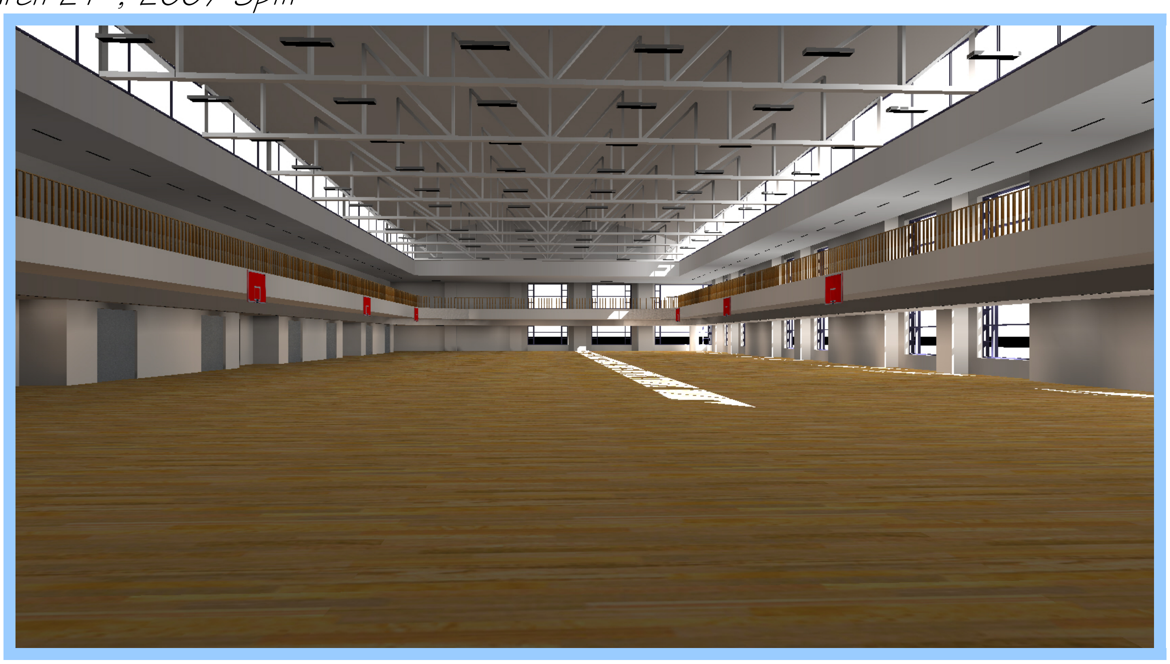
Renderings

Below is a small sampling of renderings from the daylighting study, the remainder renderings are found in Appendix B. There are also electric lighting renderings found below.

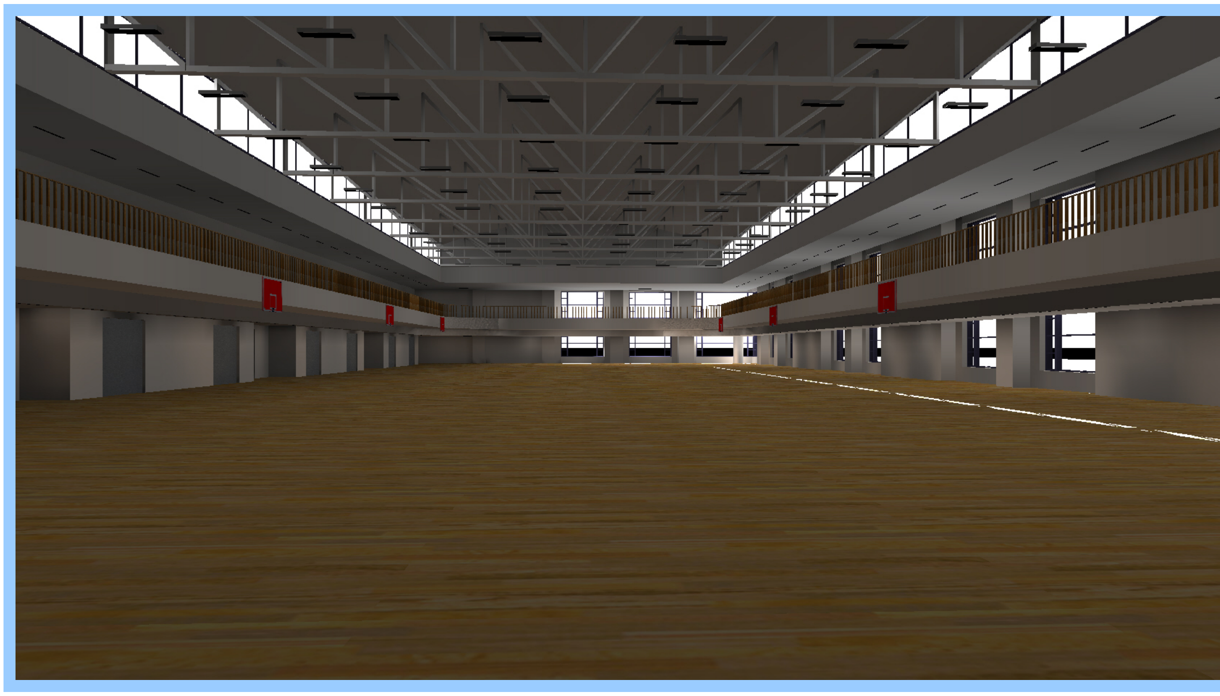
March 21st, 2007 9am



March 21st, 2007 3pm

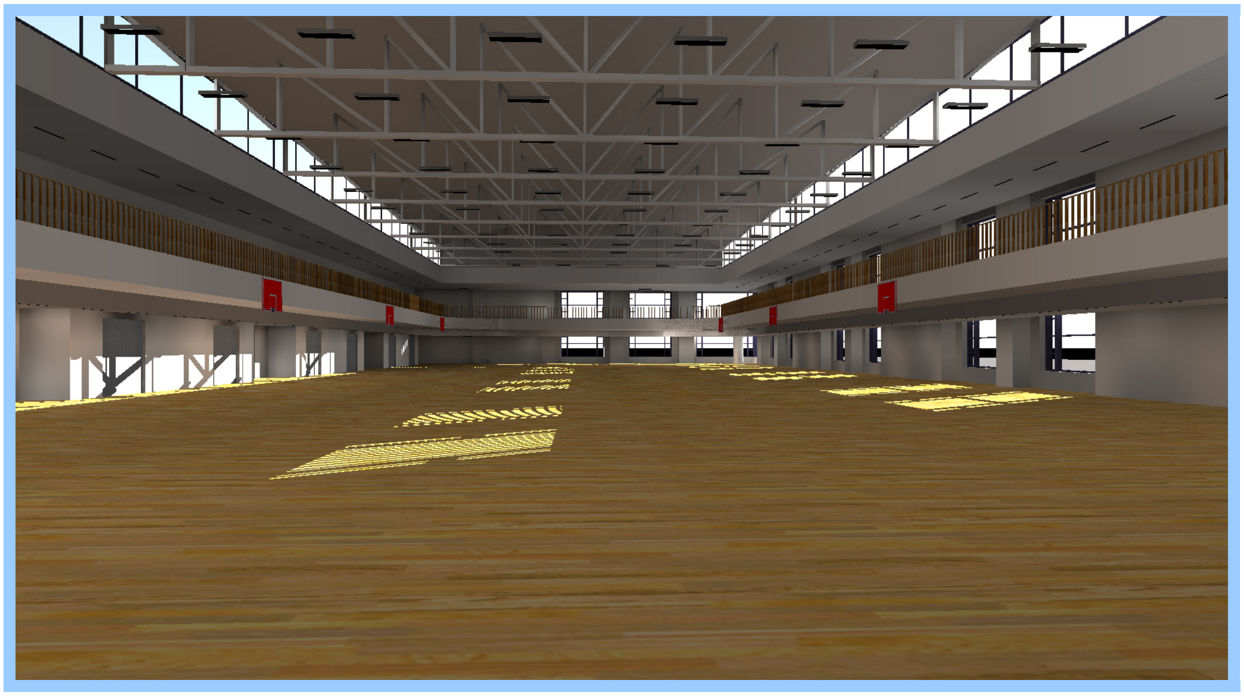


June 21st, 2007 9am

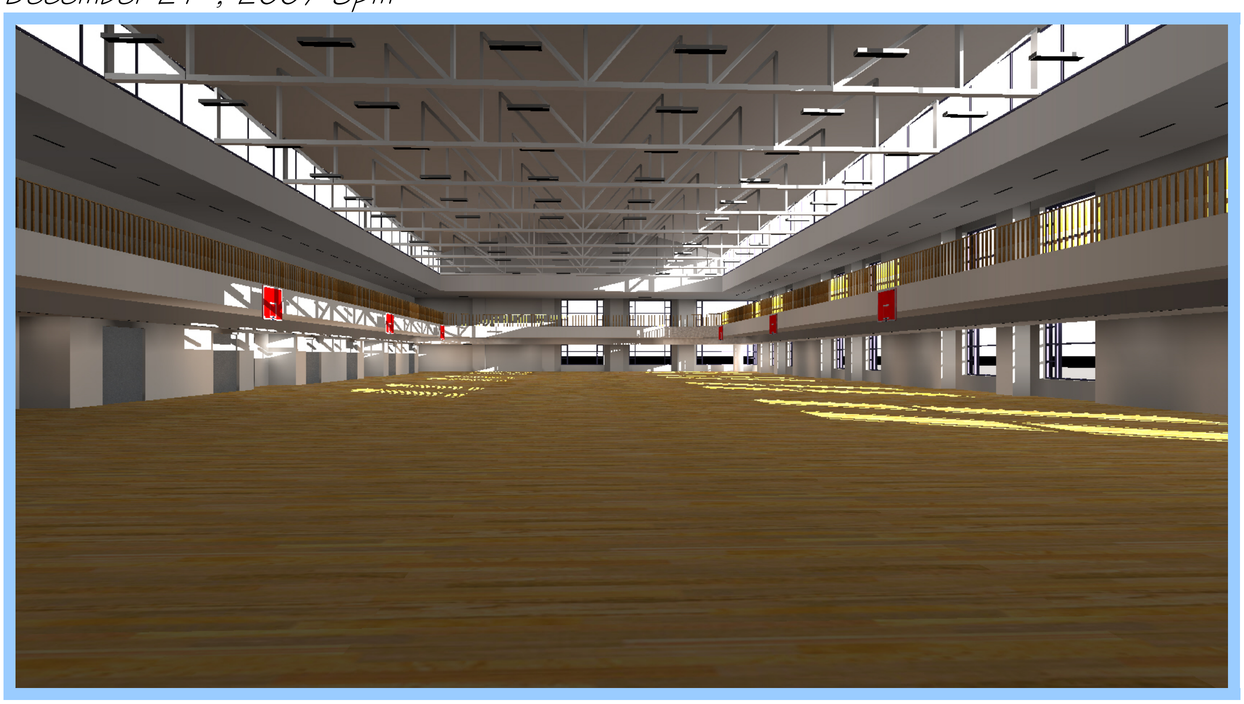


June 21st, 2007 3pm

December 21st, 2007 9am



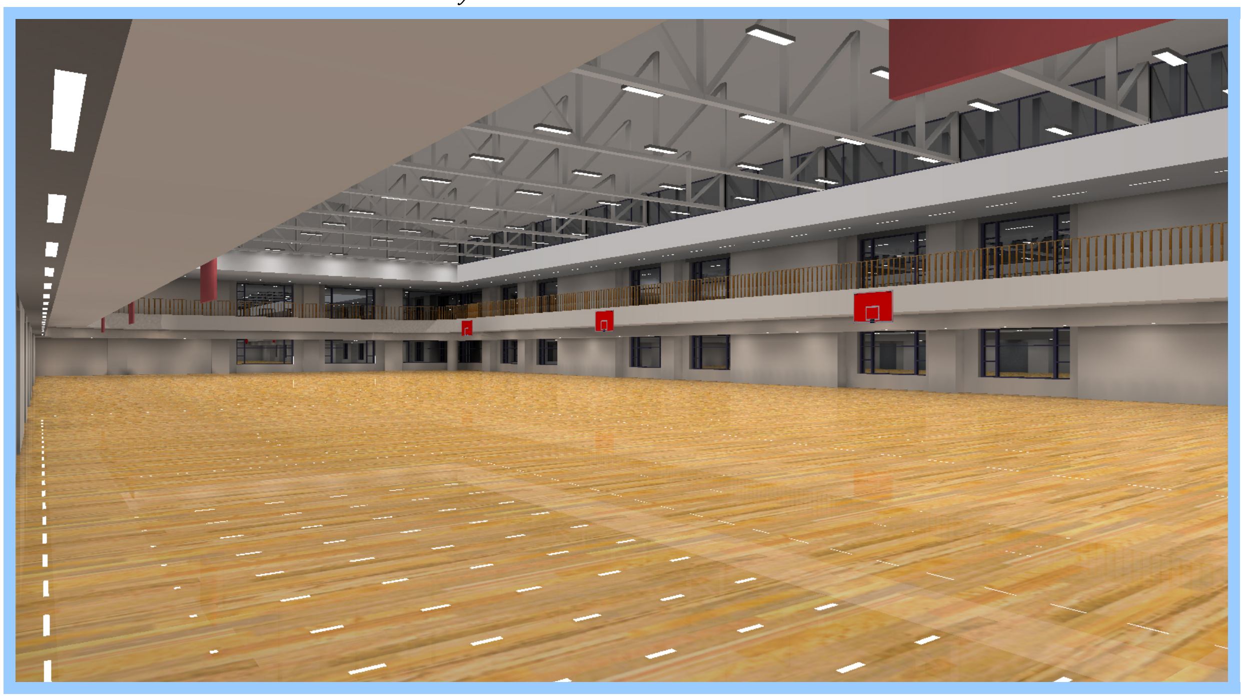
December 21st, 2007 3pm



View from West End of Gymnasium

View from North-West End of Track

View from North-West Side of Gym



Conclusion

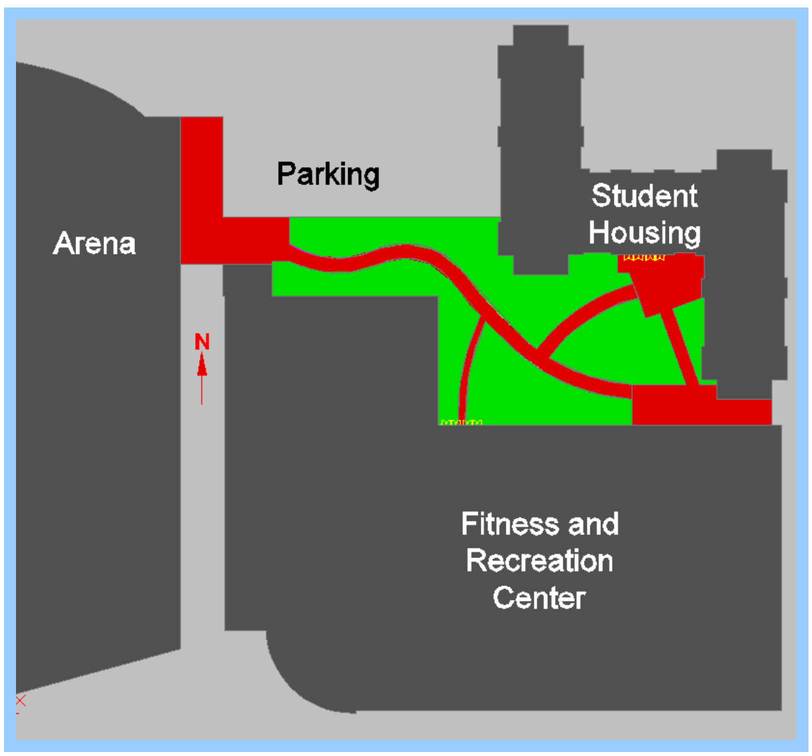
The recreational gym design took a simple space and added creative architectural elements such as, the encompassing elevated track and the floor to ceiling windows. The main goal for the gymnasium lighting design was to incorporate daylighting. The south facing windows bring in copious amounts of sunlight throughout the day, and with the addition of the north and south facing clerestories more sunlight was capable of entering the space. The high-bay linear fluorescent fixtures allow the system to be controlled by photosensors. After conducting the daylight study, during some points of the day the fixtures don't even need to be turned on. The recessed fluorescent fixtures above the track are meant to provide enough light levels for running as well as create a sense of movement around the gym. The high-bay fixtures emphasize the linear trusses and align over each court to avoid direct glare over the backboard. The daylighting integration and control will minimize the energy usage during daylight hours by dimming the fluorescent fixtures while providing enough light on the gym floor. The new lighting design is simple yet creative solution for this space.

Exterior

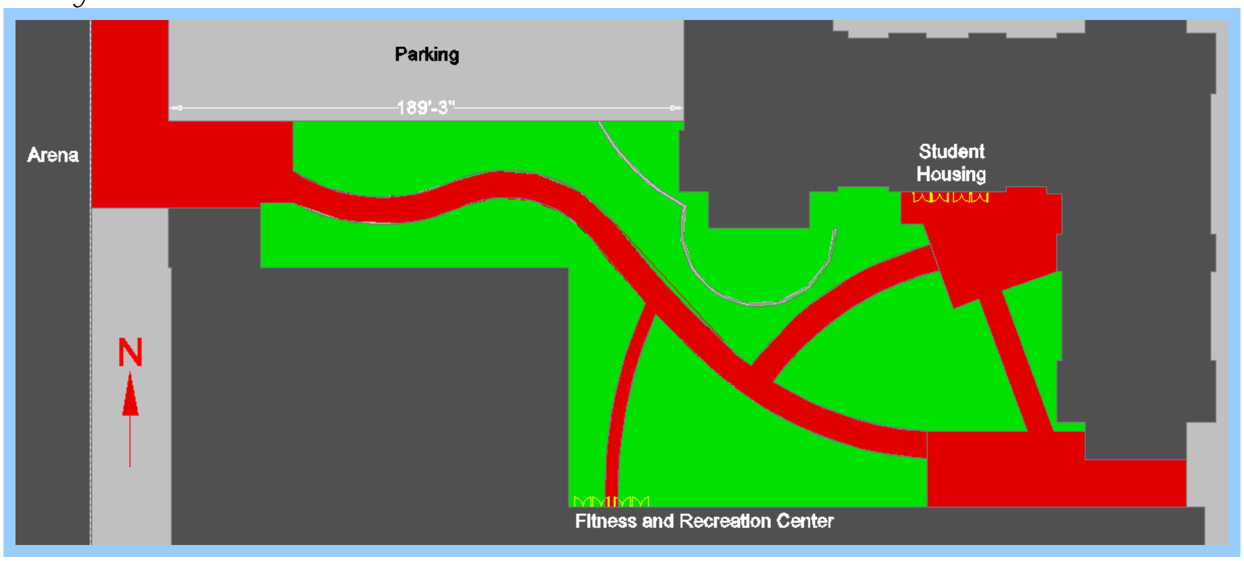
Overview

The Student Village Project, including the Arena and Recreation Center, main goal was to merge the east and west ends of campus. Because the design focuses on making the hub the "center for activity", the pedestrian traffic through this area will be heavy during all hours of the day. The main circulation path runs right between the Arena and Recreation Center then ends up in a courtyard area which must be adequately lit for safety. The Arena holds events that may carry into late hours and the Recreation/Fitness Center is open late for student convenience, so careful consideration must be taken into account for student safety. The façade and walkways are mostly brick with concrete planters and steps. The central courtyard between the Student Housing, Recreation Center, and Arena is used often with pathways leading to entrances of each building.

Site Plan



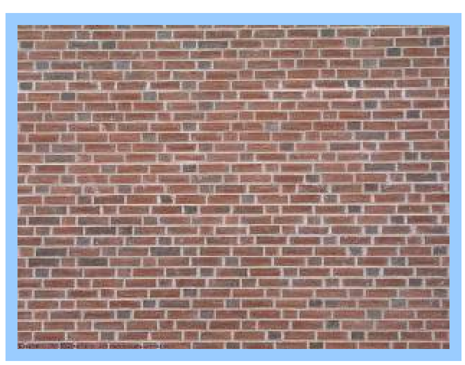
Enlarged Site Plan



Surface Characteristics

The façade and walkways within the Student Village Project are mostly brick with soft white pre-cast concrete blocks. There are many large windows throughout the building façade and a large rotunda at the Recreation Center entrance that is entirely double-pane glass. The interior of the signature rotunda features a state of the art fitness center and elevated track. At night people passing by can see directly in on the activities carrying on in the space. The windows outside the 3 court gym are also accessible for pedestrians to peer in on the athletic activities taking place. The Arena, Recreation Center, and Student Housing have many windows on the ground floor level. At night pedestrians can clearly see in and vice versa.

**The reflectance of the brick below is 26%.*



Design Criteria

Main Goal: To generate a design that provides safety for students during evening hours, while achieving dark-sky compliancy.

An important design criterion to consider for the exterior plaza on a campus setting is the illuminance level reached throughout the space. According to the IESNA Handbook, the horizontal illuminance for a plaza should reach about 5fc and the vertical illuminance should reach about 3fc. The horizontal illuminance is important for pedestrians to see while walking through the area, while the vertical illuminance is necessary for facial recognition of other pedestrians. The target horizontal illuminance for this particular lighting design will fall in the range of 2-5fc.

Another important issue regarding the lighting design of the exterior courtyard is the appearance of the space and luminaires. The area can be seen from three different, heavily used buildings: The Arena, The Recreation and Fitness Center, and Student Dormitories, therefore it should be pleasing to the eye. The luminaires should be simple, yet decorative. Because the surrounding facades and pathways are a rich brick, the luminaires should generally have a warmer color temperature to bring out the color, opposed to washing the colors out.

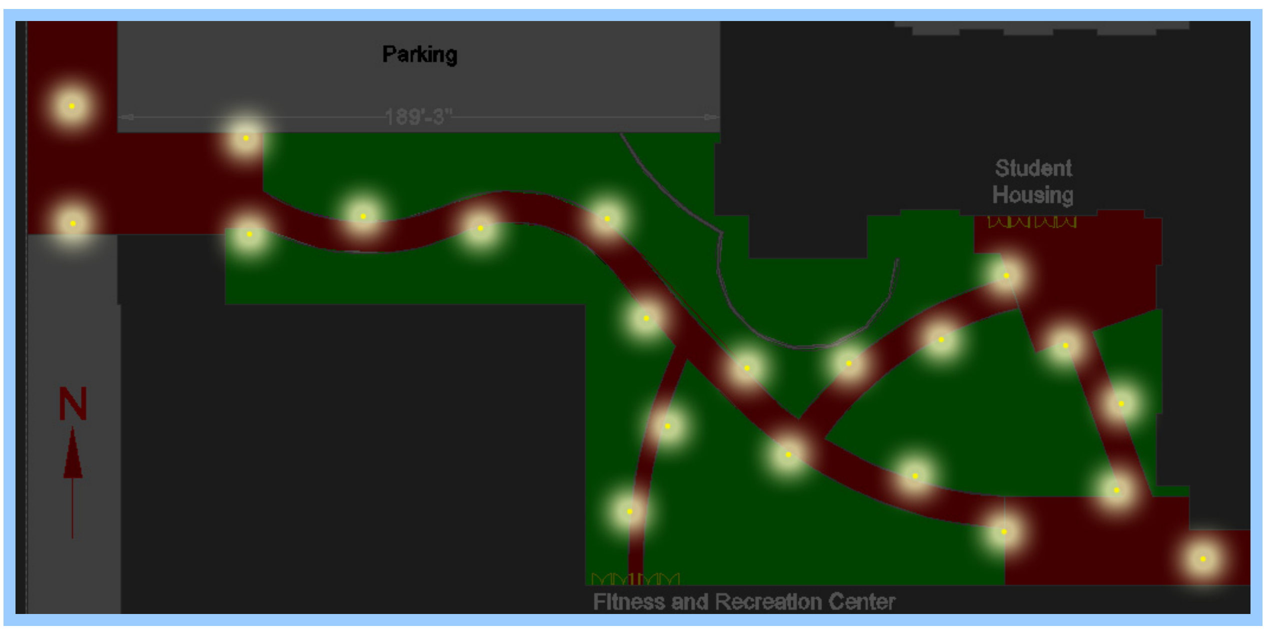
Direct glare is also a concern for exterior lighting designs. All fixtures should have a coating or enclosure to avoid direct glare. The luminaires used should not cause strong direct glare for pedestrians that may impair their vision. Avoiding too many dark areas around the pathways is preferred. The illuminance uniformity ratio on the walkways and entrances should be no greater than 4:1, max: min.

Another major criterion considered for this design is light pollution into the buildings and dark sky compliancy. Dormitory windows as well as other building windows surround the courtyard, so light into these areas needs to be avoided. At night, if students are trying to sleep, the annoyance of a bright light that they cannot control is far from desirable. Dark-sky complaint fixtures will also be a consideration. In order to avoid adding more light pollution into the Boston sky, the new lighting design will take a look at different types of dark-sky compliancy.

Design Concept

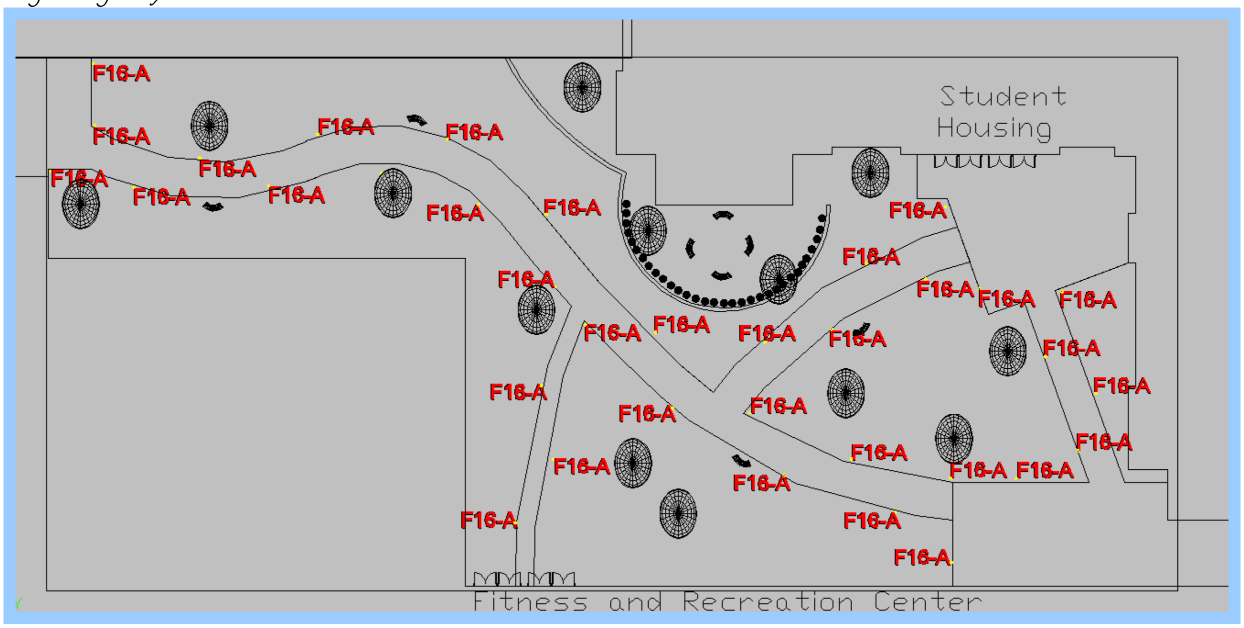
The entire courtyard is surrounded by buildings. Located to the north is a student dormitory, south is the Fitness and Recreation Center, and to the West is the Arena building. When creating a lighting design for this area, dark sky compliant fixtures and light pollution *into* the buildings are generally very important to the lighting scheme. In order to avoid light entering into the dormitory windows the fixtures will have a direct lighting distribution onto the surface below. The walkways will be illuminated for safety and visibility.

Two different approaches with the same design concept and criteria will be examined. The first design will study dark-sky compliant bollards, while the second design will look at dark-sky compliant pole mounted type fixtures. Below is a sketch of the desired lighting concept. In order to keep some variables constant for a more adequate comparison, each fixture will have the same type of lamp, lamp wattage, and ballast.

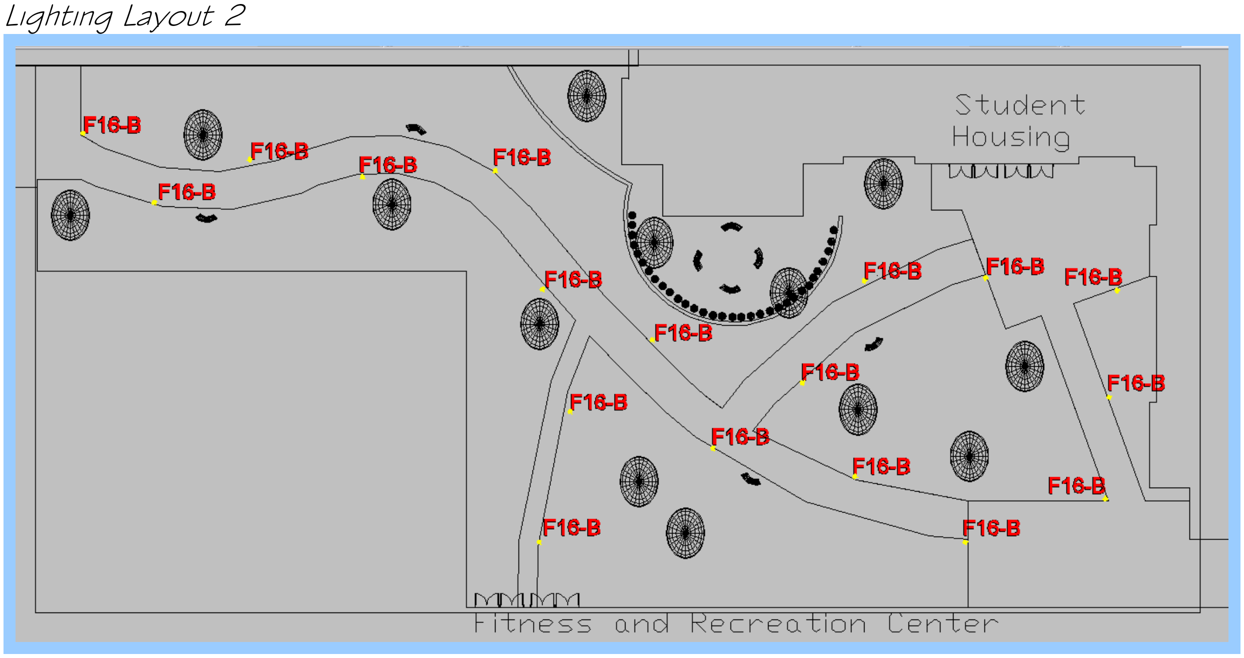


Lighting Plan

Lighting Layout 1



Lighting Layout 2



Luminaires Images

Luminaire Schedule

Label	Description	Catalogue NO.	Lamp			Ballast		Voltage	Fixture Qty.
			NO.	Type	Watts	Type	Lamps		
F16-A	360 Degree 3' Bollard	ERCO 33353.023	1	T6 70W G12 MH	70W	Electronic	1	277	35
F16-B	10' Indirect Pole, Site Luminaire, Dark-sky compliant	Gardco Lighting Gaskin Series GS04-1-10-5ID-T70CMHE-277	1	T6 70W G12 MH	70W	Electronic	1	277	18

Light Loss Factors

Luminaire Label	Maintenance Category	LLD	LDD	RSDD	BF	Total LLF
F16-A	IV	0.76	0.86	-	0.98	0.641
F16-B	IV	0.76	0.86	-	0.98	0.641
Assume: 24 month cleaning interval and a clean environment.						

Power Density

Label	Qty	Watts	Total Watts
F16- A	35	77	2695
		Total:	2695
		Sq Ft:	20000
		Power Density:	**0.13475**

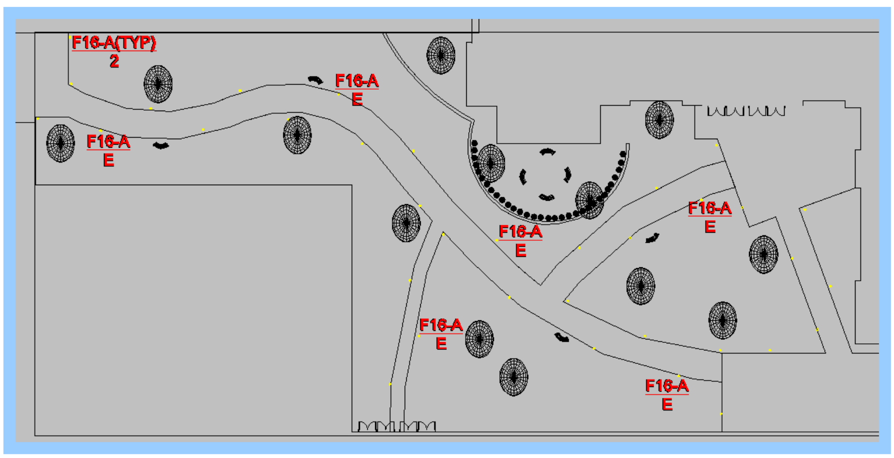
Label	Qty	Watts	Total Watts
F16- B	18	77	1386
		Total:	1386
		Sq Ft:	20000
		Power Density:	**0.0693**

Control Plan

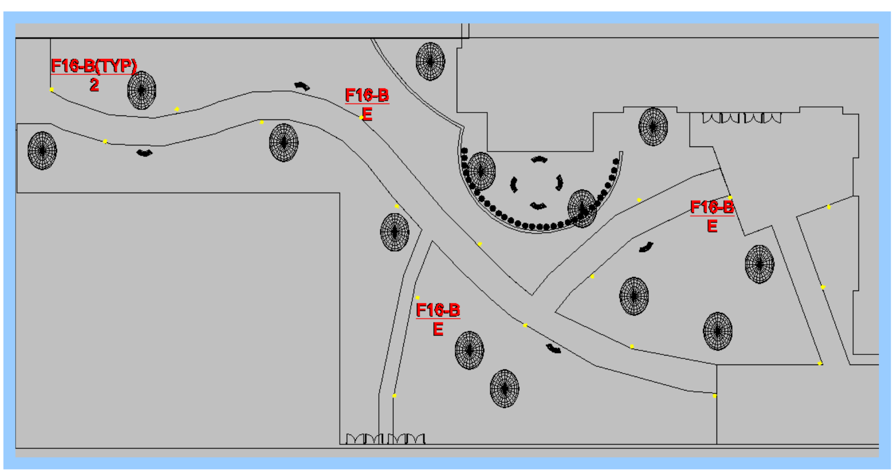
Control Equipment:

All normal branch circuits are circuited to panelboard RL1LNH1, which is a 480/277 panel. Wire all normal lighting fixtures through low voltage lighting control cabinet RL1-LCCN01. All life safety branch circuits are circuited to panelboard RL1LSH1. Wire all life safety lighting fixtures through low voltage lighting control cabinet RL1-LCCE01. All the fixtures in this layout will be on circuit 2. Emergency fixtures will have battery operated ballasts which power the fixtures if the life safety lighting is needed. The panelboard is located on lower level one in the electrical equipment room. The fixtures will be controlled first with a timer and a manual switch will also exist that can override the timer.

Switching and Circuiting



Layout 1 Circuiting



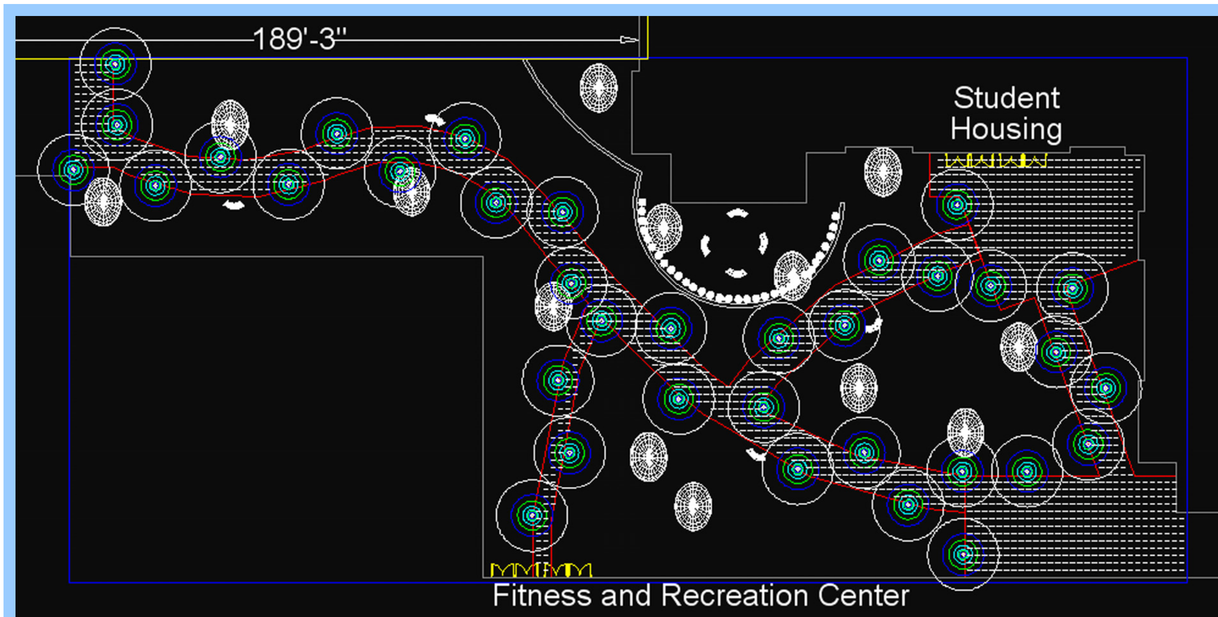
Layout 2 Circuiting

**The panelboard schedules are found in the Electrical Depth part of this report under Branch Circuit Redesign/ Exterior.*

Software Calculations

Lighting Plan 1

Illuminance levels

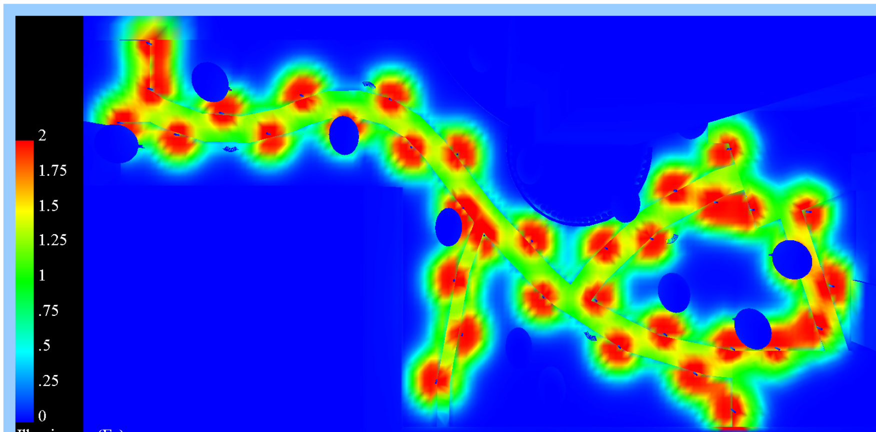


Project 1
Calc Pts

CalcPts
Illuminance Values (Fc)
Average=1.60
Maximum=6.1
Minimum=0.0

Above shows an AGI simulation of the panoramic bollards. The circles around each fixture represent the illuminance distribution. Below is a chart with the color and corresponding illuminance value.

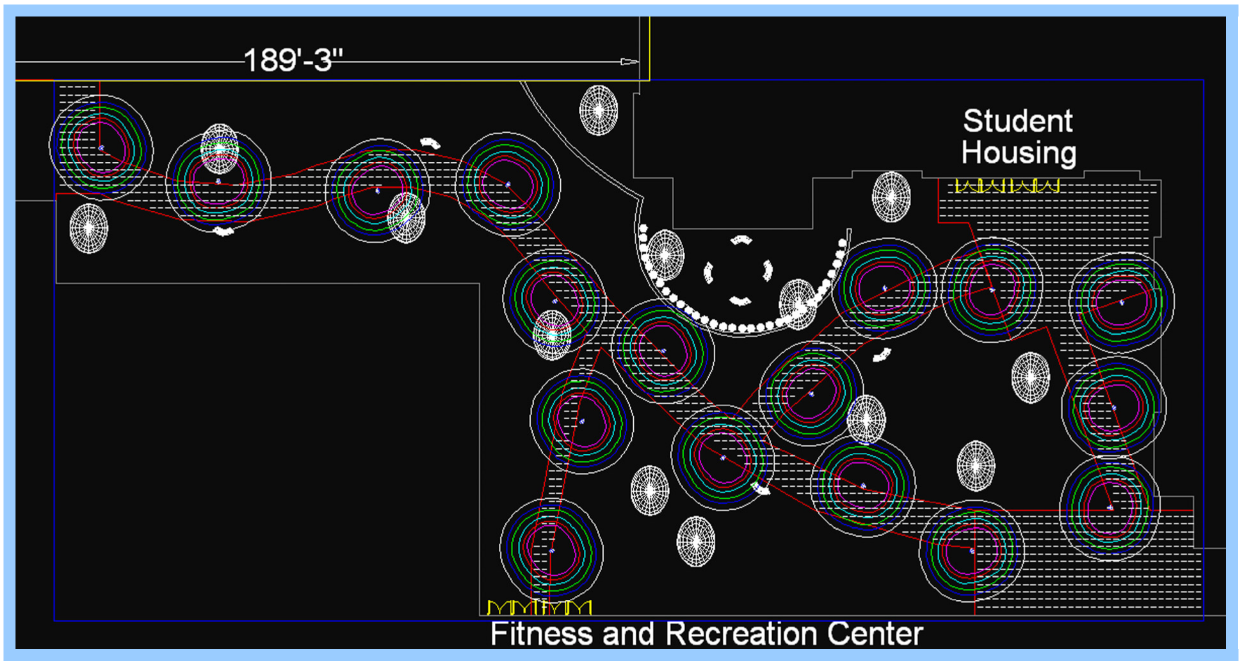
Isolines: Value (Fc)	1	1.5	2	3	4	5
Color	Black	Blue	Green	Cyan	Red	Magenta



The figure to the left represents the illuminance distribution across the courtyard. The maximum light level reached about two footcandles with an average distribution of 1.6fc. The values are a little low, but adequate levels for an exterior courtyard.

Lighting Plan 2

Illuminance levels

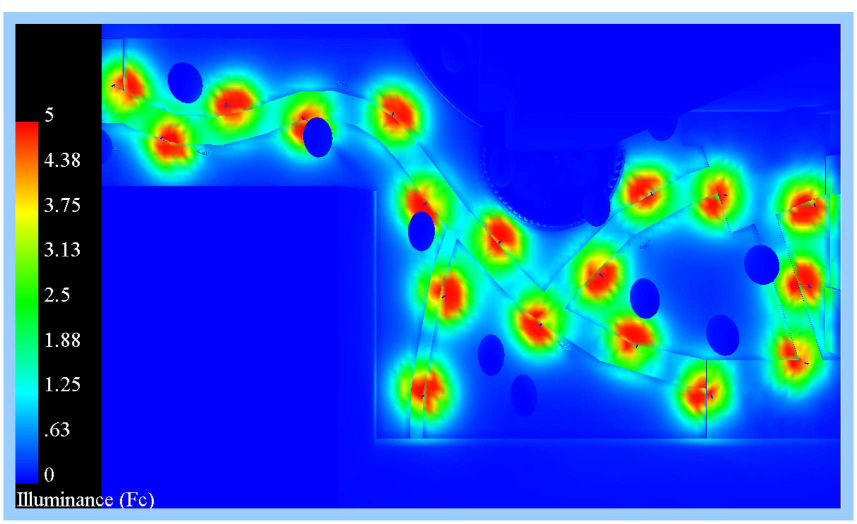


Project 1
Calc Pts

CalcPts
Illuminance Values (Fc)
Average=2.30
Maximum=9.8
Minimum=0.1

Above shows an AGI simulation of the pole mounted fixtures. The circles around each fixture represent the illuminance distribution. Below is a chart with the color and corresponding illuminance value.

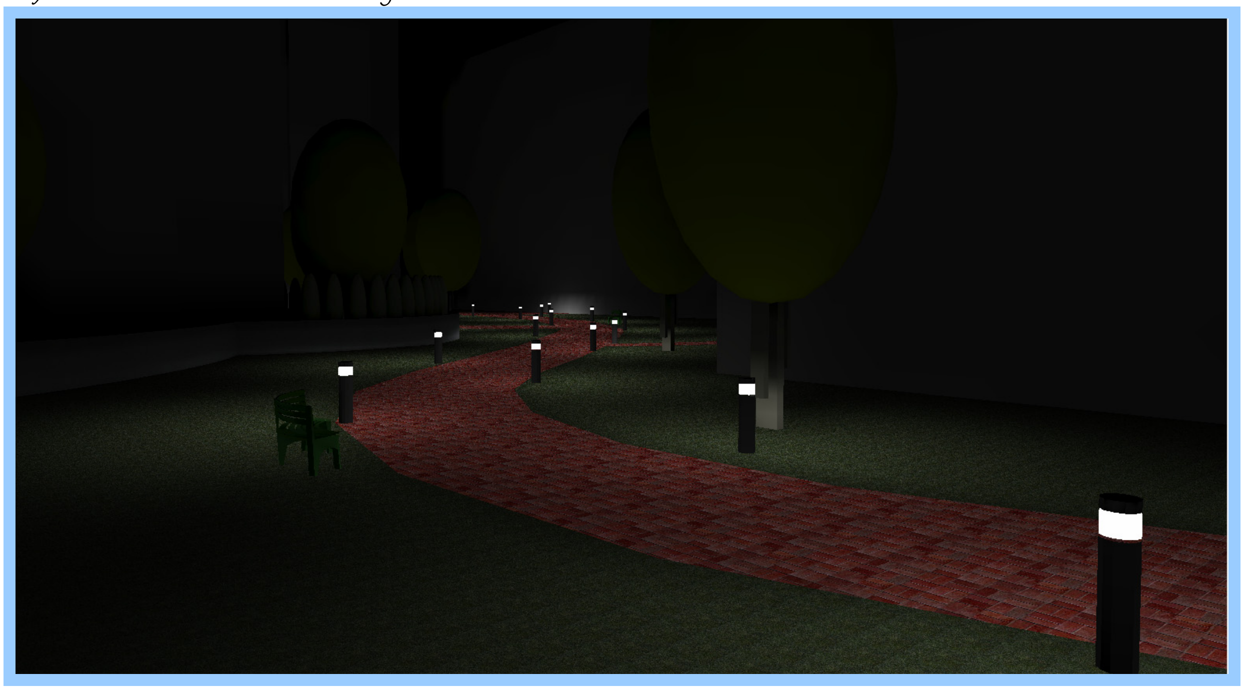
Isolines: Value (Fc)	1	1.5	2	3	4	5
Color	black	blue	green	cyan	red	magenta



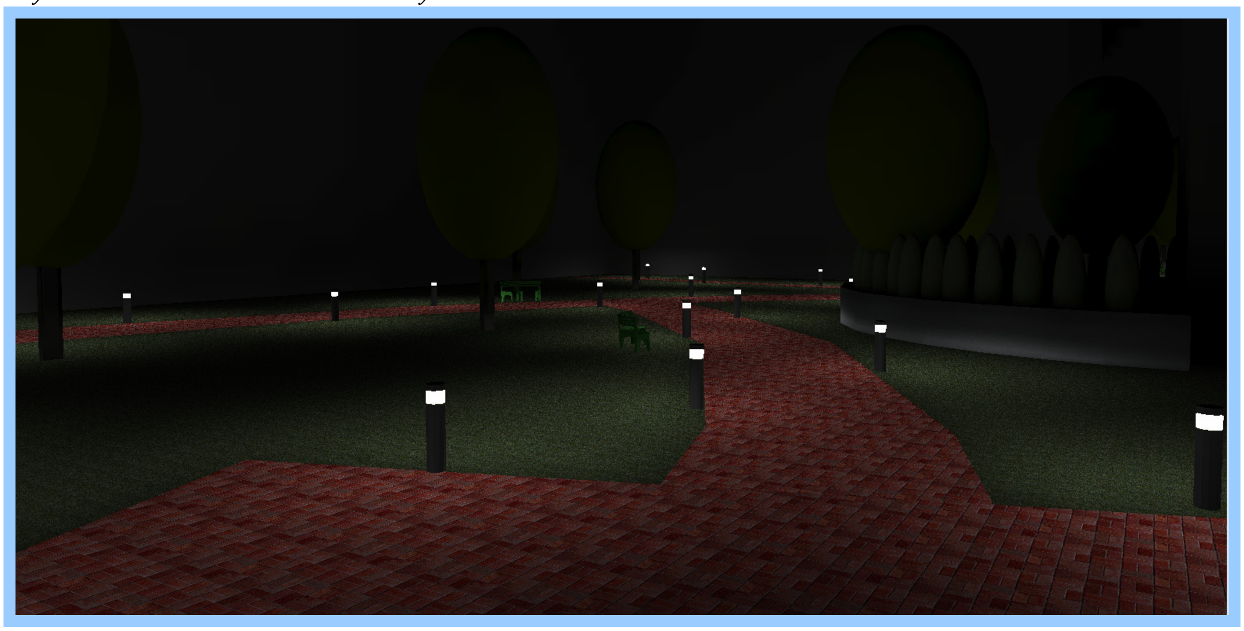
The figure to the left represents the illuminance distribution across the courtyard. The maximum light level reached about five footcandles with an average distribution of 2.3fc. The values reach between the target of 2-5fc, which will allow a safer feel within the courtyard.

Renderings

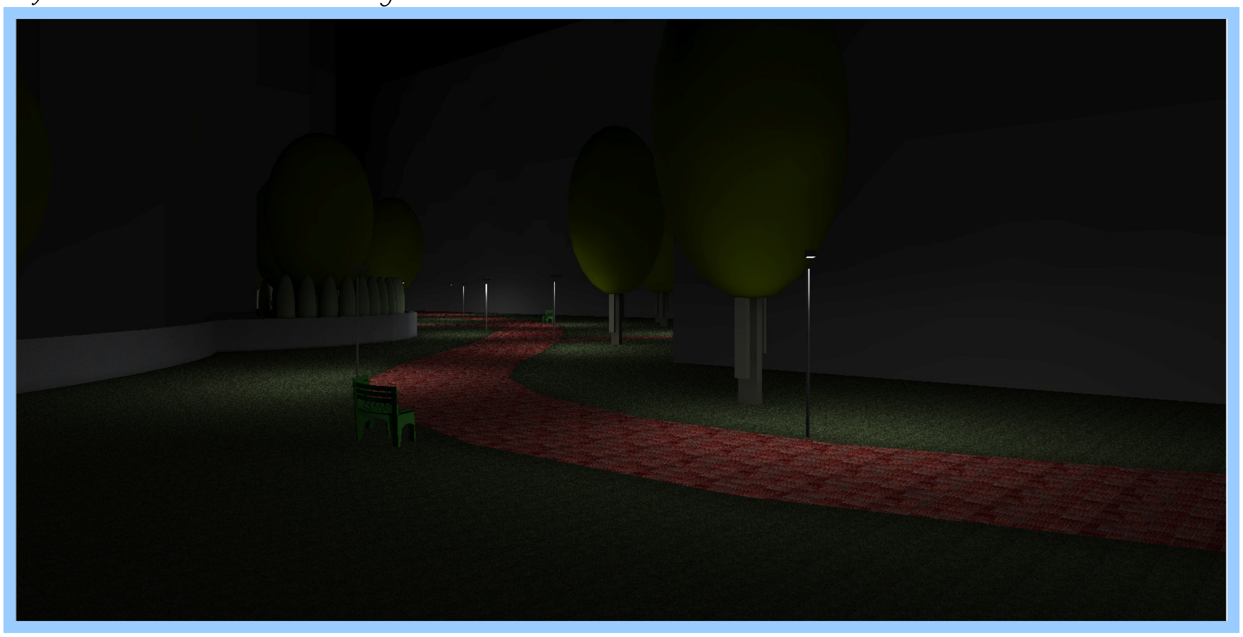
Layout 1 - View from Parking Area



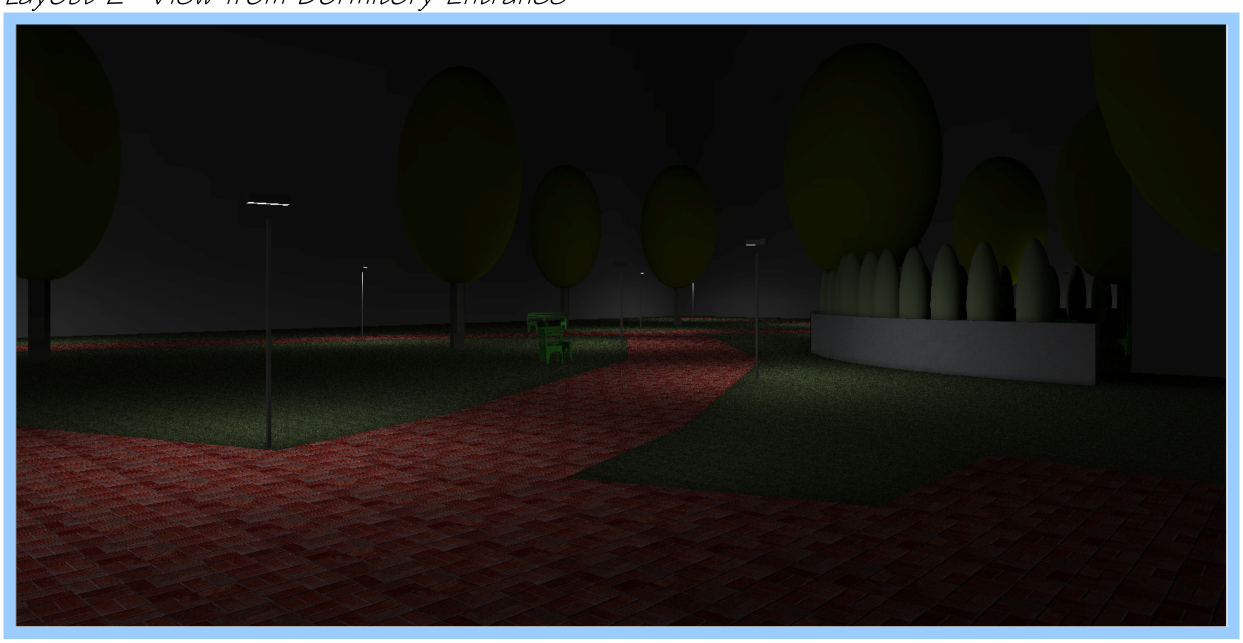
Layout 1 - View from Dormitory Entrance



Layout 2- View from Parking Area



Layout 2- View from Dormitory Entrance



Conclusion

The intent of this lighting design analysis was to create two different lighting designs for the courtyard pathways and compare their differences. The main lighting goals for both designs were to implement dark-sky compliant fixtures while creating a safe and secure atmosphere for students at night. In order to keep a few constant variables, the fixtures would use the same type of lamp and wattage. After choosing suitable fixtures, the outcomes of each were very different.

Layout 1 looked at a panorama bollard fixture. The maximum illuminance level reached 2fc. The light was generally evenly distributed along the pathways with an average of about 1.6fc. In order to provide suitable light levels, thirty-five fixtures needed to be used, which increased the power density. The panorama bollards tend to be aesthetically pleasing due to their smaller size and lack of direct glare. Unfortunately, because of the small size and dark-sky compliancy, little to no light reaches vertically enough to provide adequate facial recognition.

Layout 2 examined the use of a dark-sky compliant pole fixture. The indirect fixture provided light on the ground by using of a highly reflective optic fixture design. The maximum illuminance level reached was about 5fc with an average of about 2.5fc along the pathways. The light was evenly distributed and only 18 fixtures were needed in order to provide adequate light levels. The power density turned out to be only half that of Layout 1. The pole fixtures also provide better facial recognition which is important for safety.

After thoroughly looking at each lighting design, I would recommend Layout 2. The pole fixture is in keeping with dark-sky compliancy and is a creative yet modern fixture design. Safety and security is an important goal for exterior campus design, and this fixture provides twice as much light as the bollard with only half the amount of fixtures. The pole fixture also allows better light levels for facial recognition, which provides a better sense of security for pedestrians at night. Overall, Layout 2 is a better lighting design, cheaper (less fixtures to buy and less electricity), and visually pleasing to the eye.

Electrical Depth

Branch Circuit Redesign

Copper vs Aluminum Feeder Study

Energy Efficient Transformer Analysis

Protective Device Coordination

Branch Circuit Redesign

Below is a redesign of the panelboards, feeders, and circuit breakers that are affected by the new lighting design system. The panelboards are redesigned to accommodate the new lighting loads. The over current protection device is sized according to the new design ampacity as well as the feeder serving the panel.

Club Room

The dimming panel below is a Lutron Grafik Eye 4000 system. The feeder for this panel below runs from panel A2LNH1.

PANEL A2-DDC01						
DIMMER	ZONE	TYPE	CONTROL	LOAD (W)	VOLTAGE (V)	LOCATION
1	A	LVH WW	Dimmed	1275	120	Along North Wall
2	B	CFL DWNLT	Dimmed	1560	120	Throughout Space
3	B	CFL DWNLT	Dimmed	1365	120	Throughout Space
4	C	LVH DWNLT	Dimmed	400	120	Entrance Corridor
5	D	CFL PENDANT	Dimmed	1120	120	Throughout Space
6	E	CFL PENDANT	Dimmed	150	120	Over Bar Counter
7	F	CFL SCONCE	Dimmed	112	120	Along South Wall
8	G	LV ACCENT	Dimmed	120	120	Entrance Corridor
9	H	LED STRIP	On/Off	100	120	Bar- Back Counter
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
		TOTAL LOAD (w)		6202		
		with growth (W)		7752.50		

Design Load: 38A
Circuit Breaker: 50A
Feeder Size: (3) #8 AWG
Conduit: 3/4" C

Lobby

Below circuits 6, 8, and 10 were redesigned with the new lighting loads.

PANELBOARD SCHEDULE

VOLTAGE: 480Y/277V,3PH,4W	PANEL TAG: R1LNH1	MIN. C/B AIC: 10K
SIZE/TYPE BUS: 150A	PANEL LOCATION: R168	OPTIONS: PROVIDE FEED THROUGH LUGS FOR PANELBOARD 1L1B
SIZE/TYPE MAIN: 150A/3P C/B	PANEL MOUNTING: SURFACE	

DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS. NO.	A	B	C	POS. NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION
Lighting	Gymnasium	2000	20A/1P	1	*			2	20A/1P	1700	Toilet/Lobby	Lighting
Lighting	Gymnasium	3000	20A/1P	3		*		4	20A/1P	1700	Pool Seating	Lighting
Lighting	Gymnasium	2000	20A/1P	5			*	6	20A/1P	480	Entrance/Office	Lighting
Lighting	Gymnasium	3000	20A/1P	7	*			8	20A/1P	2000	Rotunda	Lighting
Lighting	Gymnasium	2000	20A/1P	9		*		10	20A/1P	2150	Juice Bar Area	Lighting
Lighting	Gymnasium	2000	20A/1P	11			*	12	20A/1P	2450	Exterior	Lighting
Lighting	Gymnasium	3000	20A/1P	13	*			14	20A/1P	500	Lobby/Reception	Lighting
Lighting	Gymnasium	2000	20A/1P	15		*		16	20A/1P	2000	Juice Bar	Lighting
Lighting	Gymnasium	3000	20A/1P	17			*	18	20A/1P	1000	Corridor	Lighting
Lighting	Gymnasium	2000	20A/1P	19	*			20	20A/1P	2100	Corridor/Lobby	Lighting
Lighting	Gymnasium	2000	20A/1P	21		*		22	20A/1P	1000	Corridor	Lighting
Lighting	Gymnasium	3000	20A/1P	23			*	24	20A/1P	1400	Rotunda Cove	Lighting
Lighting	Gymnasium	2000	20A/1P	25	*			26	20A/1P	0	Spare	Lighting
Lighting	Gymnasium	3000	20A/1P	27		*		28	20A/1P	0	Spare	Lighting
Lighting	Gymnasium	2000	20A/1P	29			*	30	20A/1P	0	Spare	Lighting
Lighting	Fitness 3	2500	20A/1P	31	*			32	20A/1P	0	Spare	Lighting
Lighting	Fitness 4	3000	20A/1P	33		*		34	20A/1P	0	Spare	Lighting
Lighting	Gymnasium	600	20A/1P	35			*	36	20A/1P	0	Spare	Lighting
Lighting	Exterior	3000	20A/1P	37	*			38	20A/1P	0	Spare	Lighting
Lighting	Spare	0	20A/1P	39		*		40	20A/1P	0	Spare	Lighting
Lighting	Spare	0	20A/1P	41			*	42	20A/1P	0	Spare	Lighting

CONNECTED LOAD (KW) - A	23.80	TOTAL DESIGN LOAD (KW)	95.37
CONNECTED LOAD (KW) - B	21.85	POWER FACTOR	1.00
CONNECTED LOAD (KW) - C	17.93	TOTAL DESIGN LOAD (AMPS)	115

Sizes are based on Design Load and are determined by referencing the NEC Handbook

Design Load: 115A
Circuit Breaker: 125A
Feeder Size: (3) #1 AWG THHW
Conduit: 1-¼" C
Note: Although a smaller feeder size could have been used, I chose to size up for safety.

Gymnasium

Below circuits 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 were redesigned with the new lighting loads.

PANELBOARD SCHEDULE												
VOLTAGE: 480Y/277V,3PH,4W SIZE/TYPE BUS: 150A SIZE/TYPE MAIN: 150A/3P C/B				PANEL TAG: R3LNH1 PANEL LOCATION: R311 PANEL MOUNTING: SURFACE					MIN. C/B AIC: 10K OPTIONS: PROVIDE FEED THROUGH LUGS 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	Corridor	1100	20A/1P	1	*			2	20A/1P	3500	Upper Gym	Lighting
Lighting	Rotunda	800	20A/1P	3		*		4	20A/1P	3500	Upper Gym	Lighting
Lighting	Corridor	300	20A/1P	5			*	6	20A/1P	3500	Upper Gym	Lighting
Lighting	Corridor	300	20A/1P	7	*			8	20A/1P	3500	Upper Gym	Lighting
Lighting	Bathrooms	1100	20A/1P	9		*		10	20A/1P	3500	Upper Gym	Lighting
Lighting	Corridor	1200	20A/1P	11			*	12	20A/1P	3500	Upper Gym	Lighting
Lighting	Rotunda	600	20A/1P	13	*			14	20A/1P	2250	Above Running Track	Lighting
Lighting	Rotunda	1100	20A/1P	15		*		16	20A/1P	2250	Above Running Track	Lighting
Lighting	Rotunda	800	20A/1P	17			*	18	20A/1P	2250	Below Track	Lighting
Lighting	Upper Gym court 3	2000	20A/1P	19	*			20	20A/1P	2250	Below Track	Lighting
Lighting	Fitness Ctr	1200	20A/1P	21		*		22	20A/1P	0	0	Lighting
Lighting	Rotunda	1600	20A/1P	23			*	24	20A/1P	0	0	Lighting
Lighting	Rotunda	800	20A/1P	25	*			26	20A/1P	0	0	Lighting
Lighting	Fitness Ctr	1200	20A/1P	27		*		28	20A/1P	0		Lighting
Lighting	Roof	800	20A/1P	29			*	30	20A/1P	0		Lighting
Lighting	Climbing Wall	1200	20A/1P	31	*			32	20A/1P	0		Lighting
Lighting	Upper Gym	0	20A/1P	33		*		34	20A/1P	0		Lighting
Lighting	Upper Gym	0	20A/1P	35			*	36	20A/1P	0		Lighting
Lighting		0	20A/1P	37	*			38	20A/1P	0		Lighting
Lighting		0	20A/1P	39		*		40	20A/1P	0		Lighting
Lighting		0	20A/1P	41			*	42	20A/1P	0		Lighting
CONNECTED LOAD (KW) - A		17.50								TOTAL DESIGN LOAD (KW)		69.15
CONNECTED LOAD (KW) - B		14.65								POWER FACTOR		1.00
CONNECTED LOAD (KW) - C		13.95								TOTAL DESIGN LOAD (AMPS)		83

Sizes are based on Design Load and are determined by referencing the NEC Handbook

Design Load: 83A
Circuit Breaker: 90A
Feeder Size: (3) #3 AWG THHW
Conduit: 1 - ¼" C
Note: Although a smaller feeder size could have been used, I chose to size up for safety.

Exterior

Below circuit 2 was redesigned with the new lighting loads for Layout 1.

PANELBOARD SCHEDULE												
VOLTAGE: 480Y/277V,3PH,4W			PANEL TAG: RL1LNH1						MIN. C/B AIC: 10K			
SIZE/TYPE BUS: 150A			PANEL LOCATION: RB116A						OPTIONS: PROVIDE FEED THROUGH LUGS FOR PANELBOARD 1L1B			
SIZE/TYPE MAIN: 150A/3P C/B			PANEL MOUNTING: SURFACE									
DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS NO.	A	B	C	POS NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION
Lighting	Corridor	1100	20A/1P	1	*			2	20A/1P	2695	Exterior Site	Lighting
Lighting	Classroom	2500	20A/1P	3		*		4	20A/1P	900	Classroom	Lighting
Lighting	Fitness Center	1100	20A/1P	5			*	6	20A/1P	2000	Fitness Center	Lighting
Lighting	Passage	1500	20A/1P	7	*			8	20A/1P	900	Corridor	Lighting
Lighting	Rotunda	2000	20A/1P	9		*		10	20A/1P	1500	Rotunda	Lighting
Lighting	Lobby	1700	20A/1P	11			*	12	20A/1P	600	Public Lobby	Lighting
Lighting	Corridor	1000	20A/1P	13	*			14	20A/1P	1000	Corridor	Lighting
Lighting	Rotunda Cove	2900	20A/1P	15		*		16	20A/1P	2400	Fitness Center	Lighting
Lighting	Rotunda	1700	20A/1P	17			*	18	20A/1P	2400	Classroom	Lighting
Lighting	Classroom	1300	20A/1P	19	*			20	20A/1P	800	Corridor	Lighting
Lighting	Corridor	600	20A/1P	21		*		22	20A/1P	2000	Corridor	Lighting
Lighting	Offices	1100	20A/1P	23			*	24	20A/1P	1200	Offices	Lighting
Lighting	Fitness Center	2100	20A/1P	25	*			26	20A/1P	1900	Men Faculty Locker	Lighting
Lighting	Rotunda	2000	20A/1P	27		*		28	20A/1P	2600	Men's Locker room	Lighting
Lighting	Women's Locker	2600	20A/1P	29			*	30	20A/1P	2900	Corridor	Lighting
Lighting	Women Faculty Locker	1900	20A/1P	31	*			32	20A/1P	0		Lighting
Lighting	Exterior Site	1000	20A/1P	33		*		34	20A/1P	0		Lighting
Lighting	Exterior Parking	3000	20A/1P	35			*	36	20A/1P	0		Lighting
Lighting	Exterior Site	700	20A/1P	37	*			38	20A/1P	0		Lighting
Lighting	Corridor	1100	20A/1P	39		*		40	20A/1P	0		Lighting
Lighting	Corridor	2200	20A/1P	41			*	42	20A/1P	0		Lighting
CONNECTED LOAD (KW) - A		16.90								TOTAL DESIGN LOAD (KW)		67.19
CONNECTED LOAD (KW) - B		21.50								POWER FACTOR		1.00
CONNECTED LOAD (KW) - C		22.50								TOTAL DESIGN LOAD (AMPS)		81

Sizes are based on Design Load and are determined by referencing the NEC Handbook

Design Load: 81A
Circuit Breaker: 90A
Feeder Size: (3) #3 AWG THHW
Conduit: 1 - ¼" C
Note: Although a smaller feeder size could have been used, I chose to size up for safety.

Exterior Continued

Below circuit 2 was redesigned with the new lighting loads for Layout 2.

PANELBOARD SCHEDULE												
VOLTAGE: 480Y/277V,3PH,4W SIZE/TYPE BUS: 150A SIZE/TYPE MAIN: 150A/3P C/B			PANEL TAG: RL1LNH1 PANEL LOCATION: RB116A PANEL MOUNTING: SURFACE						MIN. C/B AIC: 10K OPTIONS: PROVIDE FEED THROUGH LUGS 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	Corridor	1100	20A/1P	1	*			2	20A/1P	1386	Exterior Site	Lighting
Lighting	Classroom	2500	20A/1P	3		*		4	20A/1P	900	Classroom	Lighting
Lighting	Fitness Center	1100	20A/1P	5			*	6	20A/1P	2000	Fitness Center	Lighting
Lighting	Passage	1500	20A/1P	7	*			8	20A/1P	900	Corridor	Lighting
Lighting	Rotunda	2000	20A/1P	9		*		10	20A/1P	1500	Rotunda	Lighting
Lighting	Lobby	1700	20A/1P	11			*	12	20A/1P	600	Public Lobby	Lighting
Lighting	Corridor	1000	20A/1P	13	*			14	20A/1P	1000	Corridor	Lighting
Lighting	Rotunda Cove	2900	20A/1P	15		*		16	20A/1P	2400	Fitness Center	Lighting
Lighting	Rotunda	1700	20A/1P	17			*	18	20A/1P	2400	Classroom	Lighting
Lighting	Classroom	1300	20A/1P	19	*			20	20A/1P	800	Corridor	Lighting
Lighting	Corridor	600	20A/1P	21		*		22	20A/1P	2000	Corridor	Lighting
Lighting	Offices	1100	20A/1P	23			*	24	20A/1P	1200	Offices	Lighting
Lighting	Fitness Center	2100	20A/1P	25	*			26	20A/1P	1900	Men Faculty Locker	Lighting
Lighting	Rotunda	2000	20A/1P	27		*		28	20A/1P	2600	Men's Locker room	Lighting
Lighting	Women's Locker	2600	20A/1P	29			*	30	20A/1P	2900	Corridor	Lighting
Lighting	Women Faculty Locker	1900	20A/1P	31	*			32	20A/1P	0		Lighting
Lighting	Exterior Site	1000	20A/1P	33		*		34	20A/1P	0		Lighting
Lighting	Exterior Parking	3000	20A/1P	35			*	36	20A/1P	0		Lighting
Lighting	Exterior Site	700	20A/1P	37	*			38	20A/1P	0		Lighting
Lighting	Corridor	1100	20A/1P	39		*		40	20A/1P	0		Lighting
Lighting	Corridor	2200	20A/1P	41			*	42	20A/1P	0		Lighting
CONNECTED LOAD (KW) - A		15.59								TOTAL DESIGN LOAD (KW)		65.23
CONNECTED LOAD (KW) - B		21.50								POWER FACTOR		1.00
CONNECTED LOAD (KW) - C		22.50								TOTAL DESIGN LOAD (AMPS)		78

Sizes are based on Design Load and are determined by referencing the NEC Handbook

Design Load: 78A
Circuit Breaker: 80A
Feeder Size: (3) #4 AWG THHW
Conduit: 1" C
Note: Although a smaller feeder size could have been used, I chose to size up for safety.

Copper vs Aluminum Conductor Study

The debate between copper and aluminum conductors has been a constant struggle. The following study looks at the disadvantages and advantages of each type of metal wiring. In order to conduct the analysis, 25 different existing copper feeders found throughout Boston University's Fitness and Recreation Center's electrical distribution system were selected. The aluminum wire sizes were determined by the overcurrent protection device from the original feeder, which then determined the new conduit size.

Table 1: Price Comparison Copper vs Aluminum Conductors

FDR ID	OCPD	Length (ft)	Copper Phase Wires	Aluminum Phase Wires	Copper Cost/L.F	Copper Cost	Aluminum Cost/L.F.	Aluminum Cost	Copper Conduit Size	Aluminum Conduit Size
A4	30	80	(3) 10	(3) 8	4.7	376	3.95	316.00	1/2	3/4
A5	30	92	(3) 10	(3) 8	4.7	432.4	4.20	386.40	1/2	3/4
B4	40	56	(3) 8	(3) 6	6.7	375.2	4.20	235.20	3/4	1
C4	50	5	(3) 6	(3) 4	5.1	25.5	4.80	24.00	1	1
D4	60	10	(3) 4	(3) 4	6.35	63.5	4.80	48.00	1	1
E4	70	12	(3) 4	(3) 2	6.35	76.2	5.30	63.60	1	1-1/4
F4	90	6	(3) 2	(3) 1	8.15	48.9	5.95	35.70	1-1/4	1-1/4
G4	100	200	(3) 2	(3) 1 / 0	8.15	1630	7.25	1450.00	1-1/4	1-1/2
H4	125	168	(3) 1 / 0	(3) 2 / 0	12.25	2058	7.55	1268.40	1-1/2	1-1/2
J4	150	125	(3) 2 / 0	(3) 4 / 0	14.5	1812.5	9.95	1243.75	1-1/2	2
K4	175	178	(3) 3 / 0	(3) 4 / 0	16.75	2981.5	9.95	1771.10	2	2
L4	200	5	(3) 4 / 0	(3) 300	19	95	12.75	63.75	2	2-1/2
M4	225	10	(3) 250	(3) 350	21.5	215	13.90	139.00	2-1/2	2-1/2
N4	250	300	(3) 250	(3) 400	21.5	6450	15.30	4590.00	2-1/2	3
P4	300	250	(3) 350	(3) 500	28	7000	16.70	4175.00	2-1/2	3
Q4	350	90	(3) 500	(6) 4 / 0	35.25	3172.5	19.90	1791.00	3	3
R4	400	10	(6) 3 / 0	(6) 300	33.5	335	25.50	255.00	2-1/2	3-1/2
S4	500	30	(6) 250	(6) 400	43	1290	30.60	918.00	3	4
T4	600	150	(6) 350	(6) 500	56	8400	33.40	5010.00	3-1/2	4
U4	700	6	(6) 500	(9) 350	70.5	423	41.70	250.20	4	6
V4	800	6	(9) 300	(9) 500	74.25	445.5	50.10	300.60	4	6
W4	1000	6	(9) 400	(12) 400	94.85	569.1	61.20	367.20	6	6
X4	1200	6	(12) 350	(12) 500	112	672	66.80	400.80	6	6
Y4	1500	6	(12) 500	(15) 500	141	846	83.50	501.00	6	6+
Z4	1600	6	(15) 400	(18) 500	158	948	100.20	601.20	6	6+
					TOTAL	40,740.80		26,204.90		

**The unit costs per linear foot were taken from CostWorks. The pricing is based on 3 Copper conductors in a PVC jacket or 3 Aluminum conductors in a PVC jacket. In the event there were more than one set of 3 conductors the unit cost was multiplied by the number of sets.*

Table 2: Copper Characteristics

Copper	Higher electrical conductivity than aluminum, therefore smaller wire sizes for the same ampacity
	According to IEEE Standard 835-1994, copper's ampacity is 1.6 times that of aluminum
	Harder and stronger material which can stand much more abuse over time
	Because of the smaller wire sizing; more flexible to install and less effort
	Can withstand tighter twists, harder pulls, and more bends at junction and termination boxes without stretching or breaking
	Higher resistance to corrosion
	Forgiving metal to join electrically
	Better connections than aluminum
	Less bulky which means easier to transport to site and easier to install

Table 3: Aluminum Characteristics

Aluminum	Softer material, lower modulus of elasticity
	Need more critical installation procedures in order to secure bad connections
	Theirs is always an insulating oxide present
	The thermal expansion coefficient is much larger than copper, which causes loose connections when the wire expands and contracts
	Aluminum alloys are more active metals which make them more susceptible to corrode around moisture which causes a shorter life span

From the Table 1 above, aluminum wires are much cheaper than that of copper. For this particular set of feeders, aluminum is 36% cheaper than copper which could save the project a considerable amount of money. Although this seems like it could be very beneficial for the owner, there are many issues associated with aluminum wiring. It is recommended by the NEC that aluminum wires should not be used for distribution systems and only used for utility service feeders or where the design ampacity does not fluctuate. The utility service generally has a constant feed, unlike distribution feeders where the current running through them can have a large range.

Copper and aluminum metal have several differences that create advantages and disadvantages when wiring a building's distribution system. In order to allow the same ampacity, the aluminum wire would need to be sized larger than the copper wire. This could create a problem within the building construction process; ceiling plenum space is limited as it is. Although initial costs of aluminum are much less than copper the life cycle cost of copper is much less. Aluminum is much more difficult to install and is susceptible to damage and failure which requires re-installation of the wire. Overall, I would recommend using copper wire for building distribution systems.

Energy Efficient Transformer Analysis

Transformers tend to have low efficiencies generating electrical losses. Powersmiths manufactures energy efficient transformers which will be compared to status quo transformers in the report below. Each Recreation Center transformer will be replaced with an energy efficient transformer manufacturered by Powersmiths in order to calculate the energy savings as well as pay back period.

Transformer Takeoff

Transformers on Project		Total KW
QTY	kVA	
1	30	30
4	45	180
2	112.5	225
1	150	150
2	225	450
2	2000	4000
		5035

Available Full Load kW	5035		
Average kVA (calc)	420		
equipment operating hrs/ day	18		
equipment operating days/yr	300	Calc Load kW	Calc Annual kWh
Load during normal operating hours	50%	2518	13,594,500
Load outside operating hours	10%	504	1,691,760
		Total Annual Load kWh:	15,286,260

Annual Cost to Operate Load Only			
kWh rate	$ 0.029	Annual Consumption:	$ 440,703
demand rate ($/kW/mo) ex. $10.00	$12.00	Annual Demand:	$ 362,520
		Total Cost to run load	$ 803,223

Annual Cost of Status Quo Transformer Losses & Associated Air Conditioning (A/C) burden			
Nameplate Linear efficiency (normal op hrs)	98.0%	% electronics or current THD	30.0%
Calculated operating efficiency	97.0%		
Transformer kW Losses (Normal Operation)	78.4	kW	
Status quo Efficiency (Outside op. hrs)	91.0%		
Transformer kW Losses (Outside op. hrs)	49.8	kW	
Annual addititional kWh from transformers	590,656	kWh	
Annual Cost of Transformer Losses	$ 28,318		
A/C System Performance (kW/ton)	1.75		
Additional Tons of Cooling (on peak)	22.27	tons	
Annual addititional kWh from A/C	293,650	kWh	
Annual Cost of Associated A/C	$ 14,078		

Summary with Status Quo Transformer	
Annual Cost of feeding Building Load	$ 803,223
Annual Cost of Transformer Losses	$ 28,318
Annual Cost of Associated A/C	$ 14,078
Electrical Bill (Status Quo Transformer)	**$ 845,619**

TOTEL Electric Bill for Current Transformers: $845,619

Annual Cost of POWERSMITH's Transformer, Losses & Associated Air Conditioning (A/C) burden			
Powersmiths Efficiency (Normal Operation)	98.2%		
Powersmiths kW Losses (Normal Operation)	0.0	kW	
Powersmiths Efficiency (Outside op. hrs)	97.6%		
Transformer kW Losses (Outside op. hrs)	0.0	kW	
Annual addititional kWh from transformers	290,787	kWh	
Annual Cost of Powersmiths Losses	$ 15,028		
Additional Tons of Cooling (on peak)	13.11	tons	
Annual additional kWh from A/C	144,567	kWh	
Annual Cost of Associated A/C	$ 7,471		

Summary with Status Quo Transformer	
Annual Cost of feeding Building Load	$ 803,223
Annual Cost of Transformer Losses	$ 15,028
Annual Cost of Associated A/C	$ 7,471
Electrical Bill (Status Quo Transformer)	**$ 825,722**

TOTEL Electric Bill for Powersmith Transformers: $825,722

Comparing Status Quo & Powersmiths			
	Status Quo	**Powersmiths**	
Annual Cost of feeding Building Load	$ 803,223	$ 803,223	
Annual Cost of Transformer Losses	$ 28,318	$ 15,028	
Annual Cost of Associated A/C	$ 14,078	$ 7,471	**Reduction**
Annual estimated Electrical Bill	**$ 845,619**	**$ 825,723**	**2%**
Peak kW *REDUCTION* (normal op hours)	**32.3**	**kW**	
Annual kWh *REDUCTION*	**448,951**	**kWh**	
***REDUCTION* in Air Conditioning Load (on peak)**	**9.16**	**tons**	

Cost Analysis			
Energy Cost Escalation (above inflation)	3.0%		
	Annual	**Life Cycle Operating Cost & Savings**	
	Operating Cost	**20 years**	**32 years**
Status Quo Transformers	$42,396	$1,531,438	$3,493,543
Powersmiths Transformers	$22,500	$812,744	$1,854,047
Savings with Powersmiths	**$19,896**	**$718,694**	**$1,639,496**

Unit Costs Total	
Powersmiths Transformers	$494,000
Status Quo Transformers	$203,225

Payback Period On Total Costs	**14.61**	**years**	current kWh rate:
Cost of Energy Savings	**$ 0.020**	**/kWh**	$0.029
Cost - Benefit Ratio	**1.4**	**times less to save a kWh than to buy a kWh**	

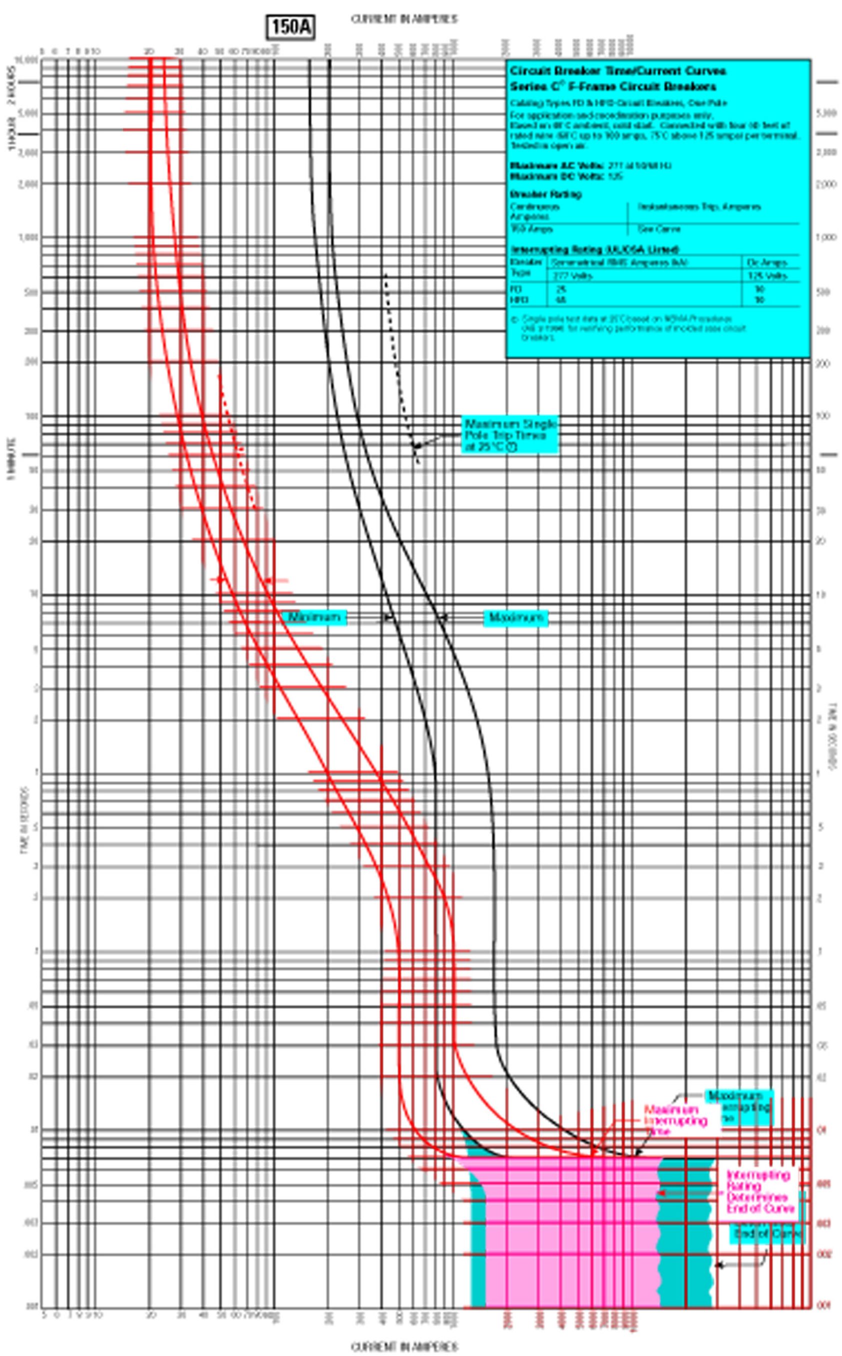
After thoroughly looking at the transformer analysis, I would recommend the high initial costs for Powersmiths transformers, which will ultimately save the owner money in the long run. Although fifteen years seems like a rather long payback period, the transformers will be worth the energy savings for the building as a whole.

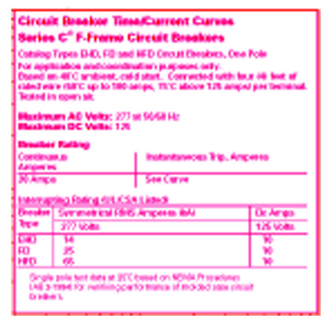
Protective Device Coordination

The chart below shows an overcurrent protection coordination study.

AB DE-ION Circuit Breakers

Types FD and HFD 150 Amperes





The Red lines represent a 20A circuit breaker from a lighting load. The Black lines with blue highlights represent a 150A circuit breaker for a panelboard. The two devices are coordinated correctly as this table shows.

Curve No. SC-4438-88A

Breadth Work

Construction Management Analysis

Mechanical Study

Construction Management Breadth

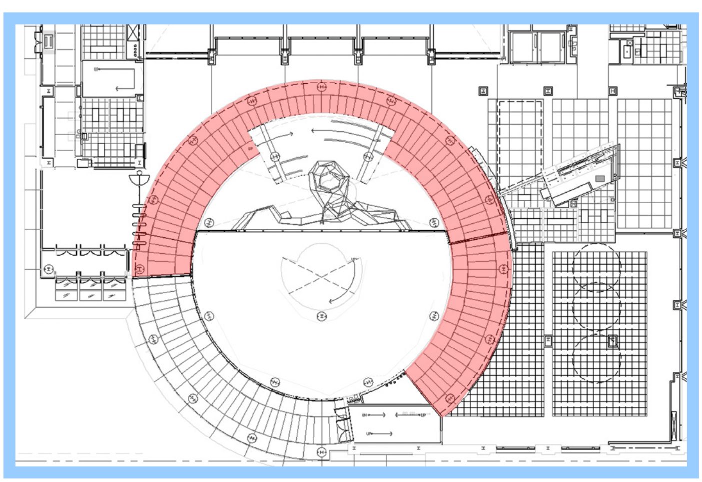
Problem: The existing ceiling in the concourse is radius metal ceiling panels. The installation was difficult and long because each piece is custom cut on a 40ft radius as well as, fitting each lighting fixture perfectly.

Solution: Change the radius metal panels to acoustic ceiling panels to decrease the schedule and the cost and improve the constructability.

Resources and Tools: Scott Mull – Barton Malow Company, Project Manager; CostWorks; Microsoft Excel

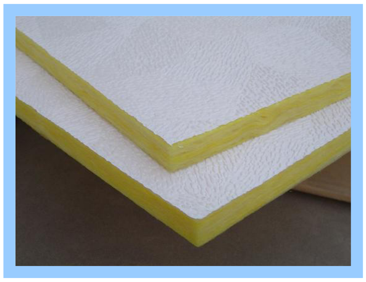
Existing Conditions: The area of the concourse to be changed from radius metal panels to acoustic ceiling panels is highlighted in the floor plan of the concourse (Figure 1). A picture of the existing metal panels and the acoustic ceiling panels to be used is depicted in Figure 2. The aluminum metal paneling is highly reflective, which could create unwanted glare issues. In order to keep the integrity of the circular design, the new lighting plan places the fixtures on the same 40ft radius circle to highlight the uniqueness of the rotunda. The space is generally all white with a few accent colors, so the acoustic ceiling panels will fit in well and won't be an eyesore, while keeping the same aesthetics. The total square footage being altered is 4,750. The current metal panel ceiling is 1'-3" below the surrounding drywall ceiling. Figure 3 depicts these existing conditions in a wall section.

Figure 1



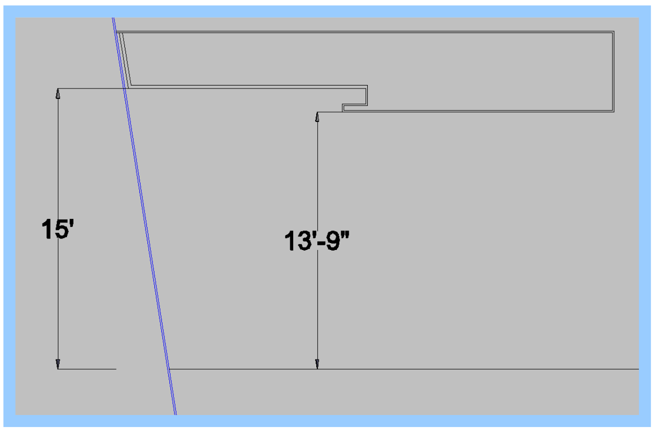
The inner radius of the metal ceiling (highlighted in red) is 40ft and the outer radius is 60ft. The bottom left corner of the circle (about ¼ of the total square footage) is located on the exterior and is a slightly different material than the inside. This area will not be examined.

Figure 2



The first picture is of the highly reflective metal ceiling; the second acoustical ceiling tile.

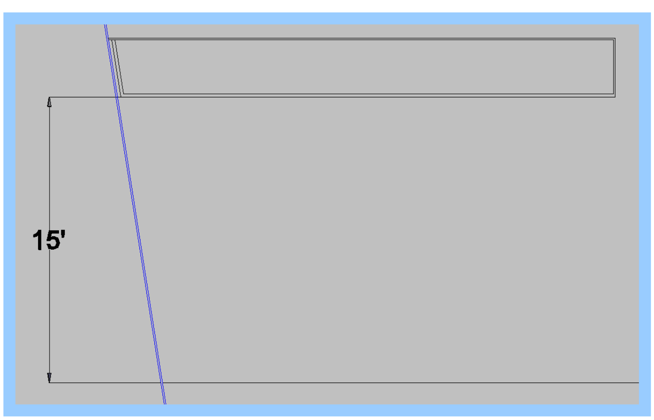
Figure 3



To the left is a section of the existing ceiling. The drop ceiling is on the right side of the picture.

Proposed Change: The highlighted ceiling in Figure 1 will be changed to acoustic ceiling panels and raised 1'-3" to meet the existing height of the surrounding drywall ceiling.

Figure 4



The redesigned wall section can be seen to the left.

Schedule Impact: The installation of acoustic ceiling panels has reduced the complexity of the ceiling installation. The centralized location of the concourse area makes it difficult to work on it all at one time. Therefore the concourse was completed a quarter at a time so that traffic patterns could be maintained and the construction of the other side of the building was not interrupted.

Acoustical ceiling tile was chosen instead of gypsum board to aid in the constructability and coordination. The acoustical ceiling tile permits the ceilings and partitions contractor to install the grid system and then put the tiles in place. This provides the contractor with an easier way to manage cuts that are not typical. Although gypsum board is easier to work with than the metal panels it is still a lengthy process. To install the gypsum board you must frame, board, tape and paint. The easy removal of the acoustical ceiling panel aids with coordination issues and maintenance. Once metal panels and gypsum board are installed it is impossible to access the plenum without ripping the ceiling out.

Changing from metal panels to acoustical ceiling panels has reduced the schedule nine days. Table 1 depicts the details of the time savings. This schedule savings reduces the entire project schedule because the metal panel installation is on the critical path. It was important that the project remained on schedule because the arena needed to be ready for a home opener. The construction manager, Barton Malow, would have received liquidated damages for every day the project was late. The nine day schedule savings gives the overall project schedule float. This will help the construction manager deal with any unforeseen conditions.

Table 1: Schedule Comparison

Material Type	Activity Duration	Hours Worked per Day	Activity Duration
Metal Panel	180	8	23
Acoustic Ceiling Panel	110	8	14
		Schedule Savings (days):	9

Cost Impact: The material cost of the designed metal panels is $40 per square foot compared to the proposed material cost of $5.05 per square foot (Table 2).

Table 2: Material Cost

Material Type	Cost ($) per Square Foot	Total Sqaure Feet	Total Material
Metal Panel	$40.00	5000	$200,000.00
Acoustic Ceiling Panel	$5.50	5000	$27,500.00

There is a significant savings in material cost and due to the schedule savings there is also a significant savings in labor cost (Table 3).

Table 3: Labor Cost Analysis

Position Title	Number of Workers per Crew	Number of Crews	Cost ($) per hour	Duration of Installation		Total Labor Cost ($)	
				Metal Panels	Acoustic Ceiling Panel	Metal Panels	Acoustic Ceiling Panel
Carpenter Foreman	1	1	$77.00	180	110	$13,860.00	$8,470.00
Carpenter Journeyman	3	1	$72.00	180	110	$38,880.00	$23,760.00
Labor Foreman	1	1	$60.00	180	110	$10,800.00	$6,600.00
Labor Journeyman	1	1	$44.00	180	110	$7,920.00	$4,840.00
					Total Labor Cost ($):	$71,460.00	$43,670.00

The total savings for changing the metal panels to acoustic ceiling panels is $200,290.00 as shown in Table 4.

Table 4: Total Cost Comparison

Material Type	Total Material	Total Labor Cost	Total Cost ($)
Metal Panel	$200,000.00	$71,460.00	$271,460.00
Acoustic Celing Panel	$27,500.00	$43,670.00	$71,170.00
		Savings ($):	$200,290.00

Recommendation:

Due to the $200,290.00 savings and nine day schedule savings it is recommended that the Boston University change concourse ceiling from radius metal panels to acoustical ceiling tiles. The original design intent was to bring out the curved architecture throughout the space. In order to preserve this concept, the new lighting design followed the same curved radius as the old ceiling. The white acoustical ceiling tiles will brighten up the space while opening up the space with the raised ceiling.

**Pricing information taken from actual project costs, provided by Scott Mull, PM with Barton Malow Company.*

Mechanical Breadth

The following Mechanical study was conducted in relationship with the addition of the gymnasium clerestories. The clerestories were added on the north and south sides of the gymnasium roof structure. The square footage of each clerestory is 480sf giving a total of 960sf of additional windows that need to be taken into consideration when calculating the heating and cooling loads required for the space. The R-value for the space envelope alters, which effects mechanical loads required for the gymnasium. The change in heating and cooling loads could cause the original mechanical equipment to be resized. It may also cause a large increase in electrical energy consumption.

In order to determine the heating and cooling loads for the space, the Hourly Analysis Program (HAP43) was utilized. The gymnasium system was created by putting in the wall assembly, window assembly, and other pertinent values. The only changes made to the system between the original and new load calculation was the window square footage on the north and south walls. From this program, the heating and cooling loads were determined. The original charts and graphs can be found in Appendix C. Below is a collaboration of the two tables and graphs.

	Original Loads		New Loads		Original & New Load Differences				Change in Tons	
	Cooling	Heating	Cooling	Heating	Cooling		Heating		Cooling	Heating
	kBTU	kBTU	kBTU	kBTU	kBTU	kwhr	kBTU	kwhr	Tons	Tons
January	30601	75301	31412	77882	811	81.10	2581	258.1	0.093866	0.298727
February	29899	41474	30732	41648	833	83.30	174	17.4	0.096412	0.020139
March	36306	34157	38133	34026	1827	182.70	-131	-13.1	0.211458	-0.01516
April	52151	6723	55963	6482	3812	381.20	-241	-24.1	0.441204	-0.02789
May	91620	3506	98206	3739	6586	658.60	233	23.3	0.762269	0.026968
June	140814	0	150134	0	9320	932.00	0	0	1.078704	0
July	162987	0	173042	0	10055	1,005.50	0	0	1.163773	0
August	159149	0	168971	0	9822	982.20	0	0	1.136806	0
September	113137	0	120939	0	7802	780.20	0	0	0.903009	0
October	71131	2633	75997	2749	4866	486.60	116	11.6	0.563194	0.013426
November	41372	20293	43057	20437	1685	168.50	144	14.4	0.195023	0.016667
December	31604	64866	32356	67155	752	75.20	2289	228.9	0.087037	0.264931
TOTAL	**960771**	**248953**	**1018942**	**254118**	**58171**	**5,817.10**	**5165**	**516.5**		

Because the COP for the mechanical equipment was unavailable the efficiency of the system was estimated using EER or Energy Efficiency Ratio. In order to convert from the thermal energy output (BTU) to electrical energy (kW-hr) needed to run the system, the following equation was used:

$$(811{,}000\ \text{BTU}) * \frac{(\text{w-hr})}{(10\ \text{btus})} * \frac{(1\text{kw-hr})}{(1000\text{w-hr})} = 81.1\ \text{kwhr}$$

**The equation basically translates to: for every 10 BTUs of thermal energy required, 1 w-hr of electrical energy is needed.*

The above chart shows that a significant amount of cooling loads are required for summer months, and less heating load for the months of March and April. To determine if the mechanical equipment needs to be resized the BTUs were converted to tons. The equation used for the conversion is: 12,000BTU/hr = 1 ton. The BTU listed in the chart is BTU/month so an average of 720hrs/month was used to convert into BTU/hr. Because the change in amount of tons between the two systems is so small the impact on the entire system will be minuscule. Mechanical equipment is also sized with a built in safety factor, therefore the change in load for this space will not cause a large change in the chiller size.

Final Conclusions

The Boston University Arena and Recreation Center encompasses a variety of student activities. The hub is used often by students, faculty, and alumni alike. The unique design created an area of energy, pride, and movement. The expansive Arena brings people together from all over to enjoy a sporting event, while the Recreation Center provides a facility for all types of extracurricular activities. Taking this into account, I was able to research and redesign certain elements of the Boston University Arena and Recreation Center building design project.

In my redesign, I have provided new lighting schemes for the Club Room, lobby, gymnasium, and exterior pathways that integrate with the architecture of each space. In each design, I kept in mind the light levels desired as well as the different uses for each space. The electrical requirements for the new lighting design loads were taken into consideration as well as the resizing of the equipment. A copper versus aluminum wire study, energy efficient transformer investigation, and a protection device coordination analysis also has been provided. In addition, this report investigates a new ceiling system in order to improve constructability of the project, as well as a mechanical study taking into account the addition of clerestories.

The Capstone Senior Project has been an invaluable experience. I have learned a great deal about the building design industry and will apply many of the lessons I have learned once I join the trade. The project has taught me that many design issues concern all engineering disciplines and the cooperation between them can create an amazing product.

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