Senior Thesis Final Report

University of California, Riverside Student Recreation Center
Riverside, CA

Daniel MacRitchie
Lighting/ Electrical Option
Faculty Advisor: Dr. Kevin Houser
04/03/2013

Thesis Abstract

University of California, Riverside Student Recreation Center

Riverside, California

Daniel MacRitchie | Lighting/Electrical Option

Building Team
Owner: University of California, Riverside
Construction Manager: Yet to be selected
Architect: Cannon Design
Landscape: Carter Romanek Landscape Arch. Inc.
Civil: Breen Engineering
Structural: Saiful Bouquet, Inc.
Mechanical/Plumbing: P2S Engineering
Electrical: Cannon Design
Aquatic Design: Counsilman Hunsaker & Associates, Inc.

Building Statistics
Size: 15,984 SF Renovation, 79,936 SF Addition
Stories: 2 above grade
Cost: $36.9 Million
Delivery: Design-Bid-Build

Architecture: The addition to the building uses a very modern style with glazing and metal panels while also reflecting the architecture of the existing building by using the same brick on the first level. The addition contains offices, classrooms, a gymnasium, a rock wall and multiple fitness areas. Outside the building there is a pool with both swimming lanes and a recreational portion that reflects the shape of the building.

Structural: The building's structural system primarily consists of steel beams for the second and roof level framing and steel columns throughout the building. The framing system uses moment connections around the perimeter of the building to resist lateral forces. The floors are comprised of a slab on grade on the first level and a concrete slab on metal decking on the second level. The foundation consists of a concrete wall below grade around the perimeter of the building and spread footings at the base of each column.

Mechanical: The mechanical system makes use of the two existing air handling units by replacing the supply air fans to increase capacity. Variable frequency drives are also added to the existing air handling units to reduce electricity usage. Three additional air handling units are used to supply air to the addition. The system also makes use of variable frequency drives and variable air volume controllers, some with carbon dioxide sensors for demand controlled ventilation.

Electrical: The electrical system for the building uses the existing 12kV switchboard to serve two additional switchboards, one at 480/277V and one at 208/120V. The 480/277V switchboard serves all of the motors in the building an a majority of the lighting while the 208/120V switchboard serves receptacle and other general loads in the building. Both new switchboards have surge protection devices to protect the electrical system.

Lighting: The lighting systems consists of primarily LED, linear fluorescent and high intensity discharge sources with a few compact fluorescent sources to minimize the power consumption. The building also integrates daylight, daylight sensors, and occupancy sensors into many of the spaces to further reduce the building's dependence on electric lighting.

http://www.engr.psu.edu/ae/thesis/portfolios/2012/drm5177/default.htm

Note: All renderings courtesy of Cannon Design

Executive Summary

This report is a summary of the analyses and design work that was completed during the Penn State Architectural Engineering's Senior Thesis Capstone course. It includes the redesign of four lighting spaces, three topics of study concerning the electrical system and three breadth topics outside of the lighting/electrical field of study. These redesigns and analyses were solely for the purpose of investigating other design alternatives that were not used in the original design of the building.

The four spaces in which the lighting was redesigned are the entrance and courtyard space, the lobby, the rock wall space and the gymnasium. These spaces were chosen in because they are close in proximity to each other and in some cases the lighting from one space affects the lighting in another space. These spaces were also selected to create a common theme throughout the spaces. The entrance is the first space that occupants will encounter so it is important that they feel comfortable in the space. A random placement of bollards in the courtyard and downlights under the breezeway create an organic pattern with pools of light. This organic pattern is continued inside in the lobby and circulation spaces with a random pattern of downlights along with a recessed slot design inspired by a network of capillaries above the workout area. The downright pattern flows into the rock wall space, where the climbing surfaces are lit by wall washers and flood luminaires. Finally the gymnasium is illuminated by high bay fluorescents, allowing for the incorporation of glazing and a daylight harvesting system.

The loads on the lighting panelboards required analysis to see if any additional panelboards would need to be added due to the redesigned lighting. The new luminaires were circuited in such a way that they are located near existing luminaires that use the same circuit to minimize wiring requirements. A generator analysis was performed to investigate if it would be worthwhile to use a single generator for the expansion and the existing building rather than a battery bank. The last electrical topic was a photovoltaic analysis. A photovoltaic array was sized for the roof of the building and determined that it would be beneficial to install.

A daylighting analysis of the gymnasium was performed with skylights, along with a mechanical analysis to determine the impact of the skylights on the mechanical loads. These studies revealed that the savings from electricity were greater than the increase in energy due to cooling loads, making the system profitable. The last topic of study was a structural study to confirm that the structure could support the weight of the solar panels.

Contents

Building Introduction

Figure 1: UCR Site Map

The University of California, Riverside Student Recreation Center is currently undergoing an expansion and renovation project in order to modernize and expand its facilities. The existing building is located on the north side of the University of California, Riverside Campus in downtown Riverside, California. The expansion will be located to the south of the existing building and the two buildings will be connected by a walkway on the second floor. The renovation will consist mostly of turning the existing exercise spaces into offices, with the expansion housing the new exercise facilities including a two story gymnasium, exercise areas, an indoor running track, multipurpose spaces, spa, and an outdoor pool located to the south of the expansion. The current tennis courts and sports fields will be rearranged to surround the new facility. The 96,000 square foot project will cost a total of about $36.9 million and will be completed in January 2014.

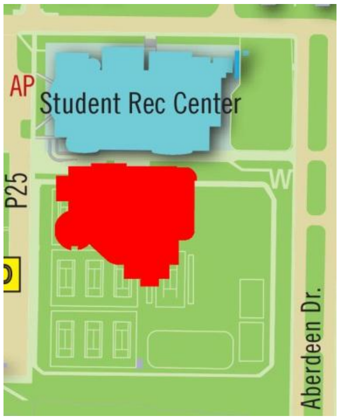


Figure 2: Site Plan

Building Information

Location: Riverside, CA

Building Occupant Name: University of California, Riverside

Occupancy or Function Types: A-3 Recreation Center

Size: 15,984 SF Renovation, 79,936 SF Addition

Stories Above Grade: Two

Dates of Construction: August 2012 to January 2014

Building Cost: $36.9 Million including construction costs

Project Delivery Method: Design-Bid-Build

Building Team

Owner: University of California, Riverside

Construction Manager: C.W. Driver

Architect: Cannon Design

Landscape Architect: Carter Romanek Landscape Arch. Inc.

Civil: Breen Engineering

Structural: Saiful Bouquet, Inc.

Mechanical/Plumbing: P2S Engineering

Electrical/Lighting: Cannon Design

Aquatic Design: Counsilman Hunsaker & Associates, Inc.

Building Systems

Architecture

The remodeling of the University of California, Riverside Recreation Center includes a 16,000 SF renovation of the existing building and an 80,000 SF expansion. The first floor of the existing building contains mostly offices, a reception area, and a multipurpose room. The second floor is connected to the expansion by a breezeway containing a fitness area and another multipurpose space. The expansion is located to the south of the existing building and has a mostly open plan on both floors containing offices, lockers, fitness rooms and a rock climbing wall. A running track on the second floor surrounds the double height exercise rooms and gymnasium. Located outside, to the south of the expansion, is a pool with both swimming lanes and a recreational portion mimicking the shape of the building. The curvilinear design of the building allows the students to look out over the pool, campus, and surrounding landscape while they exercise in the fitness rooms making up the majority of the perimeter spaces.

Major Codes

Buildings built in Riverside must comply with the codes mandated by the California Building Standards Commission. These include:

- California Building Code 2010
- California Mechanical Code 2010
- California Plumbing Code 2010
- California Electric Code 2010
- California Green Code 2010
- 2008 Building Energy Efficiency Standards

Zoning

The University of California, Riverside Campus is part of the Public Facilities Zone(PF) in Riverside, California. Zoning requirements for buildings in this zone include:

- 20 ft setbacks from all property lines
- Maximum height of 60 ft. or 4 stories, whichever is less
- Continuously maintained landscaping
- Utility substations and other similar facilities must be surrounded by screening materials

Building Facades

The new building façade incorporates elements of the existing building in order to integrate the expansion but also uses some new materials to bring a more modern feel. The brick from the existing building is used on the first floor façade. Curtain wall glazing that is similar to the glazing on the existing building is also used on the first floor, but much more extensively. Glazed aluminum curtain walls and metal wall panels are used on the upper floors, giving the building a more modern look. The brick veneer and metal wall panels are supported by metal studs and are insulated by both rigid and batt insulation. A perforated metal screen sunshade is also used on the upper floors to limit the amount of sunlight entering the building.

Roofing

The roofing system is metal roof deck topped by tapered insulation, cover board, and pvc membrane roofing for weatherproofing.

Sustainability Features

The building is designed and is to be constructed to achieve a LEED Silver rating at minimum, but a LEED Gold rating is the target. Sustainable strategies that have been implemented in the design and construction of this building include:

- Occupancy sensing
- Daylighting
- Using low power lighting fixtures

Construction

The addition and renovation to the current student recreation center will cost about 36.9 million dollars and the project was a design-bid-build project.

Electrical

The electrical system for the building is fed from the campus' electrical distribution system which distributes power at 12 kV. The 12kV feed is spliced in a manhole and feeds two outdoor, liquid filled, pad mounted transformers to the east of the building. One of these transformers provides 480/277V power to an 800A switchboard while the other provides 208/120V power to a 1,000A switchboard. The 480/277V switchboard serves all of the motors in the building and a majority of the lighting. The only lighting loads that are served by the 208/120V system are the emergency lighting loads in the elevator shafts. This allows the for more luminaires to be placed on each lighting branch circuit than if they were powered at 120V. The 208/120V switchboard serves receptacle loads for all of the space in the building, the data rooms and also provides power to two junction boxes outside intended for use by a coffee truck and a food truck. Both of the building's new switchboards have transient voltage surge suppression devices to protect the electrical system from electrical surges from the campus distribution system.

Lighting

The lighting systems consists of primarily LED, linear fluorescent and high intensity discharge sources with a few compact fluorescent sources to minimize the lighting power density of the building. The hardscape areas surrounding the building are illuminated by three foot compact fluorescent bollards and twelve foot linear fluorescent column luminaires. The area under the breezeway between the existing building and underneath the building's overhang uses LED downlights to provide the proper illuminance. Once inside, the occupant encounters similar light sources in linear fluorescent and LED. Circulation spaces such as lobbies and corridors use either two by two, parabolic, recessed linear fluorescent troffers or one by four, lensed, recessed linear fluorescent troffers. Industrial style linear fluorescent luminaires are used in back of the house spaces such as electrical rooms, storage spaces and workshop areas to reduce lighting power density while minimizing the cost of the luminaires. The workout areas are primarily lit with fluorescent as well, with the weight rooms illuminated by two by two, parabolic, linear fluorescent troffers and the track illuminated by lensed, recessed linear fluorescent troffers that follow the shape of the track. The only exception to this is in the double height workout area to the west of the gymnasium. This space is illuminated by recessed LED strips and LED cove fixtures. Metal halide luminaires are used in the gymnasium and rock wall space to provide adequate illumination. The emergency fixtures in these spaces use a halogen infrared lamp to provide illuminance in emergency mode. The building also reduces its power consumption by using under cabinet lights at desks in the lobby, rock wall space and massage rooms to reduce the required average illuminance in the whole space. The building also integrates daylight in the form of both skylights in the double height workout area and sidelight in the perimeter workout areas, lobby and rock wall space. Daylight sensors and occupancy sensors are used in the perimeter workout areas and the double height workout area to dim the luminaires in the spaces when there is sufficient daylight. This helps to further reduce the building’s dependency on electric lighting.

Mechanical

The existing mechanical system had to be updated in order to have the capacity to serve all of the existing spaces as well as all of the spaces in the addition. The supply air fans in two of the existing air handling units were replaced and variable frequency drives were added to provide increased capacity and to allow the air handling units to save energy when they do not need to be operating at full capacity. Three air handling units were added to the mechanical system to supply ventilation and cooling to the addition. One of these air handling units serves the first floor of the addition, another serves the second floor of the addition and the last air handling unit serves the gymnasium. The mechanical system makes use of variable air volume controllers to limit the amount of air to a space when it is unoccupied. This saves energy for the entire building by reducing the cooling load on the building. A few of these variable air volume controllers use carbon dioxide sensors in order to provide demand controlled ventilation to the classrooms, training rooms and conference rooms.

Structural

The building’s structural system consists of a steel frame above grade and a concrete foundation. The beams and girders for the framing for the second floor and roof are primarily I-beams with varying depths and weights. Moment connections and beam stiffener connections are used around the perimeter of the building to prevent lateral forces such as wind or an earthquake. The steel columns span from the roof down to the foundation where they are terminated on spread footings. These footings vary in size from three feet by three feet to nine feet by nine feet. Underneath these footings is a concrete pile with steel reinforcing to provide additional support. The remaining portion of the foundation is comprised of a concrete wall around the perimeter of the building. The first floor is formed by a slab on grad and the second level floor is formed by a concrete slab on metal deck. The sun screen is supported by horizontal tube supports running across the exterior of the building.

Fire Protection

The fire protection system consists of an addressable system with many different detection, notification and suppression devices. The building uses beam type smoke detectors in the gymnasium and surface mounted smoke detectors in the other required spaces. The occupants in the building are notified of a potential problem by strobes or speaker strobes depending on the space in which they are located. The sprinkler system is a dry type system so water only flows when there is a fire that needs to be suppressed.

Transportation

The vertical circulation in the building is aided by the locations of three staircases and two elevators. The three staircases are located at the southeast corner of the addition, just inside the main entrance to the addition and just inside the entrance to the renovated portion of the existing building. The elevators are located just past the lobbies for the existing building and additions that are located off of the breezeway.

Telecommunications

The telecommunication system for the building consists of single mode fiber coming into the building in room 1127 and a combination of single mode and multimode fiber distributing the service to the rest of the data rooms in the building. There are four data rooms on the first floor and one on the second floor, each with their own data rack. The telephone system uses voice over IP.

Lighting Depth

The expansion and renovation to the existing student recreation building is intended to provide a larger facility for students to exercise and interact with other students. The building has many diverse spaces with varying requirements for lighting. The four spaces selected to be redesigned were the:

- Entrance/Courtyard
- Lobby
- Rock Wall
- Gymnasium

The entrance/courtyard space and the lobby space are the two most critical spaces to the building in terms of circulation. The entrance and courtyard provides access to the main entrances to the existing building and renovation as well as the secondary entrances to each of these buildings. The lobby not only provides access to many of the building's facilities but also accommodates one of the smaller fitness areas and a portion of the running track on the floor above. The rock wall space is open to the lobby space and the gymnasium is located just beyond the east wall of the exercise space in the lobby. These areas provide places where students can learn and practice rock climbing and play other sports such as volleyball, basketball and soccer.

Entrance/Courtyard

The entrance and courtyard space provides a connection between the two buildings and is the main exterior circulation space. The main entrances to the existing building and expansion are located in this area, as well as the secondary entrances for both buildings. There are three sets of stairs and a ramp located to the west of the building that lead up to the breezeway that covers the main entrance for each building. The ramp and each set of stairs are divided by brick planters that use the same brick as the building. This is likely the direction that students will most often approach the building because the rest of campus is located in that direction. The courtyard is located on the east side of the breezeway and has benches where occupants can sit and relax on a nice day before or after exercising. The secondary entrances to both buildings are located towards the eastern end of this space. The ground throughout the space is concrete, however there are planted areas scattered throughout the courtyard, located next to the concrete benches. This area covers about 17,300 square feet of the exterior grounds. The façade surrounding this space is comprised of brick, metal panels and glazing. Exterior elevations of the expansion and a summary of the materials are given below.

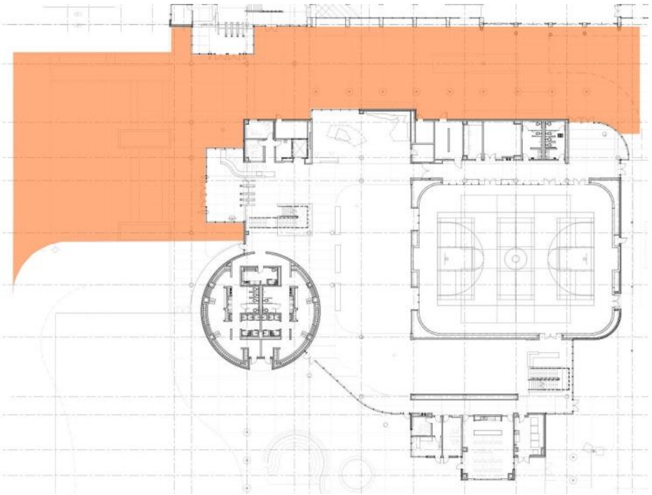


Figure 3: Entrance/Courtyard

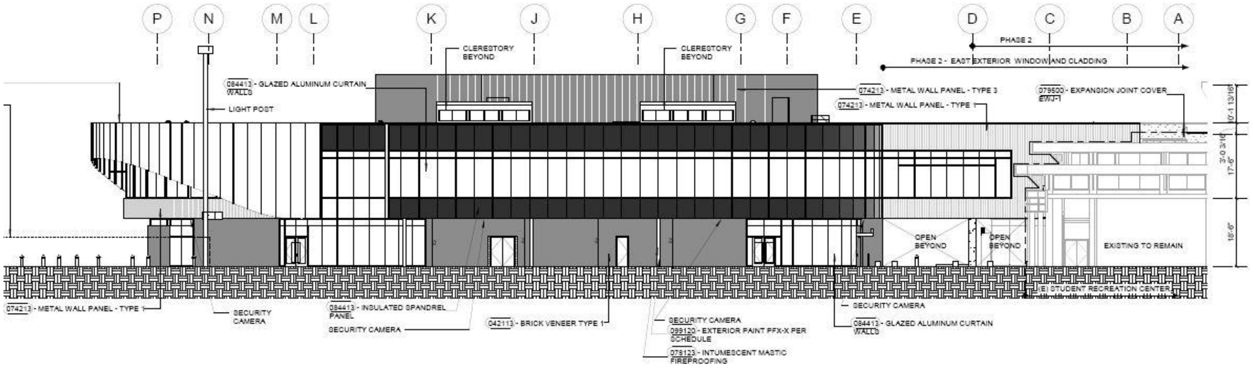


Figure 4: East Elevation

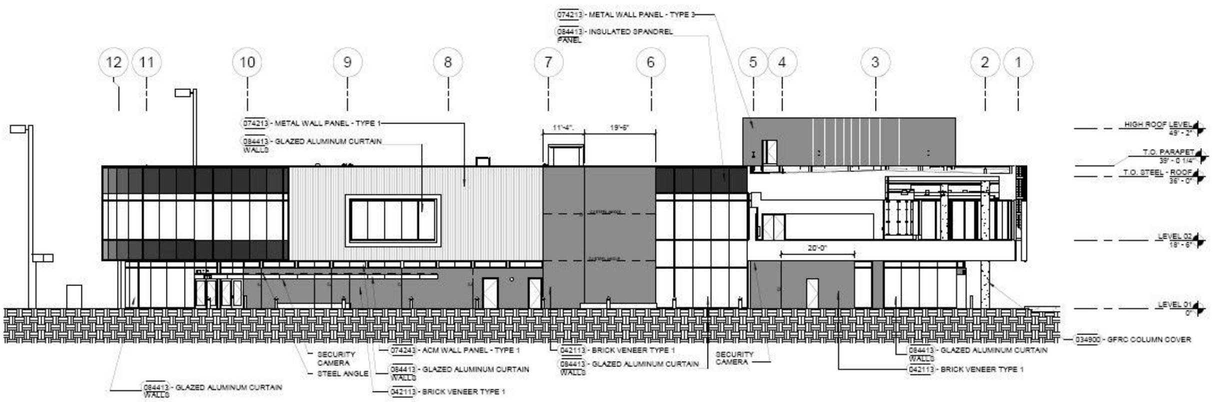


Figure 5: North Elevation

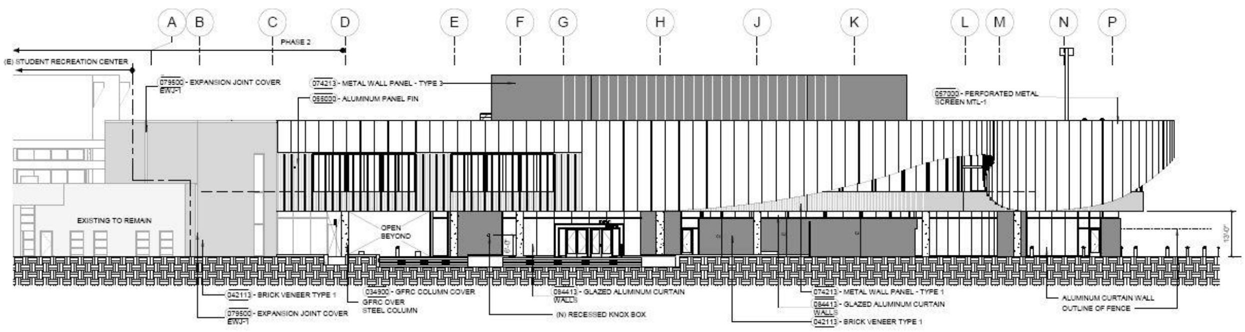


Figure 6: West Elevation

TYPE	DESCRIPTION	MANUFACTURER	COLOR	REFLECTANCE
BRICK VENEER	BLEND RUFFLED TEXTURE NORMAN FACE BRICK	PACIFIC CLAY	RED BRICK	0.30
CONCRETE	-	-	GRAY	0.30
METAL WALL PANEL	ZINC COATED STEEL SHEET	CENTRIA ARCHITECTURAL SYSTEMS	SILVER	0.60

TYPE	T_{vis}	U_{winter}	U_{summer}	SHGC	SC
PPG SOLARBAN XL70	0.658	0.28	0.26	0.28	0.32

Tasks

The main tasks that occupants are going to need to be able to accomplish are way finding and circulation. Therefore it is important that the entrances to the buildings have a higher illuminance level than the rest of the hardscape surfaces. This will allow patrons to easily find their way to the entrance of the building.

Design Criteria

Design criteria that were taken into account for this space were both quantitative and qualitative. The quantitative criteria that were taken into account were recommended illuminance levels, illuminance uniformity values and lighting power density allowances. Recommended illuminance levels and illuminance uniformity criteria were obtained from IESNA Lighting Handbook: Reference and Application (10th Edition) while the power density allowances were determined from Title 24. These criteria are summarized in the tables below.

Space	E_h (lux)	E_{avg}:E_{min}
Entrance	15	2:1
Stairs	4	5:1
Courtyard	3	5:1

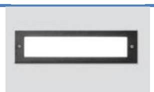
Space Type	Allowance
Area	0.092 W/SF
Linear	0.92 W/LF
Initial	770W
Building Entrance	100W/Door
Building Façade	0.35W/SF

The lighting power density for an exterior space is calculated by multiplying the area allowance by the hardscape area to be lit, multiplying the linear allowance by the perimeter of the hardscape area to be lit and adding these values to the initial wattage allowance. This wattage is tradable to specific applications. The building entrance and building façade are calculated by multiplying the allowance by the specified quantity and are not tradable.

The entrance and courtyard are the first spaces that a patron will encounter when approaching the building so it is important to make the space comfortable and inviting. This can be accomplished with appropriate illuminance levels. It is also important that the patron feel safe in the space. This can be done by ensuring that the recommended illuminance values are met for each of the areas within the space.

Equipment

The stairs and ramp to the west of the breezeway were illuminated using a step light mounted about half a foot above the ground. This light was supplemented by the compact fluorescent bollards used to illuminate the ground in front of the stairs and the downlights that were used to illuminate the entrances and area under the breezeway. Compact fluorescent bollards were also used to provide general illumination in the courtyard, while downlights illuminate the secondary entrances to the two buildings and the strip lights illuminate the canopy over the entrance to the existing building in the courtyard. A full Luminaire Schedule can be found in Appendix A and lighting plans can be found in Appendix B.

Type		Description	Lamp	Manufacturer
LX-1		Wet location 50 degree LED downright	3000K LED	USAI Lighting
LX-2		Wet location 15 degree adjustable LED Strip	3000K LED	Winona
LX-3		Wet location LED step light with white translucent tempered glass	3000K LED	Bega
CFX-1		Four foot CFL bollard with glass diffuser	PL-T 26W-830	Bega

Controls

All of the fixtures in the entrance and courtyard are controlled by a time clock to automatically turn them off during the day.

Performance

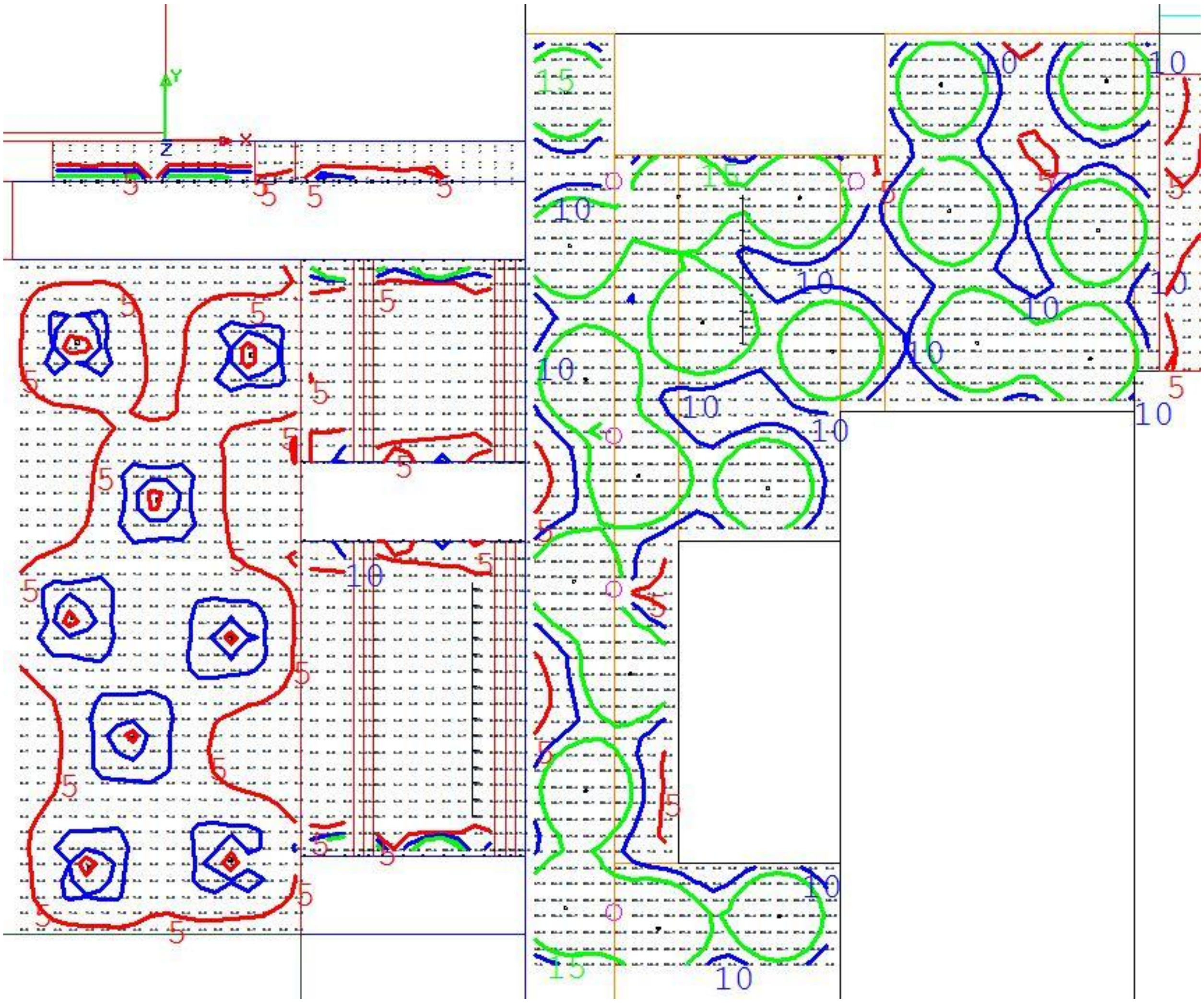


Figure 7: Stairs and Breezeway Illuminance Calculation

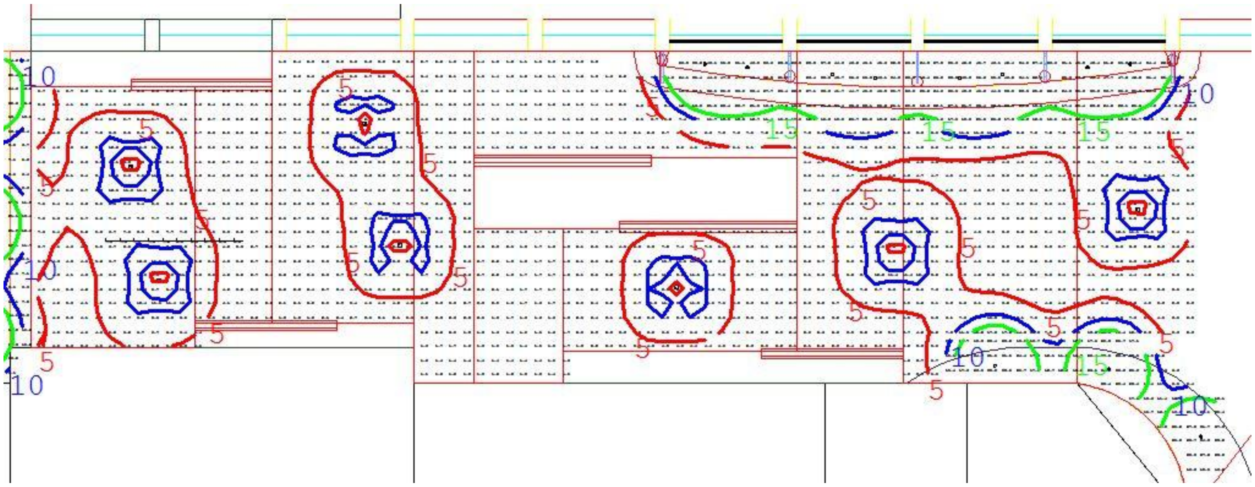


Figure 8: Courtyard Illuminance Calculation

Figure 9: Entrance Rendering

Figure 10: Courtyard Rendering

Space	E_h (lux)	E_{avg}:E_{min}
Main Entrance	16.44	4.84
Stairs	4.82	4.02
Courtyard	5.04	5.60
Existing Entrance	26.52	10.61
Secondary Entrance	19.59	2.97

Space Type	Quantity	Allowance	Allowable Watts
Area	17428	0.092 W/SF	1603
Linear	923	0.92 W/LF	849
Initial	N/A	770W	770
Building Entrance	4	100W/Door	400
Building Façade	507	0.35W/SF	178
Total	N/A	N/A	3800

Luminaire Type	Wattage	Number	Total Watts
LX-1	10	32	320
LX-2	3.2/FT	128 FT	409.6
LX-3	5	81	405
CFX-1	29	15	435
Total	N/A	N/A	1569.6

Evaluation

The exterior space provides a comfortable atmosphere for the patron to first encounter the building. The random pattern of bollards on the hard scape areas and downlights under the breezeway provide a more organic, natural feeling than if they were in a grid. The pattern of bollards encourages random movement in the courtyard while the various entrances to the building are highlighted using higher illuminance levels. The luminaires use 3000K sources in order to render the brick of the planters and the façade in a more pleasing light. The space meets lighting power density requirements according to Title 24. The wattage used to light the canopy above the entrance to the existing building is more than the allowable wattage for lighting the building façade; however the extra watts from the area and linear allowances are tradable, making the design valid. The design meets the average illuminance recommendations, however the uniformity recommendations are not met at the main entrance, courtyard or existing building entrance. This is due to the extremely low illuminance recommendations.

Lobby

The lobby provides the main circulation space for the building as well as provides a small workout area on the first floor and a running track on the second floor. When a patron first enters the building they will come to a set of turnstiles to allow the user to enter the building. On the left is an information desk and off to the right is the core of locker rooms and bathrooms. Straight ahead is the set of stairs leading to the second floor where there is additional exercise space and the running track. Beyond the stairs, on the eastern side of the space is a small exercise area. Here there is some cardio equipment as well as some weightlifting equipment for use by patrons. The floor in the lobby and circulation portions of the space is made of polished concrete while the floor of the exercise area is blue sport flooring. The walls behind the information desk are maple paneling and the locker room core is constructed of the same brick as the outside of the building, connecting the two spaces. The rest of the walls are drywall painted an eggshell color while the finished ceiling is painted white. Interior elevations and a summary of the materials are given below.

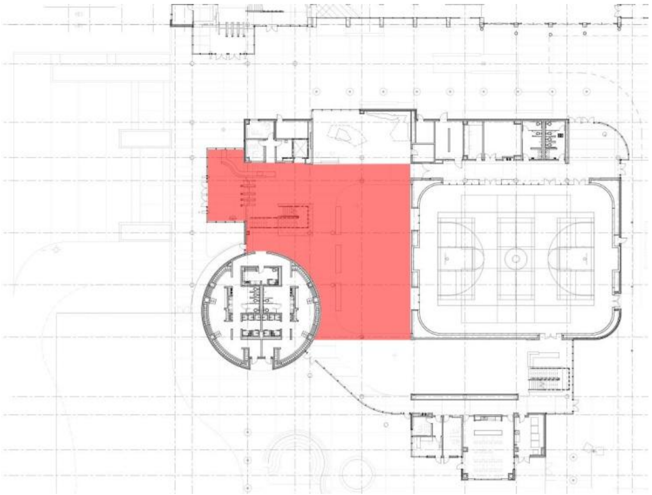


Figure 11: Lobby

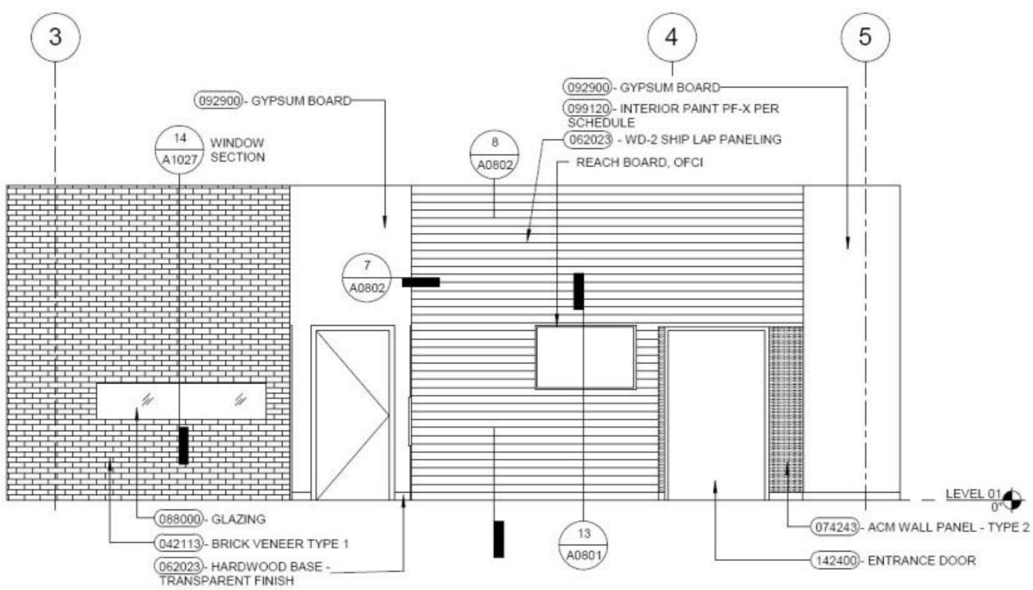


Figure 12: Control Counter North Elevation

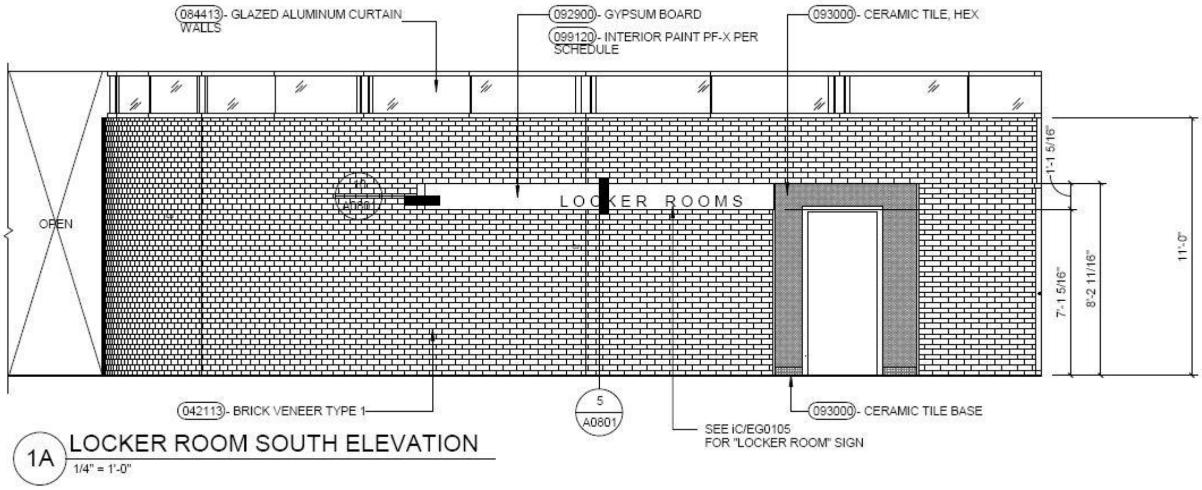


Figure 13: Locker Room South Elevation

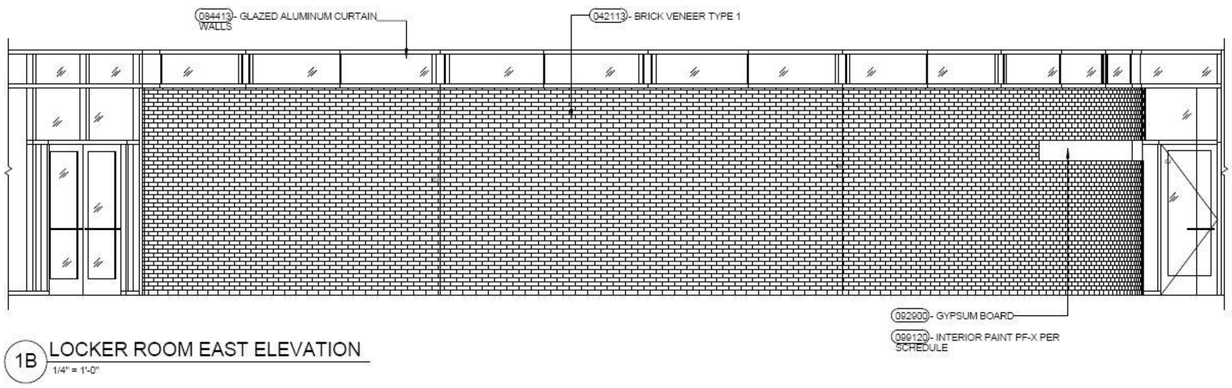


Figure 14: Locker Room East Elevation

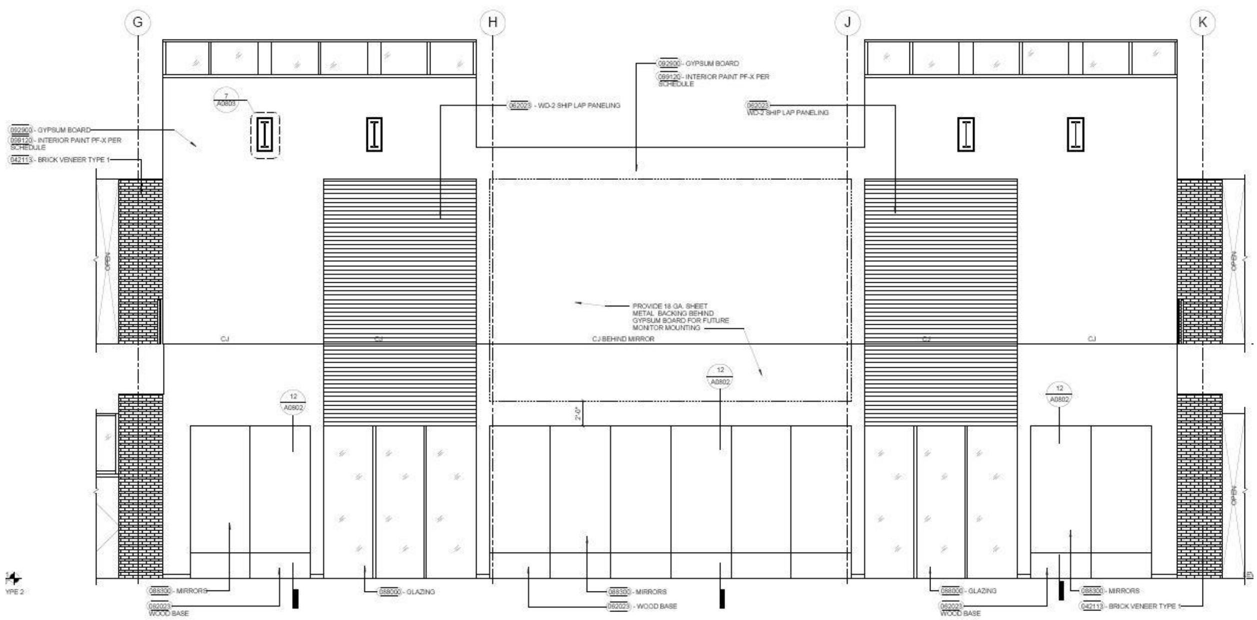


Figure 15: Exercise Space East Elevation

TYPE	DESCRIPTION	MANUFACTURER	COLOR	REFLECTANCE
BRICK VENEER	BLEND RUFFLED TEXTURE NORMAN FACE BRICK	PACIFIC CLAY	RED BRICK	0.30
POLISHED CONCRETE	GROUND, POLISHED, SEALED CONCRETE	-	NATURAL GRAY	0.30
PAINT	FLAT FINISH	DUNN EDWARDS	WHITE	0.90
PAINT	FLAT FINISH	DUNN EDWARDS	EGGSHELL	0.70
WOOD PANELING	MAPLE SHIP LAP PANELING	-	MAPLE	0.30
SPORT FLOOR	NEPTUNE COLORED SPORT FLOORING	ECORE ECOSURFACES	BLUE	0.40

TYPE	T_{vis}	U_{winter}	U_{summer}	SHGC	SC
PPG SOLARBAN XL70	0.658	0.28	0.26	0.28	0.32
FLAT GLASS	0.80	-	-	-	-

Tasks

The tasks that patrons will be performing in this space vary depending on which portion of the space that they are in. In the lobby and circulation areas the main activity will be way finding. This can be aided by highlighting different elements throughout the space. The other main activity will be exercising in the fitness area. For this task it is important to provide proper illuminance so patrons are less likely to injure themselves.

Design Criteria

Design criteria that were taken into account for this space were both quantitative and qualitative. The quantitative criteria that were taken into account were recommended illuminance levels, illuminance uniformity values and lighting power density allowances. Recommended illuminance levels and illuminance uniformity criteria were obtained from IESNA Lighting Handbook: Reference and Application (10th Edition) while the power density allowances were determined from Title 24. These criteria are summarized in the tables below.

Space	E_h (lux)	$E_{avg}:E_{min}$
Lobby	50	3:1
Transition	45	2:1
Exercise Area	150	3:1

Space Type	Allowance
Lobby	1.5 W/SF
Circulation	0.6 W/SF
Exercise	1.0 W/SF

The lobby is the first interior space that most patrons will enter in the expansion. This is a very wide open space so it is important to make the space feel very public. Many different activities will be going on in this space and patrons should feel like they are in a space with many people around. This can be accomplished by illuminating the walls and by making the space uniformly illuminated.

Equipment

The lobby space and the circulation on both the first and second floors were illuminated using LED downlights. LED downright wall washers were used to highlight the wall behind the circulation counter and the locker room core wall. The general lighting for the circulation areas was supplemented by spill light from the exercise area. The exercise area was illuminated by curved linear fluorescent slots. This light also spilled onto the track on the second floor. Downlights were used to obtain the desired illuminance on the track in combination with the fluorescent light. Lastly, a semi-recessed linear fluorescent wall washer was used to illuminate the east wall of the exercise space. A full Luminaire Schedule can be found in Appendix A and lighting plans can be found in Appendix B.

Type		Description	Lamp	Manufacturer
LD-1		LED downright	4000K LED	Kurt Versen
LD-2		LED wall wash downright	4000K LED	Kurt Versen
FR-1		Curved recessed fluorescent slot with lens	F215-841	Winona
FR-2		Semi-recessed linear fluorescent wall washer	F54T5-841	Winona

Controls

The downlights in the lobby and the fluorescent slots above the exercise area are controlled by a photosensor because they are in daylighting zones. All of the luminaires in the space are controlled by multiple occupancy sensors to automatically shut off the lamps if they are not manually shut off when not needed. Scene controllers are used to provide the users with manual control.

Performance

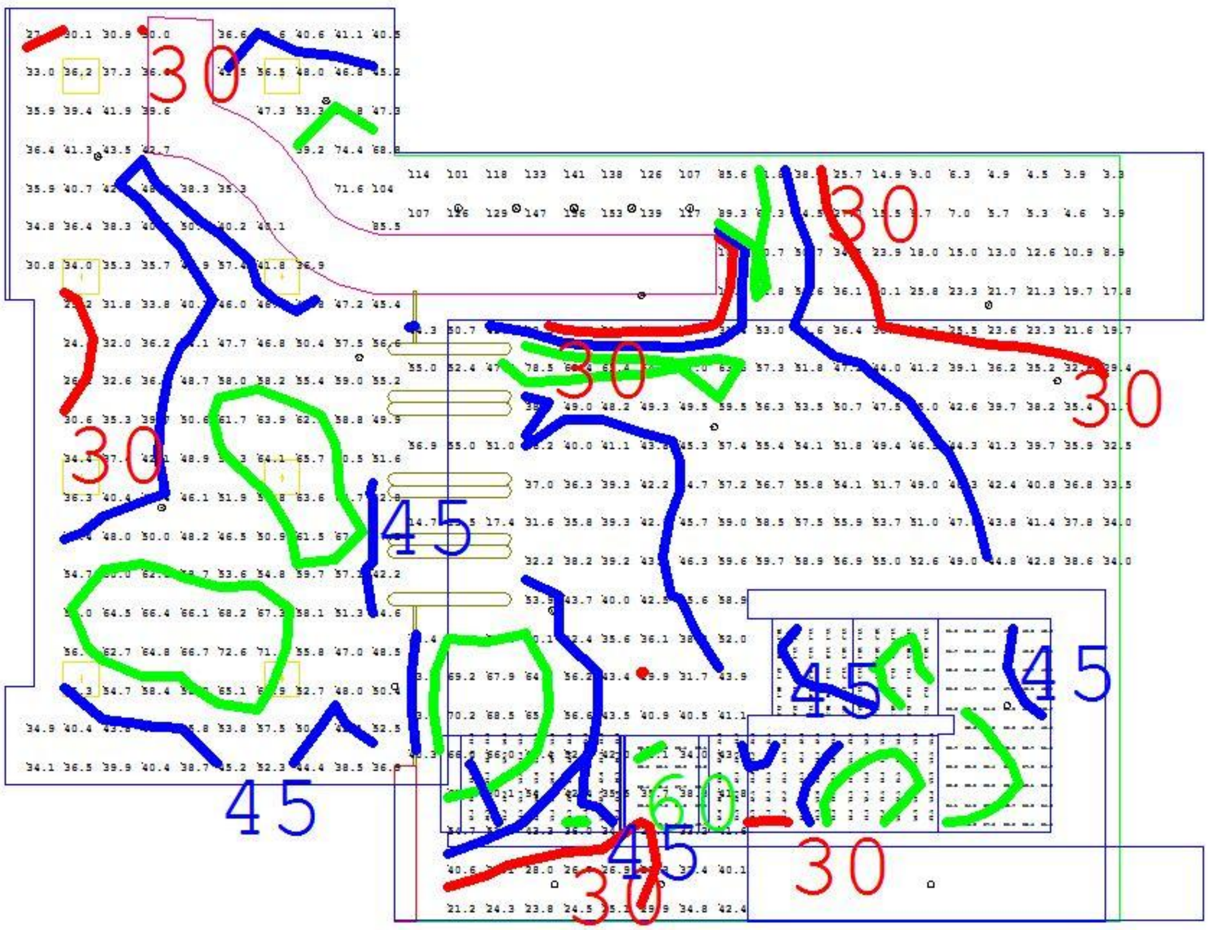


Figure 16: Lobby Illuminance Calculation

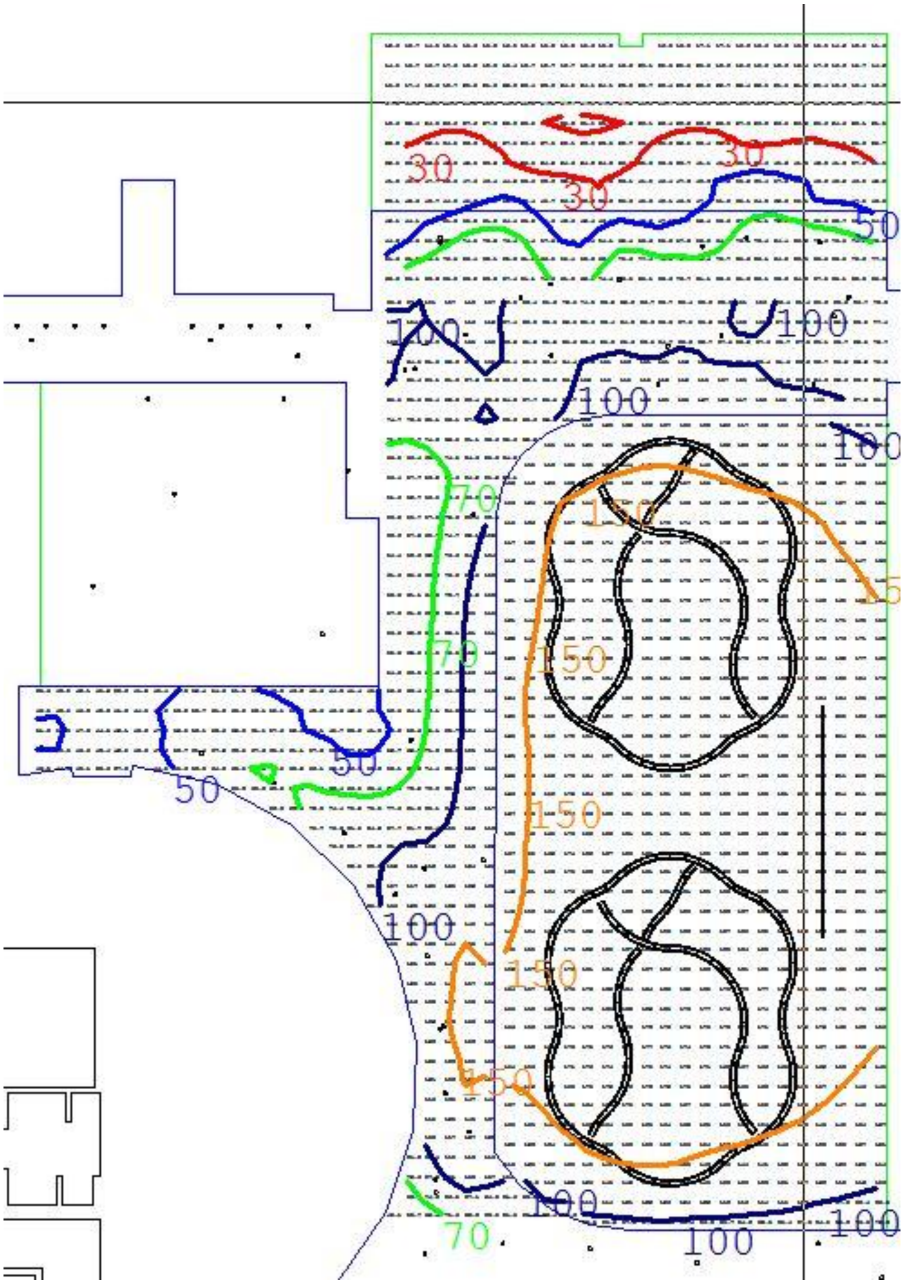


Figure 17: First Floor Illuminance Calculation

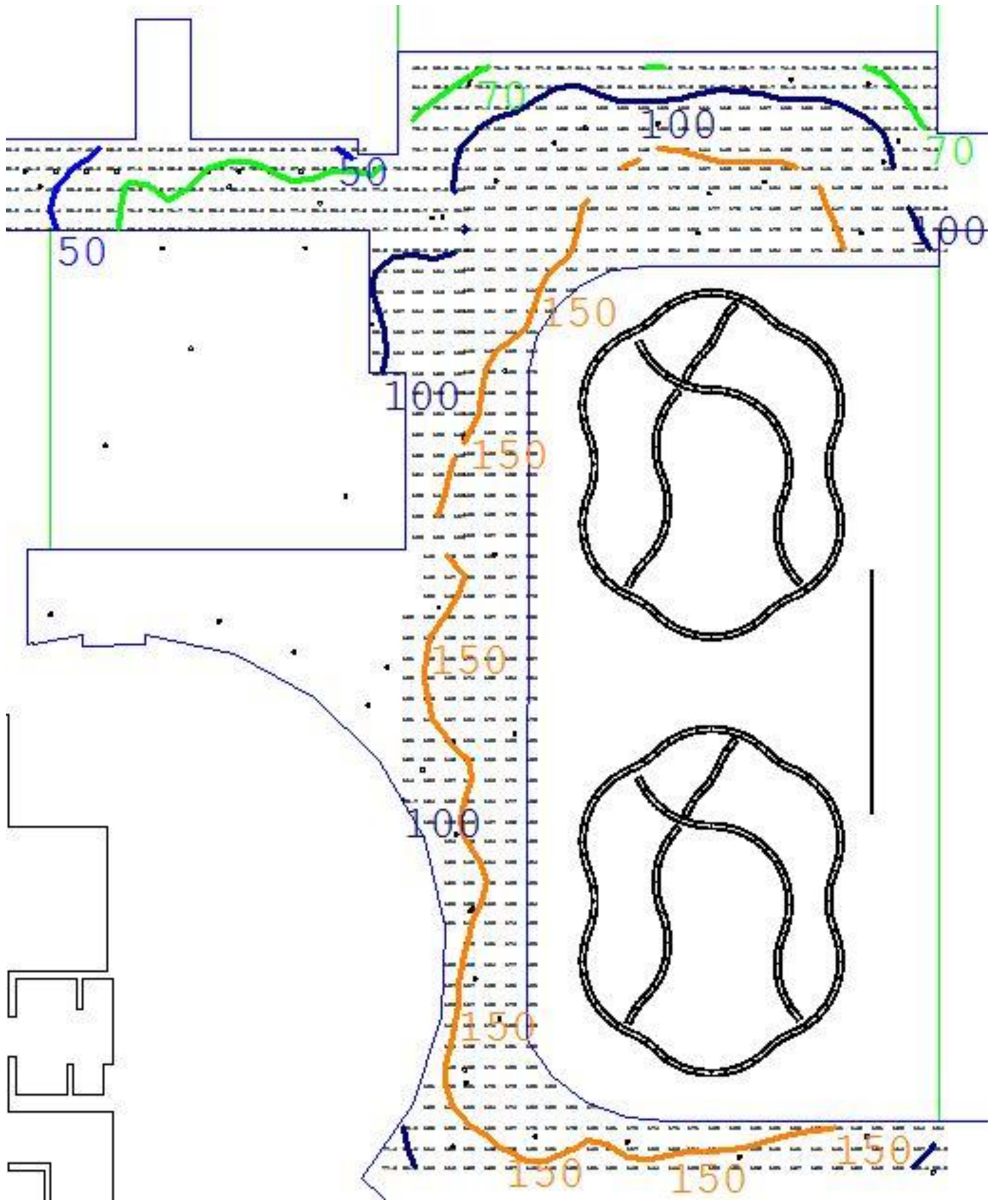


Figure 18: Second Floor Illuminance Calculation

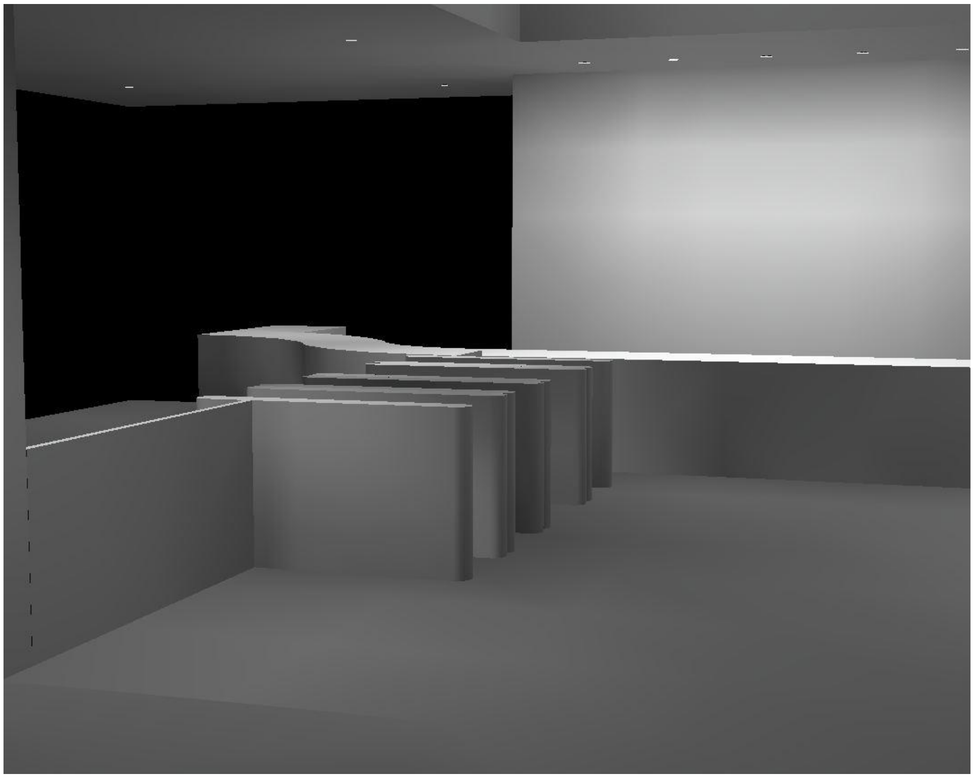


Figure 19: Lobby Rendering

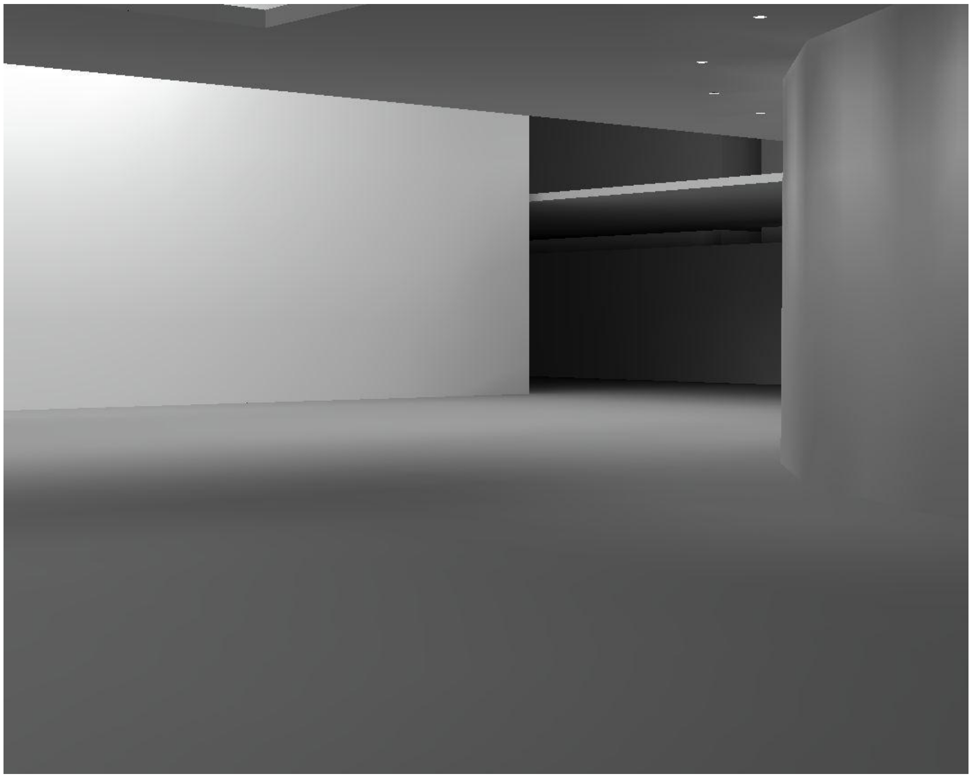


Figure 20: First Floor Rendering

Space	E_h (lux)	$E_{avg}:E_{min}$
Lobby	46.06	1.98
1st Floor Circulation	88.69	2.49
Stairs	52.10	1.85
Exercise Area	164.09	2.25
2nd Floor Circulation	93.80	3.06
Running Track	152.76	3.06

Space Type	Quantity	Allowance	Allowable Watts
Lobby	763	1.5 W/SF	1144.5
Circulation	4388	0.6 W/SF	2632.8
Exercise Area	5459	1.0 W/SF	5459
Total	N/A	N/A	9236.3

Luminaire Type	Wattage	Number	Total Watts
LD-1	28	49	1372
LD-2	28	19	532
FR-1	23	106	2438
FR-2	60	6	360
Total	N/A	N/A	4702

Evaluation

The lobby space continues the organic pattern of luminaires that was established outside under the breezeway and in the courtyard, using a random pattern of downlights in the lobby. This serves to connect the two adjacent spaces as well as continue the theme of organic patterns throughout the spaces. This theme continues throughout the circulation portions of the space and over the running track on the second floor. On the first floor wall washing downlights were used behind the information desk, on the wall to the east of the information desk and the locker room wall. In addition, a linear fluorescent wall washer was used on the east wall of the workout area. These wall washers highlight walls of destinations in the open space, helping to guide patrons through the space as well as create a more public impression. The main lighting for the workout area is provided by a curved linear fluorescent slot fixture. The luminaires were arranged in an organic pattern with inspiration from a network of capillaries. This draws on the organic design of the lighting while also connecting to a physical aspect of the human body. The design meets all of the illuminance criteria for the each space type and meets lighting power density requirements. However the uniformity criteria for the circulation spaces are not met. This is because the spaces are right next to areas with drastically different illuminance requirements without a partition between them, also causing the over-illumination of the circulation spaces.

Rock Wall

The rock wall space is located to the north of the lobby space. It is open to the circulation portion of the lobby area and provides occupants a place to learn how to rock climb. As rock climbing is a potentially activity which will require high illuminances to ensure safety. There is a boulder in the center of the space and climbing walls on the north and east walls of the space. The lower portion of the northwest corner is glazing while the rest of the wall space is finished dry wall. The double height space is also open to circulation space on the second floor of the lobby, with a railing with glass panels instead of balusters preventing occupants on the second floor from falling.

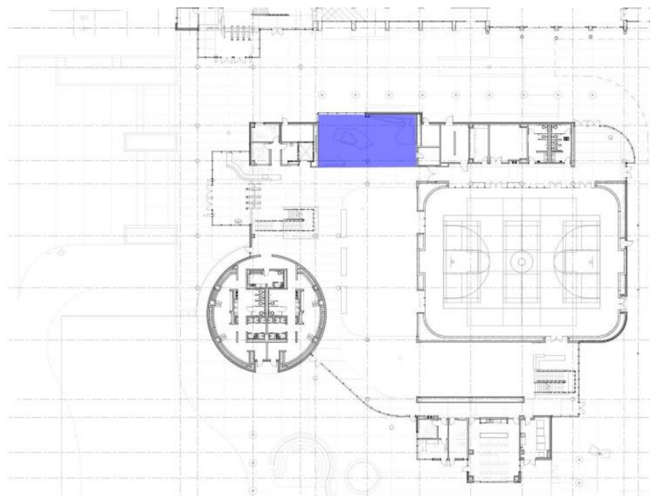


Figure 21: Rock Wall

The flooring used in this space is blue-gray sport flooring. Interior elevations and a summary of the materials are given below.

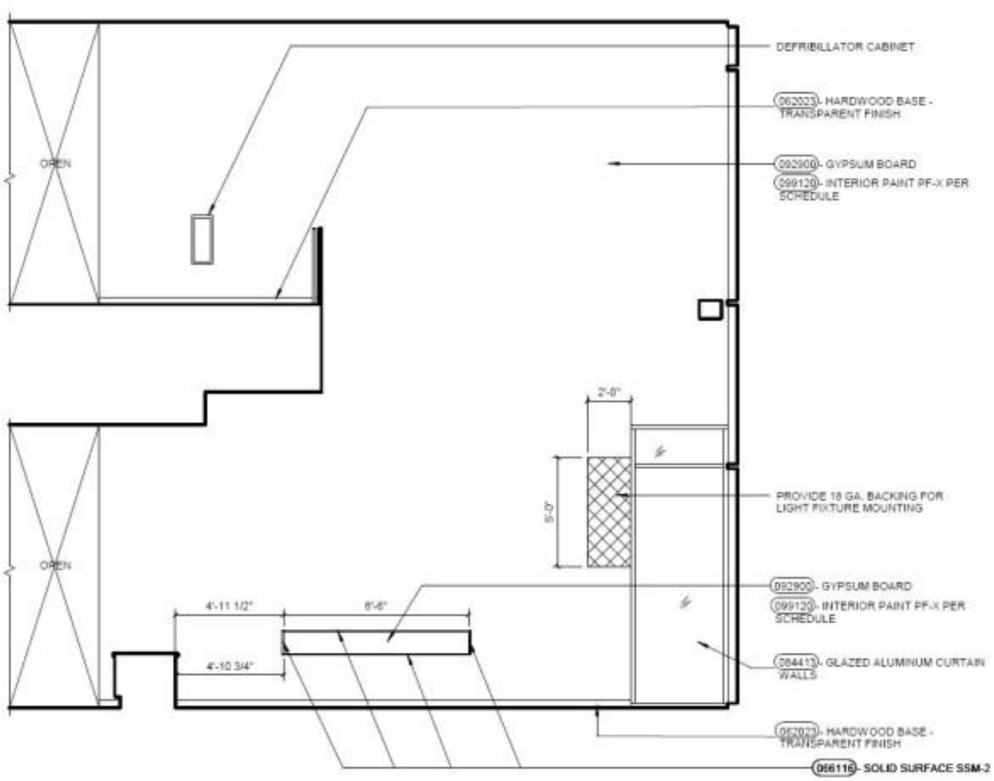


Figure 22: Rock Wall Area West Elevation

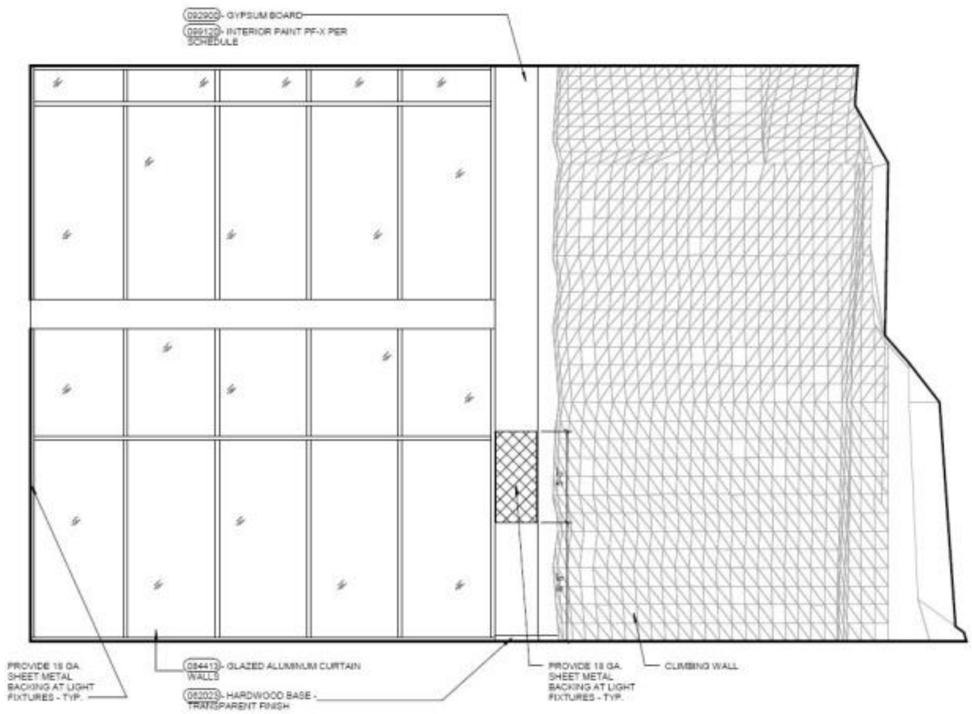


Figure 23: Rock Wall Area North Elevation

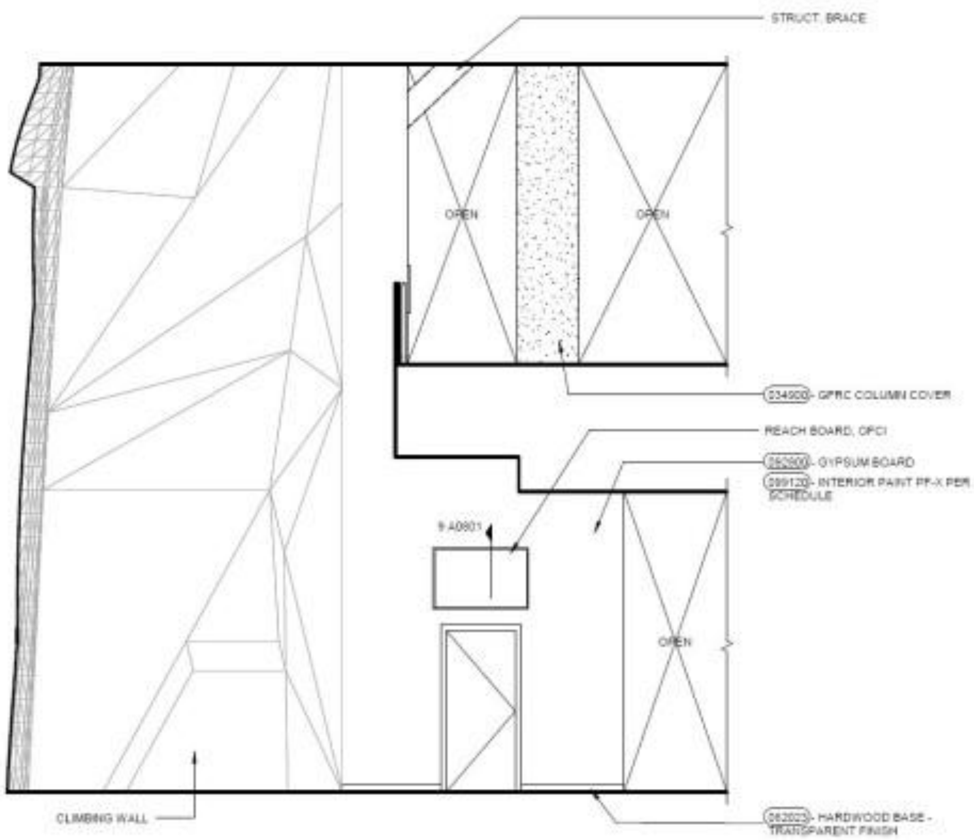


Figure 24: Rock Wall Area East Elevation

TYPE	DESCRIPTION	MANUFACTURER	COLOR	REFLECTANCE
METAL CEILING	METAL CEILING	HUNTER DOUGLAS	METALLIC SILVER	0.60
PAINT	FLAT FINISH	DUNN EDWARDS	EGGSHELL	0.70
SPORT FLOOR	SPECTRAPOUR	SPECTRATURF	BLUE-GRAY	0.25
CLIMBING WALL	CLIMBING WALL	ENTRE PRISES USA	SLECTED BY ARCHITECT	0.50

TYPE	T_{vis}	U_{winter}	U_{summer}	SHGC	SC
PPG SOLARBAN XL70	0.658	0.28	0.26	0.28	0.32

Tasks

The main task that will be performed in this space is rock climbing. Rock climbing is a potentially dangerous activity but this danger can be reduced by providing high illuminance levels to make it easier for occupants to see what they are doing.

Design Criteria

Design criteria that were taken into account for this space were both quantitative and qualitative. The quantitative criteria that were taken into account were recommended illuminance levels, illuminance uniformity values and lighting power density allowances. Recommended illuminance levels and illuminance uniformity criteria were obtained from IESNA Lighting Handbook: Reference and Application (10th Edition) while the power density allowances were determined from Title 24. These criteria are summarized in the tables below.

Space	E_h (lux)	E_v (lux)	$E_{avg}:E_{min}$
Rock Climbing	375	500	3:1

Space Type	Allowance
Exercise Area	1.0 W/SF

Equipment

The general lighting for this space is provided by high bay linear fluorescent fixtures. This provides illumination on the floor and some illumination on the climbing surfaces. Linear fluorescent wall washers and LED flood lights were used to illuminate the climbing surfaces to a level that ensures the safety of the climbers. A full Luminaire Schedule can be found in Appendix A and lighting plans can be found in Appendix B.

Type		Description	Lamp	Manufacturer
FP-1		High bay suspended fluorescent troffer with wire guard	(6) F32T8-841	Philips Day-Brite
LF-1		Surface mounted LED Flood Luminaire	4000K LED	Bega

FS-1		Surface mounted linear fluorescent wall washer	(2) F32T8-841	Engineered Lighting Products
FR-3		Recessed linear fluorescent wall washer	(2) F32T8-841	Engineered Lighting Products

Controls

All of the fixtures in this space are controlled by an occupancy sensor to turn off the lights when there is no one in the space. A scene controller near the rock climbing desk provides manual control for all of the luminaires.

Performance

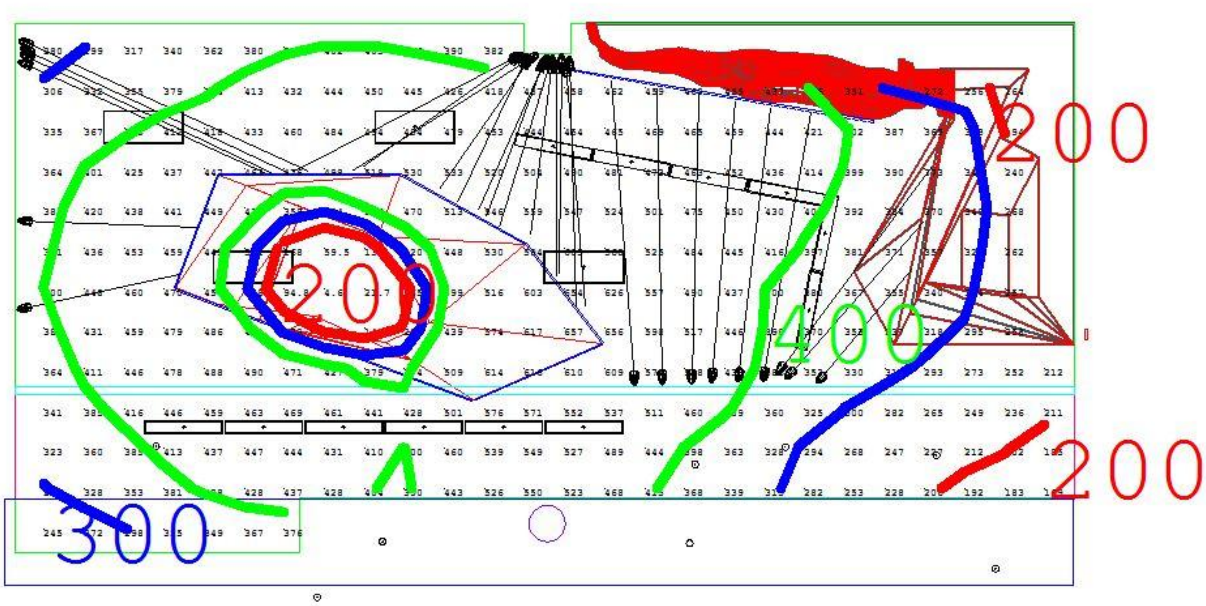


Figure 25: Rock Wall Illuminance Calculation

Figure 26: Rock Wall Rendering

Space	E_h (lux)	E_v (lux)	E_{avg}:E_{min}
Rock wall	400.74	436.93	87.12

Space Type	Quantity	Allowance	Allowable Watts
Exercise Area	1502	1.0 W/SF	1502
Total	N/A	N/A	1502

Luminaire Type	Wattage	Number	Total Watts
FP-1	186	4	744
LF-1	31	28	868
FS-1	58	6	348
FR-3	58	6	348
Total	N/A	N/A	2308

Evaluation

The general lighting for the space is provided by high bay, suspended linear fluorescent fixtures. In this space it is important to illuminate the climbing surfaces adequately. Therefore a vertical illuminance of 500 lux was chosen due to the fast reaction time that may be needed while climbing. This value is normally used for horizontal illuminance levels but was chosen for the vertical surfaces in this space because they are the primary surfaces in the space, not the floor. A horizontal illuminance level of 375 lux was chosen for the horizontal illuminance level for most sports applications. This does not need to be as high as the climbing surfaces because it is a secondary surface. The vertical illuminance on the rock wall was provided by ceiling mounted wall washers and wall mounted LED flood lights. The design does not meet lighting power density requirements but allowable watts not used in the other 3 spaces can be traded to this space in order to meet code.

Gymnasium

The gymnasium provides a space where students can play a variety of sports such as basketball, volleyball and soccer. It is located behind the east wall of the lobby space. Its walls are a combination of concrete masonry units, acoustic paneling and glass. The ceiling is comprised of exposed acoustical metal decking and is supported by a system of trusses. The floor is wood athletic flooring. Interior elevations and a summary of the materials are given below.

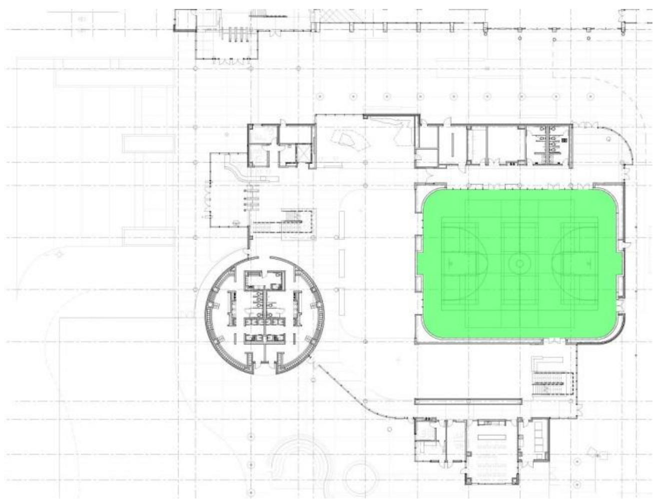


Figure 27: Gymnasium

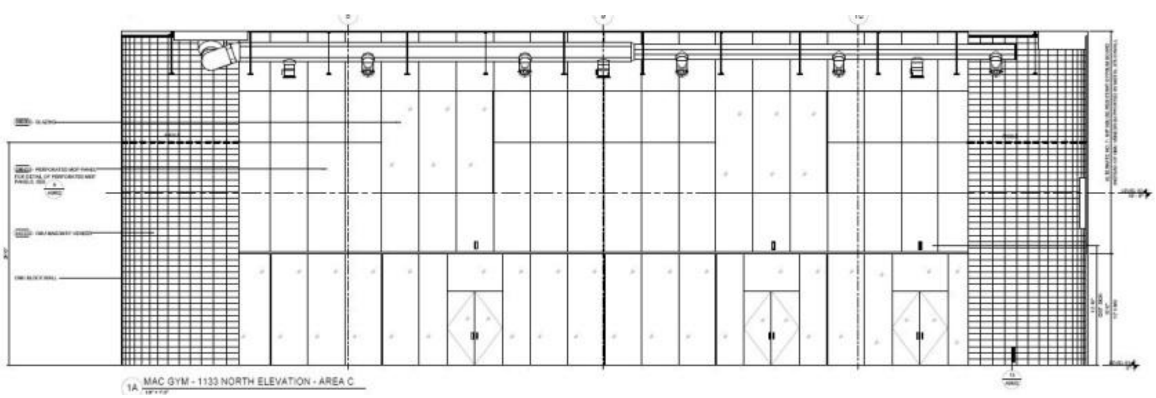


Figure 28: Gymnasium North Elevation

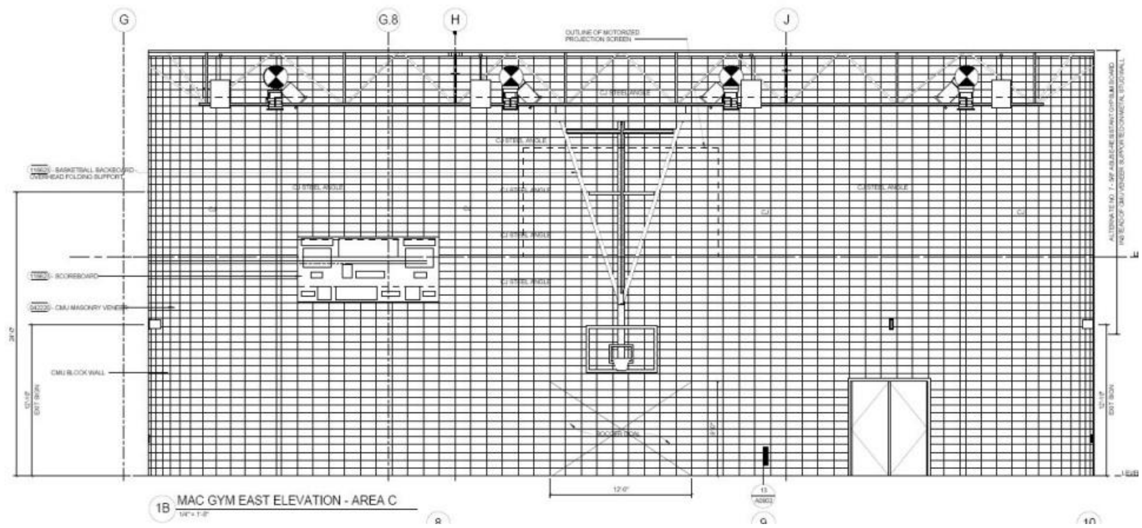


Figure 29: Gymnasium East Elevation

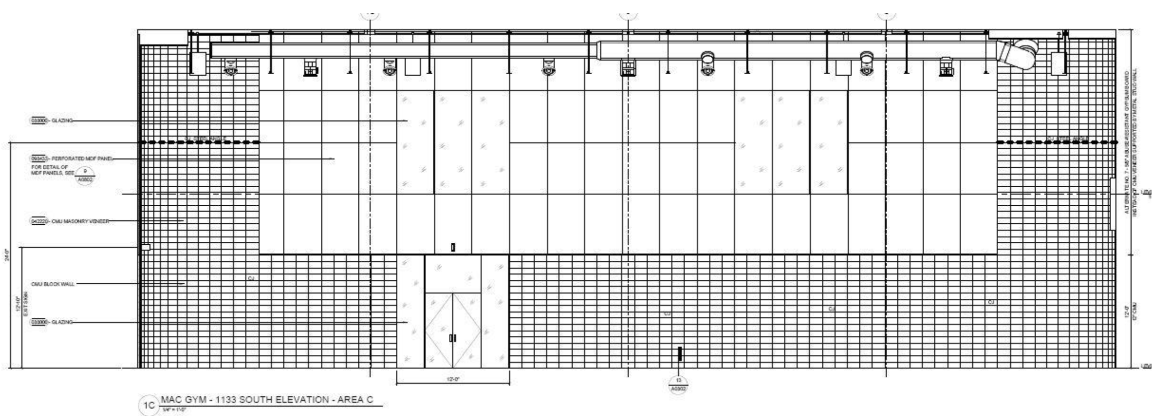


Figure 30: Gymnasium South Elevation

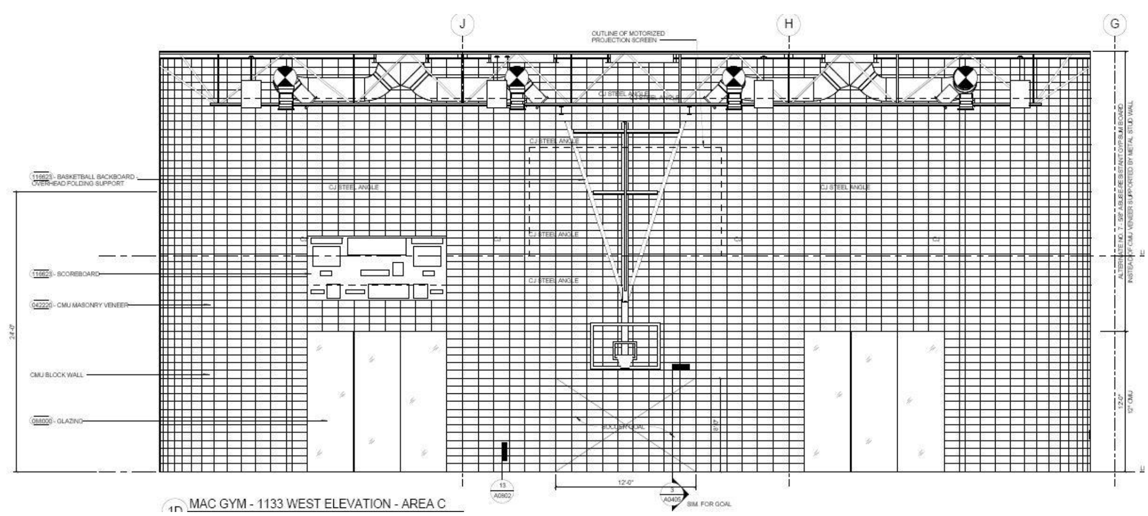


Figure 31: Gymnasium West Elevation

TYPE	DESCRIPTION	MANUFACTURER	COLOR	REFLECTANCE
ACOUSTIC WALL PANEL	PERFORATED INTEGRAL COLOR MDF PANELS	INTERLAM	BROWN	0.10
CONCRETE MASONRY UNIT	WHITE CONCRETE MASONRY UNIT	ANGELUS	GLACIER WHITE	0.65
PAINT	FLAT FINISH	DUNN EDWARDS	WHITE	0.90
FLOORING	WOOD ATHLETIC FLOORING	CONNOR	MAPLE	0.30

TYPE	T_{vis}	U_{winter}	U_{summer}	SHGC	SC
FLAT GLASS	0.80	-	-	-	-

Tasks

The main task that will be performed in this space is playing sports. The primary sports that will be played in the gymnasium are basketball, volleyball and soccer. In order to allow for the occupants to perform these tasks well it is important to provide the recommended illuminance level.

Design Criteria

Design criteria that were taken into account for this space were both quantitative and qualitative. The quantitative criteria that were taken into account were recommended illuminance levels, illuminance uniformity values and lighting power density allowances. Recommended illuminance levels and illuminance uniformity criteria were obtained from IESNA Lighting Handbook: Reference and Application (10th Edition) while the power density allowances were determined from Title 24. These criteria are summarized in the tables below.

Space	E_h (lux)	E_{avg}:E_{min}
Gymnasium	500	4:1

Space Type	Allowance
Exercise Area	1.0 W/SF

Equipment

The gymnasium is illuminated using suspended, high bay, linear fluorescent troffers. This allows for the luminaires to be dimmed in the daylighting analysis that was performed on the space. A full Luminaire Schedule can be found in Appendix A and lighting plans can be found in Appendix B.

Type		Description	Lamp	Manufacturer
FP-1		High bay suspended fluorescent troffer with wire guard	(6) F32T8-841	Philips Day-Brite

Controls

All of the luminaires in the gymnasium are controlled by a single daylight sensor to control their dimming level. The luminaires are also controlled by an occupancy sensor to ensure the luminaires are not on when the space is not being used.

Performance

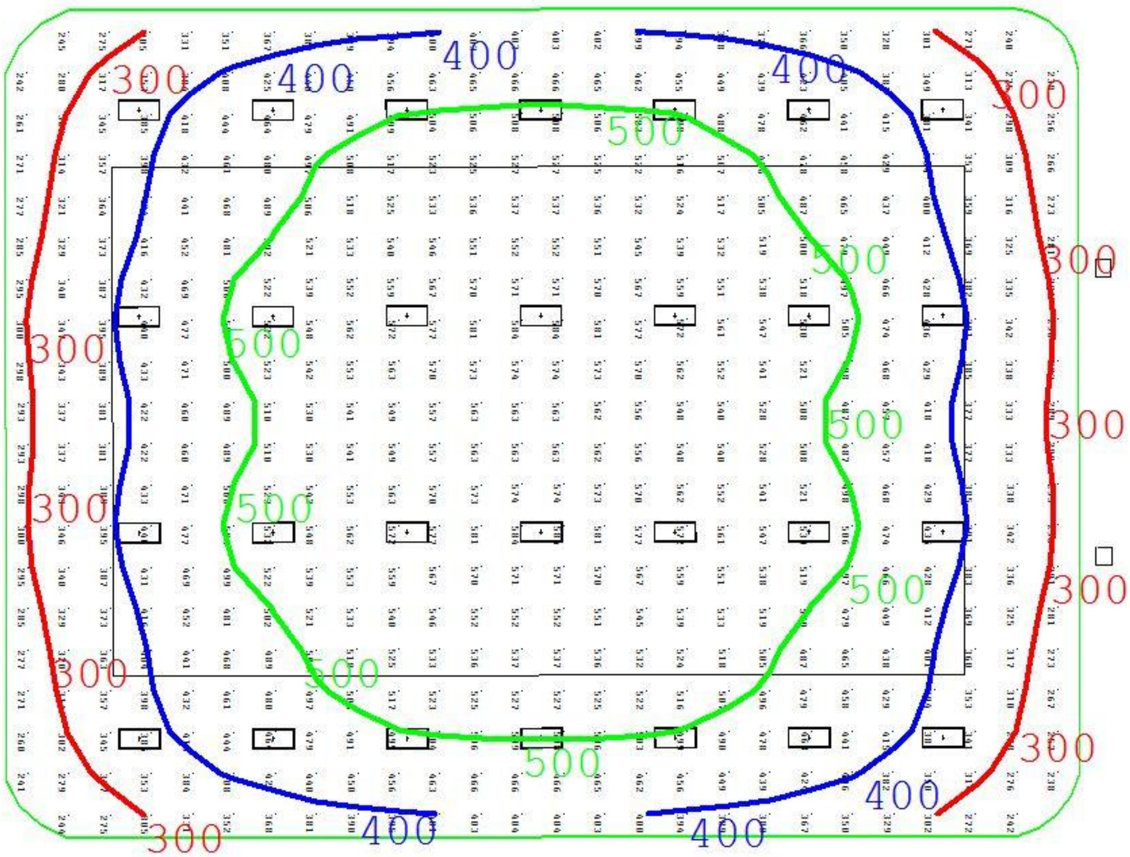


Figure 32: Gymnasium Illuminance Calculation

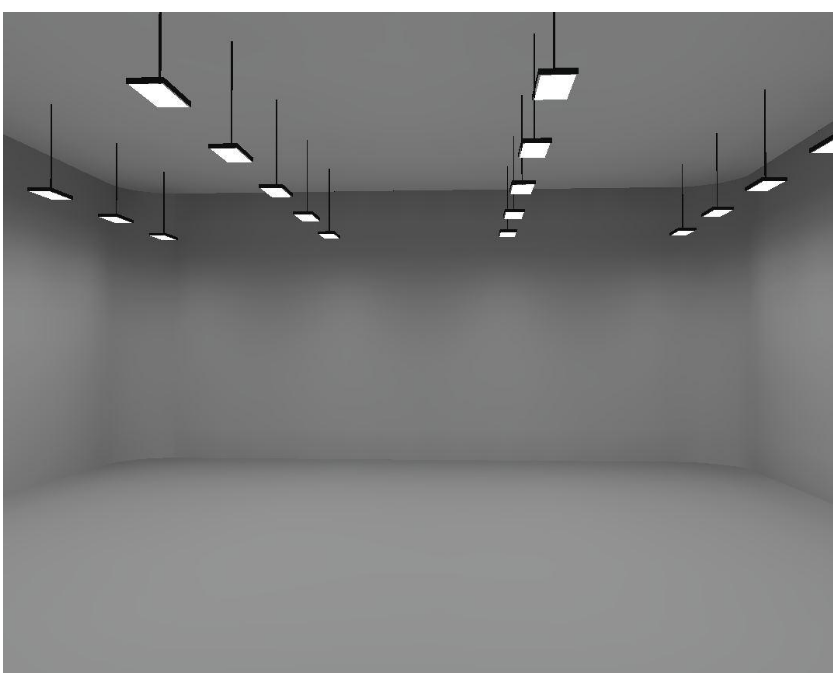


Figure 33: Gymnasium Rendering

Space	E_h (lux)	E_{avg}:E_{min}
Gymnasium	449.03	1.89

Space Type	Quantity	Allowance	Allowable Watts
Exercise Area	8230	1.0 W/SF	8230
Total	N/A	N/A	8230

Luminaire Type	Wattage	Number	Total Watts
FP-1	186	28	5208
Total	N/A	N/A	5208

Evaluation

The lighting for the gymnasium space is provided by the same high bay fluorescent luminaires used for general lighting in the rock wall space. The illuminance value of 500 lux was chosen based on the three sports that were known to be played in this space: basketball, volleyball and soccer. The most stringent values for illuminance and uniformity were used. This space meets the illuminance, uniformity and lighting power density based on the fact that illuminance level differences within 10% of each other are not noticeable.

Electrical Depth

In order to study the building's electrical distribution system, three topics were selected for analysis. The first was an analysis of the building's branch circuiting system. The existing panelboards in the building required analysis to determine whether or not they could handle the loads for the new lighting equipment. The luminaires also required circuiting to provide adequate power to each fixture. The second topic of study was the addition of a generator to provide emergency power to the building. The current system uses a bank of batteries to provide emergency power. Lastly a photovoltaic analysis was performed to study if installing a photovoltaic array would provide benefits to energy savings.

Branch Circuit Analysis

The lighting design for each of the four spaces was different than the original design and therefore the electrical loads on each of the panelboards needed to be recalculated. The lighting loads for each of the spaces are distributed between four lighting panelboards. The lighting on the first floor is split between panelboards 1LNH1 and 1LNL1, based on voltage. The lighting loads that utilize the 277V distribution system are fed from panel 1LNH1 while the 120V lighting loads are fed from panel 1LNL1. The lighting for the second floor is fed from panel 2LNH1. This is a 277V panel and all of the lighting loads on the second floor operate at 277V. All of the emergency lighting for each of the four spaces is provided power from panel 2LEH1. All of the emergency lighting utilizes the 277V distribution system.

Once it was determined which lighting panels served which luminaires, the lighting load on each circuit of the panelboard needed to be determined so it could be subtracted to the panelboard and the new lighting loads could be placed on the panelboard. The lighting loads on the existing and new panelboards are summarized in the tables below. All of the new lighting loads utilize the 277V distribution system, therefore there are no loads added onto panel 1LNL1. Full panelboard schedules for both existing panels and new panels can be found in Appendix C.

Luminaire Type	Wattage	Number	Total Watts	Circuit
FC1	30	3	90	1
FR1	30	9	270	1
FR1D	35	9	315	1
FT3	52	8	416	1
FT3D	57	3	171	5
LD1	39	9	351	7
LD1D	39	5	195	1
LF1	27	9	243	7
LF2	27	8	216	7
LL4	4.5	14	63	1
LX1	39	16	624	7

Existing Panel 1LNH1 Loads

Luminaire Type	Wattage	Number	Total Watts	Circuit
LU1	7	12	84	1
LU1	7	9	63	23

Existing Panel 1LNL1 Loads

Luminaire Type	Wattage	Number	Total Watts	Circuit
HP1	341	10	3410	17
FR3	30	22	660	11
FR3	30	22	660	19
FT3	52	13	676	7
FT3D	57	4	228	9
FT3D	57	3	171	13
LC1	12	420	5040	15
LL2	15.25	192	2928	13
LL3	15.25	29	442.25	13

Existing Panel 2LNH1 Loads

Luminaire Type	Wattage	Number	Total Watts	Circuit
HP1E	341	4	1364	4
HP1E	341	10	3410	8
FR1E	30	5	150	12
FR1DE	35	3	105	12
FR3E	30	15	450	6
FT3E	52	9	468	2
FT3E	52	3	156	12
FT3DE	57	1	57	12
FT3DE	57	3	171	2
FX1	110	9	990	3
FX1	110	4	440	1
LX1E	39	13	507	20
LX2	203	1	203	1
LX3	7.5	49	3367.5	1

Existing Panel 2LEH1 Loads

Luminaire Type	Wattage	Number	Total Watts	Circuit
FR-3	58	6	348	7
LD-1	27.1	6	162.6	1
LD-1	27.1	3	81.3	7
LD-2	27.9	18	502.2	1
LF-1	31	28	868	7

New Panel 1LNH1 Loads

Luminaire Type	Wattage	Number	Total Watts	Circuit
FP-1	186	14	2604	17
FR-1	23	78	1794	15
FR-2	60	6	360	19
FS-1	58	6	348	11
LD-1	27.1	10	271	7
LD-1	27.1	4	108.4	9
LD-1	27.1	5	135.5	13

New Panel 2LNH1 Loads

Luminaire Type	Wattage	Number	Total Watts	Circuit
CFX-1	29	8	232	1
CFX-1	29	7	203	3
FP-1	186	4	744	4
FP-1	186	14	2604	8
FR-1	23	28	644	6
LD-1	27.1	15	406.5	2
LD-1	27.1	8	216.8	12
LX-1	10	11	110	3
LX-1	10	12	120	20
LX-2	12.8	16	204.8	3
LX-3	4.6	81	372.6	1

New Panel 2LEH1 Loads

The new lighting loads were placed on circuits that included luminaires in adjacent spaces. This reduces the amount of wiring necessary because the wiring does not have to run to multiple different parts of the building. Complete lighting plans with the circuit numbers for the luminaires can be found in Appendix B. After all of the luminaires had been circuited, the loads were adjusted on the panelboards by multiplying both the existing and new lighting loads by the 1.25 continuous lighting factor and then subtracting the existing loads from the new loads. This calculation showed that all of the circuits except for one, circuit 6 on panel 2LEH1, had a reduced lighting load. This allowed for very minor adjustments for the sizing of conductors and breakers. A summary of differences in loads for each circuit can be found in the table below.

Panel	Circuit	Load Difference (Watts)
1LNH1	1	-862
1LNH1	5	-214
1LNH1	7	-58
1LNL1	1	-84
1LNL1	23	-63
2LNH1	7	-506
2LNH1	9	-150
2LNH1	11	-390
2LNH1	13	-4257

2LNH1	15	-4058
2LNH1	17	-1008
2LNH1	19	-375
2LEH1	1	-507
2LEH1	2	-291
2LEH1	3	-590
2LEH1	4	-775
2LEH1	6	243
2LEH1	8	-1008
2LEH1	12	-314
2LEH1	20	-484

The final redesign that had to be made was to resize the conductors and breakers for each of the panels. Panels 1LNH1, 2LNH1 and 2LEH1 required a smaller breaker due to the reduced load after redesign but did not require a smaller conductor size. These panels did not need a smaller conductor size because they have many empty circuits and the conductors were sized for potential growth on the panel to prevent the need to rewire in the event that loads are added to the panel in the future. Panel 1LNL1 does not utilize a main circuit breaker so only the feeder had to be resized due to the decreased load on the panel. A summary of the feeder and breaker sizes can be seen in the table below.

Panel	Existing Feeder	New Feeder	Existing Breaker	New Breaker
1LNH1	4 #1, #8G in 1-1/2" C	4 #1, #8G in 1-1/2" C	20A	15A
1LNL1	4 #4/0, #4G in 2-1/2" C	4 #2, #6G in 2" C	MLO	MLO
2LNH1	4 #1, #8G in 1-1/2" C	4 #1, #8G in 1-1/2" C	40A	30A
2LEH1	4 #4, #10G in 1-1/4" C	4 #4, #10G in 1-1/4" C	30A	25A

Generator Analysis

Emergency power is a critical part of any building's electrical system. In the event of an emergency it is important that critical equipment and lighting retain power for the safe evacuation of the building. The emergency power source for the existing building is a bank of batteries. As currently designed the bank of batteries was expanded to be able to handle the emergency loads of the expansion in addition to the existing emergency loads. This study will look into the possibility of using a generator rather than expanding the existing battery bank.

The first step to determining if this is a feasible solution was to determine the new loads that were being added to the emergency electrical distribution system. The loads from the existing building and the expansion can be seen in the table below. Refer to Appendix C for panelboard schedules.

Building	Load (VA)
Existing	8,887
Expansion	53,607
Total	62,494

After determining the loads that will be added to the emergency power system it was required to determine the size of the generator necessary based on the total load for the existing building and the expansion. After looking at a sizing chart for generators from Cummins, the 60DGBC generator was selected to provide the building with emergency power. The specifications for the generator are summarized in the table below.

Model	Standby kW/kVA	Prime kW/kVA	Continuous kW/kVA	Voltage	Frequency	Fuel Tank Size (Gal)	Circuit Breaker
60DGBC	60/75	55/69	40/50	480/208	60/50	90	400

After the generator was sized for the appropriate load, it needed to be located on the site. The generator and fuel tank take up about a four foot by eight foot area. The best location for this generator is to locate it next to the two exterior transformers for the building. This keeps the generator out of the main exterior circulation areas and concentrates the electrical equipment in one area. A sit plan with the location of the generator can be seen below.

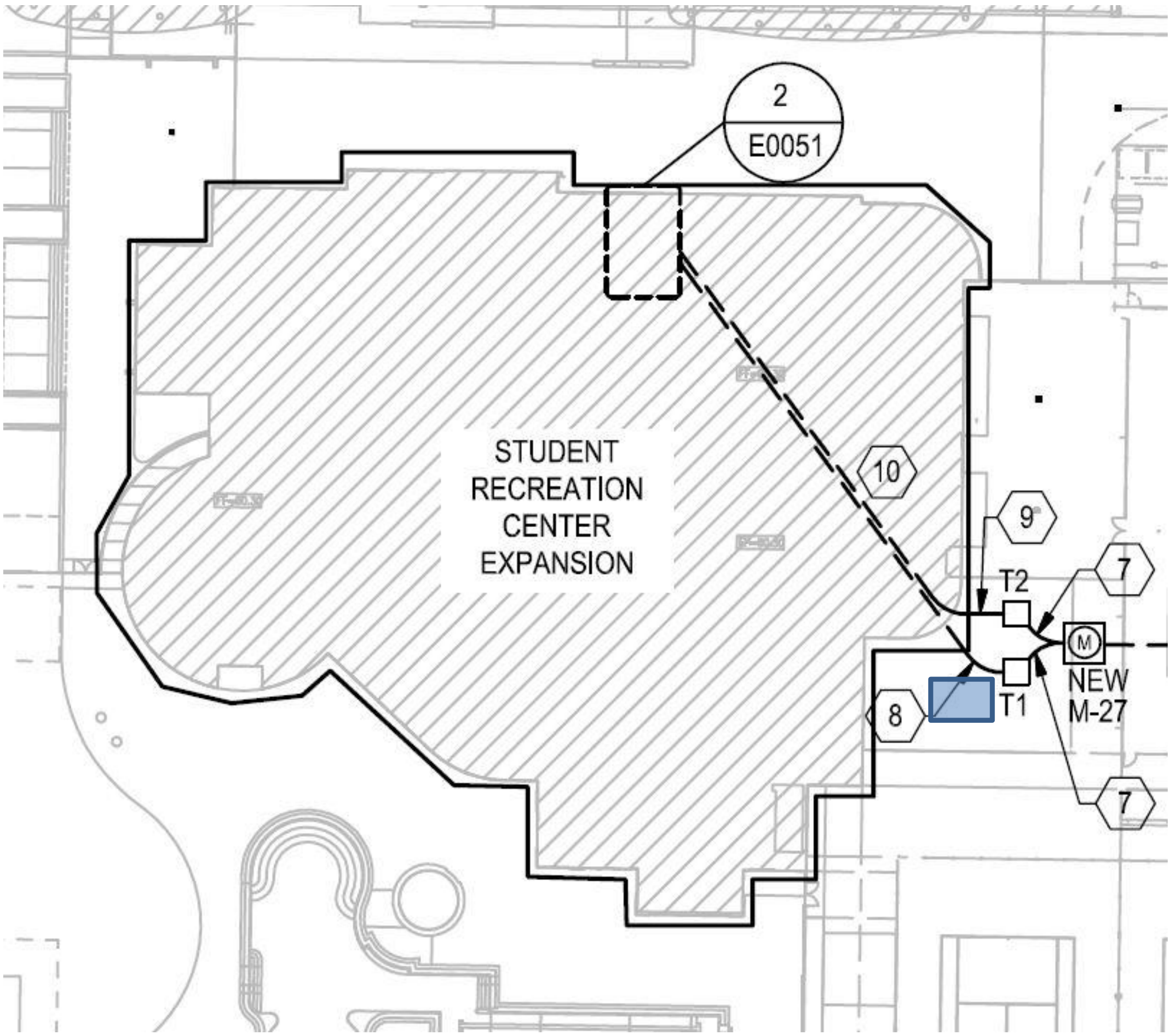


Figure 34: Generator Location

The last step to determining whether or not a generator is a viable option is to compare the cost of the two systems. The cost data for the two systems was obtained from RS means and is summarized below.

System	Material	Labor	Equipment	Total
Generator	$21,800	$1,675	$355	$23,830
Battery Bank	$28,620	$7,965	$1,701	$38,286

Based on the cost data above, it would be more efficient to use a generator than a bank of batteries.

Photovoltaic Analysis

Photovoltaic arrays are becoming an increasingly popular way to produce green energy, improve a building's sustainability and to reduce energy costs. Photovoltaic arrays not only produce electricity to reduce the amount of electricity purchased from the utility company, but also produce the most energy at the peak of a building's load profile. This means that a building could reduce its peak demand charge as well. Before a photovoltaic array can be installed on any project the system must be studied to make sure that it will fiscally make sense. Many projects will are not viable candidates for photovoltaic arrays because the payback period is too long. This period can sometimes be shortened by taking advantage of some state and federal incentives.

The first step in analyzing a photovoltaic array is determining the size of the array that is possible for a building. For the University of California, Riverside Student Recreation Center the array was decided to be split between two sections of roof. This was done in order to maximize the capacity of the system while also avoiding any structures on the roof that would cause shading. The two areas that were selected are the southern portion of the expansion and the northern part of the expansion, above the breezeway. These areas are free of structures that could shade the panels. The area of roof above the gymnasium would have also been a good area to place the array; however skylights for the gymnasium would be shadowed by the array, making them useless. A diagram of the array locations can be seen below.

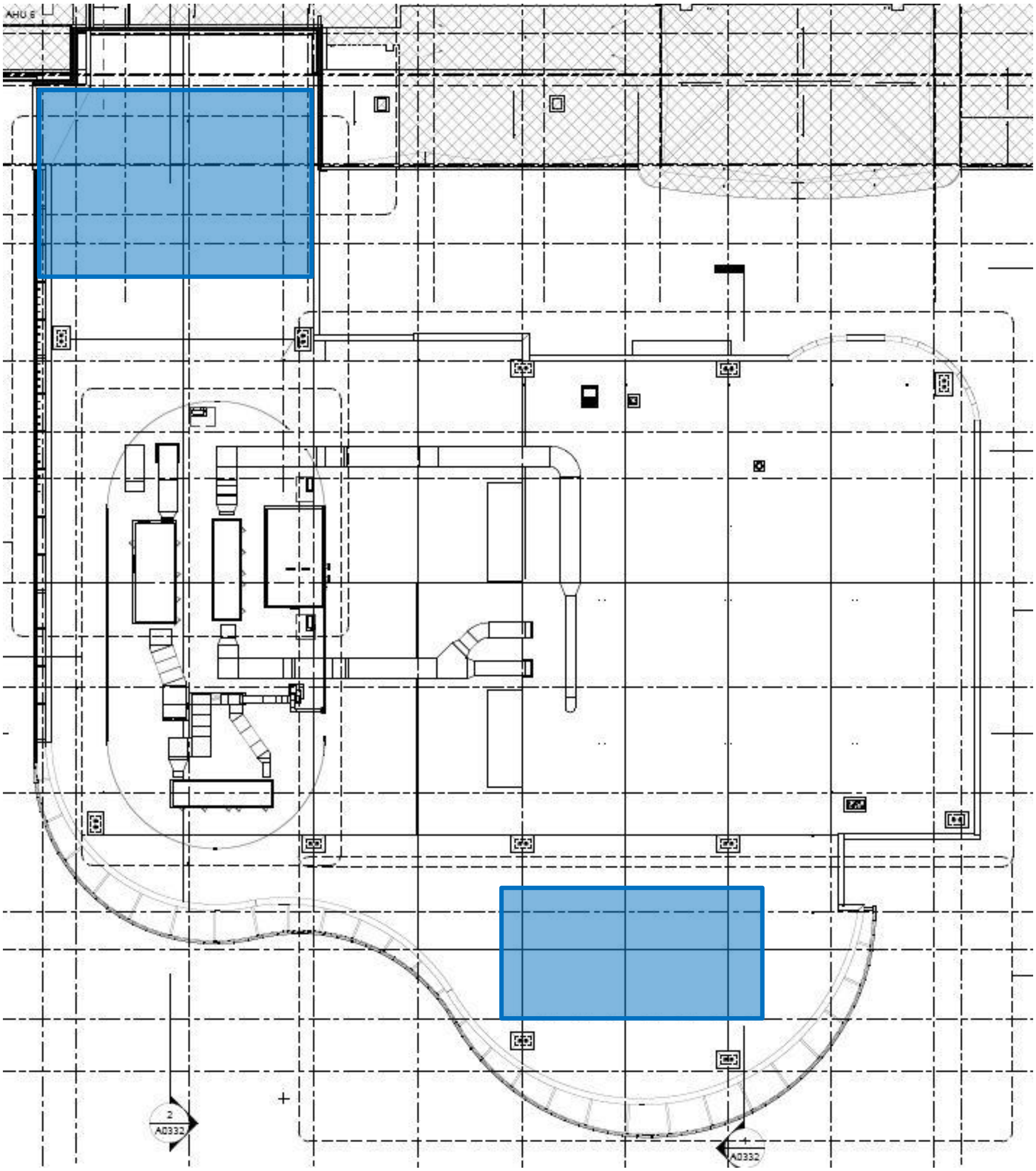


Figure 35: Solar Panel Location

After the available area has been determined, the capacity of the system based on this area must be calculated. This was done by calculating the spacing between panels using the size of the panel used, which was the SunPower SPR-210-BLK-U. This panel is about six feet by two and one quarter feet. Based on the short side of the panel being placed vertically, at a thirty four degree angle with the roof, and a lowest solar altitude angle of thirty two degrees, the distance between panels was determined to be 1.98 feet to prevent shading of panels. The panels were angled at thirty four degrees because a general rule of thumb is to angle solar panels at the latitude of the site to maximize performance. Once the spacing was determined, it was calculated that ten rows of panels could be placed on the southern portion of the roof and fifteen rows of panels could be placed on the northern portion of the roof. Multiplying each number of rows by the width of the area to be used, the width of the width of the panels and the general rule of nine watts per square foot of solar panel area produced the capacity of the system. A summary of the calculations can be seen below.

Section	Number of Rows	Width of Solar Panel (ft.)	Roof Area Width (ft.)	Watts/SF	Total Capacity (kW)
North	15	2.21	72	9	21.48
South	10	2.21	75	9	14.92
Total	N/A	N/A	N/A	N/A	36.40

Once the capacity of the array was determined, the information was brought into the System Advisor Model software to create a financial model for the system. Using the SunPower module and the SMA America ST36 (277) 277V inverter it was determined that 168 modules would be needed and 2 inverters would be required. A 0.5% year to year compounded decline in output was taken into account for the solar panels. After performing the analysis the predicted annual energy produced was 58,398 kWh.

The total installed cost of the system as predicted by SAM was $104,996.56. This cost could partially be offset by possible incentives for renewable energy sources. The Database of State Incentives for Renewables & Efficiency was consulted to look for possible incentives of which the University of California could take advantage. The University of California's status as a state government entity limits the available incentives that are available, as most incentives are for residential or commercial projects. Net metering is not available for state government projects, however production based incentives of $0.139/kWh was available to the University. The University is also exempt from property and income taxes which make this project feasible. Assuming that the University of California would pay for the entire system up front with the cost of the rest of the building and an electricity cost of the average California commercial price of $0.12/kWh produces a favorable payback period of just less than five years. Based on these favorable numbers it is recommended that the system be installed. A summary of performance as well as graphs for monthly output and cash flow over the 25 year analysis period can be seen below.

Metric	Base
Annual Energy	58,398 kWh
LCOE Nominal	14.75 ¢/kWh
LCOE Real	11.63 ¢/kWh
Total revenue without system ($)	$ -581,803.56
Total revenue with system ($)	$ -567,812.88
First Year Net Revenue	$ 14,015.95
Net present value ($)	$ 90,729.84
Payback (years)	4.92891 years
Capacity Factor	18.4 %
First year kWhac/kWdc	1,615
System performance factor (%)	0.83
Total Land Area	0.13 acres

Figure 36: Photovoltaic Analysis Summary

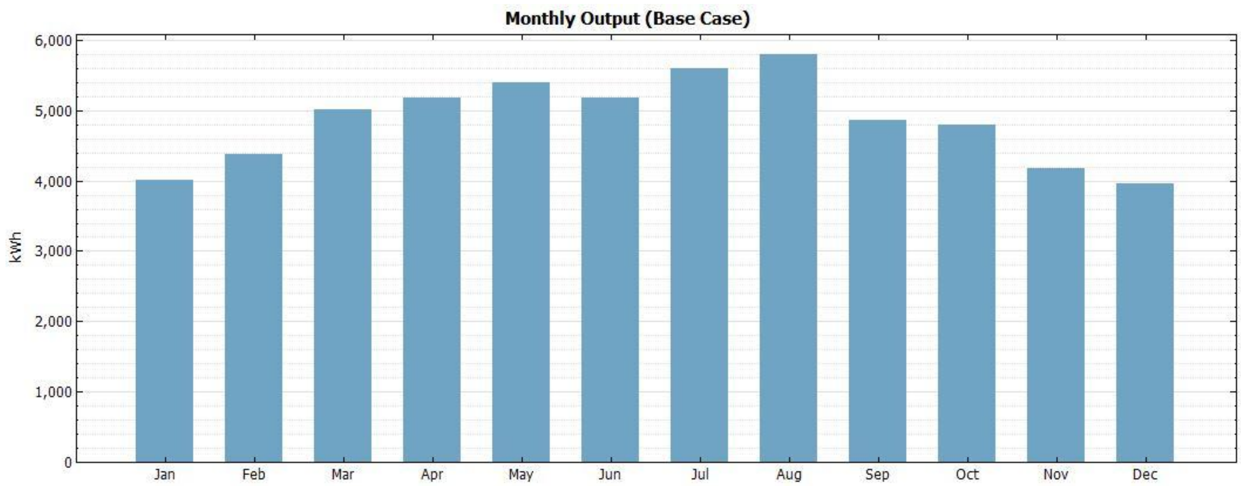


Figure 37: Monthly Output

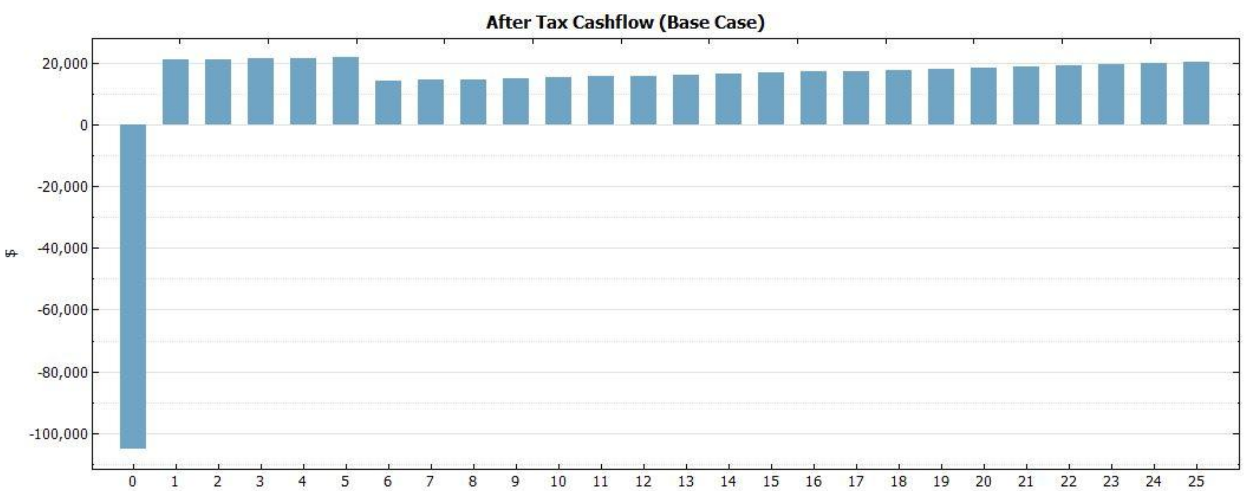


Figure 38: Cash Flow

MAE Breadth: Daylighting

One of the most important aspects to integrating lighting with a building's architecture, structural system and mechanical system is daylighting. Natural light can reduce the amount of energy needed for lighting through the use of daylight sensors to dim the lighting in the space. This will often increase mechanical loads on the space, however if proper design is utilized this increase in load will cause an increase in energy use that is less than the decrease in lighting load. In certain situations the buildings structure and architecture will need to be taken into account and slightly adjusted. This is the material studied in AE 565: Daylighting.

One of the spaces that does not utilize daylighting currently is the gymnasium. This space is an area that could possibly benefit greatly from daylighting because it has a high illuminance requirement of 500 lux. For a complete overview of the electric lighting system in the gymnasium, see the gymnasium section of the lighting depth. The most efficient way to utilize daylighting in this space would be to implement a top lighting system, using either skylights or clerestories. In this case skylights are used to in order to minimize the impact of the structural system and mechanical ducts in the space on the daylight delivered to the space. The first step in the creating a successful skylight design was to determine the percentage of floor area that the skylights should cover. This was determined using the Excel based program Skycalc. After inputting all of the space's information graphs were produced to show the skylight to floor area ratio and how much energy will be saved per year. The graph can be seen in the figure below.

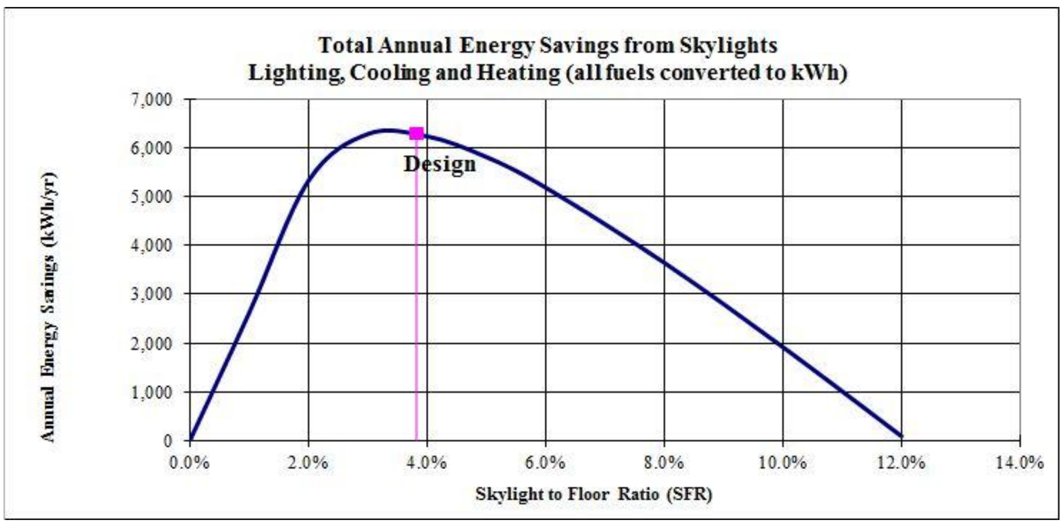


Figure 39: Annual Energy Savings vs. Skylight to Floor Ratio

The ideal skylight to floor ratio for this space was found to be between three and four percent. The final design for the gymnasium used a skylight to floor ratio of about 3.8%, slightly above the optimal ratio in order to maintain a uniform layout of skylights.

A diffusing skylight was then selected in order to minimize glare. The skylight system used for daylighting the space is the EcoSky3 skylight unit from Wasco Skylights. The deck mounted pyramid skylight was selected to increase the well depth of the skylight. The physical properties for the skylight unit can be seen in the table below. The 55" by 55" unit was used in order to fit between the structure, mechanical equipment and lighting equipment.

EcoSky3 Skylight Unit Information	
U-Factor (BTU/HR*FT^2*^{O}F)	0.82
Solar Heat Gain Coefficient	0.47
Visible Light Transmission	0.62
Size (inches)	55 x 55
Curb Height (inches)	12

The skylights were then arranged such a way to minimize the impact of the structural, mechanical and electrical systems on the daylighting performance. A layout of the different systems can be seen in the figure below. The mechanical system is outlined in blue, the structural system is outlined in red, the luminaires are outlined in dark green and the skylights are outlined in orange.

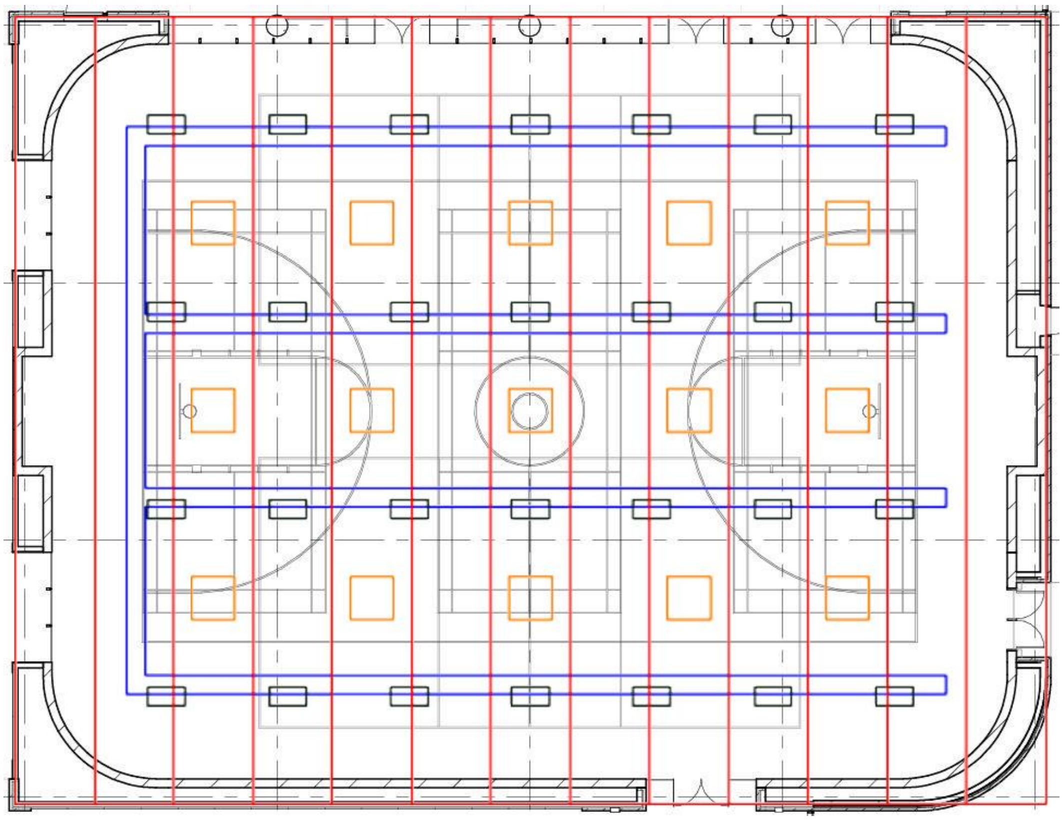


Figure 40: System Coordination

Once the skylight layout was determined, Daysim was used to analyze the lighting system and how well the system performed. Due to the uniform layout of skylights throughout the space and the diffuse material of the skylights the daylight illuminance values are very uniform throughout the space. Therefore, all of the luminaires were controlled in one zone, creating the simplest system possible while also achieving necessary dimming levels to save as much energy as possible. The daylight sensor to control the luminaires was placed on the center luminaire of the southern-most row of luminaires. This allowed the sensor to get a more accurate reading because it was not receiving signal from light reflected off of the trusses and ducts.

After the daylight sensor was placed, the critical point was determined using Daysim's critical point tool. The critical point is the point in the space that requires the most amount of light from the dimmed zone to maintain the target illuminance. This point is often at the edge of a space but it is often not the desired point. The edges of a space are often not used less frequently and therefore do not need to maintain the target illuminance throughout the year. For the gymnasium, a point was selected that was just outside the main playing area for basketball and volleyball. This ensures that the illuminance at any point in the playing area will not fall below the target illuminance because the system is being over dimmed.

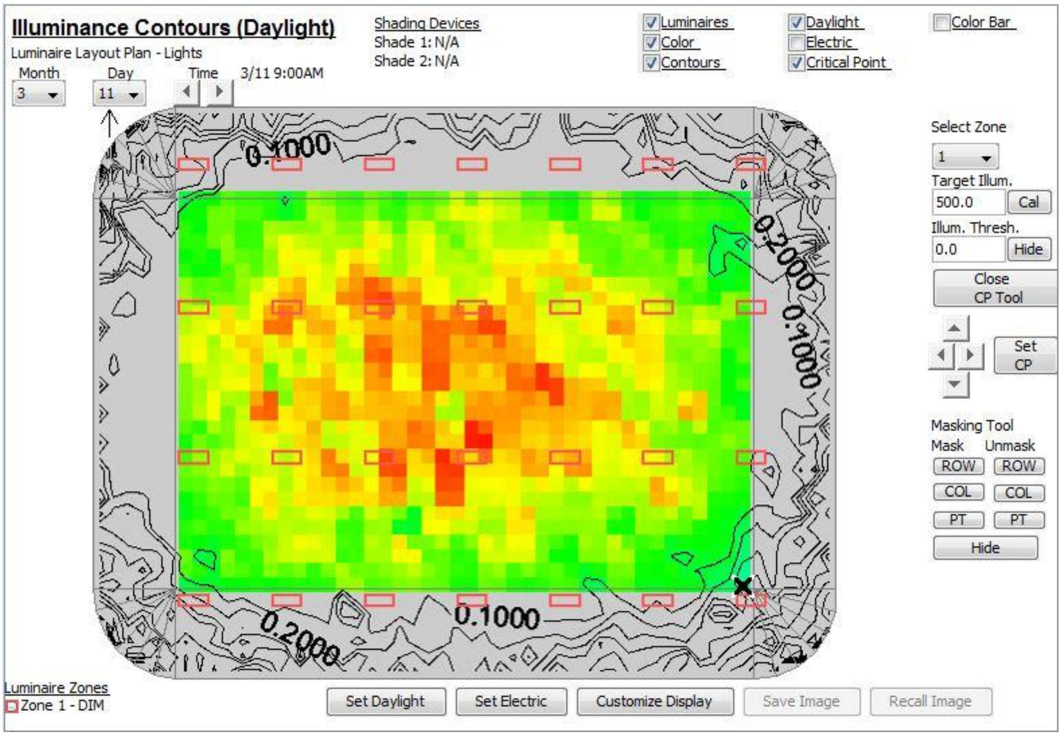


Figure 41: Critical Point Selection

After the critical point was set, the signals for the daylight sensor could be calculated and the daylight sensor could be calibrated. The daylight sensor was calibrated on March 11th at 9:00am. This required a dimming level of about 15% during calibration. This ensured that the system would reduce to the lowest light output when there was sufficient daylight in the space.

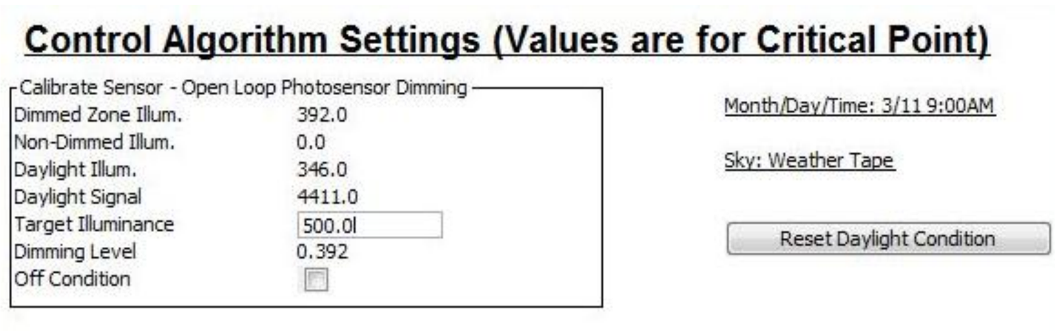


Figure 42: Daylight Sensor Calibration

This calibration allowed for the lighting control system to very accurately dim the electric lighting to the appropriate level based on the amount of daylight in the space. A system will never be able to maintain the target illuminance at the critical point year-round, which is why it is important to calibrate the system during a time that will give the closest results possible. The results of this dimming system are reflected in the lighting energy savings. As seen in the figure below, the difference between the optimal performance of the system, where the critical point is at the target illuminance year-round, and the actual performance of the system is only about 50 watts for the entire year. Whenever the system is using less than the optimal amount of watts it is over dimming the lighting and providing slightly less light than the target illuminance and the opposite is true when the system is using more watts than the optimal amount.

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Base	2676.91	2479.0	1697.8	2562.33	2640.45	1781.13	2656.08	2609.2	1874.88	2656.08	2614.41	1177.0	27425.32
Optimal	2220.65	1973.03	1210.07	1594.13	1547.8	953.02	1448.29	1448.88	1290.92	2028.19	2064.28	995.1	18774.44
Algorithm	2182.73	1941.62	1196.51	1598.48	1565.5	974.87	1483.13	1480.78	1280.73	1997.45	2051.74	971.97	18725.56
Savings	494.17	537.38	501.28	963.85	1074.95	806.26	1172.94	1128.41	594.14	658.62	562.67	205.03	8699.75

Figure 43: Energy Table

Structural Breadth

Solar panels are a common way for buildings to reduce the amount of electricity consumed from the utility company, thereby reducing the operating cost of the building while producing electricity from a renewable source. While this offers many benefits, one of the pieces of coordination that must be done is a structural analysis to ensure that the structural system can support the weight of the system. The load for the photovoltaic system will affect two areas of the roof structure, on the south side of the expansion and on the north side of the expansion. A roof framing plan showing the array areas can be seen in the figure below.

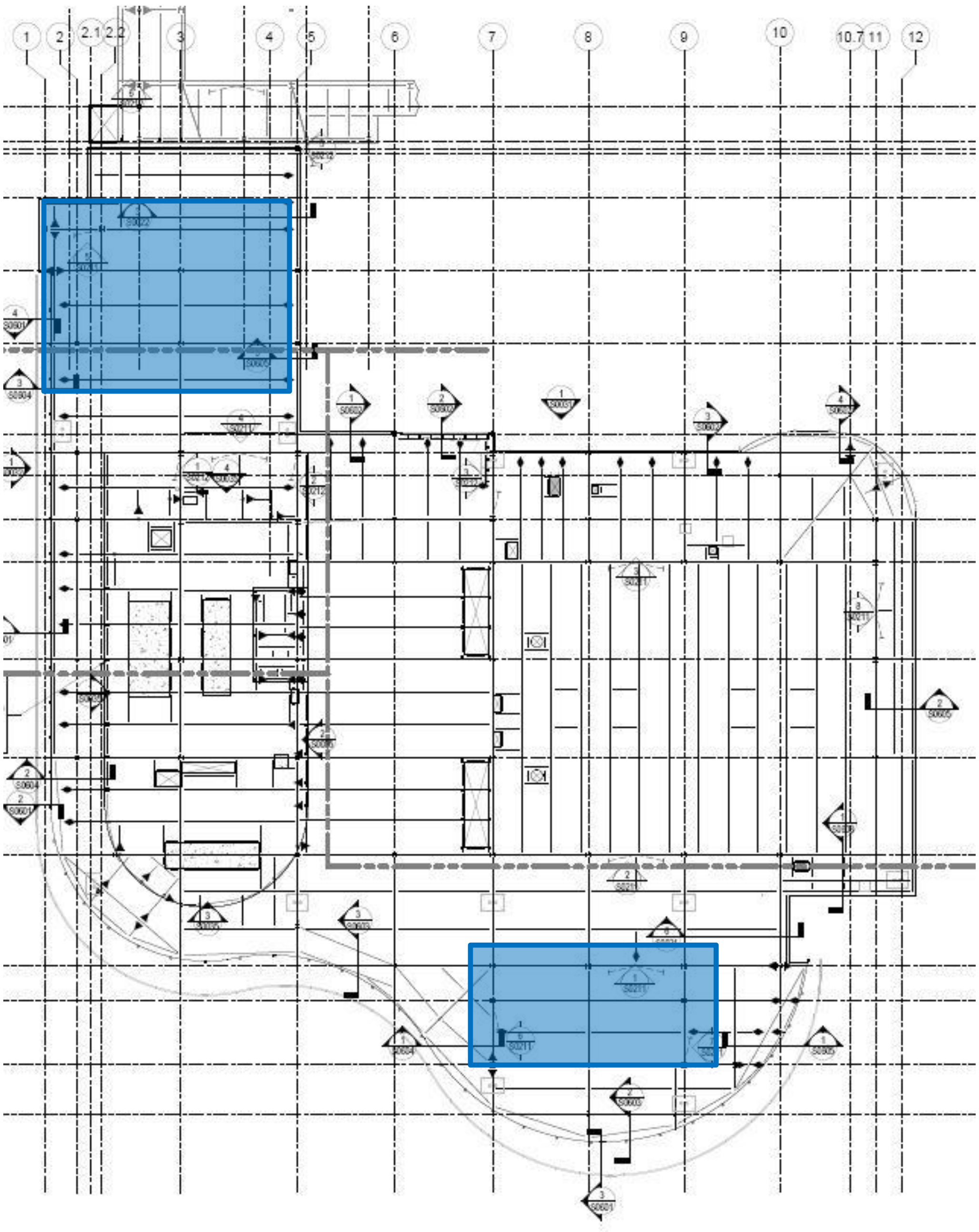


Figure 44: Photovoltaic Array Areas

The bay that was chosen to be analyzed was the bay on the north side of the expansion bounded by column line C on the north, column line D on the south, column line 3 on the west and column line 5 on the east. This bay was chosen because it had solar panels covering the entire bay and also had the smallest beam sections. If these beams can support the additional weight of the solar array, the rest of the beams will be able to support the array as well. A figure of the bay to be analyzed can be seen below.

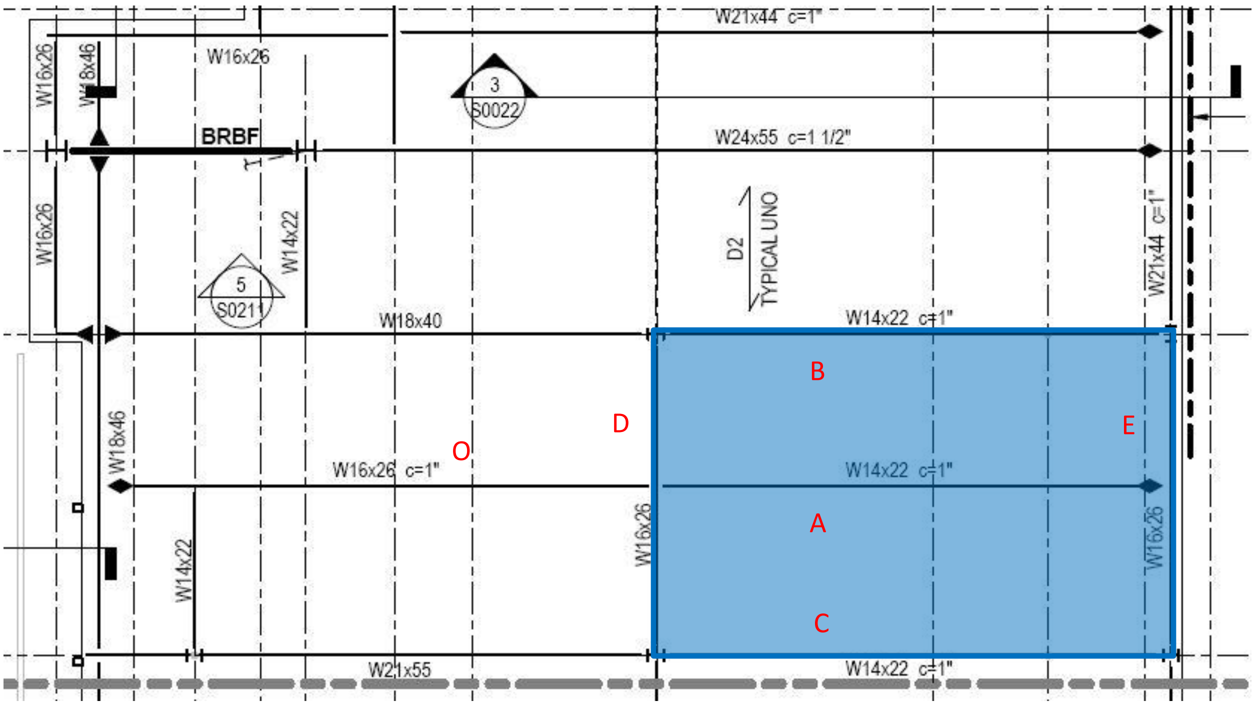


Figure 45: Bay to be Analyzed

The five beams that were analyzed are the beams marked A, B, C, D and E in the figure above. Beam O was not analyzed to support the load because of its larger cross sectional area, but its reaction forces were determined in order to analyze beam D.

The loads that affect this structure are the dead load on the roof and the live load on the roof. These loads were based off of ASCE standards and are summarized below.

Dead Load

- Roof deck: 2 psf
- Insulation: 1 psf
- Miscellaneous Dead Load (Lighting, ducts, sprinklers, etc.): 10 psf
- Member Self Weight: 5 psf
- Solar Panels: 5 psf
- Total Dead Load: 23 psf

Live Load

- Roof Live Load: 20 psf

After the loads were calculated, the roof loads were factored based on ASCE 7-05. Because the loads that control the structure are not lateral loads the load combination of 1.2*DL+1.6*R_L was used.

1.2*23 psf + 1.6*20 psf = 59.6 psf

After finding the factored load each of the beams can be analyzed for supporting the additional weight of the solar array. A uniformly distributed load was determined for beams A, B, C and O by multiplying the factored load by the tributary width for each beam. This is half of the bay width on either side of the beam. Then reactions were calculated at each support for the beams by multiplying the distributed load by the span and dividing by two, because the force is evenly divided between the two supports. Each beam was analyzed with a pin connection at one end of the beam and a roller connection at the other end. The maximum factored moment in the beam was then determined by multiplying the reaction by half of the span and then by one half. This gave the moment halfway along the span of the beam, where the moment is greatest. The equations used and the summary of calculations can be seen below.

w_u = 59.6 psf *tributary width

support reaction = w_u*span*0.5

maximum moment = reaction*span*0.5*0.5

Beam	Tributary Width (ft)	w_u (plf)	Span (ft)	Reaction at Each Support (kips)	Maximum Factored Moment (kip*ft)
A	10.5	625.8	33.5	10.48	87.77
B	10.875	648.15	33.5	10.86	90.95
C	10.75	640.7	33.5	10.73	89.86
O	10.5	625.8	36.25	11.34	N/A

The reactions from beams A and O were then used to calculate the reactions for beams D and E, as A frames into both beams and O frames into beam D. Both beams D and E can be analyzed with one pin support and one roller support, just like the previous beams, except now the beams have a single point load from the beams that frame into them. The point source for each beam is eleven feet away from the southern support at column line D and ten feet away from the northern support at column line C. The reactions at each support can be calculated by summing the moments about one support and setting the sum equal to zero because neither a pin nor a roller support can support a moment. The process can then be repeated for the other support. The maximum moment was then calculated at the point where the point load is applied. This was done by multiplying the reaction at column line D by eleven feet. The equations used and the summary of calculations can be seen below.

Column Line D Reaction = point load*10 ft/21 ft

Column Line C Reaction = point load*11 ft/21 ft

Maximum Moment = Column Line D Reaction * 11 ft

Beam	Point Load (kips)	Reaction at C (kips)	Reaction at D (kips)	Maximum Moment (kip*ft)
D	21.82	11.43	10.39	114.3
E	10.48	5.49	4.99	54.9

After all of the maximum moments were calculated for each member, the values were compared to the allowable values from the Z_x tables in the AISC Steel Construction Manual. As long as the maximum factored moment does not exceed the $\Phi_b M_{px}$ value for the given member size the member can support the load. A table summarizing this check for flexural strength can be seen below.

Beam	Size	Maximum Factored Moment (kip*ft)	$\Phi_b M_{px}$ (kip*ft)
A	W14x22	87.77	125
B	W14x22	90.95	125
C	W14x22	89.86	125
D	W16x26	114.3	166
E	W16x26	54.9	166

Because maximum factored moment for each beam was less than the $\Phi_b M_{px}$ value none of the beams needed to be resized and the existing structure could support the additional weight of the solar panels.

Mechanical Breadth

The use of daylighting can be used to reduce the building's electricity consumption due to lighting but it also has an effect on the mechanical system. Any daylighting system will have a lower thermal resistance than the wall or roof in which it is installed, making it much easier for heat to enter the space in warm weather and exit the space in cold weather. In addition to these conductive heat load differences, glazing allows for infrared solar radiation to directly enter the space. The additional infrared radiation further increases the cooling load required for the space during the warm weather months but can help to reduce heating loads in the space in the cooler weather months depending on the proportion of heat lost through the glazing system compared to the infrared radiation.

The first step to calculating the difference in cooling and heating loads for the space was to calculate the thermal properties of the roof system and the skylight system. The thermal resistance for the roof was determined by looking at a roof section and finding the thermal properties for each component. These properties were then all summed together to find the thermal properties for the entire assembly. A roof section and the properties can be seen in the figure and table below.

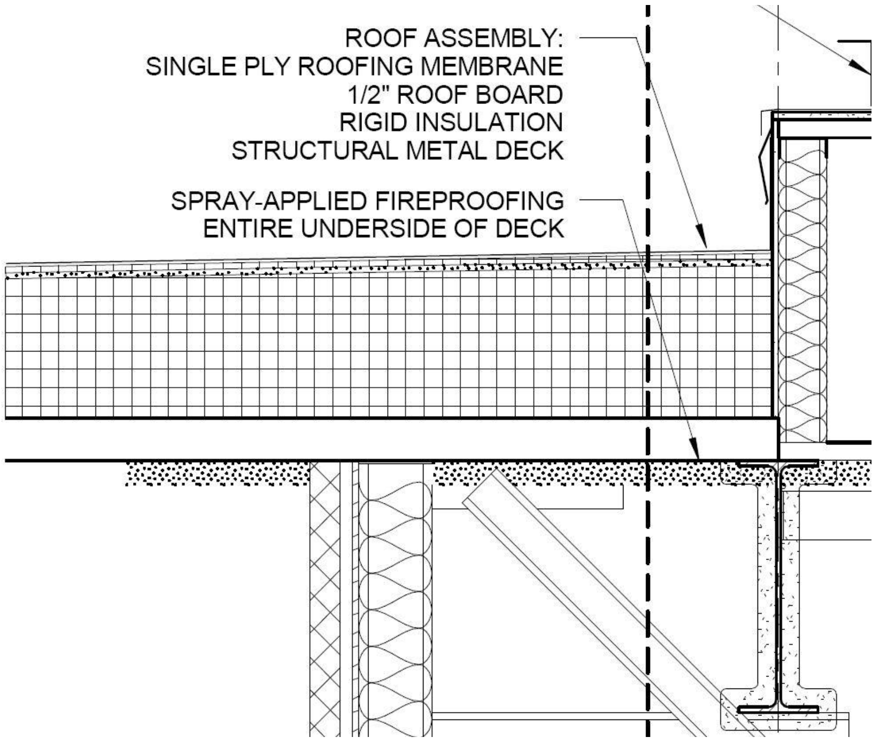


Figure 46: Roof Assembly

Item	R Value	U Value
Roof Membrane	0.24	4.12
½" Roof Board Insulation	3.15	0.32
Structural Metal Deck	0	0
Fireproofing	0.51	1.95
Total	3.90	0.26

After the thermal properties of the roof were determined a skylight was selected. As described in the Daylighting breadth section, a diffuse skylight unit was selected to avoid high illuminance values from direct sunlight entering the space through transparent glass. The thermal and light transmission properties for the skylight system are summarized below.

Item	R Value	U Value	SHGC	Tvis
Skylight	1.22	0.82	0.47	0.62

Once all of the thermal properties had been established for the roof assembly and skylight system the information was taken into SkyCalc to determine not only the recommended skylight to floor ratio but also the potential energy savings from the skylight system. As expected, the majority of the energy savings was from the lighting and the cooling load increased with the addition of the skylights. The heating loads for the space decreased as well, meaning that the energy the space received from the infrared radiation was greater than the energy lost through the less thermally resistant skylights. Using an average cost of electricity of $0.12/kWh for California commercial businesses, annual cost savings can be calculated as well. A summary of the energy savings can be seen in the table below.

Load	Annual Savings (kWh/yr)	Annual Cost Savings ($/yr)
Lighting	7,780	$933.60
Cooling	-1,804	-$216.48
Heating	312	$37.44
Total	6,288	$754.56

The savings for the lighting load is slightly below the estimated annual lighting savings predicted in Daysim. This is partially due to the fact that Daysim used a minimum dimming level of 3% while Skycalc is only able to use a minimum dimming level of 5%. Because of the potential energy savings of the skylight system, it is recommended that it be implemented.

Summary and Conclusions

The overall goal of this thesis was to investigate the building systems of the University of California, Riverside Student Recreation Center and other possible design decisions that could have been made. This was done by analyzing the lighting in four spaces, conducting analyses on the electrical system, studying the effects of a skylighting system on lighting and mechanical loads and analyzing the structural system supporting the photovoltaic array added to the roof.

The four lighting spaces that were redesigned were the entrance and courtyard space, the lobby, the rock wall space and the gymnasium. The entrance is the first space that patrons encounter and it is important for it to feel comfortable while also guiding patrons using different light levels throughout the space. Random placement of bollards and downlights gave the space a more organic feel rather than a structured one. This organic pattern was continued in the lobby space with interior downlights. Another organic pattern of luminaires inspired by a network of capillaries was used above the workout area. In addition, wall washers were used to brighten the walls, creating a more public space. The rock wall space is connected to the lobby space and has a few randomly placed downlights near the entrance while high bay fluorescent fixtures provide general illumination. Wall washers and LED flood lights provided additional illumination on the climbing surfaces to ensure adequate light levels. Lastly high bay linear fluorescents were implemented in the gymnasium in order to install skylights and use a daylight harvesting system. This system provided large lighting savings while illuminating the space to the required illuminance level often during the day. The mechanical analysis showed that the energy saved from lighting was greater than the increase in mechanical loads, therefore making the system a feasible option. Because of the lighting redesign, all of the branch circuiting had to be calculated again. The goal was to attempt to put new luminaires on the same circuit as luminaires around them to reduce wiring requirements. A generator was then analyzed to see if it would be a more cost effective way to supply emergency power than a bank of batteries. Lastly a photovoltaic analysis was performed that showed that the building would benefit from adding solar panels and a structural analysis was performed to ensure the weight could be supported.

These studies showed that there are many design decisions that are taken into account when designing a building. Each option comes with a set of benefits and weaknesses such as cost, energy savings or integration impacts. When a building is designed, the design team must work together to create the most efficient building possible.

References

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- DiLaura, Houser, Mistrick, and Stefy. The IESNA Lighting Handbook: Reference & Application. 10th ed. New York, NY: Illuminating Engineering Society of North America, 2011.
- National Fire Protection Association. NFPA-70 – National Electric Code. 2011 Edition. Quincy, Massachusetts: National Fire Protection Association, 2008. Print.

Software

- AGI32
- Autodesk AutoCAD
- DAYSIM
- Adobe Photoshop

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