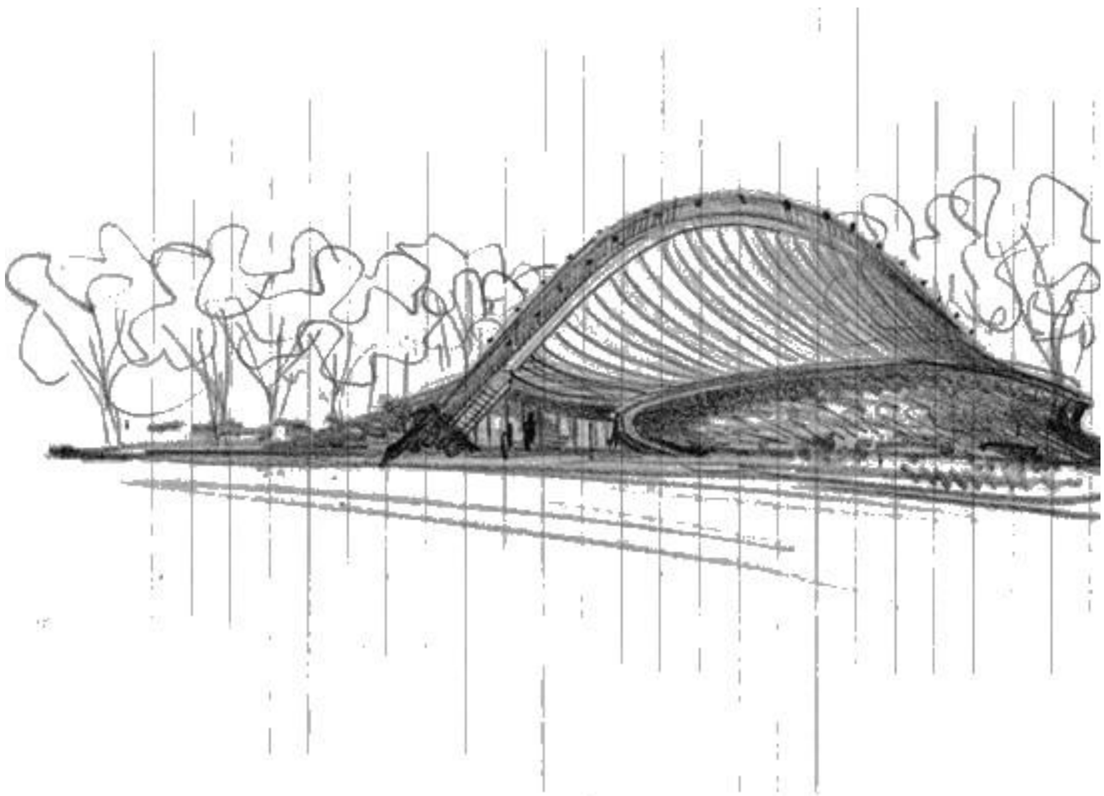

David S. Ingalls Rink

73 Sachem Street, New Haven, CT 06501

Final Thesis Report

Amy Chengyue Huan

Lighting/Electrical

Faculty Advisor: Dr. Houser

04/09/13

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All fellow AE friends

~ For Mama and Papa ~

Executive Summary

This thesis report contains detailed building system analysis and proposed changes for David S. Ingalls Rink. Investigation of existing building system was conducted with the goal of finding potentials in new design solutions. Detailed contents include lighting depth, electrical depth and two breadths studies. Senses of seeing, feeling, hearing are engaged through alternative design solutions in lighting, electrical, acoustic, architecture and structure.

The lighting depth involves design of four spaces: building exterior, circulation corridor, rink, and Schley Club Room. With an overall concept of HABITATION, the proposed lighting design is aimed for an illuminated environment that suites both for the architecture and the people. Elements such as architectural statistics, design criteria and system implementation were comprehensively studied and analyzed to achieve the ultimate lighting solution. Calculations and renderings were generated to simulate the design outcome.

Three topics studied for electrical depth include branch circuit analysis, short circuit analysis and copper vs. aluminum wire cost estimation. With proposed system lighting, new panel board loads were analyzed for evaluation of feeder upsizing potentials. Short circuit analysis was performed at five selected points to ensure feeders are effectively rated for fault protection. A cost analysis of copper versus aluminum wire was conducted to compare and investigate the possibility of saving labor and material cost.

For acoustic breadth, a calculation of reverberation time was conducted to evaluate the acoustic performance of the rink area. A change in ceiling material was proposed to optimize the sound absorption performance. The structural breadth contains research of Saarinen, the building architect, and his architectural practice in material. Wind analysis and glazing load resistance analysis were examined for building structural stability.

Table of Contents

|Background

Building name: David S. Ingalls Rink
Date Constructed: 1953 - 1959 (Renovation 2008-2010)
Location: New Haven, CT
Site: 73 Sachem St, New Haven, CT
Building Occupant Name: Yale University
Occupancy or function types: Assembly A-4. The constructed building contains ground floor Rink, Concourse, lower level Locker Rooms, Fitness Center, Schley Club Room and other utility rooms.

Site Area:	1.48 ac
Building Footprint:	47,983 sf
Total gsf:	61,646 sf
Num. of Stories above Grade:	1
Total Levels:	2

Primary Project Team (Renovation)

Client:	Yale University
Architect:	Kevin Roche John Dinkeloo and Associates LLC
Landscape Architect:	Towers | Golde
Lighting Consultant:	Atelier Ten Consulting Designers
Structure Engineers:	Severud Associates Consulting Engineers, P.C.
Mechanical Consultants:	AltieriSeborWieber LLC
Construction Manager:	Turner Construction Company
Civil Engineer / Landscape Architect:	Tighe & Bond
Acoustics, Audio Visual and Sound System:	Cavanaugh Tocci Associates, Incorporated

General Building Statistics

Construction

The David S Ingalls Rink at Yale University is an extraordinary building designed by architect Eero Saarinen and originally completed in 1958. The multi-million renovation taken in year 2008-2010 restored the previous architectural appearance of the building and added an underground training room and locker room addition. Turner Construction Company was the primary construction management firm for this project.

Electrical

The building power of David S. Ingalls Rink is served by Yale's Central Power Plant. The building electrical system has a utilization voltage of 480Y/277V. Main service and distribution equipment includes metal enclosed NEMA 1 enclosure switchboards and 480Y/277V panelboards to serve motors and lightings. Automated Transfer Switch (ATS) was used to switch the emergency panels to emergency power in the case of main power failure. A step-down transformer with a secondary end of 208Y/120V was installed to provide lower voltage for the emergency receptacle panel. The equipment that are connected to the emergency power systems include emergency lighting, low air compressor and fire alarm control panels.

Lighting

High-bay luminaire mounted with slight changes following the ceiling curves were used to provide recommended light levels for athletic competition for the rink area. Fluorescent lighting fixtures were used in the rest of the space inside the building including concourse, Schley Memorial Club Room, and the lower level new addition. The system utilizes Lutron lighting control system which is designed to provide two-level output: full output for varsity practice and games, then 50% output for recreational skating to save further energy.

Mechanical

Two Air Handling Units each with 10,800 CFM and 3,000 CFM are located in the lower level renovation addition to serve for building ventilation and exhaust. Two air condition systems each with 10,000 CFM capacity located in the ice arena were the full replacement for the existing heating ventilation units. Each unit has two supply fans operation continually when building is occupied. Two Desiccant Dehumidification systems located in the rink area were used to remove moisture from the air at low temperature and increase the cooling coil capacity. Run-around Heat Recovery Coils were placed throughout the lower level to transfer sensible and latent heat carried by airflow via liquid medium.

Structure

The David S. Ingalls Rink has a structural system which consists of reinforcing steel frames and cast-in-place concrete slab on grade. All concrete works are class I normal weight with a minimum ultimate compressive strength of 4000 PSI. The building has a slab on grade Caisson-pile supported foundation, reinforced CMU bearing exterior walls and oak wood roof hung from the central concrete spine and held in place by grid of aluminum cables running perpendicular to the spine. Because of the innovative roof structure, the ground level interior of David S. Ingalls Rink is free of columns.

|Additional Engineering Support Systems

Fire Protection

The fire alarm system receives 120 VAC emergency power via circuit breakers with handle locking devices. The system incorporates one-way voice communication and tone generating capabilities.

Audio/Video System

The rink video and support systems include video and audio monitoring, video distribution of game cameras to support spaces, sound playback, television production tie lines and cable pathways, production intercom, an assistive listening system, and digital signage. The rink sound system was designed to provide high quality audio performance while maintaining a low visual profile and controlling acoustic wastes in a highly reverberant rink space.

Special Systems

- Acoustical panels and exposed suspension systems at rink area.
- Camera video distribution system and instant replay system are provided in the rink area. Additional audio system was added to the Team Lounge, Strength and Conditioning Room, Locker Room during renovation.
- Electric Frost Prevention: Cables are mineral insulated type with two conductors with a single cold splice at one end. Each system is controlled by a combination time clock and temperature sensing probe. 3 wire temperature sensing probes were used for automatic operation of the system.

Lighting Depth

Introduction

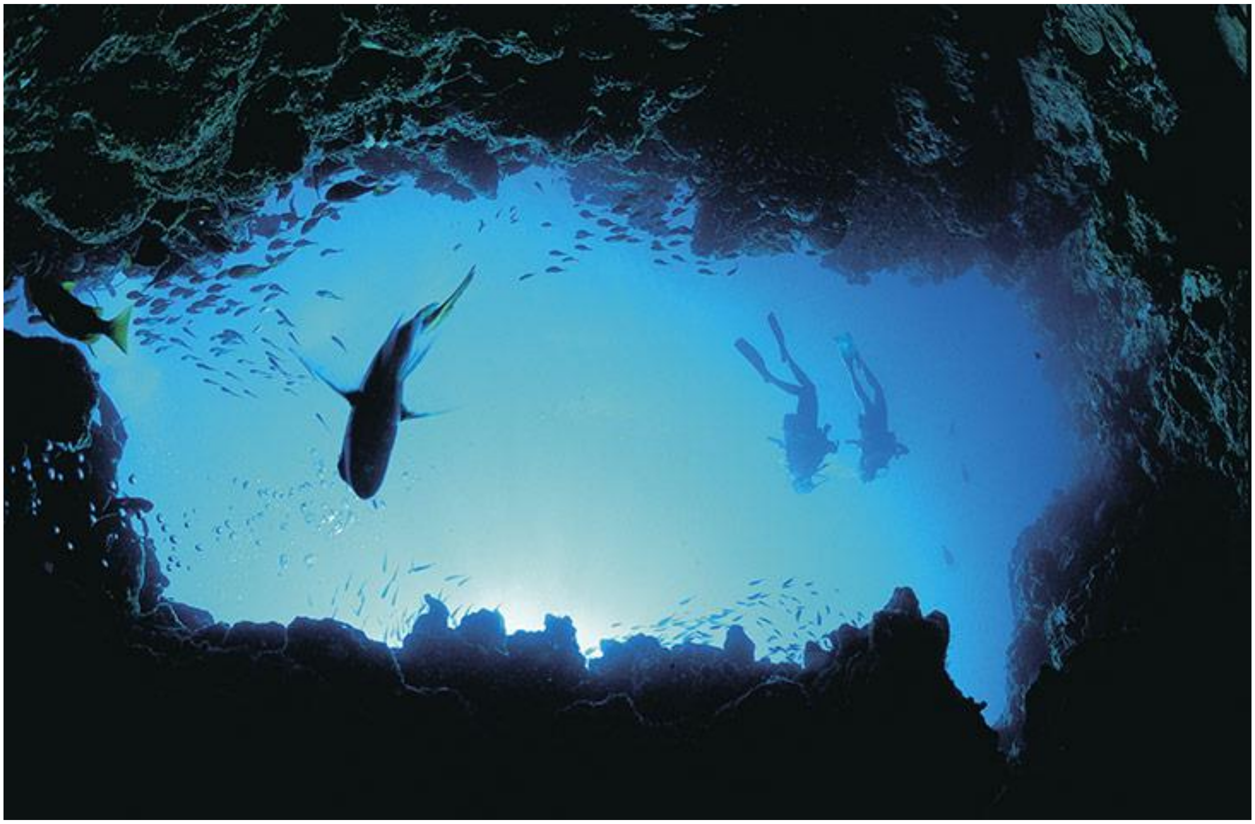


Figure 1| Concept Image - Habitation

Le Corbusier once said: "*Light creates ambiance and feel of a place, as well as the expression of a structure."* Good lighting design illuminates the mind by polarize both sensibility and accessibility. The underlying story of this building was observed by seeing the unchangingness of the beauty of building architecture, and reacting to the activities and senses. With an overall concept of ***Habitation***, the lighting design of David S. Ingalls rink strives to create a living environment for the beloved "Yale Whale", as well as the people who "habitats" inside the building. On one hand light for building by connecting and embracing separate architectural features into a whole; on the other hand light for people by enabling them to experience and react to each illuminated scenes.

Lighting | Building Exterior

|Architectural Description

The exterior of David S. Ingalls Rink establishes its visual identity – "the Yale Whale" with the dramatic sweeping roof. The elliptical shaped building has its main structure of 290 foot long reinforced concrete spine for cable net to hang from to support the iconic roof. The side walls are the same shape in plan as the arch is in section, acting as a counter part of the arch. The exterior walls are also sloped to increase the structural integrity, in the meantime enhance the visual expression of the arch. The rink sits in a quiet neighborhood of residential houses inside Yale Old campus, with several educational buildings on its south side. The parking lot is a place of socialization on the game day with food stands around the arena.

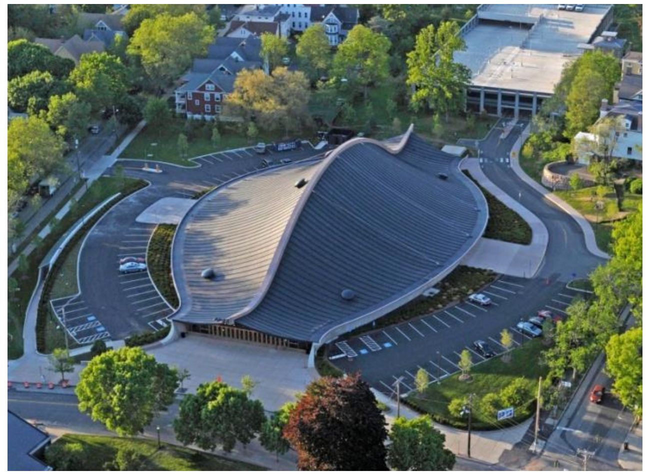


Figure 2| Building Exterior Arial View

Figure 3 | Building Facade

Geometry

Maximum Length: 335'
Maximum Width: 196'
Maximum Height: 66'
Building Footprint: 47,983 SF

Material Finish

Surface	Material	Description	Reflectance	Transmittance
Roof	Oak Wood	Existing oak wood roof in dark finish	0.2	-
	Aluminum	Metal framing to help resist snow load	0.6	-
Formwork	CMU	Unfinished concrete with wood texture	0.4	-
Façade	Wood Framing	Existing wood frame in light finish	0.7	-
	Glass	Insulated Opaque Spandrel Glass	0.51	0.28

Table 1 | Building Exterior Material Properties

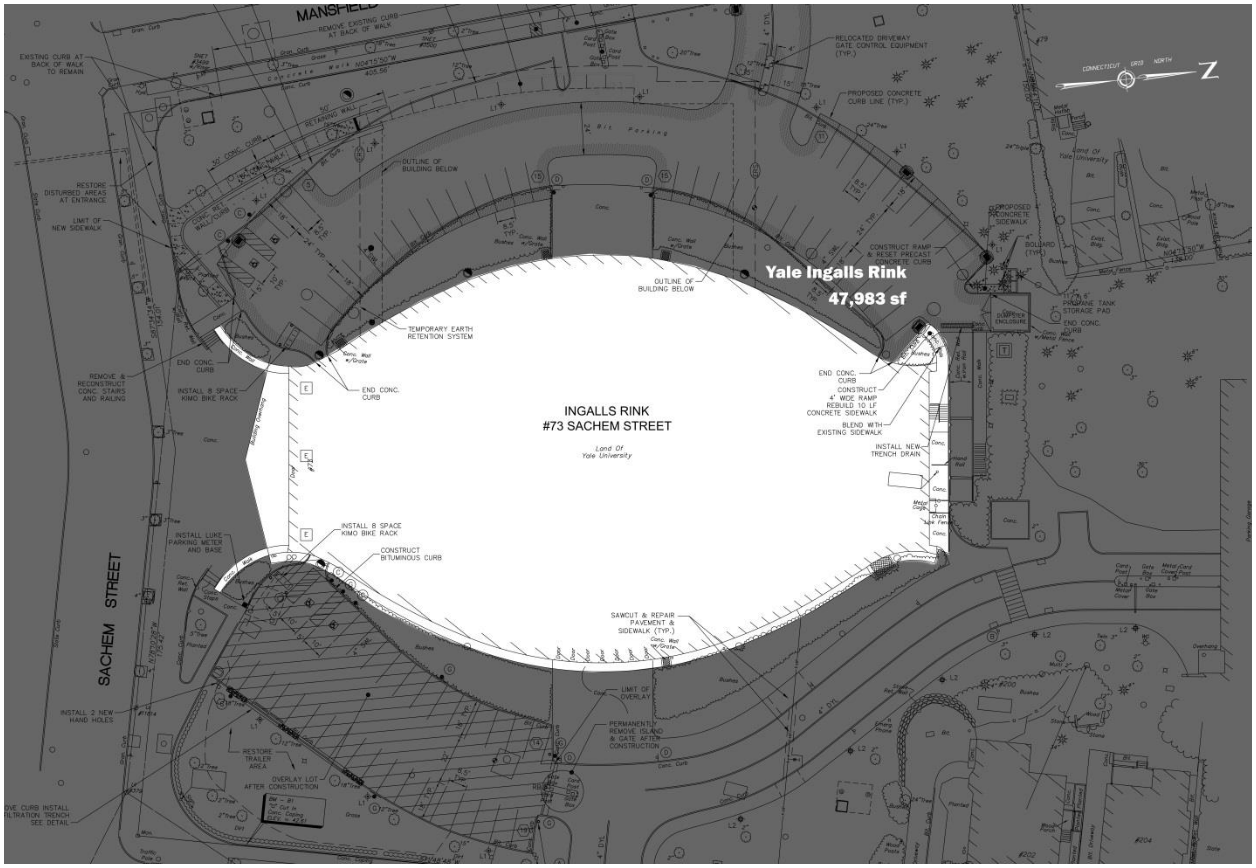


Figure 4 | Site Plan

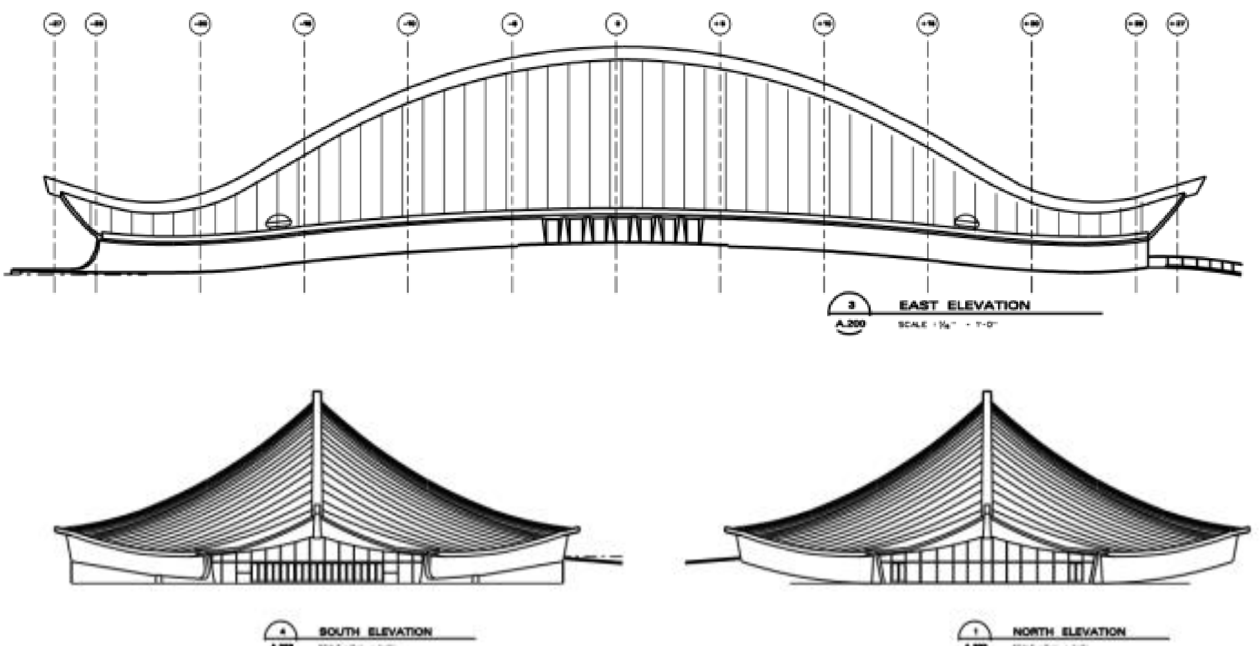


Figure 5| Building Elevations

|Design Consideration and Criteria

David S. Ingalls Rink is the home of numerous national championship collegiate hockey teams, and is recognized as the rink with the “best design” across all of America by *New York Times*. As such, it has an admired history and reputation for the university. The architect Eero Saarinen was very enthusiastic about three common principles of the architecture of his time: function, structure, and being a part of his time. In relation to the neighborhood, the mass and scale of Ingalls Rink together with the dramatic structural elements harmoniously enhanced the surrounding environment.

The lighting design of the building exterior needs to respect the historically significant architecture of Ingalls Rink. Installation of lighting fixtures should have minimum impact of the day-time building appearance. In the meantime, lighting should act to structurally and visually integrate the building with existing landscape such as trees and street poles. With the consideration of respecting neighborhoods and wildlife, the exterior lighting should provide enough light level to give sense of security. The design also has to follow city codes, and be able to resist strong winds and snow.

Illuminance Recommendation

Space Type	E_v
Facades Activity Level [Medium][Low] Lighting Zone[LZ3]	200lux high activity/100lux low activity for darker toned surface materials (reflectance <0.5); 100 lux high activity/50lux low activity for lighter-toned façade materials (reflectance ≥0.5)

IES Lighting Handbook 10th Edition (Table 26.2, 26.4, 22.4)

Energy Allowance

Space Type(zone3)	Power Density (W/sqf)
Main Entries	30W/linear foot of door width
Entry Canopies	0.4W/ft^2
Building Façade	0.15W/ft^2 for each illuminated wall or surface or 3.75 W/linear foot for each illuminated wall or surface length
Building Grounds	0.8W/linear foot for walkways less than 10 ft wide. 0.16W/ft^{2}for walkway 10 ft wide or greater, plaza areas, and special feature areas.

ASHRAE standard 90.1 – 2010 (Table 9.4.3A, 9.4.3B)

Exemptions – lighting used to highlight features of public monuments and registered historical landmarks structures or buildings.

Sky Glow

Luminaires should be aimed to minimize the upward spread of light near to and above the horizontal.

|Concept Statement

The design of exterior lighting is intended to create the motion of a **Whale Dive**. David S. Ingalls Rink was given the amiable nick name – "the Yale Whale" because of its beloved dramatic soaring roof. The main spine structural component will be highlighted by linear fixtures to recreate the beauty of back spine curvature in the dark. In response to the smooth and strong spine ribbon, linear flood light will be used to light up the roof perimeter, which has the same curved shape in plan as the structural spine in section. The bright ribbon on center and the graceful grazing coming up from the side will act together to create the "lifting" motion of the sweeping roof and float the whole building, bringing the whale to life. The continuous flow and motion will be highlighted with a strong finish by the high illuminance fixtures mounted inside the light sculpture on the roof end, give dramatic impression of a whale tail, and throw ambient and uniform light pool to the front plaza.

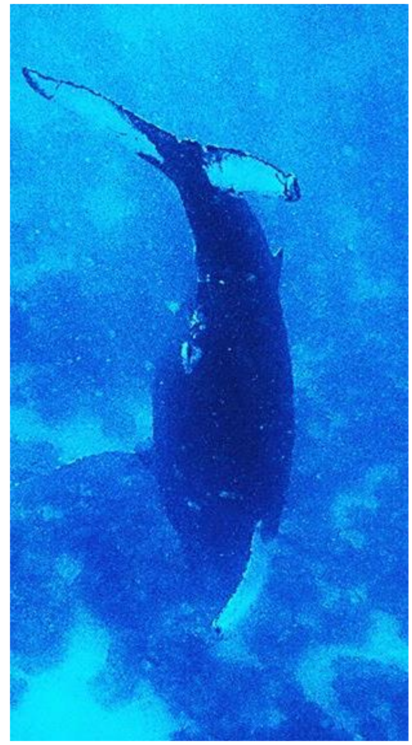


Figure 6 | Whale Dive

|System Implementation

Description

The designed lighting system combines four different types of linear LED fixtures, each with different lumen output and light distribution to bring motion and dynamic to the building exterior nighttime appearance. *Lumen Pulse* surface mounted adjustable linear grazing fixture with six inches arm will be mounted on both sides of the spine. The fixture has a narrow 10° by 60° light distribution, together with the 30° aiming angle allowing just enough light to brighten up the spine with limited spilled illuminance to the sky. *Phillips* linear exterior flood light are mounted along the curved perimeter of the roof with three different light output to coordinate with projection distance on the sloped roof. The top half of the roof is intentionally left dark in order to further bring out the structural form using the contrast between light and shadow. Four 100 watts *Lumen Pulse* LED fixtures are placed inside the light sculpture. High lumen output gives highlight to the end of the spine curvature, and provides additional security lighting for the front plaza.

Original façade lighting and rink lighting penetrating through the glass curtain walls will add more illumination to the front plaza. The existing street poles provide required 1fc light level on the parking plaza.

Lighting Plan

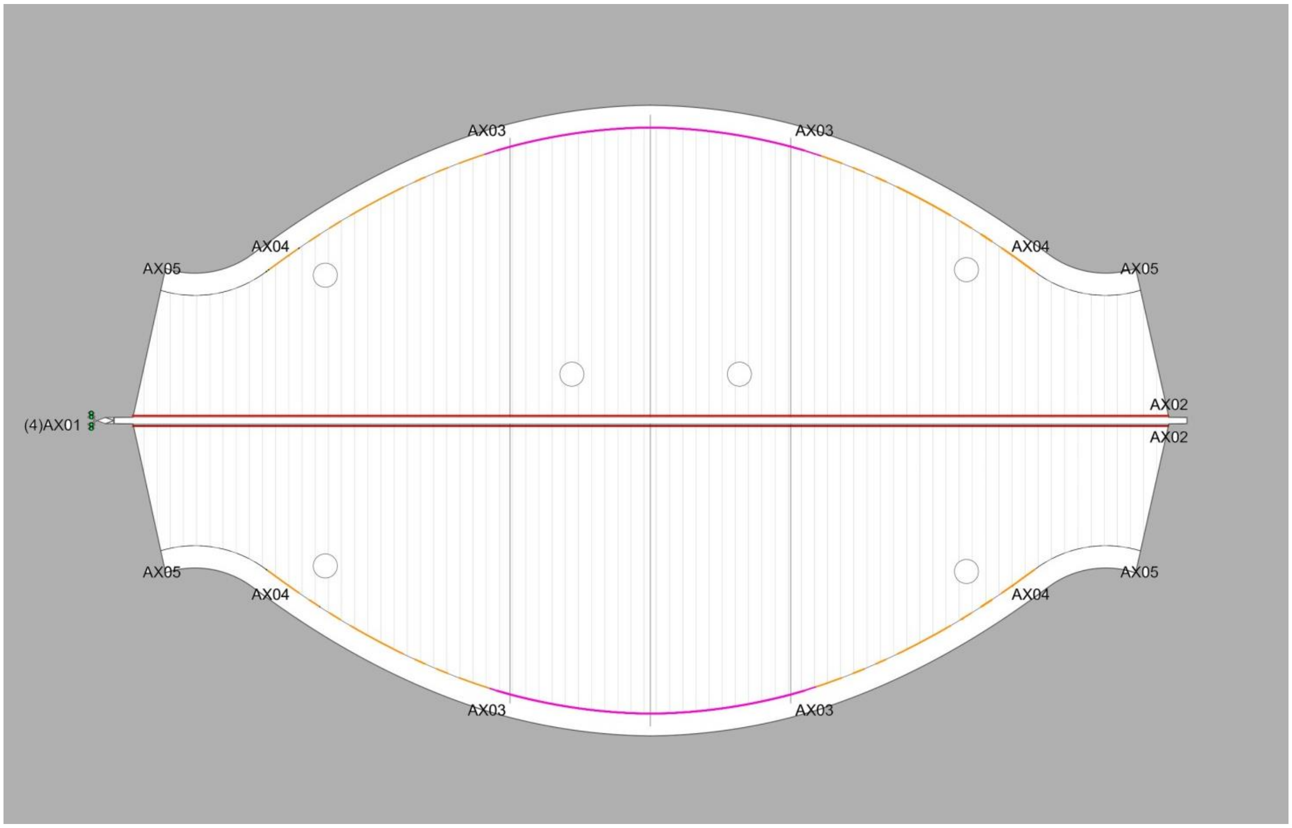


Figure 7 | Exterior Roof Lighting Plan

Fixture Schedule

Type	Luminaire	Mounting	Description	Lamps	Power	Model	Remarks
●**AX01**	Exterior Downlight	Surface	Nominal 13 3/8" D x 5 3/4"H Housing: Die-cast aluminum Lens: Clear tempered glass CRI: 78+ CCT: 4000K	LED	100W	*Lumen Pulse* LBG-277-40K-WFL-LSLH-BK-NO-TBD	UL Wet Location Listed
●**AX02**	Exterior Linear Grazing Fixture	Surface Adjustable arm 6"	Nominal 4' L x 2 7/16"W x 1 5/16"H Housing: Die-cast aluminum Lens: Clear tempered glass CRI: 78+ CCT: 4000K	LED	5W/ft	*Lumen Pulse* LOGR_ASHRAE-24V-48-40K-60x60-WAMR6-BK-DMX 1FX-CRC	UL Wet Location Listed 'Surface Mounted 20° rotated towards the spine 'DMX 1FX Dimming, Resolution per fixture

●AX03	Exterior Linear Floodlight	Surface	Nominal 4' L x 2 4/5"W x 2 7/10"H Housing: Extruded anodized aluminum Lens: Clear Polycarbonate CRI: 81 CCT: 4000K	LED	15W/ft	*Philips* 523-000080-46	UL Wet Location Listed 'reverse phase ELV-type dimmer
●AX04	Exterior Linear Floodlight	Surface	Nominal 4' L x 2 4/5"W x 2 7/10"H Housing: Extruded anodized aluminum Lens: Clear polycarbonate CRI: 81 CCT: 4000K	LED	10W/ft	*Philips* 523-000081-46	UL Wet Location Listed 'reverse phase ELV-type dimmer
●AX05	Exterior Linear Floodlight	Surface	Nominal 4' L x 2 4/5"W x 2 7/10"H Housing: Extruded anodized aluminum Lens: Clear Polycarbonate CRI: 81 CCT: 4000K	LED	5W/ft	*Philips* 523-000086-46	UL Wet Location Listed 'reverse phase ELV-type dimmer

|Performance Analysis

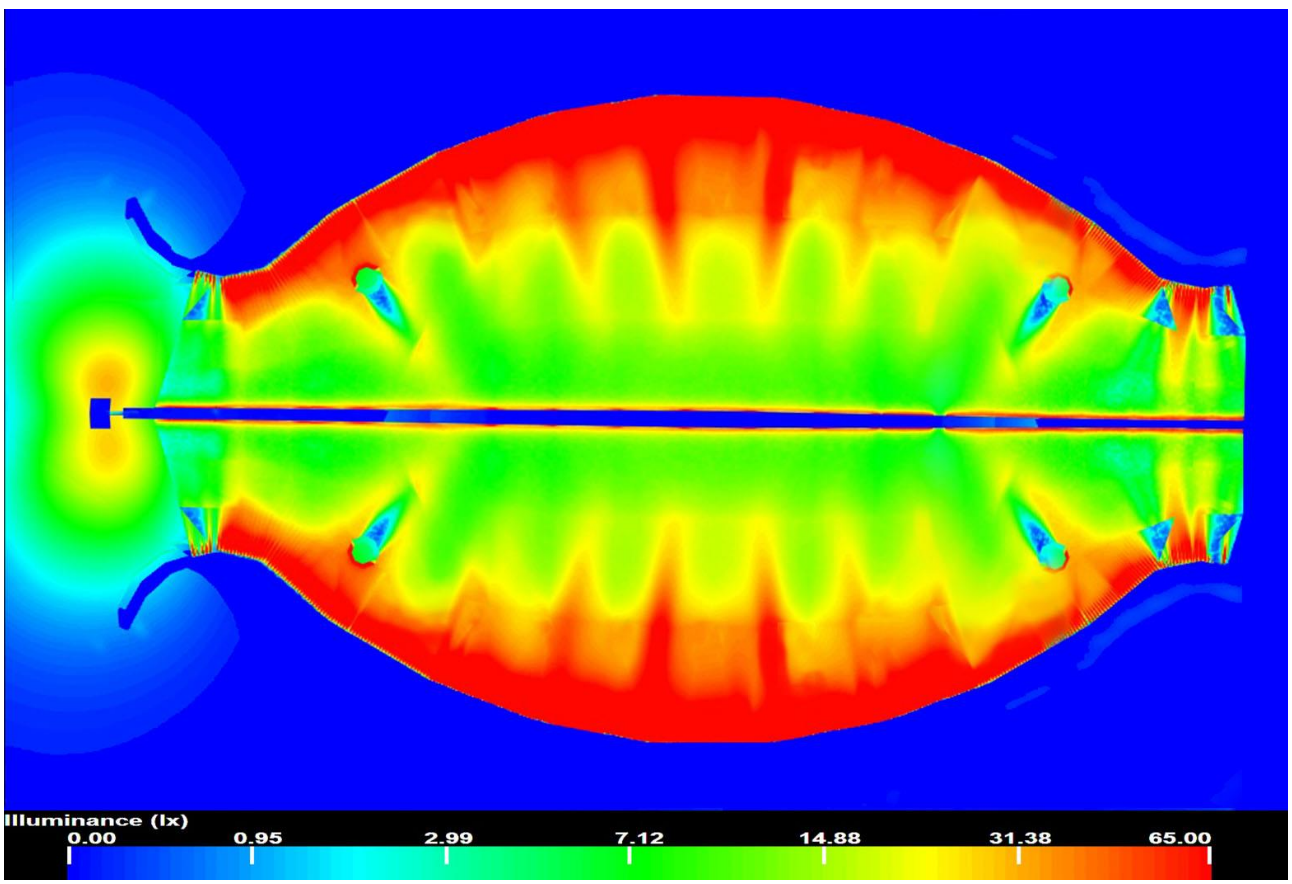


Figure 8 | Exterior Roof Pseudo Color

Illuminance Levels

Location	Avg	Max	Min	Avg/Min	Max/Min
Roof Surface	4	110	0	NA	NA
Roof Spine	50	68	26	1.92	2.62
Front Plaza	2.5	3.6	.4	6.25	9

Light Loss Factor

All light loss factors for LED fixtures are assumed to be 0.7.

Lighting Power Density

Location	Fixture	#of fixtures	$Power_{total}$(W)	Area(ft^2)	$LPD_{designed}$	$LPD_{allowed}$
	Lumen Pulse 5W LED	646	3230			
	Philips 15W LED	192	2880			
Façade/Exterior	*Philips* 10W LED	344	3440	65660	0.156	0.15
	Philips 5W LED	136	680			
		TOTAL	10230			
Front Plaza	100W LED	4	400	6667	0.060	0.16

System Evaluation

For an iconic building with long history and reputation, it is necessary to have a lighting system which emphasizes the building architecture, as well as adapt to the surrounding environment. To respect the historical importance of the building, the designed lighting system has a minimal touch to the building exterior structure. The main spine curvature is effectively highlighted by linear grazers, employing narrow beam and adjusted aiming angle to control light pollution. The dramatic curvature is again echoed on the edge of the roof, with linear flood light shining up towards half way of the sloped roof. With this design, the dramatic appearance of David S. Ingalls rink is recreated with a powerful lifting and floating effect. In the end, the curvatures are ended with a strong highlight created by high output flood light mounted inside the lighting sculpture on the building front. The historical appearance of the building in daytime is well preserved with unnoticeable fixture mounting locations.

The lighting power density is slightly above the ASHRAE Standard recommended value. This is reasonable considering the area used for lighting power density calculation is the measured area on the site plan instead of the actual curved roof surface area which would be larger. With only LED flood light fixtures located in the lighting sculpture, the front plaza is dimly lit with an average of 2.5 foot candles. The overall light level will be raised with existing façade lighting providing adequate amount of illuminance for security purposes. The retrofit LED fixture has a higher lumen output when comparing to the original induction lamp, resulting a stronger sparkle at the “whale tail”. Through appropriate lighting practices, Ingalls Rink is celebrated with natural and harmonious sense suitable to the historic site; with soft yet prominent glow and highlight to establish its prominent role as an important landmark.

|Renders

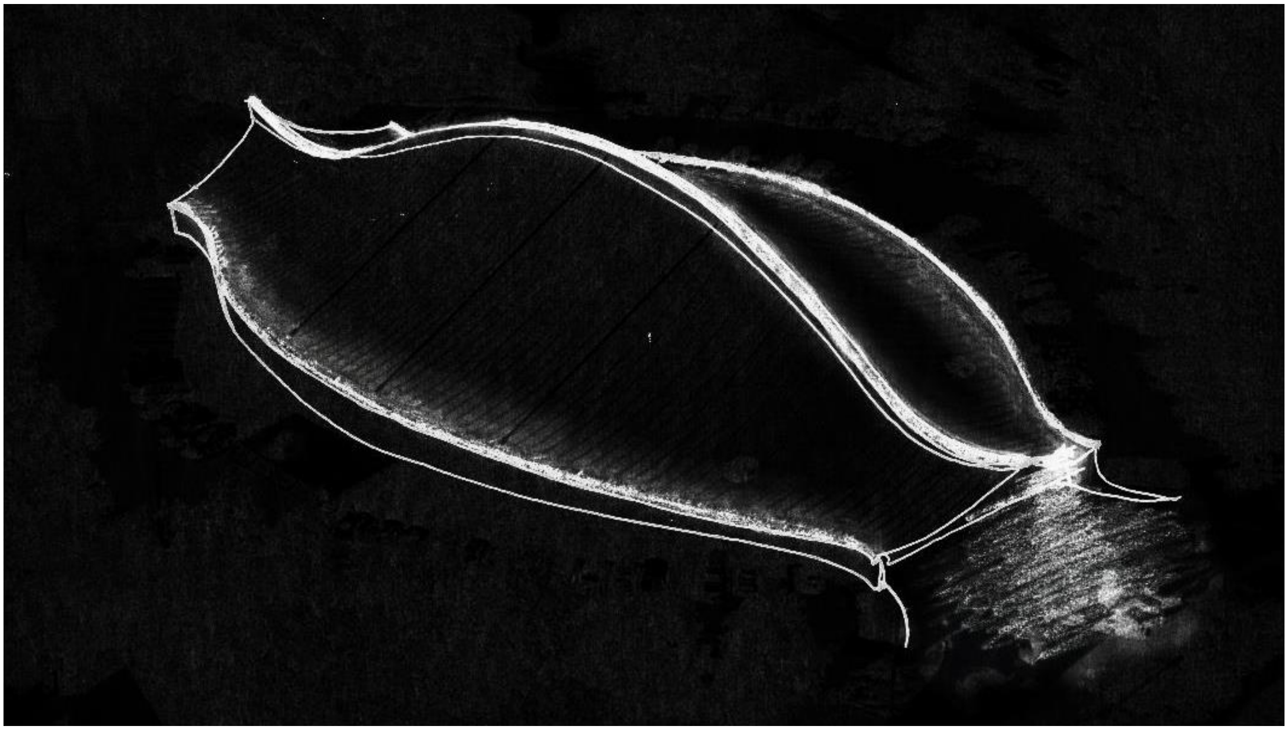


Figure 9 | Building Exterior - Initial Lighting Sketch

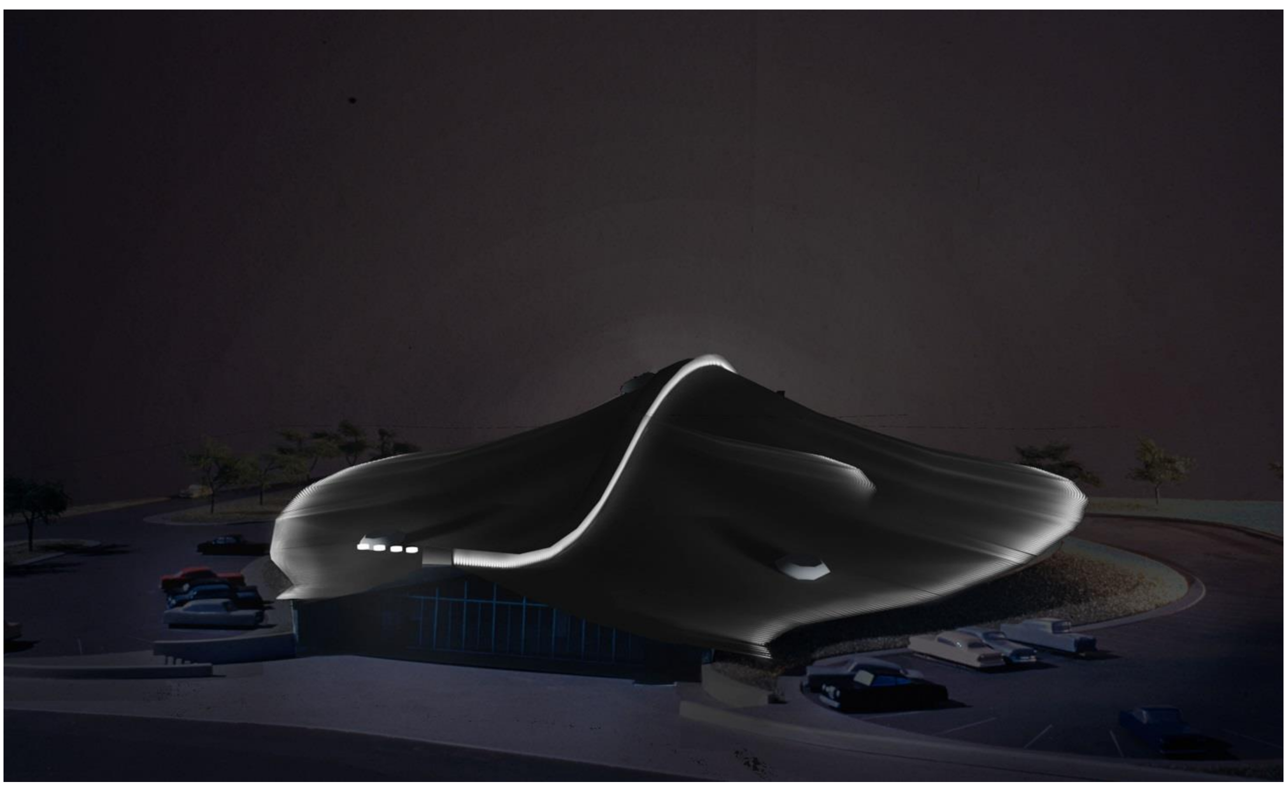


Figure 10 | Building Exterior – Perspective Rendering

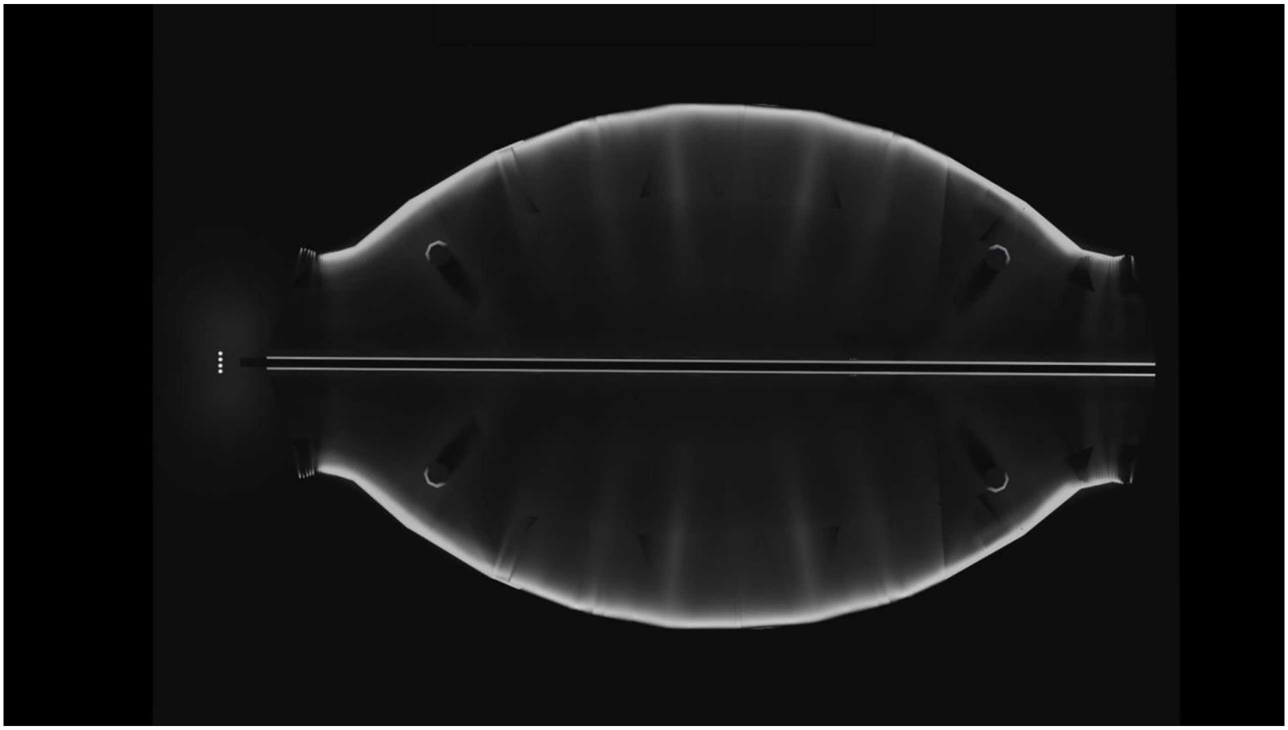


Figure 11 | Building Exterior – Top View

Lighting | Circulation Corridor

|Architectural Description

The concourse surrounds the rink and provides main circulation to the public. Building entrances are located on the east and west end, whereas seven exit doors are located on the north and south. There are a total of fifteen rows of benches, with press box located on the back row of north and south side. There are four isles each lead to the seating on the north and south and two on the east and west. During any event, public enter through the main entrance, then follow the concourse corridor to individual seats.

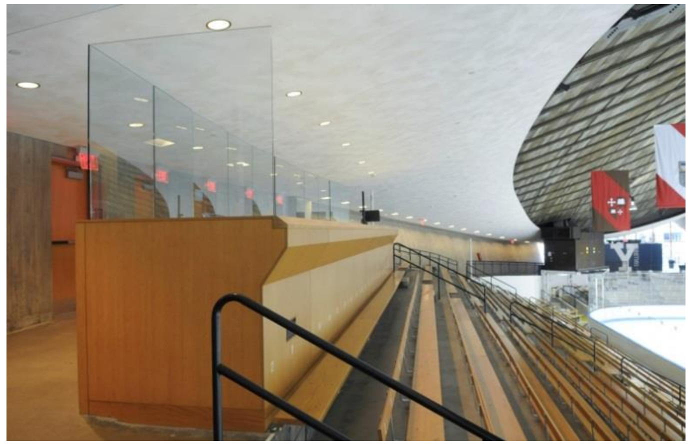


Figure 12| Press Box

Figure 13| Concourse

Geometry

Concourse Width: 8’
Isle Width: 4’
Sloped Ceiling: 10’ max
Concourse Area: 8274 SF

Material Finish

- Perimeter Corridor

Surface	Material	Reflectance
Floor	Sealed Concrete	0.2
Walls	Concrete	0.5
Ceiling	Plaster	0.8

Table 5 | Perimeter Corridor Material Properties

- Press Box

Surface	Material	Reflectance
Floor	Resilient Flooring	0.2
Walls	CMU Paint Type B	0.5
Ceiling	Painted gyp board	0.6

Table 6 | Press Box Material Properties

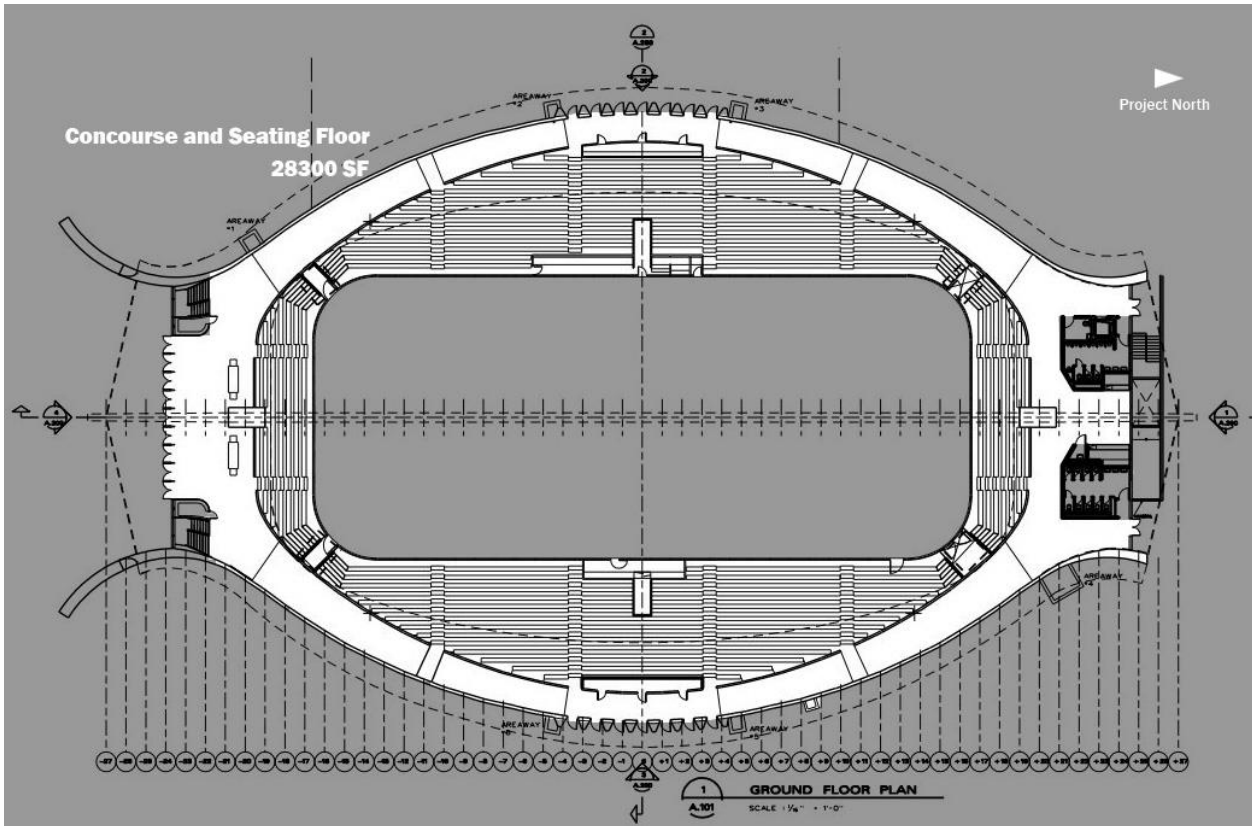


Figure 14| Ground Floor Plan – Concourse and Seating Floor

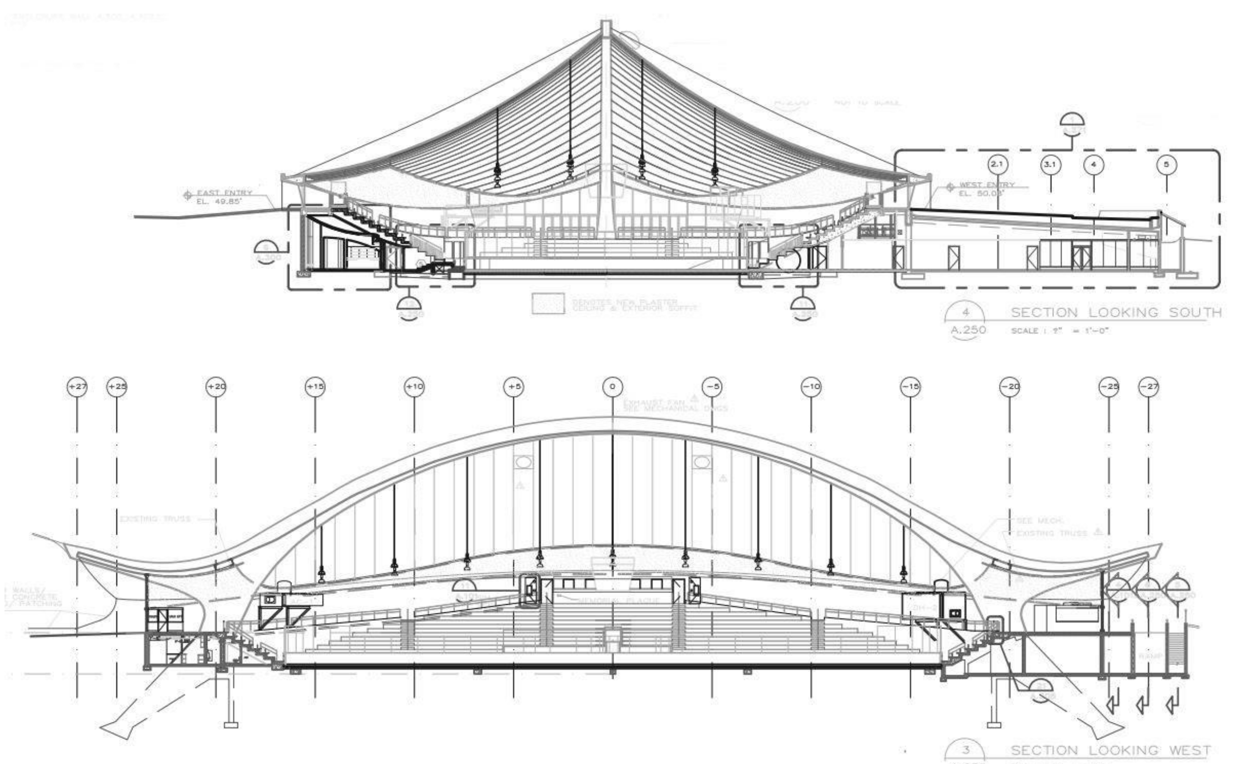


Figure 15| Building Section- Concourse and Seating Floor

|Design Consideration and Criteria

Once entering into the building, people flow into the circulation corridor. It surrounds the rink and seating area and serves its main purpose as a circulation space to direct and guide pedestrians to their point of interest. Although the whole ground floor can be considered as an open space, dropped plaster ceiling above the circulation area separates it from the rink and seating area and gives the space its own definition. The slightly sloped unfinished concrete interior walls with vertical wood patterns bring a clean and somber impression.

The circulation lighting should illuminate the walkways, defines the boundaries and provide a clean and simple rendering to the architectural concrete wall. In an effort of avoiding busy visual appearance for a narrow space, the fixture around the perimeter should provide just enough illuminance to guide audience to individual isles. Excessive light levels may lead to confusion and inconvenience since it lowers the contrast between seating floor and playfield. For a functional space as this, the lighting fixture is to disappear and unnoticeable. An evenly lit solution will serve its purpose by creating a comforting environment and embrace the slightly sloped architecture wall. Appropriate amount of illuminance should be provided on the work plane height for press box area to support reading, writing, and computer usage.

Illuminance Recommendation

- Circulation Corridors

Space Type	E_h	E_v	Avg:Min
Public adjacency passageway	avg ≥0.2 times task E_h of adjacent space or as cameras require, but with min≥10lx	avg ≥0.2 times task E_h of adjacent space or as cameras require	3:01

IES Lighting Handbook 10th Edition (Table 22.2)

- Reading and Writing

Space Type	E_h	E_v	Avg:Min
CSA/ISO types I and II Positive Polarity	300 lx	150 lx	1.5:1

IES Lighting Handbook 10th Edition (Table 22.2)

Energy Allowance

Space Type	Power Density (W/sqf)
Corridor/Transition	0.66

ASHRAE standard 90.1 – 2010 (Table 9.6.1)

|Concept Statement

The rink and seating area is harmoniously surrounded by the circulation corridor which acts as an adjoining border of the whole ground floor. If we unfold the space and look at the architectural elements individually, one eye-catching feature of this space is the vertical unfinished concrete wood pattern, just like **coral reefs**. To engage the architecture to a sense of verticality, light stripes will be projected to the floor to lead the direction for pedestrians. Linear patterns are continually carried on to the sloped concrete wall from ground up at correspond step light locations. The upwards projection of light pattern will emotionally expand the sense of dimension and increase the feeling of accessibility. By implementing one pattern on two different surfaces, the space appears connected and engaged. The moment you start to move, the light starts to move, the reef starts to move, and the space become alive and reachable.

Figure 16| Coral Reef

|System Implementation

Description

The circulation space implements step lights and in ground uplights to create vertical linear patterns on the floor and walls. *Bega* wall recessed step light are mounted to the railing base, 6' apart from each other to project bright linear stripes on the circulation floor. This pattern functions to direct and guide the pedestrians. The reflector of the fixture is adjustable 0° to 30° in 5° increments. After the angle is adjusted to the mounting position, it can be locked in place with an internal fastener. The square shape of the fixture acts to pair with the architectural spatial dynamics. *Bega* 1.5' in-ground uplights are mounted in the projected position of step light pattern on the contrary side of the floor. The upwards linear patterns extend the verticality of linear stripes on the floor and function to engage the functionality with architectural structure. In addition, the in-ground fixtures project a smooth halo on the ceiling perimeter, enhancing the overall brightness of the space. Both fixtures have a correlated color temperature of 4000K with intention of bringing up the somber and formal characteristic of concrete material.

Cree 13W LED ceiling recessed fixtures are mounted on top of the press box area. The fixture provides soft and uniform illumination to the task surface to support reading, writing and computer usage.

Lighting Plan

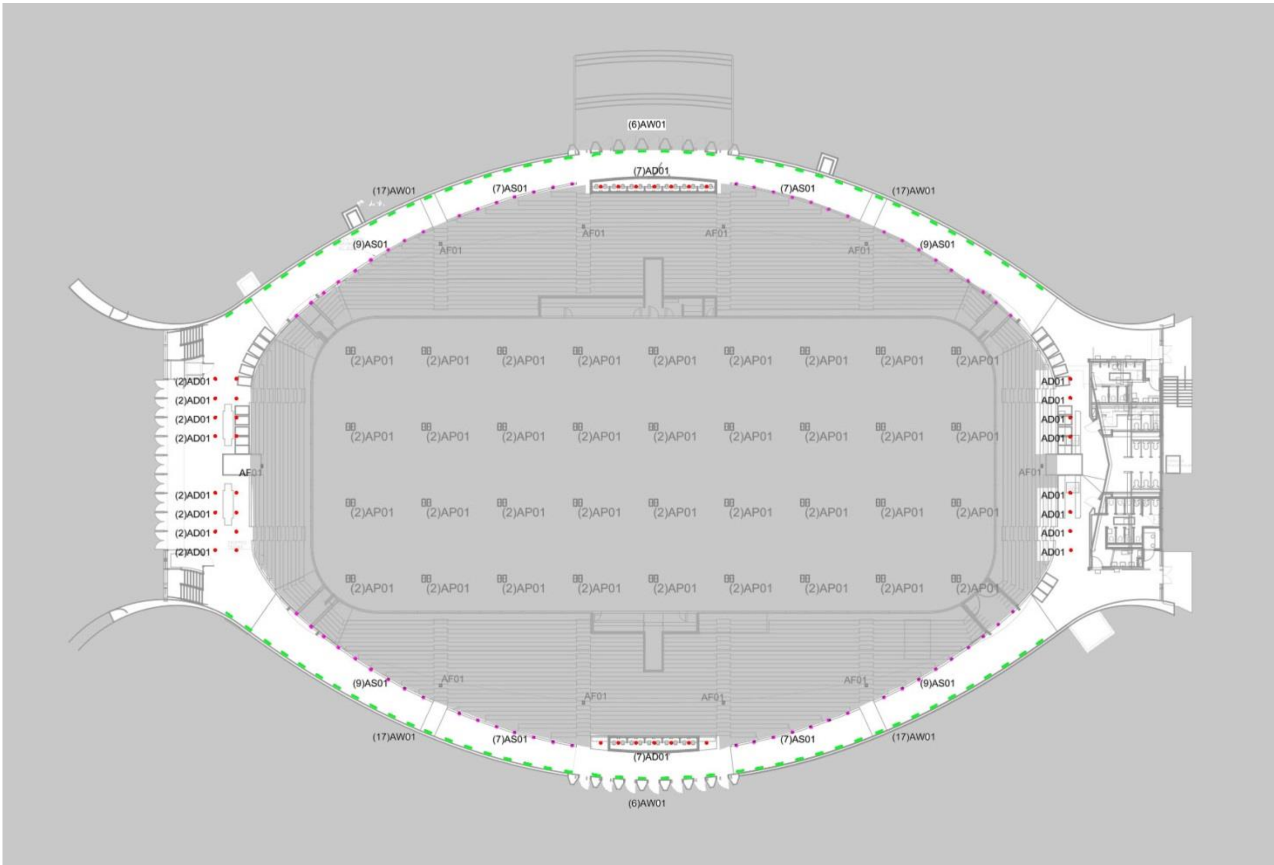


Figure 16| Circulation Lighting Plan

Fixture Schedule

Type	Luminaire	Mounting	Description	Lamps	Power	Model	Remarks
●**AS01**	Steplight	Wall Recessed	Nominal 7 1/2" L x 7 1/2"W x 5 1/2"H Housing: Die-cast aluminum Lens: Clear tempered glass CRI: 80+ CCT: 4000K	T4 GU6.5MH	20W	*BEGA* 2198 MH	adjustable optical assembly
●**AW01**	Asymmetrical Wall washer	In-ground	Nominal 20 7/8" L x 3 1/2"W x 5"H Housing: Extruded stainless steel Lens: matte tempered safety glass CRI: 80+ CCT: 4000K	LED	22W	*BEGA* 7917LED	UL Wet Location Listed

●**AD01**	Downlight	Ceiling Recessed	Nominal 5 1/4" D x 7 1/4"H Housing: Extruded anodized aluminum Lens: Clear tempered glass CRI: 78+ CCT: 3500K	LED	18W	*Cree* KR-4-9L-35-277V-10V	0-10V dimming

|Performance Analysis

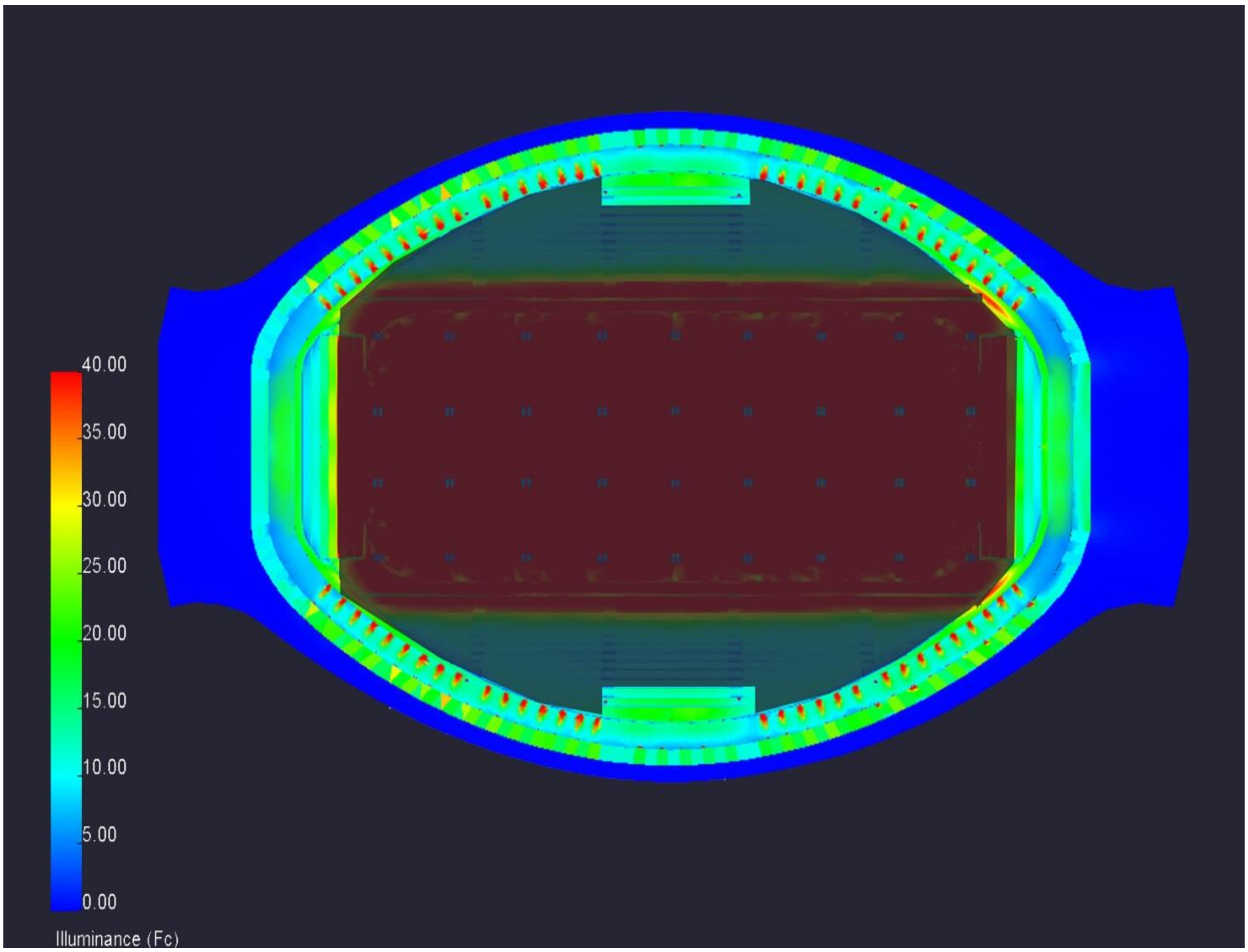


Figure 17 | Circulation Corridor Pseudo Color

Illuminance Levels

Location	Avg(fc)	Max(fc)	Min(fc)	Avg/Min	Max/Min
Circulation Floor	27.68	335	7.5	3.5	42.46
Circulation @ 5'6	10.50	12.50	5.80	1.86	2.16
Press Box	17.69	19.00	14.80	1.20	1.28
Wall (vertical)	16.9	37.70	12.80	1.32	2.95
Seating	18.72	53.80	9.50	1.97	5.66

Illuminance Levels - Emergency

Location	Avg(fc)	Max(fc)	Min(fc)	Avg/Min	Max/Min
Circulation Floor	7.53	324	1	7.53	324.4
Circulation @ 5'6	1.71	2.4	1.2	1.43	2
Press Box	1.24	1.4	1.1	1.13	1.27
Wall (vertical)	1.13	1.3	0.8	1.41	1.63
Seating	3.56	16.7	0.9	3.96	18.56

Light Loss Factor

All light loss factors for LED fixtures are assumed to be 0.7.

LLF_{MH} = LDD X LLD X BF = 0.9 X 0.95 X 1 = 0.855

Lighting Power Density

Location	Fixture	#of fixtures	$Power_{total}$(W)	Area(ft^2)	$LPD_{designed}$	$LPD_{allowed}$
Circulation Corridor	*Bega* 20W MH	70	1400	8274	0.44	0.66
	Bega 22W LED	85	1870			
	Cree 13W LED	14	182			
Press Box	*Cree* 13W LED	24	312	332		
		TOTAL	3764	8606		

System Evaluation

Overall, the lighting system in circulation corridor has successfully achieved the design goals. Step lights with adjustable optical system act as direction leaders by creating strong stripes of light on the circulation floor. The vertical pattern is then carried on from the horizontal floor to the vertical wall by use of linear in-ground uplights. The smooth vertical wash on the wall allows light to integrate with the architectural material, reinforce the formal and calm appearance of concrete. The two fixtures functioned together to give the space a new verticality expression, with adequate light levels for way finding and security camera usage. The overall uniform wash on the wall and ceiling also enhanced the overall spatial dimension. Press box and entrance area are effctively lit with LED downlights with sufficient amount of light for task performances.

The average to minimum illuminance level on the floor surface is the one design parameter that was not met to compromise the strong light stripe visual appearance. Due to the mounting height of step lights, the readings on the floor level slightly exceed the IES recommended values; however the light level at eye level appears to be uniform and achieves a visual comfortable level. The seating area adjacent to the corridor has light level of 10 fc, which is close to that of corridor to establish a smooth boundary between two spaces.

|Renders

Figure 18| Circulation Corridor – Initial Sketch

Figure 19| Circulation Corridor – Perspective Rendering

Figure 20| Circulation Corridor – Emergency Mode

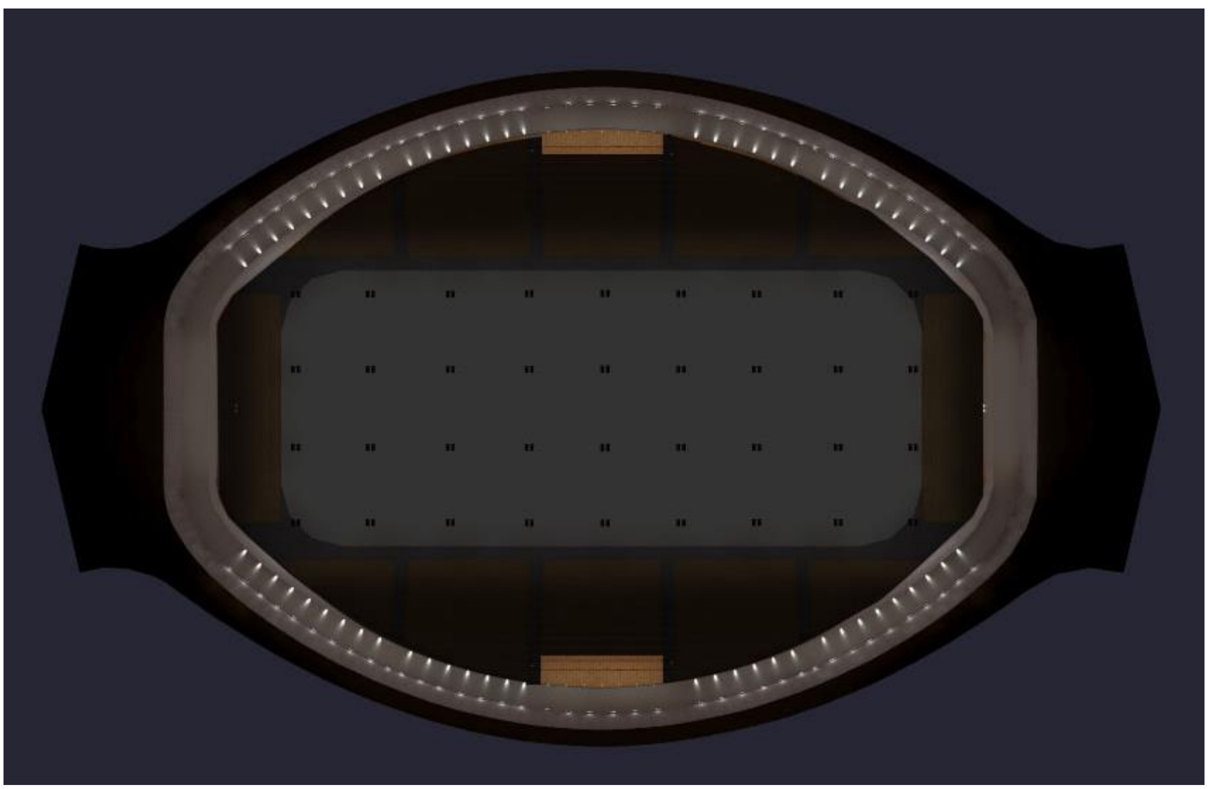


Figure 21| Circulation Corridor – Top View

Lighting | Ice Rink

|Architectural Description

With 290 feet spine and cables to support the iconic roof, the interior of the rink does not have any columns inside. The curved ceiling looks like the bottom of a boat, giving an open impression with a maximum ceiling height at 76 feet. The materials used for exterior of the building got carried inside, combined together to give a remarkable visual appearance. The arena can be used for purpose of hockey, figure skating and recreational use.

Figure 20 | Ice Rink

Geometry

Length: 200'
Width: 85'
Maximum Height: 76'
Area: 17,000 SF

Task:

- Hockey
- Recreational skating
- Figure skating
- broadcasting

Figure 21 | Ice Rink – Ceiling Detail

Material Finish

Surface	Material	Description	Reflectance
Rink Floor	Concrete	Concrete floor base with ice sheet on top	0.79
Ceiling	Oak Wood	Existing oak wood roof in dark finish	0.2
Hockey Boards	Plexi-Glass	-	0.3

Table 3 | Ice Rink Material Properties

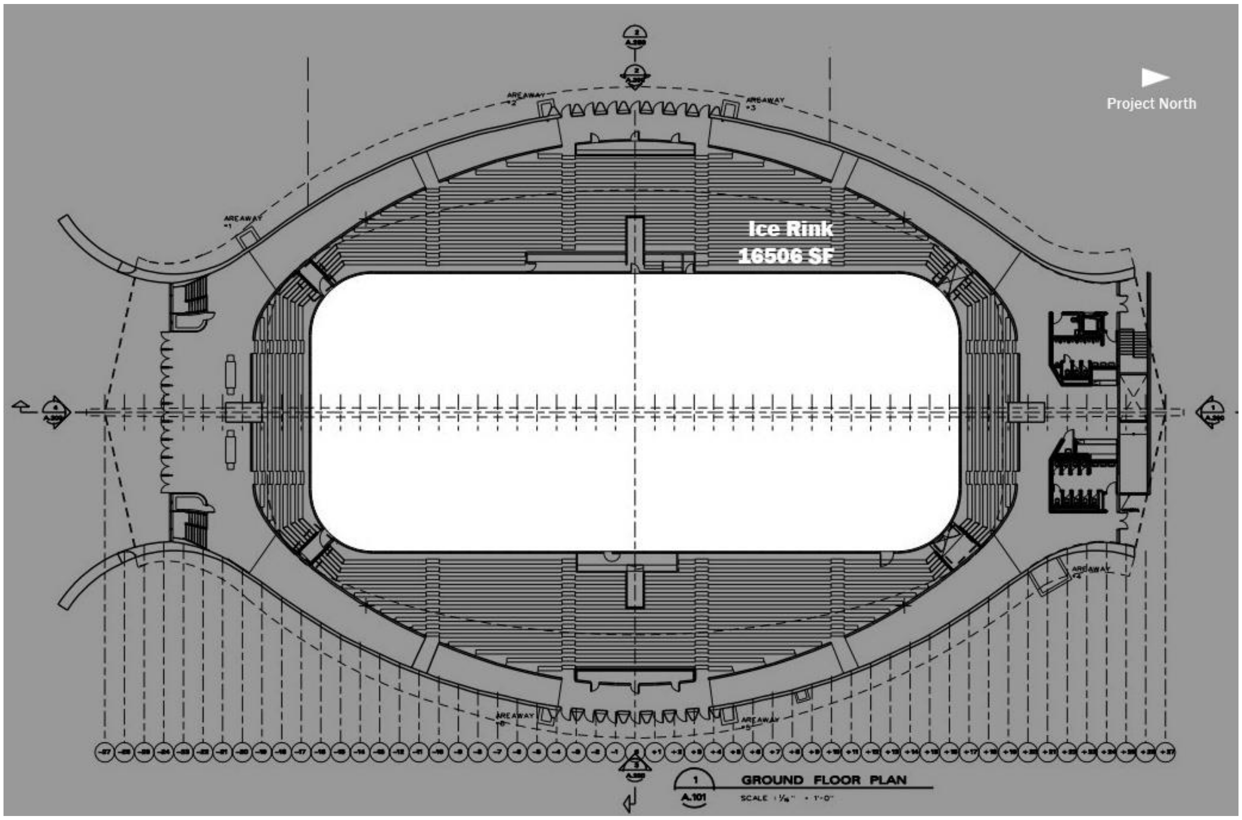


Figure 22 | Ground Floor Plan - Ice Rink

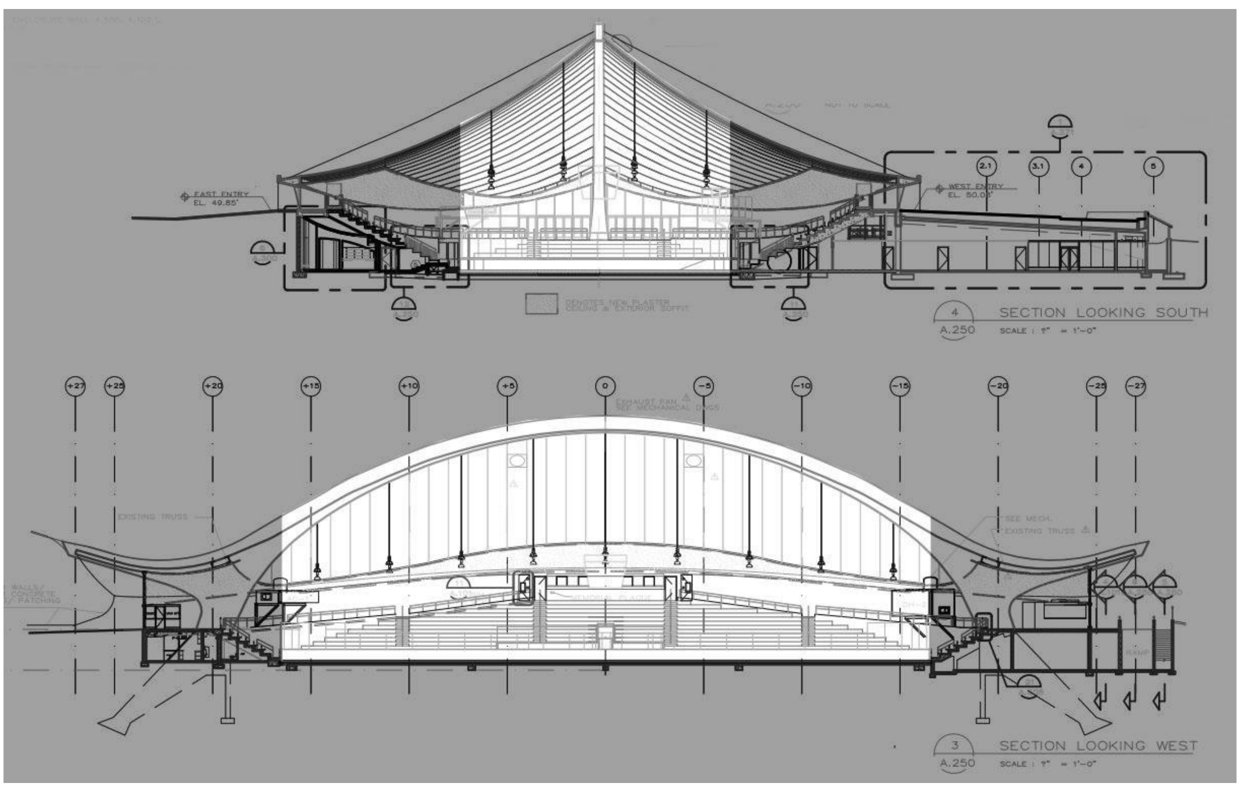


Figure 23 | Building Section - Ice Rink

|Design Consideration and Criteria

Once inside, public will immediately experience the same dramatic and harmonious design of the interior space which got carried in from outside. The two by eight oak wood ceiling with a maximum ceiling height of 70 feet provides an open impression. To enhance the visual appearance, an appropriate amount of uplight should be provided to accentuate the ceiling. Along with the aesthetic goals, lighting fixtures mounted above the ice also needs to be energy efficient since it generates large portion of radiation heat which can add to the refrigeration load. High-bay sports fixture should be specified with proper spacing and mounting height in order to achieve the desired light level and uniformity with control of direct and reflected glare issue. Typically, the ice arenas are used 18 hours per day on weekends and 12 hours per day during weekdays. Long durability is critical to efficiency and sustainability since resurfacing is required if a lamp accidentally exploded. In addition to that, the fixtures need to be impact resistant for safety consideration.

National Collegiate Athletic Association indicates that with a horizontal light level of 100 fc and uniformity of 2.5:1, the level of facility will provide standard intercollegiate play with no requirements for television broadcasts. Minimum lamp color temperature must be 3600 degrees Kelvin. Minimum color rendering index must be 65. Following the recommended best practices will help ensure quality of light needed for the safety of participants and the enjoyment of spectators.

Illuminance Recommendation

Space Type	E_h	E_v	CV_{max}	Max:Min
Ice Hockey Class II	1000 lux	300 lux	0.21	2.5:1

College Sports Facility: Class II – Competition play with facilities for up to 5000 spectators.

IES Lighting Handbook 10th Edition (Table 35.3)

Energy Allowance

Space Type	Power Density (W/sqf)
Sports Arena - Class II	1.92

ASHRAE standard 90.1 – 2010 (Table 9.6.1)

Broadcast

Facility Type	E_h	Horizontal Uniformity	Typical Seating	Pole Position
Intercollegiate Play (no broadcast)	1000 lx	2.5:1	N/A	N/A

Note: New Lighting System designs are recommended to use 0.7 recoverable Light Loss Factor.

NCAA Best Lighting Practices

|Concept Statement

Inspiration of the rink area comes from the overall lighting concept and skaters. Considering figure skaters with flowing movements like beautiful fish, or hockey players with speed like sharks, the design of rink lighting is intended to create a playground for the those who habitat inside the building. Since the rink is sorrounded by the circulation corridor, it is like the **Ocean** area that is sorrounded by coral reefs. Uniform illumination will be provided to sports function for hockey players, whereas more romance will be created on the ice surface for figure skaters during performance events. Strong vertical stripes will be projected upwards towards the ceiling, like sun strokes shining through the water surface, adding the sense of dimension by playing with the sense of space.

Figure 24 | fish + shark

|System Implementation

Description

The rink lighting design consists of a series of high performance LED pendants and narrow beam spread flood light. The new LED pendant system are suspended from building ceiling with steady Gripple Y-fit hangers. With a 22' spacing in both x and y cartetian directions, pairs of *Philips GentleSpace* 267W high bay LED fixtures provide uniform distribution on the ice surface for sports purpose. The mounting height varies in 3 feet with the purpose of reducing the variance of light level between center and edge of the ice surface ; on the other hand, ,the variance in mounting height complements the flow of ceiling curvature. *LumenPulse* 50W LED floodlight with narrow beam will be used to create linear patterns to further engage the sense of dimension and accentuatue architectural wooden ceiling with minimum distractions to the activities. By directing the view with the direction of light flow, floodlights mounted on ceiling perimeter further expand the ceiling towards the sky, enhancing the volume of the whole arena.

Temporary theater fixtures with colored gels and gobos will be used to accentuate the ice surface for figure skating performances and special events. Chain motors are installed on the ceiling surface to allow temporary truss lifing. Conventional moving light will be used to project soft wash on the ice surface, whereas profile theater fixtures will be used with adjustable edge and gobo to provide special accents. All fixture wires will run to the temporary dimmer rack located in a secure location.

Lighting Plan

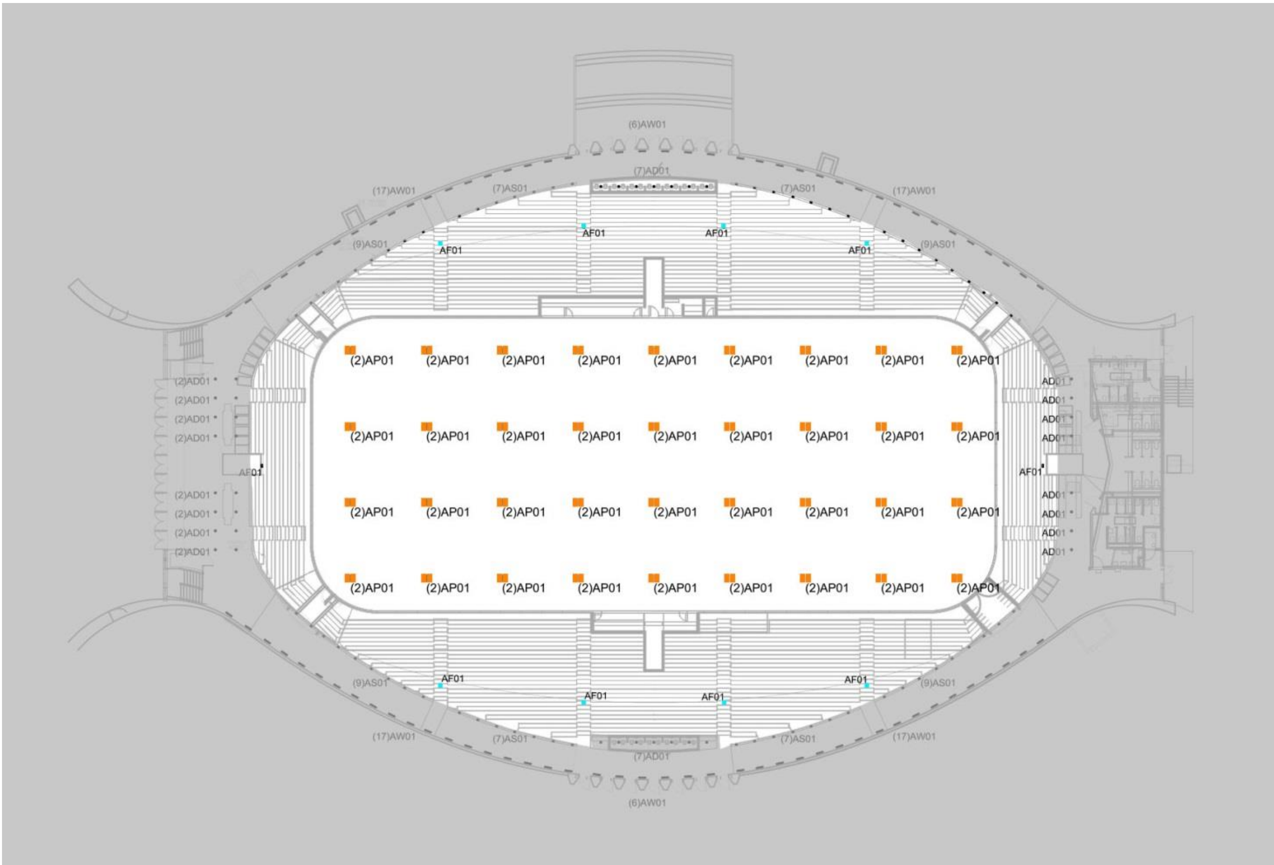


Figure 25 | Building Section - Ice Rink

Fixture Schedule

Type	Luminaire	Mounting	Description	Lamps	Power	Model	Remarks
●**AP01**	Downlight	Pendant	Nominal 2' L x 1'W x 4"H Housing: aluminum Lens: Polymethyl methacrylate CRI: 76 CCT: 4000K	LED	267W	*Philips* BY461P LED240S/740 PSD WB GC SI MB	Suspension accessory: Mounting bracket
●**AF01**	Floodlight	Surface	Nominal 10 1/8" D x 4 3/4"H Housing: Die-cast aluminum Lens: Clear tempered glass CRI: 78+ CCT: 4000K	LED	50W	*Lumen Pulse* LBL-120/277-40K-VN-SI-DIM-SY	adjust aiming angle to match the ceiling slope

|Performance Analysis

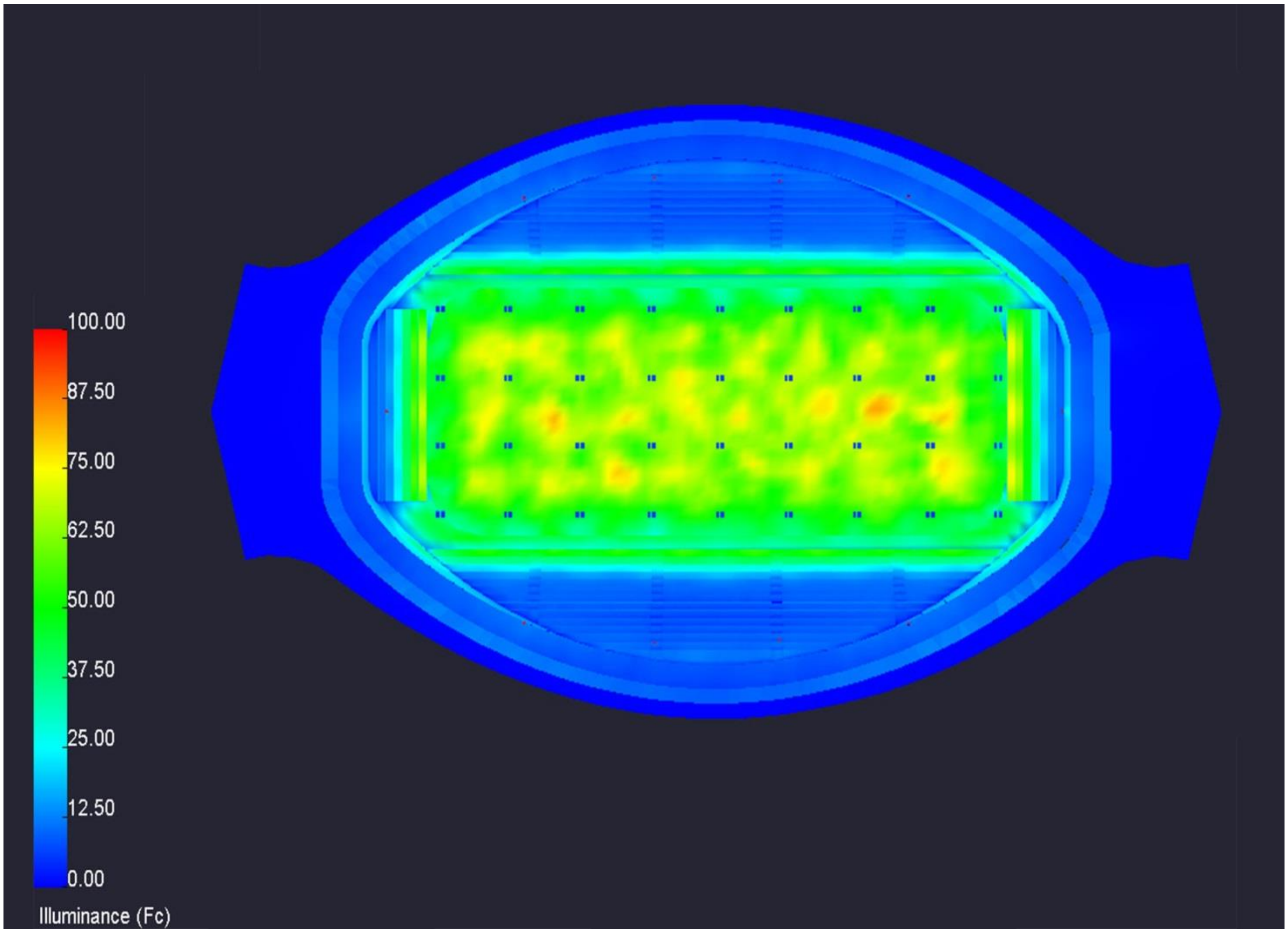


Figure 25 | Ice Rink Pseudo Color

Illuminance Levels

Location	Avg	Max	Min	Avg/Min	Max/Min
Rink	95.85	125	61.90	1.55	2.01
Seating	18.72	53.80	9.50	1.97	5.66
Ceiling	19.34	60.50	9.50	2.04	6.37

Light Loss Factor

All light loss factors for LED fixtures are assumed to be 0.7.

Lighting Power Density

Location	Fixture	#of fixtures	$Power_{total}$(W)	Area(ft^2)	$LPD_{designed}$	$LPD_{allowed}$
Rink	*Philips* 267W LED	72	19224			
	Lumen Pulse 56W LED	10	560	17000	1.16	1.92
		TOTAL	19784			

System Evaluation

The designed rink lighting system with (72) 267W *Philips* High Bay LED fixture paired in 36 locations effectively creates a uniform distribution of illuminance on the playing surface. Besides the extraordinary lamp performance characteristics such as effective heat dissipation, lamp efficiency and long life span, the new LED system also provides equivalent light level with **30%** lower power output comparing to the original Metal Halide. At a decreased lumen output, the LED light may remain operational for a long time, in the meantime generates less heat to the surrounding atmosphere, which can make a great difference to the system refrigeration load. According to NCAA lighting performance checklist for Collegiate Ice Hockey Arena, the calculation grid are created with a size of 14' by 14' in the simulation tool to allow accurate readings. The design met both illuminance and power density criteria from IES and ASHRAE Standard, providing adequate amount of illuminance to support the activities such as hockey games, figure skating and recreational usage. Reflected light from ice surface successfully brightens up the curved wood ceiling with average light level of **20 fc.** *Lumen Pulse* dimmable spotlight are positioned on top of audience walking isles, projecting vertical linear patterns on the roof to further accentuate the ceiling. All fixtures are dimmable to accommodate the variety of events.

Permanent chain motors are installed at different locations on the ceiling to allow theatrical truss mounting for the figure skating performance and special event purposes. Since the overall ceiling height reaches 76 feet on the zenith, the size of chain motors is negligible considering overall clean ceiling appearance.

|Renders

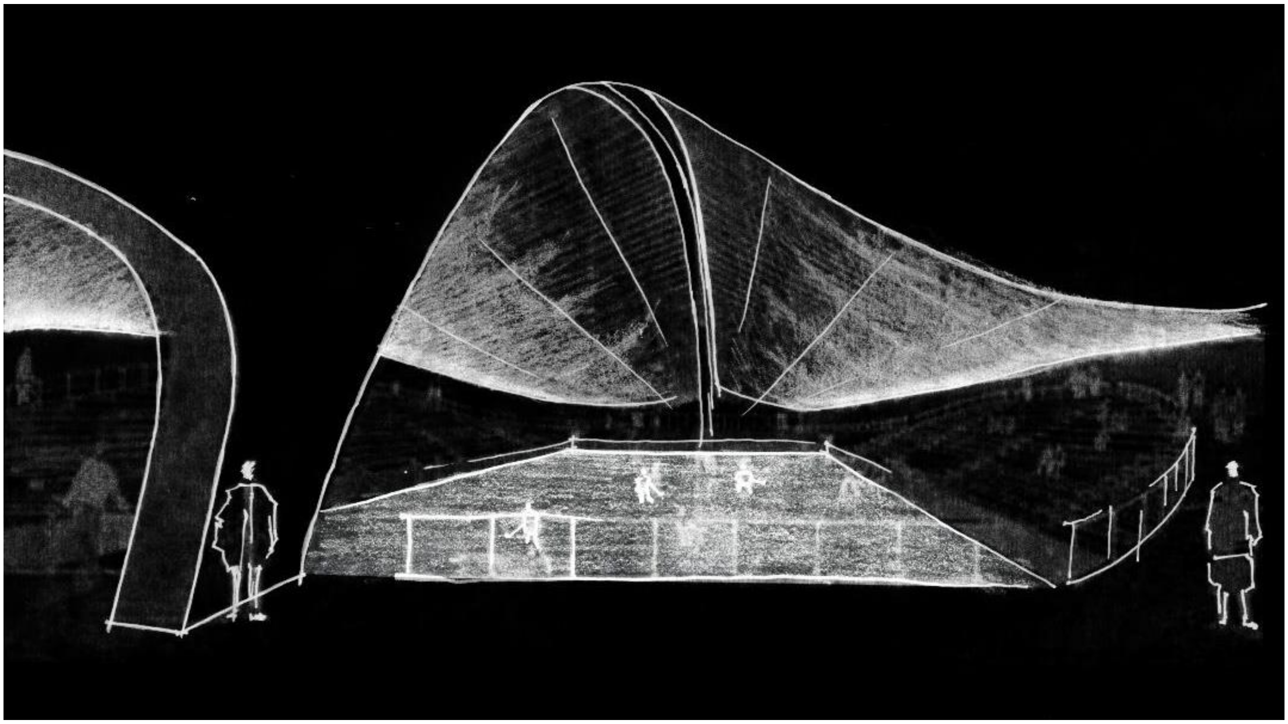


Figure 25 | Ice Rink – Initial Sketch

Figure 26 | Ice Rink – Perspective Rendering

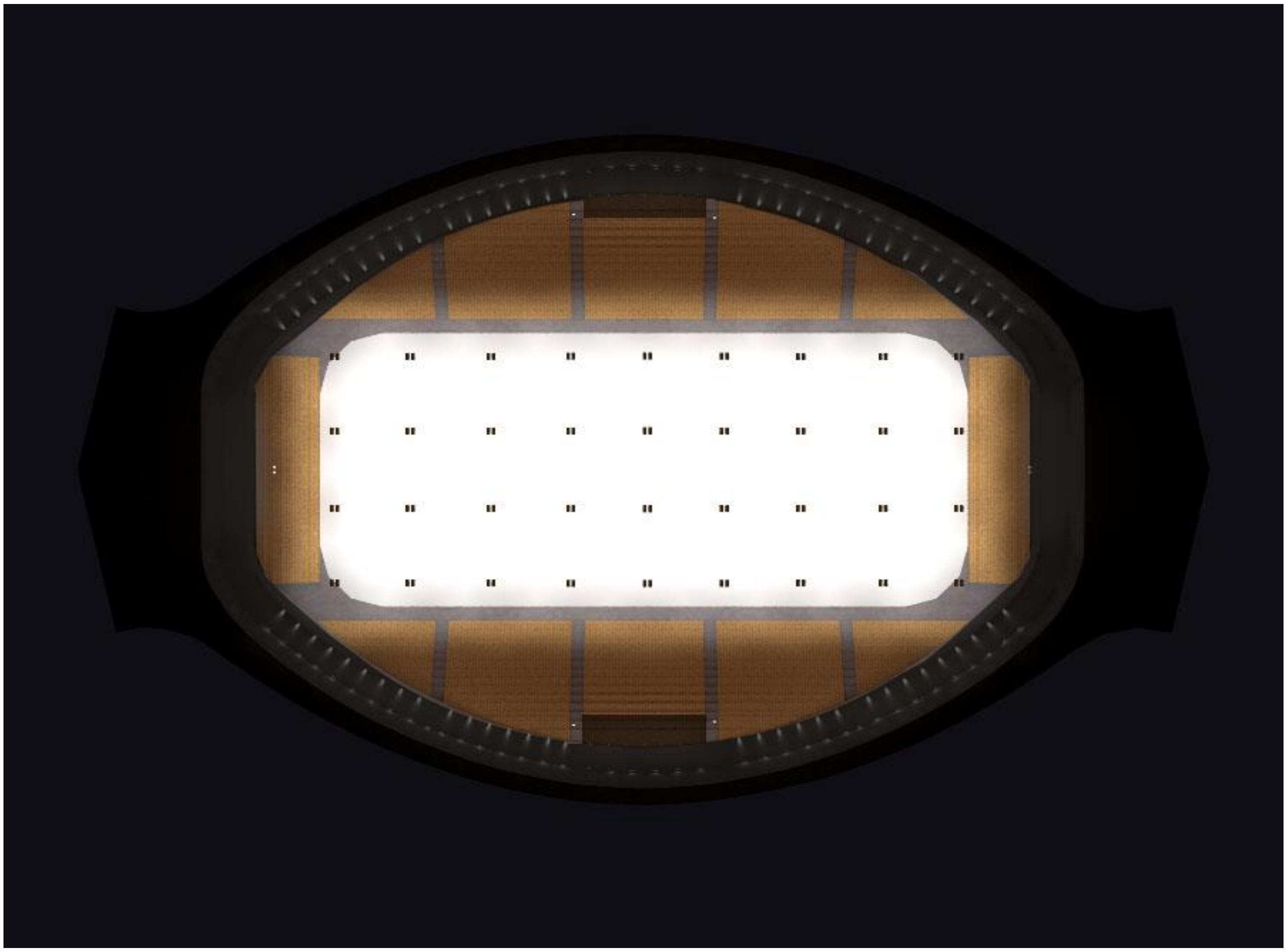


Figure 27| Ice Rink Rendering – Top View

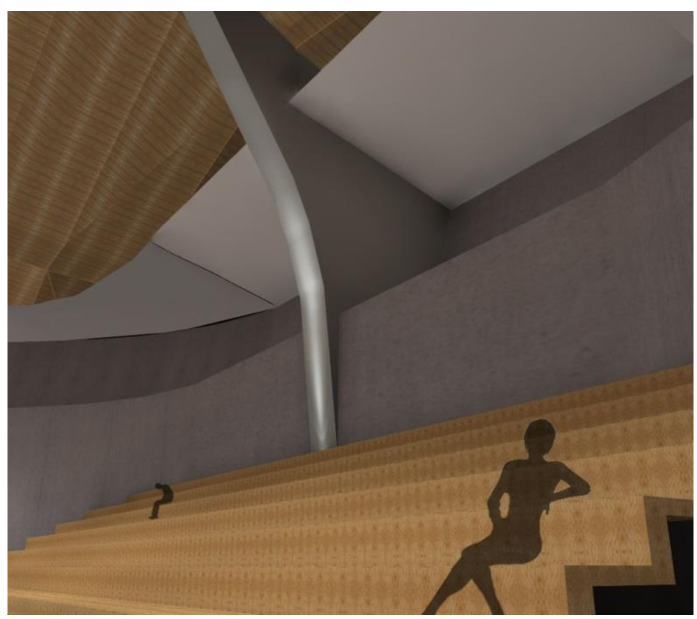


Figure 28| Ice Rink – Spine Detail

Lighting | Schley Memorial Club Room

|Architectural Description

The Schley Memorial Club Room provides an intimate atmosphere for visitors to sit and rest. There are display cases and timeline photos spanned across the entire wall highlighted by wall mounted accent fixtures, telling the story of Yale hockey history dated back to 1895. This space will be designed to give a lighting solution with unique psychological reinforcement. The room locates directly below the seating area on building south. The original room had an exposed ceiling, whereas the renovation added a new customized wood ceiling to enhance the welcome environment and adds warmth to the room.

Figure 29 | Schley Memorial Club Room Original

Geometry

Length: 77'
Width: 22'
Height: 14' max

Figure 30| Schley Memorial Club Room

Material Finish

Surface	Material	Reflectance
Floor	Carpet Type B1&B2	0.2
Walls	Painted Gyp Board	0.6
Ceiling	Plaster	0.8
	Custom Wood Panels	0.4

Table 8| Schley Memorial Club Room Material Properties

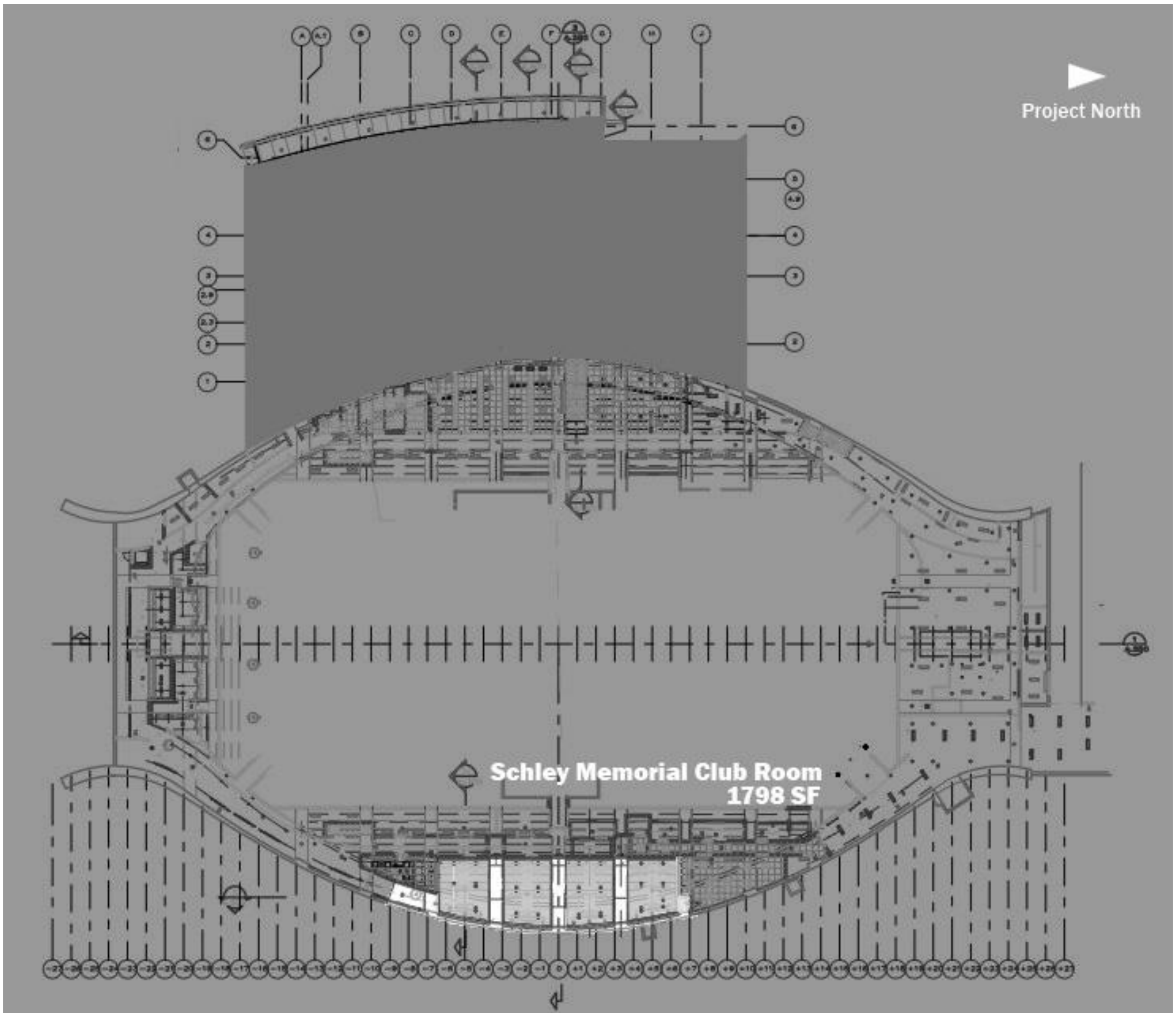


Figure 31 | Basement Floor Plan – Schley Memorial Club Rom

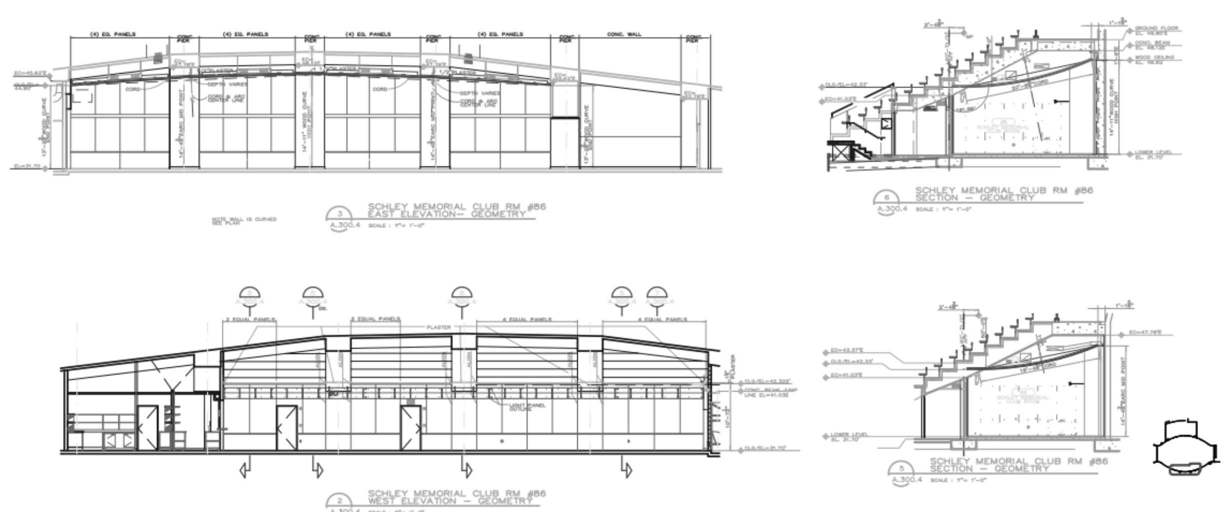


Figure 32| Building Section- Schley Memorial Club Room

|Design Consideration and Criteria

The multi-functional Club Room is used for socialization and display. It is important to create focal point on art works and timelines with aiming strategy on each side of north and south to emphasis the significance of the historical building. The general seating area should have a lower illuminance compared to the timeline/art display in order for it to appear dramatically lit. The light levels should also appear balanced for seating area to create a comforting atmosphere. Across the space, ambient illumination can be added to the sloped customized wood ceiling panel, which helps creating a comforting atmosphere and resembles an upscale lounge. This space is designed and studied with progress based off from John Flynn's psychological mode. A private impression will be achieved with contrast in light levels and the use of brightness and shadows.

Illuminance Recommendation

- Club Room

Space Type	E_h	E_v	Avg:Min
Social/Waiting Areas	100	30	3:1

IES Lighting Handbook 10th Edition (Table 22.2)

- Timeline Display

Attraction	Role	Illuminance Ratio	Application Notes
Moderate	Feature	5:1 focal point to task	Used on focal points or features for visual interest. Long-term exposure may fade-degrade focal. Focal plane may be different from takes plane.

IES Lighting Handbook 10th Edition (Table 15.2)

Energy Allowance

Space Type	Power Density (W/sqf)
Multipurpose	1.23

ASHRAE standard 90.1 – 2010 (Table 9.6.1)

-Accent lighting

Accent lighting is necessary in many situations.it can address some spatial and psychological factors and establish boundaries of space without the visual monotony and equipment.

-Display

The circulation/general purpose space lighting should have a lower light level compared to the display to establish the strong contrast, dramatically illuminate the space.

|Concept Statement

After **diving** through the ocean surface, swimming past the **coral reefs** in the **ocean**, you get to the **deep ocean floor**, which is the Schley Club Room located in the lower level. To impement the private psychological impression, the ligthing design of this space tends to use the contrast between light and shadow and layers of light to contribute to the overall quiet and enclosed sense of deep ocean. Recessed downlight will be mounted on the ceiling to give a uniform distribution of light on the floor, whereras adjustable spotlight will be used to give highlight on the wall mounted timline artworks. Curved ceiling will be grazed up in the direction of the elevated slope, giving a sense of extention.

Figure 33| Deep Ocean Floor

|System Implementation

Description

Schley Club Room implements three different types of fixtures to create layers of light. *Cree* 4'' ceilling recessed downlights are used to provide smooth and ambient light level on the floor. In contrast, *WAC Lighting* 6" x 6" adjustable ceiling recessed spot light mounted 4 feet away from the wall creates bright scallop patterns on timeline photos. The sloped wooden ceiling panels are accentuated using the same lighting approach as the concrete walls in circulaiton areas – with linear *Lumen Pulse* adjustable linear fixtures to graze it up. This approach allows an extention of eyesight, which leads to an expansion of the space dimension. These grazer fixtures will be concealed to prevent direct glare which may lead to visual discomfort. All fixtures are dimmable in order to cordinate with the presentation, special event and social interaction purposes.

The overall private psychological impresseion is achieved by layers of light with different brightness. Upon entering into the space, the bright spots on the wall surface directly attracts attention to the most important historical timeline feature. Inaddition, the wooden architectural ceiling is smoothly grazed by the linear fixtures towards the slope top. Lastly, ambient illuminacce on the fllor surface provides the overall comfattable and calm atomosphere.

Lighting Plan

Figure 34 | Schley Club Room Lighting Plan

Fixture Schedule

Type	Luminaire	Mounting	Description	Lamps	Power	Model	Remarks	Location
●AD01	Downlight	Ceiling Recessed	Nominal 5 1/4" D x 7 1/4"H Housing: Extruded anodized aluminum Lens: Clear tempered glass CRI: 78+ CCT: 3500K	LED	13W	*Cree* KR-4-9L-35-277V-10V	0-10V dimming	Schley Club Room
●AD02	Spotlight	Ceiling Recessed	Nominal 6 3/4" L x 6 3/4"W x 6"H Housing: Die-cast aluminum Lens: TBA CRI: 85 CCT: 3500K	LED	11W	*Wac Lighting* MT-LED118-S-35HS-WT	ELV dimmer	Schley Club Room

●AG01	Linear Grazing Fixture	Surface	Nominal 48 3/4" L x 6 3/4"W x 6"H Housing: Extruded aluminum Lens: Clear tempered glass CRI: 85 CCT: 3500K	LED	6W/ft	*Lumen Pulse* LCSRO-277-48-35K-CL-RF-WH-DIM	0-10V dimming	Schley Club Room
●AG01 (a)	Linear Grazing Fixture	Surface	Nominal 12 3/4" L x 6 3/4"W x 6"H Housing: Extruded aluminum Lens: Clear tempered glass CRI: 85 CCT: 3500K	LED	6W/ft	*Lumen Pulse* LCSRO-277-48-35K-CL-RF-WH-DIM	0-10V dimming	Schley Club Room

|Performance Analysis

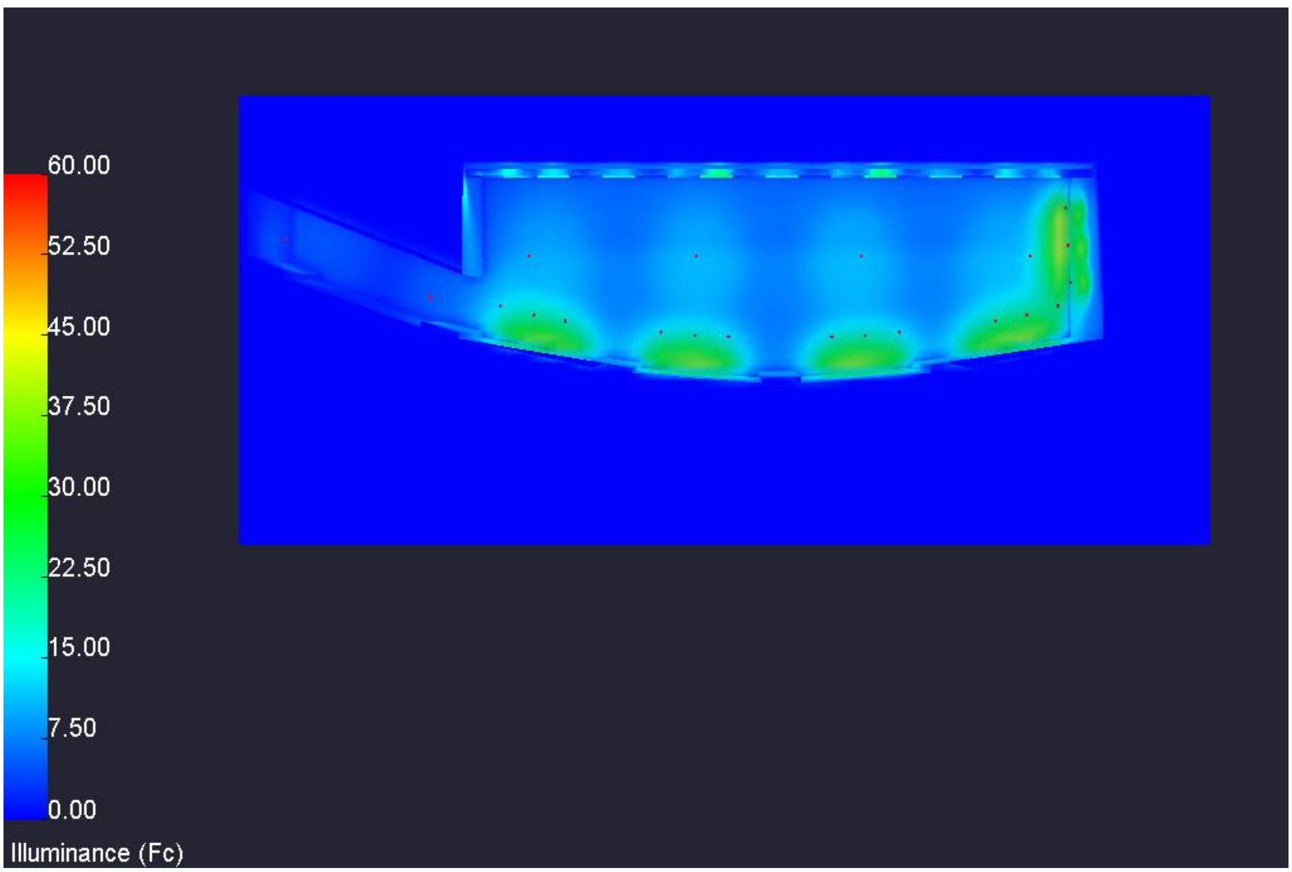


Figure 35 | Schley Club Room Pseudo Color

Illuminance Levels

Location	Avg	Max	Min	Avg/Min	Max/Min
Floor	95.85	39.70	4.90	2.60	8.10
Wall	11.84	26.60	2.70	4.39	9.85
Ceiling	20.96	150	1.5	13.97	100

Light Loss Factor

All light loss factors for LED fixtures are assumed to be 0.7.

Lighting Power Density

Location	Fixture	#of fixtures	$Power_{total}$(W)	Area(ft^2)	$LPD_{designed}$	$LPD_{allowed}$
Schley Memorial Club Room	*Cree* 13W LED	6	48	1754	0.38	1.23
	Wac Lighting 11W LED	15	165			
	Lumen Pulse 6W LED	77	462			
		TOTAL	675			

|System Evaluation

The designed lighting system for schley club room successfully establish the private impression through strong contrast betwee light and shadow while providing adequate amount of light for social interaction. Adjustable spot light cast storng scallop patterns on the timeline artworks with 26fc on the focal point center. The linear grazer mounted on the lower side of the sloped ceiling panel projects a smooth gradient of light on the wood to extend the spacial dimension with a light level slightly lower than the timeline focal point.

Size and shape of ceiling recessed downlights are carefully selected to ensure minimal apperance on the wooden panels. When entering into the space, occupants are able to distinguish the importance between each feature in the room, without noticing the exsitance of lighting fixtures. In the meantime, overall space will be illuminated uniformly with recommended light levels for social interaction to create a comforting environment.

|Renders

Figure 36 | Schley Club Room – Initial Sketch

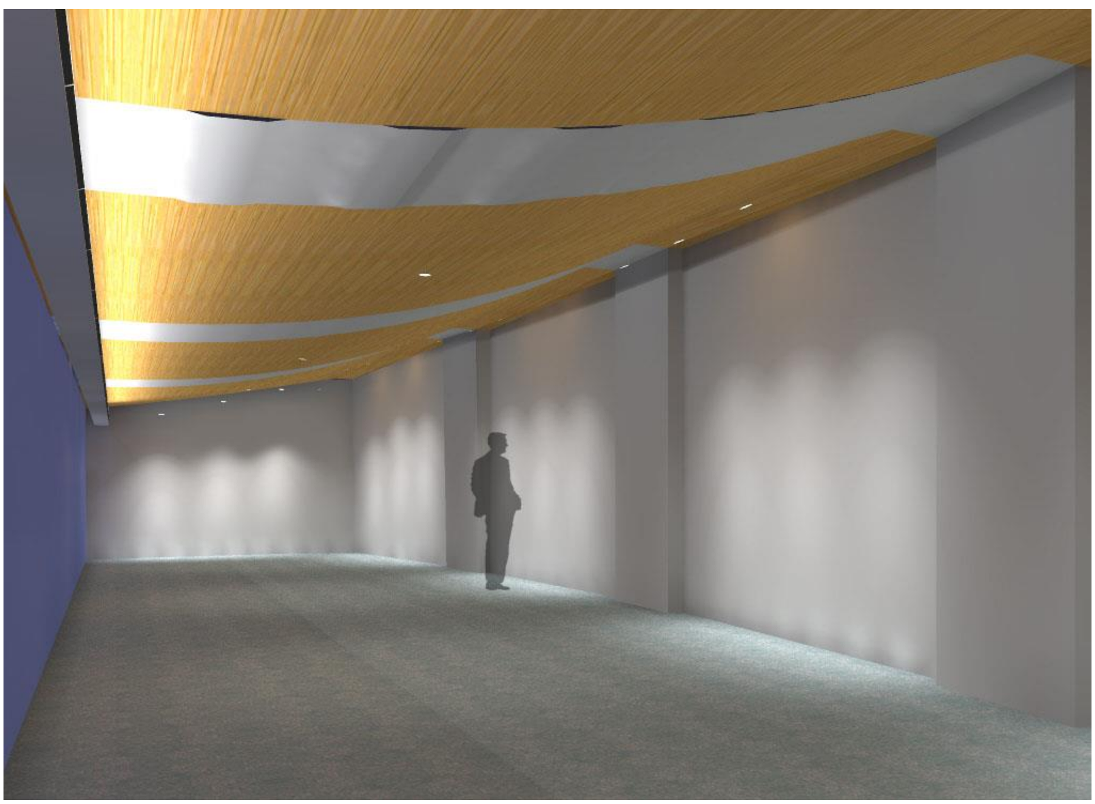


Figure 37 | Schley Club Room – Perspective Rendering

Electrical Depth

|Introduction

Three topics were selected for analyzing the exisitn g building electrical system. Branch circuit analysis was performed by replacing new designed lighting fixtures with the original fixutres on the panel board schedule. The overall voltamps for each new panelboard was calculated to evaluate the possibilities of feeder upsizing. The second analysis contains short circuit analysis between primary/secondary transformers and switchboards. Following procedures of Cooper Bussman short circuit analysis, fault current protection of selected five points in the electrical diagram was calculated and compared to the existing switchboards Amperes Interuption Current rating. Lastely, a cost estimation was performed to evaluate the benefit of replacing copper wires with aluminum regarding construction and material budget.

Electrical I | Branch Circuit Analysis

Existing Panelboard Schedule

Highlighted in red are lighting loads that are taken out based on the adjustments made to the original lighting design. Adjusted spaces include Rink, Circulation, exterior, and team lounge.

	480 Y/277V 42K AIC 3Ø-4W				LP-N								BUS: 100 AMP MAIN: 100 AMP CB		
	LOAD SERVED	WIRE SIZE	TRIP	POLE	LOAD IN kVA ØA		ØB		ØC		POLE	TRIP	WIRE SIZE	LOAD SERVED	
1	Lower Level Lighting	2#12+G- 3/4"C	20	1	1.52	0.69					1	20	2#12+G- 3/4"C	Upper Level Bathrooms	2
3	SPARE	2#12+G- 3/4"C	20	1			0.00	0.30			1	20	2#12+G- 3/4"C	North Entrance Lighting	4
5	Exterior South Lighting	2#12+G- 3/4"C	20	1					0.50	0.50	1	20	2#12+G- 3/4"C	Interior South Lighting	6
7	Pole Lighting	2#12+G- 3/4"C	20	1	2.03	1.58					1	20	2#12+G- 3/4"C	Pole Lighting	8
9	Ramp Lighting	2#12+G- 3/4"C	20	1			0.50	0.47			1	20	2#12+G- 3/4"C	South Lower Lighting	10
11	South Lower Lighting	2#12+G- 3/4"C	20	1					2.49	3.33	1	20	2#12+G- 3/4"C	West Lighting	12
13	West Lighting	2#12+G- 3/4"C	20	1	2.99	1.47					1	20	2#12+G- 3/4"C	Team Lounge	14
15	Time Clock	2#12+G- 3/4"C	20	1			0.50	4.14			1	20	2#12+G- 3/4"C	Schley Room	16
17	SPARE		20	1					0.00	0.00	1	20		SPARE	18
19	SPARE		20	1	0.00	0.00					1	20		SPARE	20
21	SPARE		20	1			0.00	0.00			1	20		SPARE	22
23	SPARE		20	1					0.00	0.00	1	20		SPARE	24
25	SPARE		20	1	0.00	0.00					1	20		SPARE	26
27	SPARE		20	1			0.00	0.00			1	20		SPARE	28
29	SPARE		20	1					0.00	0.00	1	20		SPARE	30
31	SPARE		20	1	0.00	0.00					1	20		SPARE	32
33	SPARE		20	1			0.00	0.00			1	20		SPARE	34
35	SPARE		20	1					0.00	0.00	1	20		SPARE	36
	LOAD PER PHASE				10.27		5.91		6.82						
	TOTAL =				23.00 kVA						28 AMPS			A = AFI BREAKER	

NOTES: FEED THROUGH LUGS FLUSH 600KCM LUGS ISOLATED GROUND BUS G = GFI BREAKER

480Y/277 VOLT.
14,000 A.I.C. 1
3 PHASE – 4 WIRE

DIMMER PANEL EDR – SEC1 3

REFER TO DETAIL #3/E.404 FOR DETAILS

ROOM/AREA	CONTROLS	CIRCUIT # NORM.	CIRCUIT # EMERG.	ZONE	DESCRIPTION	# OF LAMPS	TOTAL WATTS	I	HID	ND	F	WIRE & CONDUIT	REMARKS
RINK	–	–	1	2b	A01	1	750		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	–	2	3b	A01	1	750		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	–	3	4c	A01	1	750		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	–	4	4d	A01	1	750		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	–	5	4e	A01	1	750		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	–	6	4f	A01	1	750		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	–	7	4g	A01	2	1500		X			4#12+G-3/4"C.	0-10 VOLTS
UPPER EAST CORNER	–	–	8	5	A02	13	416			X		2#12+G-3/4"C.	–
UPPER WEST CORNER	–	–	9	6	A02	13	416			X		2#12+G-3/4"C.	–
UPPER NORTH/SOUTH ENTRIES	–	–	10	7	A03	8	256			X		2#12+G-3/4"C.	–
UPPER EAST ENTRY	–	–	11	8	A03	3	96			X		2#12+G-3/4"C.	–
UPPER WEST ENTRY	–	–	12	9	A03	3	96			X		2#12+G-3/4"C.	–

SEE NOTE #2

SEC1 + SEC2 TOTAL LOAD =9,666 VA – 11.6 AMPS TOTAL LOAD = 7,280 VA – 8.8 AMPS

480Y/277 VOLT.
14,000 A.I.C. (1)
3 PHASE – 4 WIRE

DIMMER PANEL EDR – SEC2

REFER TO DETAIL #3/E.404 FOR DETAILS

ROOM/AREA	CONTROLS	CIRCUIT # NORM.	CIRCUIT # EMERG.	ZONE	DESCRIPTION	# OF LAMPS	TOTAL WATTS	I	LV	ND	F	WIRE & CONDUIT	REMARKS
UPPER NORTH CONCESSION	–	–	13	10	A03	2	64			X		2#12+G-3/4"C.	–
RMS 80,95,95A	–	–	14	11	A21A,ASW1	4,2	336			X		2#12+G-3/4"C.	–
CORRIDOR 81E	–	–	15	12 (12)	A13	3	318			X		2#12+G-3/4"C.	–
RMS 94,94B,94C,94D, 73	–	–	16	13	A21	8	448			X		2#12+G-3/4"C.	–
RMS 93,93A,60	–	–	17	14	A14,A17	6,4	324			X		2#12+G-3/4"C.	–
RM 96	–	–	18	15	A21	5	280			X		2#12+G-3/4"C.	–
RMS 91, 92	–	–	19	16	A14,A21	4,2	280			X		2#12+G-3/4"C.	–
RMS 90,90A,90B	–	–	20	17	A24	12	336			X		2#12+G-3/4"C.	–
SPARE	–	–	21	–	–	–	–					–	–
SPARE	–	–	22	–	–	–	–					–	–
SPARE	–	–	23	–	–	–	–					–	–
SPARE	–	–	24	–	–	–	–					–	–

TOTAL LOAD = 2,386 VA – 2.9 AMPS

480Y/277 VOLT.
14,000 A.I.C. (1)
3 PHASE – 4 WIRE

DIMMER PANEL DR – SEC1 (3)

REFER TO DETAIL #3/E.404 FOR DETAILS

ROOM/AREA	CONTROLS	CIRCUIT # NORM.	CIRCUIT # EMERG.	ZONE	DESCRIPTION	# OF LAMPS	TOTAL WATTS	I	HID	ND	F	WIRE & CONDUIT	REMARKS
RINK	–	1	–	1a	A01	6	3000		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	2	–	1b	A01	6	3000		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	3	–	2a	A01	4	2000		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	4	–	2b	A01	3	1500		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	5	–	3a	A01	4	2000		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	6	–	3b	A01	3	1500		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	7	–	4a	A01	8	4000		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	8	–	4b	A01	8	4000		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	9	–	4c	A01	5	2500		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	10	–	4d	A01	5	2500		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	11	–	4e	A01	5	2500		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	12	–	4f	A01	5	2500		X			4#12+G-3/4"C.	0-10 VOLTS
RINK	–	13	–	4g	A01	2	1000		X			4#12+G-3/4"C.	0-10 VOLTS
UPPER EAST CORNER	–	14	–	5	A02	28	896			X		2#12+G-3/4"C.	–
UPPER WEST CORNER	–	15	–	6	A02	28	896			X		2#12+G-3/4"C.	–
UPPER NORTH/SOUTH ENTRIES	–	16	–	7	A03	15	480			X		2#12+G-3/4"C.	–

SEC1 + SEC2 TOTAL LOAD =38,284 VA – 46.0 AMPS   TOTAL LOAD = 34,272 VA – 41.2 AMPS   SEE NOTE #2

480Y/277 VOLT, 14,000 A.I.C. ⟨1⟩ 3 PHASE – 4 WIRE	DIMMER PANEL <u>DR</u> – SEC2												REFER TO DETAIL #3/E.404 FOR DETAILS
ROOM/AREA	CONTROLS	CIRCUIT # NORM.	CIRCUIT # EMERG.	ZONE	DESCRIPTION	# OF LAMPS	TOTAL WATTS	I	LV	ND	F	WIRE & CONDUIT	REMARKS
UPPER EAST ENTRY	–	17	–	8	A03	9	288			X		2#12+G–3/4"C.	–
UPPER WEST ENTRY	–	18	–	9	A03	9	288			X		2#12+G–3/4"C.	–
UPPER NORTH CONCESSION	–	19	–	10	A03	4	128			X		2#12+G–3/4"C.	–
RMS 80,95,95A	–	20	–	11	A21A,ASW1	4,4	448			X		2#12+G–3/4"C.	–
CORRIDOR 81E	–	21	–	12 ⟨12⟩	A13	3	468			X		2#12+G–3/4"C.	–
RMS 94,94B,94C,94D, 73	–	22	–	13	A21	12	672			X		2#12+G–3/4"C.	–
RMS 93,93A,60	–	23	–	14	A14, A17	12,3	438			X		2#12+G–3/4"C.	–
RM 96	–	24	–	15	A21	5	280			X		2#12+G–3/4"C.	–
RMS 91, 92	–	25	–	16	A17,A21	3,3	294			X		2#12+G–3/4"C.	–
RMS 90,90A,90B	–	26	–	17	A24	11	308			X		2#12+G–3/4"C.	–
UPPER SOUTH	–	27	–	18	AX15	8	400			X		2#12+G–3/4"C.	–
SPARE	–	28	–	–	–	–	–					–	–
SPARE	–	29	–	–	–	–	–					–	–
SPARE	–	30	–	–	–	–	–					–	–
SPARE	–	31	–	–	–	–	–					–	–
SPARE	–	32	–	–	–	–	–					–	–
TOTAL LOAD = 4,012 VA – 4.8 AMPS													

Adjusted Panelboard Schedule

Total volt amps of new lighting equipment are employed in the panel board schedules in replacement of the original lighting. With a primary utilization voltage of 480Y/277V, the maximum volt-amps for each circuit equals: **277V x 20A x 0.8(Continuous load) x 0.8(spare) = 3.5 KVA.**

480Y/277VOLT 144,000 A.I.C. 3 PHASE - 4 WIRE	**DIMMER PANEL <u>EDR</u> - SEC 1**							
ROOM/AREA	**CIRCUIT # NORM.**	**CIRCUIT # EMERG.**	**DESCRIPTION**	**# OF FIXTURES**	**LAMP TYPE**	**TOTAL VA**	**WIRE & CONDUIT**	**REMARKS**
RINK	-	1	AP01	2	LED	534	4#12+G - 3/4"C.	0-10V
RINK	-	2	AP01	2	LED	534	4#12+G - 3/4"C.	0-10V
RINK	-	3	AP01	2	LED	534	4#12+G - 3/4"C.	0-10V
RINK	-	4	AP01	2	LED	534	4#12+G - 3/4"C.	0-10V
CORRIDOR SOUTHEAST	-	5	AS01	5	T4 GU6.5MH	100	2#12+G - 3/4"C.	-
CORRIDOR SOUTHWEST	-	6	AS01	5	T4 GU6.5MH	100	2#12+G - 3/4"C.	-
CORRIDOR NORTHEAST	-	7	AS01	5	T4 GU6.5MH	100	2#12+G - 3/4"C.	-
CORRIDOR NORTHWEST	-	8	AS01	5	T4 GU6.5MH	100	2#12+G - 3/4"C.	-
CORRIDOR SOUTHEAST	-	9	AW01	5	LED	135	2#12+G - 3/4"C.	-
CORRIDOR SOUTHWEST	-	10	AW01	5	LED	135	2#12+G - 3/4"C.	-
CORRIDOR NORTHEAST	-	11	AW01	5	LED	135	2#12+G - 3/4"C.	-
CORRIDOR NORTHWEST	-	12	AW01	5	LED	135	2#12+G - 3/4"C.	-
NORTH ENTRY	-	13	AW01	2	LED	54	2#12+G - 3/4"C.	-
SOUTH ENTRY	-	14	AW01	2	LED	54	2#12+G - 3/4"C.	-
					TOTAL LOAD	= **3184**	VA - **3.8 AMPS**	

480Y/277VOLT 144,000 A.I.C. 3 PHASE - 4 WIRE			DIMMER PANEL DR - SEC 1					
ROOM/AREA	CIRCUIT #		DESCRIPTION	# OF FIXTURES	LAMP TYPE	TOTAL VA	WIRE & CONDUIT	REMARKS
	NORM	EMERG						
RINK	1	-	AP01	12	LED	3204	4#12+G - 3/4"C.	0-10V
RINK	2	-	AP01	12	LED	3204	4#12+G - 3/4"C.	0-10V
RINK	3	-	AP01	12	LED	3204	4#12+G - 3/4"C.	0-10V
RINK	4	-	AP01	12	LED	3204	4#12+G - 3/4"C.	0-10V
RINK	5	-	AP01	8	LED	2136	4#12+G - 3/4"C.	0-10V
RINK	6	-	AP01	8	LED	2136	4#12+G - 3/4"C.	0-10V
CIRCULATION CORRIDOR	7	-	AS01	50	LED	1000	2#12+G - 3/4"C.	-
CIRCULATION CORRIDOR	8	-	AW01	61	LED	1647	2#12+G - 3/4"C.	-
RINK	9	-	AF01	10	LED	500	-	-
RINK	10	-	AD01	7	LED	91	-	-
RINK	11	-	AD01	7	LED	91	-	-
CIRCULATION CORRIDOR	12	-	AD01	16	-	208	-	-
CIRCULATION CORRIDOR	13	-	AD01	8		104		
					TOTAL LOAD	= **20729**	VA - **23.7 AMPS**	

480 Y/277V 42K AIC 3Ø-4W						**LP-N**						BUS: 100 AMP MAIN: 100 AMP CB			
	LOAD SERVED	WIRE SIZE	TRIP	POLE	LOAD IN kVA						POLE	TRIP	WIRE SIZE	LOAD SERVED	
					ØA		ØB		ØC						
1	Lower Level Lighting	2#12+G- 3/4"C	20	1	1.52	0.69					1	20	2#12+G- 3/4"C	Upper Level Bathrooms	2
3	SPARE	2#12+G- 3/4"C	20	1			0.00	0.30			1	20	2#12+G- 3/4"C	North Entrance Lighting	4
5	Exterior South Lighting	2#12+G- 3/4"C	20	1					0.50	0.50	1	20	2#12+G- 3/4"C	Interior South Lighting	6
7	Pole Lighting	2#12+G- 3/4"C	20	1	2.03	1.58					1	20	2#12+G- 3/4"C	Pole Lighting	8
9	Ramp Lighting	2#12+G- 3/4"C	20	1			0.50	0.47			1	20	2#12+G- 3/4"C	South Lower Lighting	10
11	South Lower Lighting	2#12+G- 3/4"C	20	1					2.49	3.33	1	20	2#12+G- 3/4"C	West Lighting	12
13	West Lighting	2#12+G- 3/4"C	20	1	2.99	1.47					1	20	2#12+G- 3/4"C	Team Lounge	14
15	Time Clock	2#12+G- 3/4"C	20	1			0.50	0.627			1	20	2#12+G- 3/4"C	Schley Room	16
17	SPARE		20	1					0.00	0.00	1	20		SPARE	18
19	SPARE		20	1	0.00	0.00					1	20		SPARE	20
21	SPARE		20	1			0.00	0.00			1	20		SPARE	22
23	SPARE		20	1					0.00	0.00	1	20		SPARE	24
25	SPARE		20	1	0.00	0.00					1	20		SPARE	26
27	SPARE		20	1			0.00	0.00			1	20		SPARE	28
29	SPARE		20	1					0.00	0.00	1	20		SPARE	30
31	SPARE		20	1	0.00	0.00					1	20		SPARE	32
33	SPARE		20	1			0.00	0.00			1	20		SPARE	34
35	SPARE		20	1					0.00	0.00	1	20		SPARE	36
	LOAD PER PHASE				10.27		5.91		6.82						
	TOTAL =				23.00 kVA						28 AMPS			A = AFI BREAKER	

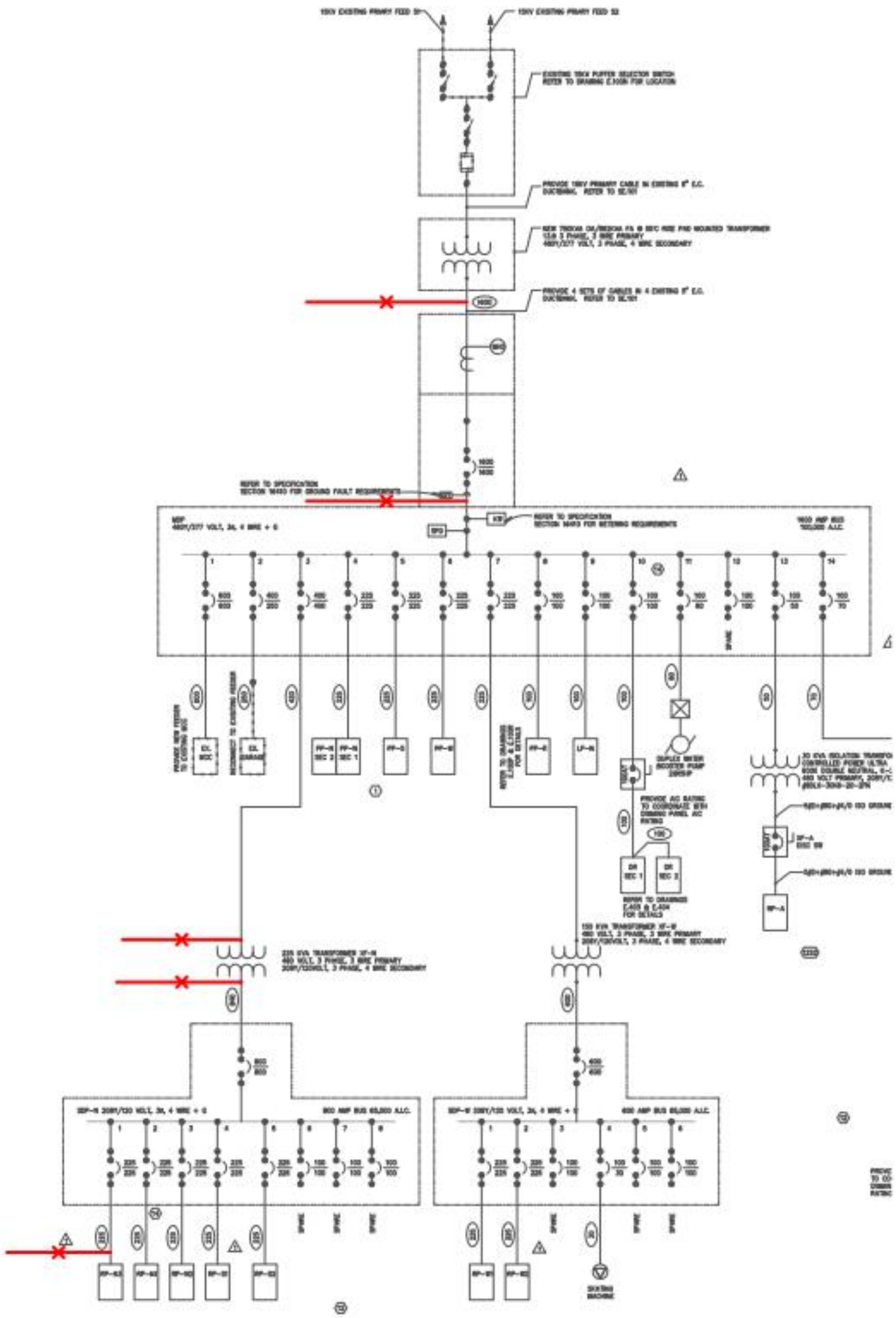
NOTES: ☐ FEED THROUGH LUGS ☐ FLUSH ☐ 600KCM LUGS ☐ ISOLATED GROUND BUS G = GFI BREAKER

480Y/277VOLT **42k A.I.C.** **3 PHASE - 4 WIRE**						**LP-N**						BUS: 100 AMP MAIN: 100 AMP CB	
	LOAD SERVED	**WIRE SIZE**	**TRIP**	**LOAD IN KVA**						**TRIP**	**WIRE SIZE**	**LOAD SERVED**	
				ΘA		**ΘB**		**ΘC**					
1	Lower Level Lighting	2#12+G - 3/4"C.	20	1.52	0.69					20	2#12+G - 3/4"C.	Upper Level Bathrooms	**2**
3	SPARE	2#12+G - 3/4"C.	20			0.00	0.30			20	2#12+G - 3/4"C.	North Entrance Lighting	**4**
5	Exterior South Lighting	2#12+G - 3/4"C.	20					0.50	0.50	20	2#12+G - 3/4"C.	Interior South Lighting	**6**
7	Pole Lighting	2#12+G - 3/4"C.	20	2.03	1.58					20	2#12+G - 3/4"C.	Pole Lighting	**8**
9	Ramp Lighting	2#12+G - 3/4"C.	20			0.50	0.47			20	2#12+G - 3/4"C.	South Lower Lighting	**10**
11	South Lower Lighting	2#12+G - 3/4"C.	20					2.49	3.33	20	2#12+G - 3/4"C.	West Lighting	**12**
13	West Lighting	2#12+G - 3/4"C.	20	2.99	1.47					20	2#12+G - 3/4"C.	Team Lounge	**14**
15	Time Clock	2#12+G - 3/4"C.	20			0.50	0.63			20	2#12+G - 3/4"C.	**Schley Room**	**16**
17	**Exterior Spine**	2#12+G - 3/4"C.	20					3.23	3.23	20	2#12+G - 3/4"C.	**Exterior Spine**	**18**
19	**Exterior Perimeter**	2#12+G - 3/4"C.	20	1.44	1.44					20	2#12+G - 3/4"C.	**Exterior Perimeter**	**20**
21	**Exterior Perimeter**	2#12+G - 3/4"C.	20			1.72	1.72			20	2#12+G - 3/4"C.	**Exterior Perimeter**	**22**
23	**Exterior Perimeter**	2#12+G - 3/4"C.	20					0.34	0.34	20	2#12+G - 3/4"C.	**Exterior Perimeter**	**24**
25			20							20			**26**
27			20							20			**28**
29			20							20			**30**
31			20							20			**32**
33			20							20			**34**
35			20							20			**35**
		LOAD PER PHASE		13.16		5.84		13.96					
			TOTAL =			**32.96 KVA**						**38AMPS**	

The total load in KVA for each adjusted panelboard is less than the original design. Therefore, resizing the feeder is unnecessary considering the original feeder was sized to the meet the requirements.

Electrical II | Short Circuit Analysis

Fault current is analyzed at five points in building electrical system as shown below.



Following Cooper *Bussmann*'s basic point to point calculation procedure for three-phase short circuits, the level of fault current at primary and secondary transformer is calculated and evaluated. As a result, the fault current protection for MDP and SDP switchboard are effectively rated to prevent overcurrent and short circuit conditions.

Transformer to MDP

Fault X_1

KVA	E_{L-L}	$I_{F.L.A.}$	%Z	Multiplier	$I_{S.C}$
750	480	902.14	3.5	28.57	25775.32

Fault X_2

L	C	n	f	M	$I_{S.C.sym.RMS}$
65	22965	4	0.0658	0.9383	24183.77

MDP to XF-N

L	$I_{3Ø}$	C	n	E_{L-L}	f	M	$I_{S.C.sym.RMS}$	MDP
2	24183.77	22965	1	208	0.0175	0.9828	23766.95	100000 A.I.C

XF-N to RP

Fault X_3

$I_{S.C.primary}$	$V_{primary}$	%Z	$V_{transformer}$	f	M	$I_{S.C.secondary}$
23766.95	480	1.2	225	1.0538	0.4869	26704.94

L	$I_{S.C.secondary}$	C	n	E_{L-L}	f	M	$I_{S.C.sym.RMS}$	SDP
17	26704.94	15082	1	208	0.2506	0.7996	21352.86	65000 A.I.C

Electrical III | Copper vs. Aluminum Feeder Analysis

|Introduction

Copper wires are known as a stable and powerful conductor to the electrical industry. Because of its long life and resistance to damage, the price of it tends to be high. Aluminum wires on the other hand, is significantly less expensive, however are more vulnerable to corrosion. Recent research shows that despite the difference in stability, the performance of aluminum wires is in some way under-rated. The performance of equipment with aluminum conductors, which often times is questioned by clients, is in fact similar to that of copper conductors in commercial buildings. Most importantly, the equipment with aluminum will significantly weigh less than the same equipment with copper. The unit cost of material and labor will be another significant factor when distance between equipment is comparatively long.

This electrical breadth contains detailed cost analysis between the applications of original copper versus proposed aluminum conductors on building electrical systems. According to industry recommendation, all wiring at 1/0 or larger are resized to copper conductors since installing smaller conductors tends to become more expensive. *RS Means Electrical Cost Data 2014* was used as reference for cost of conductors and conduit. Wires are resized based on *NEC 2011*.

|Cost Analysis

Copper

Tag	From	To	Length	No. of sets	Conduit (Per Set)			Conductors								Total Cost
								Phase Conductors				Ground Conductors				
					Size	Type	Cost/LF	No.	Size	Type	Cost/LF	No.	Size	Type	Cost/LF	
1	Service Transformer	MDP	65	4	4"	EMT	26	16	600	XHHW-2	54.25	4	4	THHN/THWN	5.68	64656.8
2	MDP	EX. MCC	27	2	3"	EMT	19.6	8	350	XHHW-2	40.25	2	1	XHHW-2	6.83	10121.22
3		EX. GARAGE	16	1	2 1/2"	EMT	16.65	4	250	XHHW-2	32.15	1	4	THHN/THWN	5.68	2414.88
4		PP - N	12	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	1566.36
5		PP - S	195	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	25453.35
6		PP - W	195	1	2 1/2"	EMT	16.65	5	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	30728.1
7	MDP	XF - N	2	1	4"	EMT	26	4	600	XHHW-2	54.25	1	2/0	XHHW-2	7.76	501.52
8	XF-N	SDP - N	2	2	4"	EMT	26	8	600	XHHW-2	54.25	2	2/0	XHHW-2	7.76	1003.04
9	SDP - N	RP - N3	15	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	1957.95
10		RP - N1	129	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	16838.37
11		RP - N2	118	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	15402.54
12		RP - S1	240	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	31327.2
13		RP - S2	188	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	24539.64
14	MDP	XF - W	190	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	24800.7
15	XF - W	SDP - W	9	2	3"	EMT	19.6	8	350	XHHW-2	40.25	2	1	XHHW-2	6.83	3373.74
16	SDP - W	RP - W1	3	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	391.59
17		RP - W2	142	1	2 1/2"	EMT	16.65	4	4/0	XHHW-2	27.05	1	4	THHN/THWN	5.68	18535.26
															Total	273612.3

Aluminum

Tag	From	To	Length	No. of sets	Conduit (Per Set)			Conductors								Total Cost
								Phase Conductors				Ground Conductors				
					Size	Type	Cost/LF	No.	Size	Type	Cost/LF	No.	Size	Type	Cost/LF	
1	Service Transformer	MDP	65	8	4"	EMT	26	32	500	XHHW	26.24	4	4	THHN/THWN	4.82	69352.4
2	MDP	EX. MCC	27	2	2 1/2"	EMT	16.65	8	400	XHHW	19.92	2	2/0	XHHW-2	6.29	5541.48
3		EX. GARAGE	16	1	2 1/2"	EMT	16.65	4	350	XHHW	16.43	1	2	THHN/THWN	5.24	1401.76
4		PP - N	12	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	1046.28
5		PP - S	195	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	17002.05
6		PP - W	195	1	2 1/2"	EMT	16.65	5	300	XHHW	16.43	1	4	THHN/THWN	4.82	20205.9
7	MDP	XF - N	2	2	4"	EMT	26	8	500	XHHW	26.24	1	2/0	XHHW-2	6.29	536.42
8	XF-N	SDP - N	2	2	4"	EMT	26	8	500	XHHW	26.24	2	2/0	XHHW-2	6.29	549
9	SDP - N	RP - N3	15	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	1307.85
10		RP - N1	129	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	11247.51
11		RP - N2	118	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	10288.42
12		RP - S1	240	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	20925.6
13		RP - S2	188	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	16391.72
14	MDP	XF - W	190	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	16566.1
15	XF - W	SDP - W	9	2	2 1/2"	EMT	16.65	8	400	XHHW	19.92	2	2/0	XHHW-2	6.29	1847.16
16	SDP - W	RP - W1	3	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	261.57
17		RP - W2	142	1	2 1/2"	EMT	16.65	4	300	XHHW	16.43	1	4	THHN/THWN	4.82	12380.98
															Total	206852.2

Copper Feeders	$273,612.30
Aluminum Feeders	$206,852.20
Savings	$66,760.10

Conclusion

As shown above, replacing the copper feeders with aluminum feeders can save approximately $66,760 (24%) of the original material and labor cost. Along with lower cost, aluminum also has multiple profits such as higher amperage capability per weight and better flexibility. These characteristics are most beneficial when making connections across long distance. Problems with oxidation and durability can be easily solved today by using the proper installation methods and incorporating special accessories. The alternative copper material is evidently an economical and effective solution to the building electrical system design.

Breadth Topic I | Acoustic – Reverberation Time Study

|Introduction

This acoustic breadth contains the reverberation time calculation for original and proposed changes of ground floor of David S. Ingalls Rink with supporting documents. The reverberation time of the original and proposed acoustical design was calculated based on the ceiling, wall, floor materials and space dimensions. The space is composed of concrete floors and walls, hardwood seating and oak wood ceiling. To improve the acoustical system qualities, a new wood acoustic ceiling material was proposed in replacement of the original oak wood ceiling.

|Background

When a sound wave is produced, it travels in various directions and strikes the surfaces within the space. From which portion of the sound will get absorbed by the surface it reaches, and the rest will get reflected and re-reflected. The total energy of sound will eventually be completely depleted within several bounces. Characteristic of reflection and absorption are measured by degree of sound absorption in a space. Using material sound absorption coefficient and room surface areas, reverberation time of a space can be calculated and evaluated for acoustic analysis.

For ice rinks, the most significant acoustical parameter is the reverberation time, which should be low enough to enable clear understandable speaking for spectators and music for performers. High quality acoustic system performs helps engaging the spectators more closely in the action of the games and figure skaters to keep up with music. Reflective surfaces such as hardwood seating, concrete walls and ice surface can cause sound to bounce around space, creating echoes. Combining this with cheering from the crowd, it can make speech very difficult to be heard. Oftentimes, the rink sound problems are solved by installing powerful hardware with bigger amplifiers at louder sound levels. The problem to this solution is that the system will waste energy and the sound is still delayed. Therefore, one other possibility comes into play where a change in room surface materials can aid the acoustical problem by the time sound wave hits the surface.

|Room Finish

Surface Description	Material Description	Sound Absorption Coefficient, α					
		Frequency (Hz)					
		125	250	500	1000	2000	4000
Wall_Concrete	Unfinished concrete	0.010	0.020	0.040	0.060	0.080	0.100
Wall_Glass	Glass, large panels	0.180	0.060	0.040	0.030	0.020	0.020
Corridor_Floor	Sealed Concrete	0.010	0.010	0.010	0.020	0.020	0.020
Ceiling	Oak wood	0.240	0.190	0.140	0.080	0.130	0.100
Ceiling	Plaster	0.140	0.120	0.080	0.060	0.060	0.060
People - Seats	Seating, empty, wood	0.080	0.110	0.150	0.160	0.180	0.200
Rink_Floor	Sealed Concrete	0.010	0.010	0.010	0.020	0.020	0.020

|Reverberation Time Analysis

Reverberation time can be calculated using the following two equations:

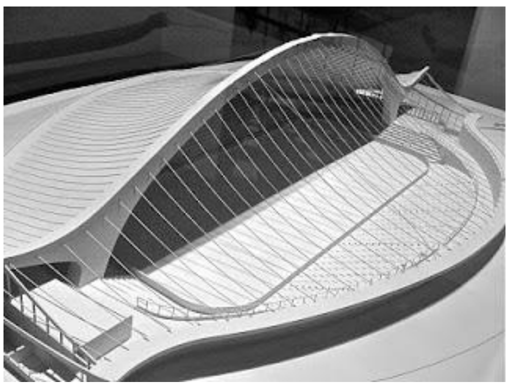
Sabine(**Avg.α≤0.2**) : $T = \frac{0.161V}{S\bar{\alpha}}$ **Norris Eyring**(**Avg.α>0.2**) : $T = \frac{0.161V}{-\sum_i S_i \ln(1-\alpha_{Ei})}$

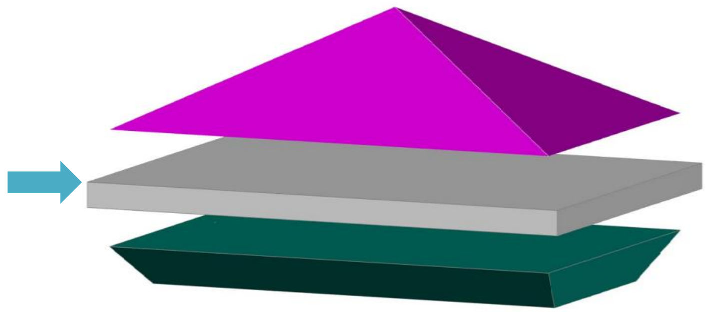
Where V = room volume in ft^3

S= Room surface areas

ā = average absorption coefficients

With simplified geometry, the building overall volume is calculated as V = 1,657,203 ft^3





Original Reverberation Time Calculation:

Surface Description	Surface Area, S (ft^2)	S*α (sabins) Frequency (Hz)					
		125	250	500	1000	2000	4000
Wall_Concrete	6789.50	67.90	135.79	271.58	407.37	543.16	678.95
Wall_Glass	1600.00	288.00	96.00	64.00	48.00	32.00	32.00
Corridor_Floor	8044.00	80.44	80.44	80.44	160.88	160.88	160.88
Ceiling	43317.00	10396.08	8230.23	6064.38	3465.36	5631.21	4331.70
Ceiling	5895.00	825.30	707.40	471.60	353.70	353.70	353.70
People - Seats	20011.17	1600.89	2201.23	3001.68	3201.79	3602.01	4002.23
Rink_Floor	18669.00	186.69	186.69	186.69	373.38	373.38	373.38
	ΣSα=	13445.30	11637.78	10140.37	8010.48	10696.34	9932.84
	Avg. α=	0.13	0.11	0.10	0.08	0.10	0.10
Air absorption constant for 20°C and 40% RH, m		0.00	0.00	0.00	0.00	0.00	0.00
Sabine Reverb Time: (s)	RT=	6.04	6.98	7.15	7.98	5.10	3.02
Norris-Eyring Reverb Time: (s)	RT=	5.64	6.58	6.83	7.74	4.92	2.96
Calculated RT (s)		6.04	6.98	7.15	7.98	5.10	3.02

With the building geometry and its surface finish material, the original reverberation time of ground floor at 500 Hz which sound wave is mostly produced critically exceeds the recommended reverberation time (2-3s) for ice arenas.

Considering the historical importance of the building, the proposed acoustical solution has a minimum effect on the building interior appearance. The original oak wood ceiling is replaced with *Acoustical Solutions* wood plank style wall treatment featuring a series of grooves and slots to achieve the satisfactory acoustic results. The material has NRC ratings up to 0.85`` with overlap edge s to create the original monolithic finished look. There are adequately amount of veneer material to choose from for achieving desirable architectural appearances.

Proposed Reverberation Time Calculation:

Surface Description	Surface Area, S (ft^2)	S*α (sabins) Frequency (Hz) 125	250	500	1000	2000	4000
Wall_Concrete	6789.50	67.90	135.79	271.58	407.37	543.16	678.95
Wall_Glass	1600.00	288.00	96.00	64.00	48.00	32.00	32.00
Corridor_Floor	8044.00	80.44	80.44	80.44	160.88	160.88	160.88
Ceiling	43317.00	34220.43	38985.30	35086.77	41151.15	42883.83	42883.83
Ceiling	5895.00	825.30	707.40	471.60	353.70	353.70	353.70
People - Seats	20011.17	1600.89	2201.23	3001.68	3201.79	3602.01	4002.23
Rink_Floor	18669.00	186.69	186.69	186.69	373.38	373.38	373.38
	ΣSα=	12145.79	31130.43	53890.54	53926.50	39285.56	8243.48
	Avg. α=	0.12	0.30	0.52	0.52	0.38	0.08
Air absorption constant for 20°C and 40% RH, m		0.00	0.00	0.00	0.00	0.00	0.00
Sabine Reverb Time: (s)	RT=	2.18	1.92	2.01	1.70	1.53	1.24
Norris-Eyring Reverb Time: (s)	RT=	1.76	1.49	1.61	1.30	1.17	0.99
	Calculated RT (s)	1.76	1.49	1.61	1.30	1.17	0.99

|Conclusion

The original reverberation time far exceeded the recommendation values due to the large space volume and high reflective surface material furnish. With proposed change in ceiling material, the rink acoustic performance in reverberation time at low, mid and high frequency is significantly improved while the interior appearance is effectively preserved. The low and high frequency reverberation time are effectively controlled with sealed air space behind the panels. Furthermore, acoustical problem at high frequency can be improved by installing additional insulation such as fiber glass above the wooden acoustic ceiling with openings to further absorb the sound. In addition, the overall acoustic performance of reverberation field will be improved when the rink is occupied since cloth fabrics are also example of sound absorptive material.

Breadth Topic II | Architectural + Structural Façade Study

|Introduction

For this breadth topic, the building façade is studied in both architectural and structural aspect. For architectural topic, detailed research was conducted for information regarding Saarinen's architectural design beliefs and his famous architectural projects. A propose in mullion material was stated regarding material stability and durability. For structural topic, windward and leeward wind analysis is conducted for building front and back entrances. Load resistance is calculated following procedures in ASTM E-1300 for existing glass curtain walls to examine the resistivity of wind load.

|Material

For Saarinen, the hybrid materiality of architectural always takes role as an important and complex part of his design. Throughout his practice, complex material selections has played an essential role in his success – staring from combination of steel and concrete of (*the Gateway Arch in St. Louis*), transitioned into the steel alone (*General Motors Technical Center*), then into the concrete (*the Kresge Auditorium at MIT*), into a combination of wood and concrete with steel cables (*David S. Ingalls Rink*), back to concrete (*the TWA Terminal*), and finally to the most complex hybrid of all materials (*Dulles International Airport*). To him, material, materiality, and materialism are a string of associations that leads people to the nature essence and the soul of the architectural construction.

David S. Ingalls Rink is well-known for her dramatic appearance and structural spine. When Saarinen was designing the building, he wanted it to be a projection of Yale University's contemporary academic pursuits. The concrete and wood material used improvises the stability and elegance to the overall building appearance and sense. The curtain wall façade has a wooden frame which is not common for the New England area due to heavy snow. The wood and glazing façade was replaced and repaired during the renovation taken in 2009. Under the weather circumstance, wood is not the ideal material due to its nature of erosion under humidity. Saarinen is always careful with material selections for his belief in materiality; in this case, wooden frame was chosen to echo the wood roof material. Given that the building has a deep canopy of 14' over the building façade, most of the snow will be prevented from reaching towards the mullion.

|Wind Analysis

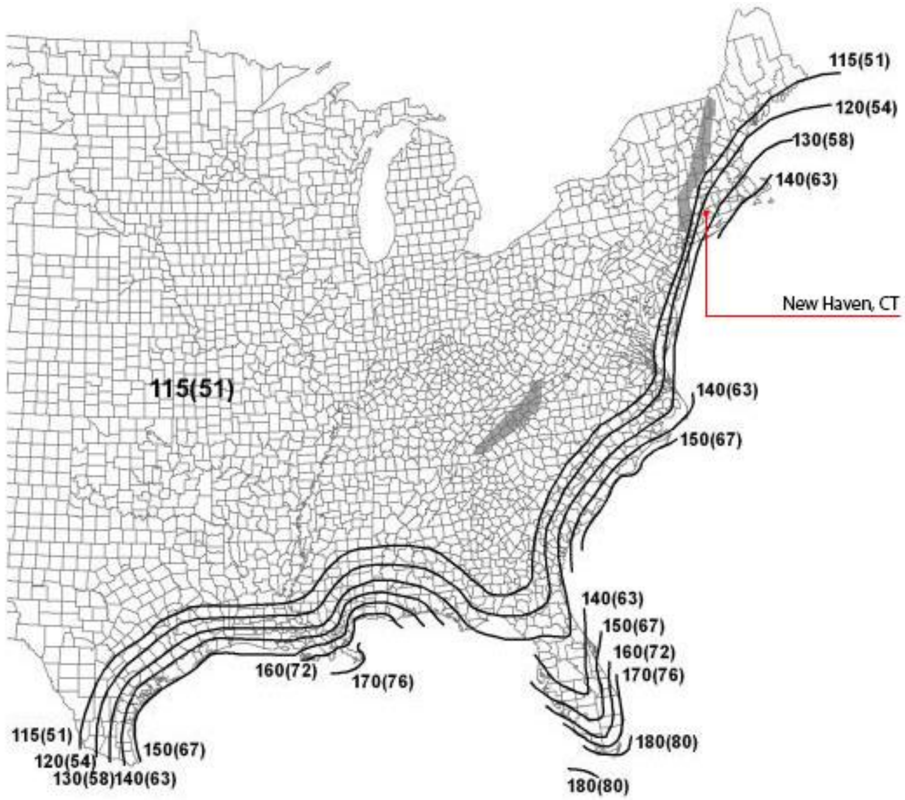
All steps of wind analysis for David S. Ingalls Rink follow procedures from *ASCE 7-10 Table 27.1: Steps to Determine MWDRS Wind Loads for Enclosed, Partially Enclosed and Open Buildings of all Heights.*

Step 1: Determine risk category of building or other structure

Use of Occupancy of Buildings and structures	Risk Category
All Buildings and other structures except those listed in Risk Categories I, III, and IV	II

ASCE 7-10 Table 1.5-1

Step 2: Determine the basic wind speed, V, for the applicable risk Category



ASCE 7-10 Figure 26.5-1

- According to Figure 26.5 – 1A, New Haven, CT has a wind load of 130 Vmph (58 m/s)

Step 3: Determine wind load parameters

K_d	K_{zt}	G	GC_{pi}
0.85	1	0.85	± 0.18

ASCE 7-10 Section 26

Note:

- Considering overall roof geometry, the building roof is assumed to be arched ->Wind Directionality Factor (K_d) = 0.85. (*ASCE 7-10 Table 26.6-1)*
- Considering surrounding neighborhood and mean roof height (65' above grade), David S. Ingalls Rink belongs to Surface Roughness B and Exposure Category B. (*ASCE 7-10 Section 26.7)*
- The Gust Effect Factor(G) = 1 for rigid buildings.
- The internal pressure coefficient (GC_{pi}) = ± 0.18 for fully enclosed buildings.
- Plus and minus signs for internal pressure coefficient signify pressures acting toward and away from the internal surfaces, respectively.

Step 4: Determine velocity pressure exposure coefficient

Height Above	Exposure B

60ft	$K_h = 0.89$

ASCE 7-10 Table 27.3 -1

Exposure	α	z	z_g	k_z
B	7	65	1200	0.87

ASCE 7-10 Table 26.9- 1

Step 5: Determine velocity pressure

$$\boxed{q_z = 0.00256 k_z k_{zt} k_d V^2}$$

ASCE 7-10 Eq. 27.3 -1

k_h	k_z	K_{zt}	K_d	V	q_h	q_z
0.89	0.87	1	0.85	130	32.73	31.99

Step 6: External pressure coefficient

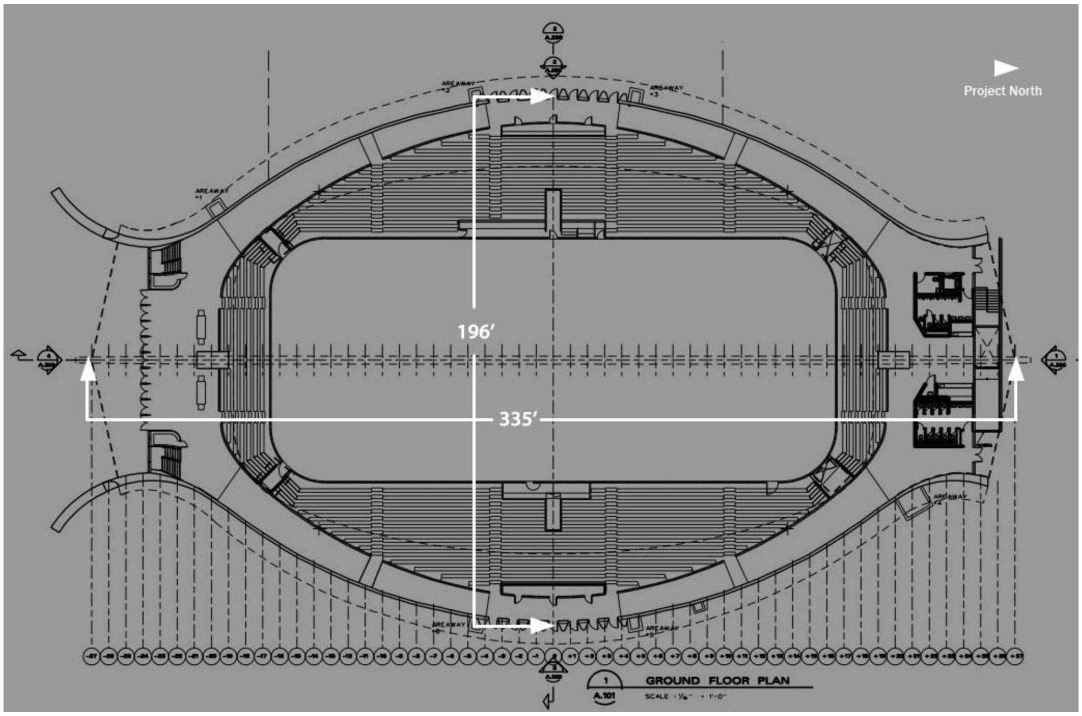
Surface	L/B	C_p	Use With
Windward Wall	All Values	0.8	q_z
Leeward Wall	N-S = 1.7	-0.3	q_h

ASCE 7-10 Table 27.4 -1

Note:

- B: Horizontal dimension of building, in feet, measured normal to wind direction.
- L: Horizontal dimension of building, in feet, measure parallel to wind direction.

- For analyzing building entrances, leeward wind pressure will be analyzed in north – south direction.



Step 7: Calculate wind pressure on building surface

$$P = qGC_p - q_i(GC_{pi})\ (lb/ft^2)$$

ASCE 7-10 Eq.27.4 -1

Wind pressure on walls for David S. Ingalls Rink in longitudinal direction can be analyzed as indicated below:

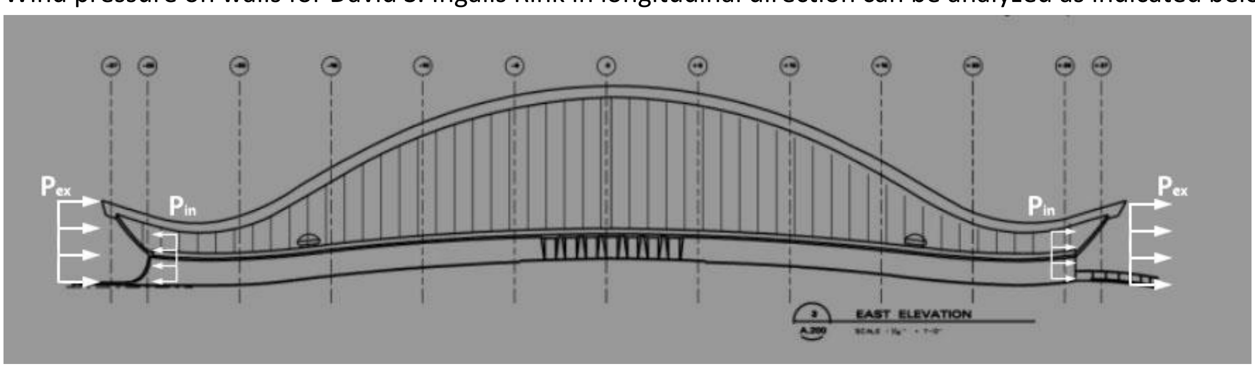


Figure 62 – Wind Pressure Building Section

Windward (Building Façade)

q_z	G	C_p	q_h	GC_{pi}	$P(lb/ft^2)$
31.99	0.85	0.8	32.73	0.18	15.86

Leeward (Building Façade)

q_h	G	C_p	q_h	GC_{pi}	$P(lb/ft^2)$

32.73	0.85	-0.3	32.73	0.18	-14.24

|Glazing Study

In order to pick the glazing type with proper thickness, window unit with the largest area will be analyzed for getting the optimum solution.

- Existing Condition

Glass Type	Location	Description	Components
AT	North & South entries - Glazed Walls	Insulating glass unit of nominal 1-1/8" overall thickness	Outer light - 5/16" clear fully tempered glass with low emissivity coating on no.2 surface
			Air Space - 1/2"
			Inner light - 5/16" clear fully tempered glass
BL	North & South entries - Glazed Doors	Laminated glass unit of nominal 5/16" overall thickness	1/8" clear heat strengthened glass
			0.060" clear PVB interlayer
			1/8" clear heat strengthened glass
CL	South entry	Insulating glass unit of nominal 1-1/8" overall thickness	Outer light - 5/16" laminated glass(type BL) with low emissivity coating on no.2 surface
			Air Space - 1/2"
			Inner light - 5/16" laminated glass(type BL)
CLO	North and South Entry	Insulating glass unit of nominal 1-1/8" overall thickness	Outer light - 5/16" laminated glass(type BL)
			Air Space - 1/2"
			Inner light - 5/16" laminated glass(type BL) with ceramic frit opacifer on no. 3 surface

Table xxx– Glass Type Schedule

Geometry

Glass Type	Length	Width
AT	10'	5'2
BL	5'9	1'8
CL	7'7	5'2
CLO	7'7	5'2

Table xxx– Building Entrances Glazing Geometry

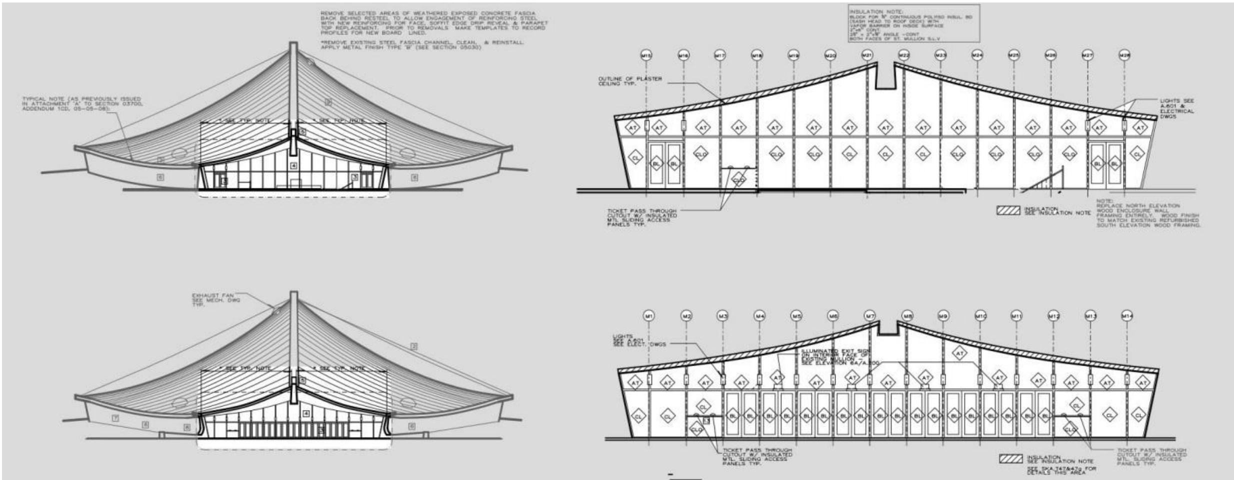


Figure xxx – Building Entrances

Load Resistance Determination

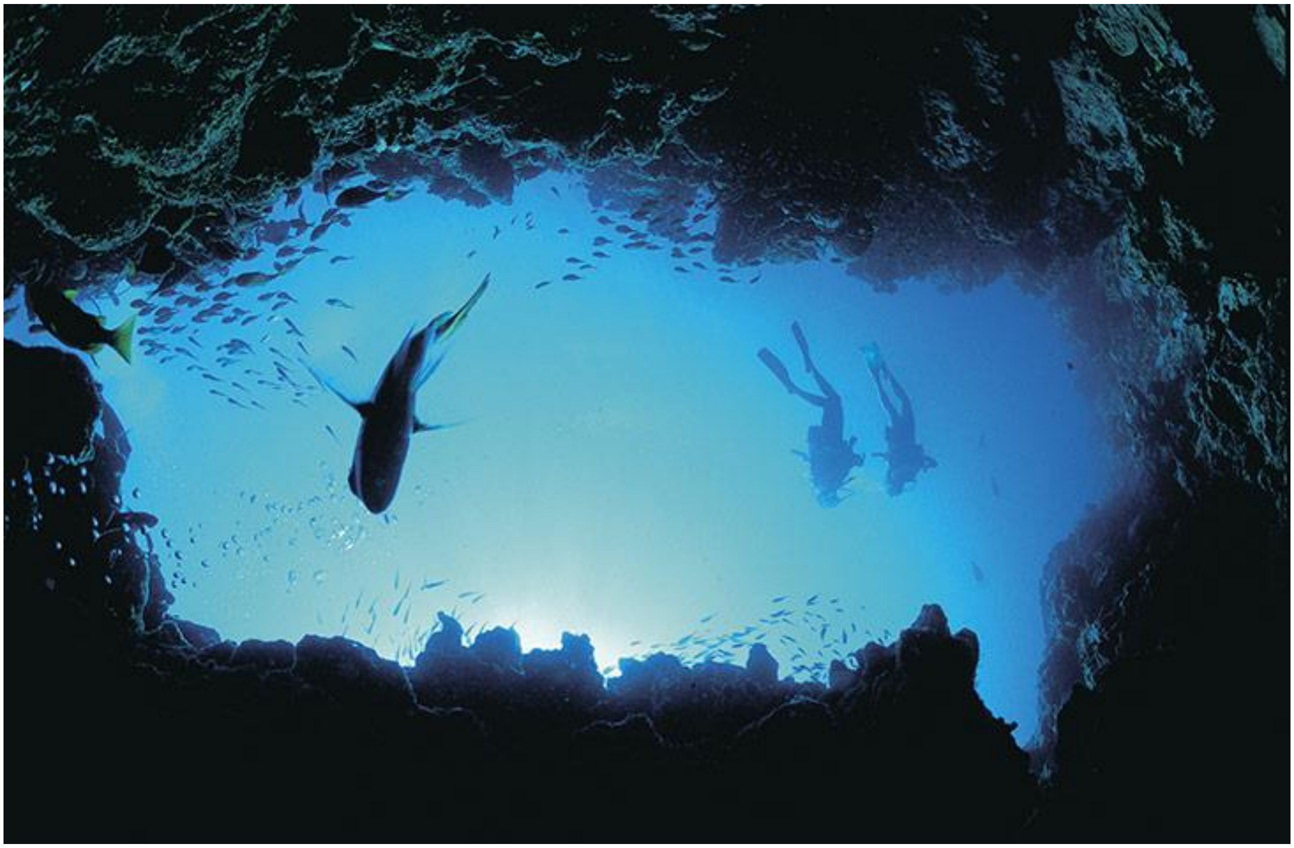
All steps of Glazing LR analysis for David S. Ingalls Rink follow procedures from *ASTM E1300 – 12a: Standard Practice for Determining Load Resistance of Glass in Buildings.*

Glass Type	Type	NFL	Short Duration			Long Duration			lb/ft^2
			GTF	LS	LR	GTF	LS	LR	
AT	5/16" tempered glass	1.4	3.6	2	10.08	2.85	2	7.98	166.6224
BL	1/8" heat strengthened glass	2.5	1.8	2	9	1.25	2	6.25	130.5
CL	5/16" laminated glass	1.7	1.8	2	6.12	1.25	2	4.25	88.74
CLO	5/16" laminated glass	1.7	1.8	2	6.12	1.25	2	4.25	88.74

|Conclusion

The glazing analysis above shows that the glass type used for building façade effectively resists windward and leeward load with building surroundings construction materials.

Conclusion



The works presented in this thesis represents an in-depth study of the overall architecture and engineering systems of David S. Ingalls Rink. The new proposed lighting system enhanced the overall visual appearance and energy usage of each designed space, with an underlying story of journey on the whale back. Building electrical system was analyzed to support changes made in lighting system. The structural and acoustic analysis was performed to analyze and evaluate on aspect of stability and hearing perceptions. By integrating all elements of architecture and egineering within the building, the new proposed design for each building system is engaged together for human body to react and experience, which leads to a sensation of being part of the whole both physically and emotionally.

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Software Used:

AutoCAD 2013

AGI 32

Adobe Photoshop CS6

Microsoft Office

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Image Credit

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