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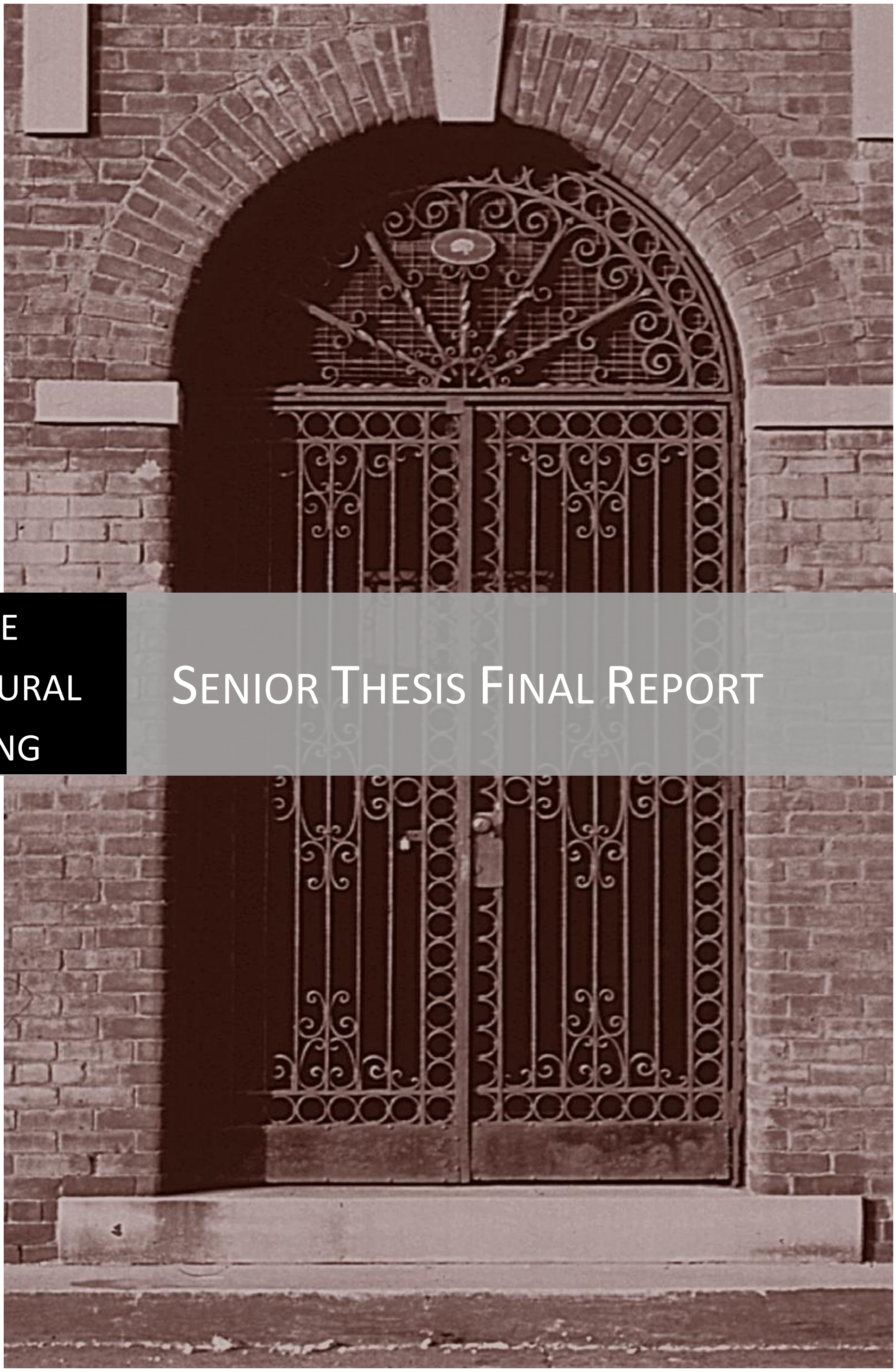


PENN STATE
ARCHITECTURAL
ENGINEERING

SENIOR THESIS FINAL REPORT

The Web Shop | Eric M Anderson

The Web Shop - Elliptipar Headquarters

Eric Anderson –L/E

West Haven, CT

Electrical System

- One 4160 V feeder
- 480/277, 3 phase, 4 wire system
- 208/120, 3 phase, 4 wire system
- 1,200,000 kWhr annually
- Fluorescent and metal halide lamps

Mechanical System

- **Heating:** Consists of a 9.8 million BTU gas fired steam boiler, operating at 15 psi. Steam condensate is collected in a 1000 gallon tank.
- **Cooling:** Consists of a well water pumping system, which supplies 150 gpm of chilled water through 7 AHUs

Structural System

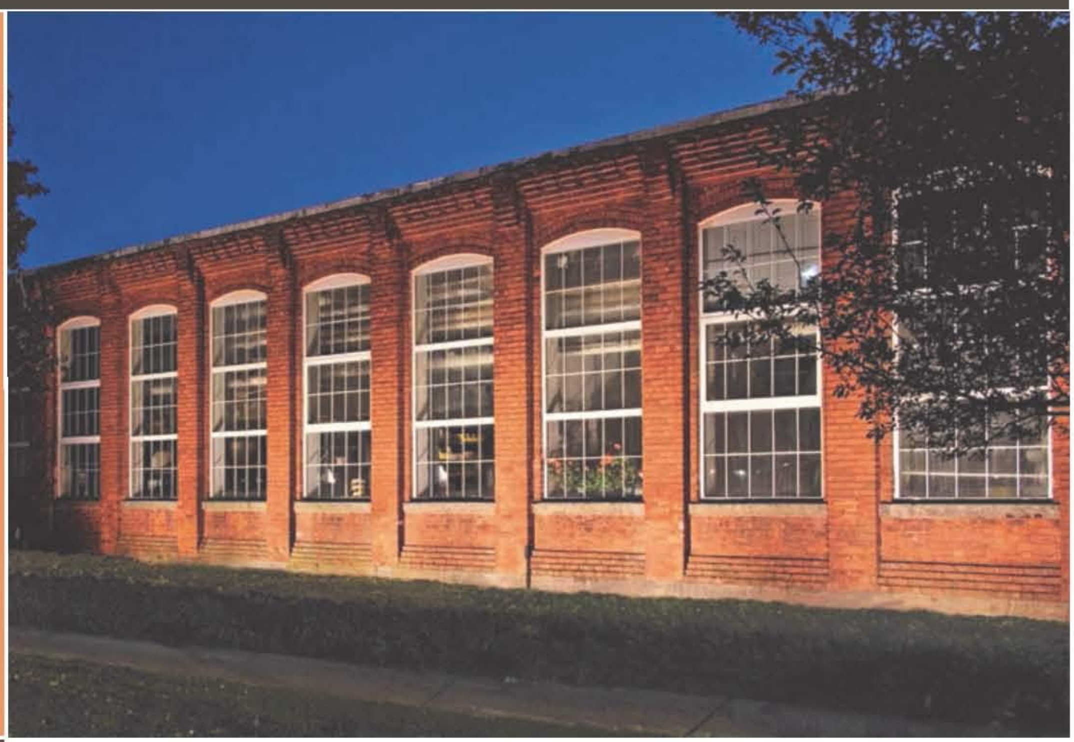
- The entire building is primarily wood framing. The interior spaces showcase the exposed columns and joists.

Project Overview

- The project consists of a series of renovations dating back to 1981, in an effort to update the historic building so that it makes the best use of the expanding company's needs.

Architectural Features

- The restored exterior of the complex exemplifies early 20th century industrial architecture in the Italianate style. It retains most of the original features including corbeled cornices, blue stone sills, brick piers, and segmented arch fenestrations



THE LIGHTING QUOTIENT

elliptipar There is no equal™

tambient Green in any color

Executive Summary:

The Web Shop is the main headquarters of the worldwide lighting manufacturer The Lighting Quotient. The building, originally a factory, has been renovated to meet the needs of the company. The building houses all areas of the company, including research and development, customer service, sales, applications, and product production.

The following document contains reports centered on the lighting and the electrical systems of the building. Four spaces were studied and redesigned as part of the lighting analysis. The four spaces studied include the main entrance, the main lobby, a conference room, and an open office. For these four spaces, an analysis of code compliance, as well as the impact to the existing electrical system was calculated. Hand calculations of the short circuit currents through the path to a panel board are included.

Two electrical depths included in this document are the addition of a photovoltaic array, and the consolidation of the existing transformers. Two breadth topics include an architectural breath and an acoustical analysis of the conference room.

The contents of this report are for the purposes of studying building systems pertaining to subjects studied in the Architectural Engineering program. Conclusions are merely suggestions for improvement, and are not meant to imply that the systems are designed improperly.

Contents

BUILDING INFORMATION AND STATISTICS

Building Name:
The Lighting Quotient Headquarters, also known as "The Web Shop," as a salute to the building's history.

Location and Site:
114 Boston Post Road, West Haven, CT

Building Occupant Name:
The Lighting Quotient: a parent company to Elliptipar, Tambient, and Fraqtir

Building Function:
The building consists of two large offices for engineering, research and development, applications, marketing, and sales. Manufacturing, including painting, assembly, testing, and shipping, takes place in the attached factory.

Size:
100,000 SF. The factory floor is roughly 75,000 SF and the offices and circulation space makes up about 25,000 SF. The factory is one story, and the office is three stories.

Design and Functionality:
The building was designed in the early 1900's in an Industrial Italianate style. The blue stone sills, corbled cornices, and archtop fenestrations exemplify this style. The factory space presents itself with much in the way of daylight, including an expansive array of sawtooth fenestrations. The office space is embellished with restored woodwork, including beautiful floors in the lobby, and formidable columns and beams in the open office.

Building Enclosure:
The facade of The Web Shop is almost exclusively brick, laid in a running bond fashion. The only exception is the blue stone sills. The roof is coated with a tar and gravel built up roof system. This also coats the exterior of the sawtooth monitors. Insulation is scarce, as the building is over a hundred years old. Much of the perimeter walls are solid brick through to the interior.

Electrical System:
The Web Shop receives its power via overhead utility lines provided by The United Illuminating Company, or UI for short. The voltage comes onsite at 4160V, where it splits into two sets of transformers, providing two service entrances. It would seem ideal in this circumstance for once service entrance to power the factory, and the other to power the offices. However, this is not the case, as the electrical system has had to change with the evolution of the company's needs over the years. The first service entrance feeds a set of 480V transformers located on an overhead rack outside of the Utility Room. The second service entrance enters the Brick Vault Room, where it feeds 3-phase 240V and 1-phase 120/240V switchgear. A third service entrance exists but is no longer in use. It consists of 240V overhead service from UI. The service entrance was used to more accurately bill a previous subtenant for their electrical usage. However, The Lighting Quotient now utilizes the space using power from the 4160V service.

Mechanical System:

Air Conditioning Description:

The existing system is comprised of (7) horizontal air handling units mounted within the space of the roof structure. Each unit consists of a return intake/filter section, steam coil, chilled water coil, supply fan and supply air duct work generally extends from the east side of the plant to the west. Operating airflow, and heating and cooling output is not known. The (2) most southern AHUs do not have steam control valves. The remaining (5) AHUs have control valves interlocked with associated temperature sensor attached to the condensate return line. All (7) AHUs do not have chilled water control valves. Each AHU is controlled by a local, non-programmable thermostat. The fan cycles as required based on the temperature set point.

Heating Plant:

The heating plant consists of a 9,800,000 BTU gas fired steam boiler. The boiler nameplate indicates a manufactured date of 1958. However, the gas burner is relatively new. The boiler operating pressure is 15 psi. The boiler operates through a local boiler control panel.

Steam condensate is collected in a 1000 gallon steam condensate duplex pump receiver set. The pumps are electrically driven. The steam condensate duplex receiver operates through a float switch control system. The steam system serves the factory heating load through steam coil per AHU as well as the heating load associated with the office building through steam to hot water heat exchangers. Steam and steam condensate piping runs adjacent to the cast exterior wall in the factory. Branch piping extends to each of the (7) AHUs. It is suggested that the steam piping is chemically treated.

Cooling Plant:

The cooling plant serving the factory consists of a well water pumping system. A vertical turbine pump supplies approximately 150 gpm of chilled water to (7) AHU chilled water coils throughout the factory. Return water discharges to the storm sewer.

Chilled water supply piping and chilled water return piping is mounted to the east exterior wall in the factory. Branch piping extends to each of the (7) AHUs.

Structural:

The exterior wall structure consists of load bearing brick. The interior is supported by 8” wood columns. Other than retrofitted transfer girders where columns were removed for large equipment, the entirety of the roof structure is wood framing.

ARCHITECTURAL BREADTH

Description:

The Web Shop has experienced a number of tenants in its 100 year history, all of whom have had different need. The building's current owner, The Lighting Quotient restored and remodeled much of the interior spaces to best suit their needs. One of these changes was the relocation of the main entrance. The original main entrance was located on the Boston Post Road side of the building, along the sidewalk. This entrance is a strong architectural statement, and depicts prominence over all other entrances. Since the original main entrance is no longer in use, one of the side entrances has established itself as the most prominent entrance. It is located at the intersection of the factory and office wings. This entrance leads to the main lobby and reception area from the parking lot. It is one of the most highly trafficked entrances in the building for employees. And for a guest arriving at The Web Shop, this entrance is the more appropriate of the two guest accessible entrances.

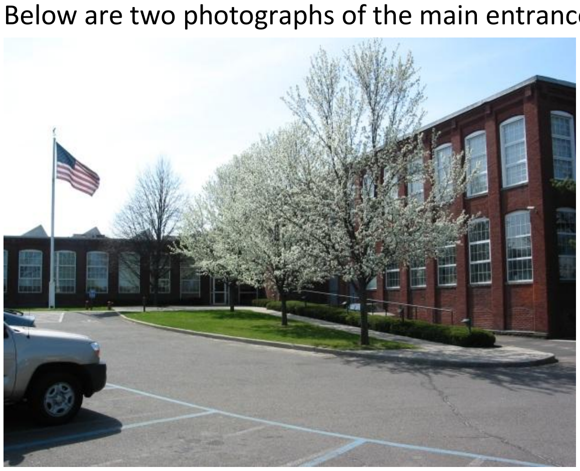
Design Issue:

The entrance does not express an importance over other side entrances. To the uninformed guest, it is very difficult to locate the main entrance. One of the adjacent entrances is an employee-only entrance to the factory. It has an awning over it, which actually looks more prominent than the actual current main entrance. This is certainly not the desired effect.

Design Considerations:

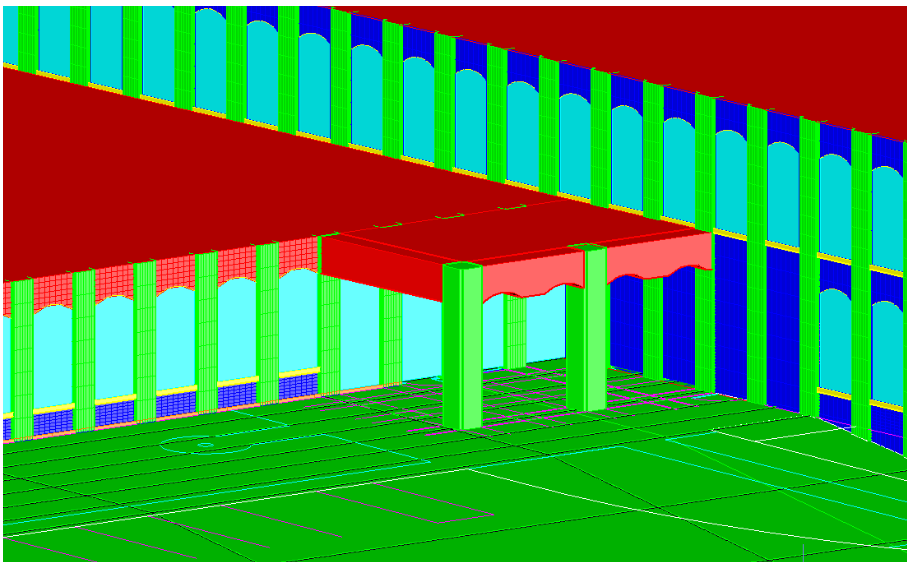
The objective of the design is not to overshadow the original main entrance, but to acquire architectural dominance over the other entrances adjacent to the parking lot. Once a guest enters the parking lot, it should be clear where he or she needs to go. It is important to note that the heritage of the building is a major consideration. The entrance should complement the architecture of the building, and use similar materials.

Below are two photographs of the main entrance, taken from the parking lot.



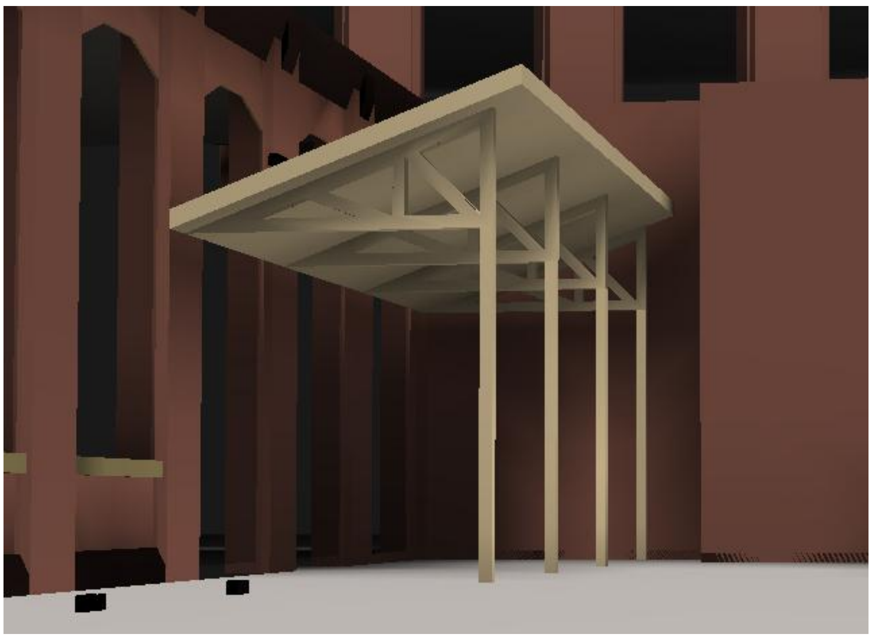

Discarded Solutions:

Several previous designs were considered before the final design was conceived. In this example, the brick columns of the main building were repeated outward into the courtyard. But the largest issue with this design is that it blocks out much of the daylight that would otherwise be present in the lobby. This goes completely against what the building stands for. Daylight was carefully considered when this building was designed over a hundred years ago. It would be a shame to dishonor the heritage in this way. Other options needed to be explored. Below is a Cad model showing this discarded design.

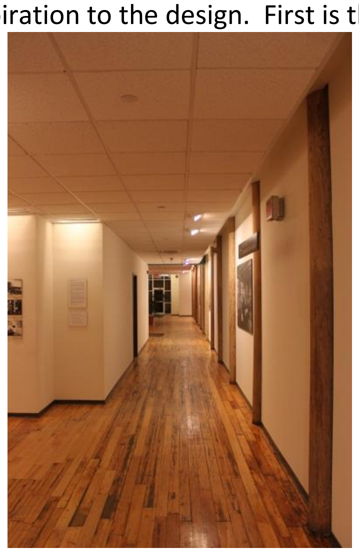


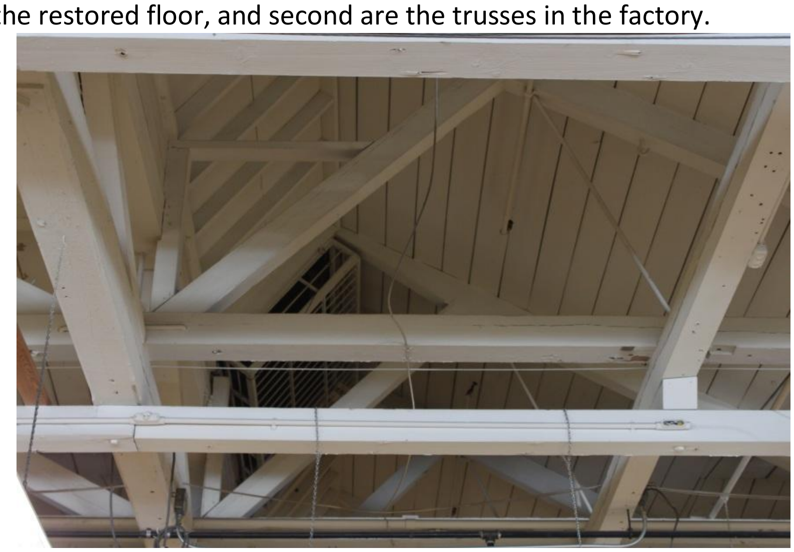
Final Solution:

The final design is a simple angled overhang. It is supported by four wood columns, reminiscent of the wood columns inside the lobby. Both the overhang columns and the lobby columns line up perfectly. The overhang is further supported by wood trusses. These trusses were inspired by the wood trusses supporting the sawtooth fenestrations in the factory. The underside of the overhang is finished in wood planks, similar to the floor in the lobby and hallway. The sides of the overhang are to be finished in a similar metal flashing as the rest of the building. The top of the overhang is to be finished in a standing seam interlocking metal roof. The roof should be finished in an attractive material since it will be viewable from the interior of the space.



Above is a rendering of the overhang. Below are photos, taken throughout the building, that were inspiration to the design. First is the restored floor, and second are the trusses in the factory.

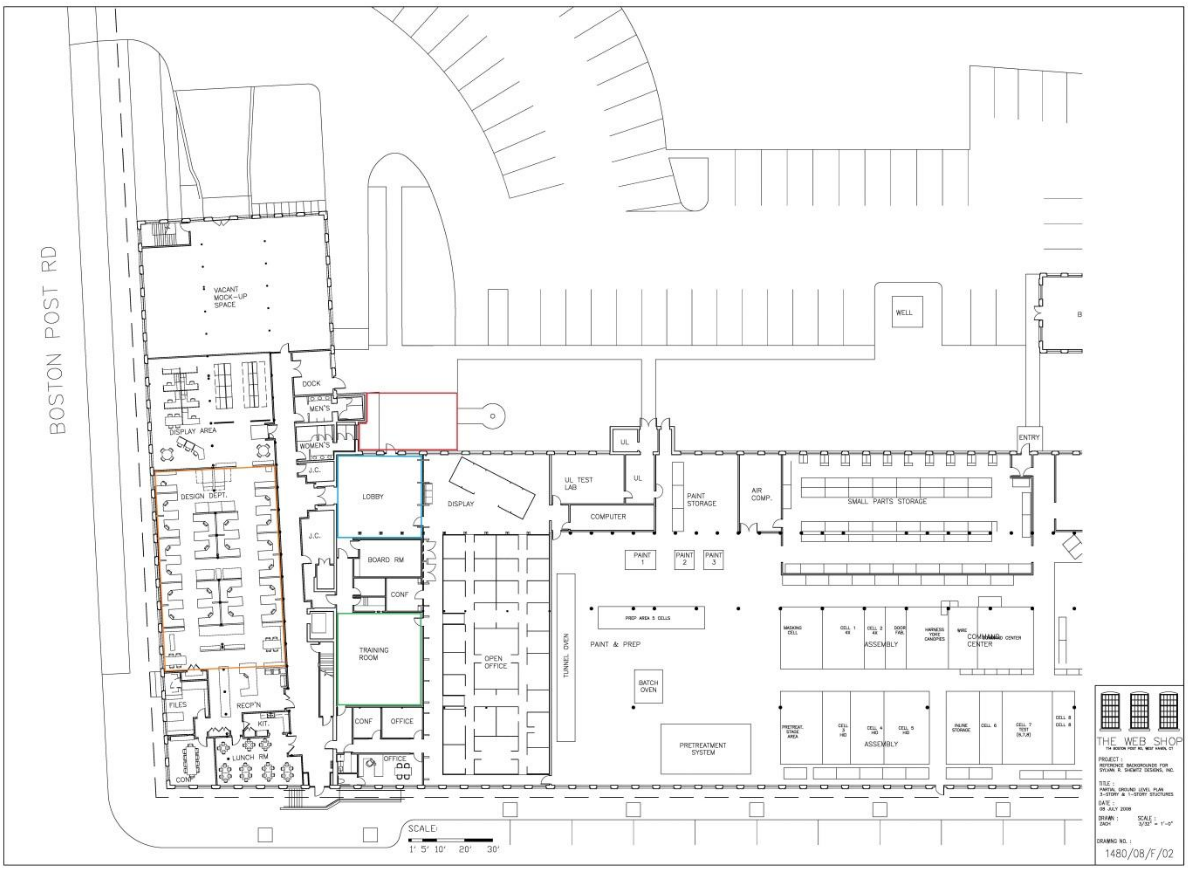




LIGHTING REDESIGN

For the lighting portion of the report, students are required to redesign the lighting in four spaces. The restrictions state that the spaces must be selected based on four different types of spaces: an outdoor space, a circulation space, a work space, and a special purpose space. In addition, students must produce a variety of analyses to convey the performance of each space. To aid in visualization of the spaces, the models were built in Autodesk's AutoCAD 2011 and rendered in Lighting Analysts' AGi32 Version 2.1. Additional image editing was done with the aid of Adobe Photoshop CS5.

The spaces that were analyzed are listed below, and are outlined in a plan-view.



Outdoor Space: Main Entrance and Façade, shown in red
Circulation Space: Main Lobby, shown in blue
Work Space: Open Office, shown in orange
Special Purpose Space: Training and Meeting Room, shown in green

Main Entrance

Description:
Employees and guests will enter through the main entrance from the parking lot to get to the lobby and reception area. The main entrance, as described previously in the Architectural Breadth, has been redesigned with an overhang. The overhang consists primarily of wood, and the façade is primarily red brick. The palate of materials used in this building is very minimal. However, a small selection of materials reveals subtle architectural features more clearly. Take for example the brick detail at the column pediments. This is a subtle, yet defining feature representing the strength of a brick exterior.

Design Criteria: As interpreted from the IESNA Handbook

Building Exteriors – Entrances – Active (pedestrian/ conveyance)

Illuminance Values

- Horizontal – 5 fc
- Vertical – 3 fc

Appearance of Space and Luminaires

- The appearance of the luminaires should implement the exterior architecture by being simple and not interrupting the task in the space. In the case of the building façade and sidewalk, the fixtures should not be obvious.

Color Appearance

- Color rendering in dimly lit situations becomes increasingly more difficult. A lamp with a high CRI value and low CCT value should be chosen.

Direct Glare

- Use of cut off optics or semi-cutoff optics can control glare. Avoid using luminaires where the bare lamp can be seen.

Light Pollution/Trespass

- Avoid using luminaires that emit light above the horizontal plane. Minimize direct light onto nearby windows and illumination onto adjacent properties.

Modeling of Faces or Objects

- If it is important to identify faces, provide adequate vertical and horizontal illuminance. Diffuse illumination from luminaires and from surface reflection is helpful.

Points of Interest

- Make sure signs, special landscaping, and other points of interest are clearly visible to attract attention.

Power Allowances and Control Requirements:

According to ASHRAE 90.1, power densities for plaza areas shall not exceed 0.2 W/ft^2. Walkways less than 10 ft wide shall not exceed a power density of 1.0 W/linear foot. Walkways greater than 10 ft wide shall not have a power density exceeding 0.2 W/ft^2. Lighting for all exterior applications shall have automatic controls capable of turning off exterior lighting when sufficient daylight is available or when the lighting is not required during nighttime hours.

Lighting Plans:
For a complete list of lighting plans, see Appendix A

Luminaires:
All luminaire schedules are listed in Appendix B

Cut Sheets:
Cut Sheets are located in Appendix C

Controls:
The entrance and walkway will be controlled by a Lutron Grafik Eye System. This system optimizes efficiency by monitoring surrounding light levels and only turning the circuit on when it is needed.

Materials and Reflectance:
Walls:
- Red Brick
- Reflectance: 0.3

Windows:
- Double Pane Glass
- Reflectance: 0.15
- Transmittance: 0.85

Sidewalk:
- Concrete:
- Reflectance: 0.3

Overhang:
- Wood:
- Reflectance: 0.5

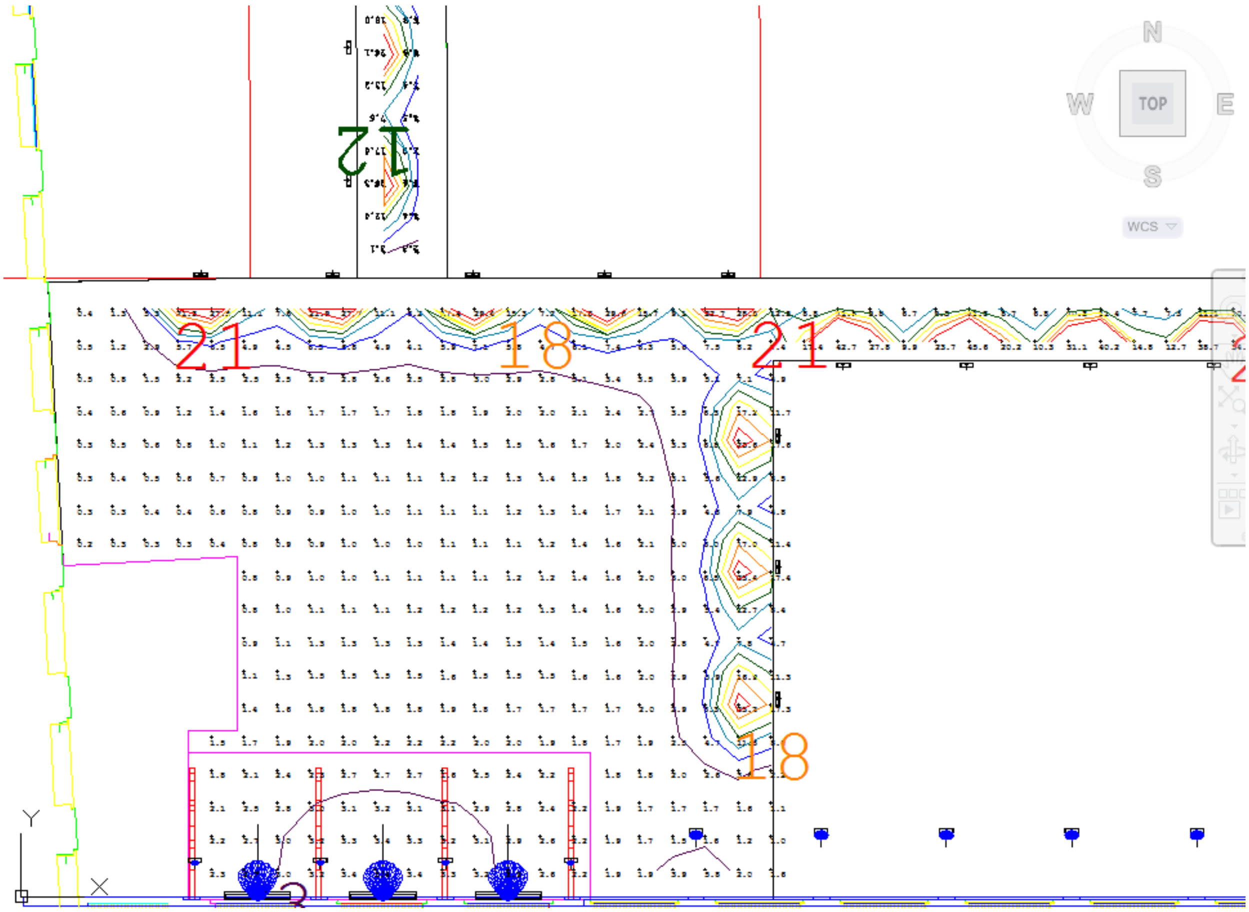
Lighting Design:
The design of the main entrance can be broken up into three categories: the overhang, the façade, and the walkway. The first to be addressed will be the façade. The façade consists of strong brick columns between large arch top windows. By washing the columns with light with a point source at ground level, not only does the strength of the columns become evident, but the pattern that the columns create is enriched. Another benefit to washing the brick is its texture becomes more pronounced. A shadow is formed over the concave mortar joint from the brick below. The combination of repeating columns and the texture within them creates the basis for a wonderful scene. The next component of the main entrance is the overhang designed in the Architectural Breadth. By asymmetrically lighting the underside of the overhang, several effects occur. The underside is filled with light in a soft gradient, which not only catches the eye from a distance, but also reflects the light back down, indirectly illuminating the walkway in front of the door. The mounting location of these fixtures is just above the door, and though the fixtures don't necessarily make a large architectural impact, the fact that they are visible does not detract from what they accomplish. This is a great way to showcase the performance of one of Elliptipar's own products. The walkways are an important feature to the entrance. In a literal sense, they physically lead the guest to the door. But at night, they must guide the guest subconsciously. At night, light becomes the guiding force, when it is no longer the sole responsibility of individual materials to suggest a path. The lights mark a path from both directions, which terminates at the destination. When all of these individual elements come together, a clear and purposeful scene is created.

Psychological Impression:
When the guest approaches the main entrance, they will experience a visual compression under the overhang. When they enter the door, the above boundary will be lifted, and they will be released into the lobby. This compression and release phenomenon momentarily expresses the full extent of the 13 foot ceilings throughout the first floor.

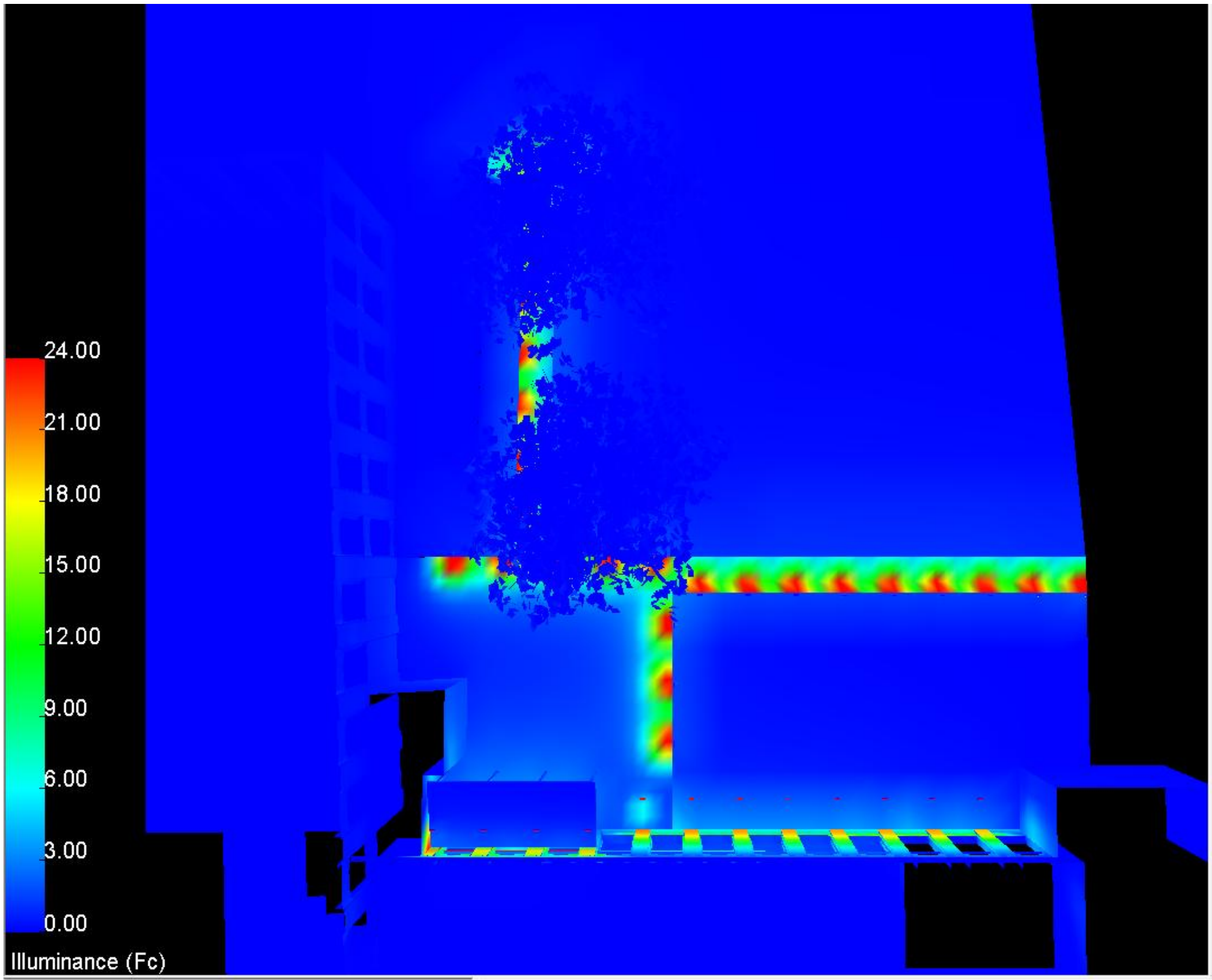
Renderings:

Design Performance:
The target illuminance on the walkways is 5 fc. The achieved average illuminance level is 6.48 fc.

Isoline Drawing:
Each isoline is 3 footcandles from the next. The purple isoline represents 3 fc, and the red isoline represents 21 fc.



Pseudo Color Rendering:
The pseudo color rendering graphically displays the illuminances from an overhead view.



Energy Code Compliance:

ASHRAE 90.1 Lighting Power Density				
Area	Allowable Power	Size	Allowable Wattage	Designed Wattage
Walkways over 10' wide	0.2 W/sq ft	1431 sq ft	286 W	160 W
Walkways under 10' wide	1.0 W/ft	122 ft	122 W	360 W
Canopies	1.25 W/sq ft	231 sq ft	289 W	282 W
Façade	5 W/ft	97 ft	485 W	340 W
Total			**1182 W**	**1142 W**

Lobby

Description:
As guests enter the lobby, they will be greeted by a cheerful exhibition of natural wood tones. The restored wood floor and columns hint at the heritage of the building. Though light in color, they enrich the environment. The columns also help to further express the height of the room. Between the columns, and also on the wall to the right are large black and white photographs that were taken early in the building's history. These photographs are the center piece of the lobby.

The lobby acts as the main junction between the two building halves. Immediately to the left is a glass curtain wall. Beyond the glass, the expansiveness of the converted factory is evident. In this space is one of the two large open offices. Past the lobby to the front is the main conference room. To the right lies a corridor that runs the length of the office wing.

Design Criteria: As interpreted from the IESNA Handbook

Offices – Lobbies, lounges, and reception areas

Illuminance Values

- Horizontal – 10 fc
- Vertical – 3 fc

Appearance of Space and Luminaires

- IESNA puts great importance on this topic. The interior architecture should speak for itself, yet coincide with the overall theme of the building. The appearance of the luminaires should implement the interior architecture by being simple and not interrupting the task in the space. The lobby is usually the first impression a person will get of the building. It is important that the first impression is a good one. Also, luminaires giving direction to the guests is helpful.

Color Appearance (and Color Contrast)

- Though not of the highest importance, IESNA still sees color appearance to be moderately important. Color appearance of this space should be welcoming and warm. Proper color rendering is important for complementing skin tones.

Daylight Integration and Control

- Daylight integration and control is only somewhat important to IESNA in a lobby space. However, since lobbies are generally adjacent to an outdoor space, daylight integration is usually not an issue. The issue of daylight control may not be necessary, as the curtain wall does not suffer from direct sunlight penetration.

Direct Glare

- Direct glare can cause visual discomfort to a guest. In order to reduce direct glare, luminaires should be placed accordingly so that they minimize direct line of sight. As a compromise, a glare shield can be specified.

    Light Distribution on Surfaces

- The beam distribution on the walls is important. The correct fixtures should be chosen and aimed properly to minimize undesirable beam spread. This is key in the proper illumination of the black and white photographs on the north wall.

Luminance of Room Surfaces

- Luminance is important in creating a visual hierarchy in the space. Although the large photographs on the north wall are major focal points of the room, the other wall surfaces must not be left out. Luminance on the walls acts as a defining border, but can also give the sense of spaciousness.

Modeling of Faces or Objects

- It is likely that while walking through the lobby, an employee or guest will pass another person. A high percentage of communication is nonverbal. It is important that the pattern of light on faces enables clear recognition and interpretation of expression by enhancing contrast in certain areas around the mouth and eyes.

Surface Characteristics

- Dark surfaces, saturated colors, and glossy finishes can maintain visual interest and stimulation, but they should be used to a limited degree. In the lobby the floor is polyurethaned wood, which has a distinct shine to it

Psychological Reinforcement

- A psychological impression, or Flynn impression, that would be most fitting to a lobby space is that of spaciousness. This would be achieved by brightly illuminating the walls and ceiling.

Power Allowances and Control Requirements (ASHRAE 90.1):

For convenience, this space will be considered as a lobby while referencing ASHRAE 90.1. ASHRAE 90.1 states that the maximum lighting power density for a lobby, if using the Space-by-Space Method, is 1.3 W/ft^2. As for lighting controls, because the building is over 5000 ft^2 "all interior lighting shall be controlled with an automatic control device to shut off building lighting in all spaces."

Lighting Plans:
For a complete list of lighting plans, see Appendix A

Luminaires:
All luminaire schedules are listed in Appendix B

Cut Sheets:
Cut Sheets diagrams are located in Appendix C

Controls:
The lobby lighting is broken up into zones that are easily dimmable to accommodate for the abundant amount of daylight that is received.

Materials and Reflectance:
Floor:
  Polyurethaned wood
  Reflectance: 0.4 (assumed)
Ceiling:
  White acoustical tile.
  Reflectance: 0.8 (assumed)
Woodwork:
  Wood columns.
  Reflectance: 0.5 (assumed)
Walls:
  White paint on brick.
  Reflectance: 0.5 (assumed)
Partition:
  Glass curtain wall.
  Reflectance: 0.15 (assumed)
  Transmittance: 0.85 (assumed)
Wall Hangings:
  Pictures.
  Reflectance: 0.5 (assumed)

Lighting Design:
A majority of the ambient light comes from fixtures hidden above the platform in the partition. These linear fluorescent fixtures wash the ceiling. The distribution is a soft gradient from left to right. The second layer of light in the room comes from the accented photographs. The fixtures that were used to accent the photographs are cantilevered asymmetrical wall washers, which utilize a halogen source. Halogen was chosen over other types of lamps due in part to its high CRI and consistency of CCT. Most importantly, though, is the fact that lamps requiring a ballast in a similar product can cause the luminaire to be nearly twice the size. A larger luminaire may detract from the artwork being accented.

Psychological Impressions:
The first time entering a building can be unnerving, especially if there is no indication of a correct path. However, there are alternatives to typical arrows pointing the way. The light on the ceiling plane in the main lobby of The Web Shop is used to guide the guest to his or her destination. The majority of the light on the ceiling is a soft gradient that starts from the left. This brightness creates a subconscious lure toward this side of the room, where beyond the curtain wall is the reception area. Another subtle but effective guide is the light emanating from the far corner of the room. In this nook is the entrance to the conference room, where guests are likely to go to.

Renderings:
The first image is positioned just inside the door of the main entrance.

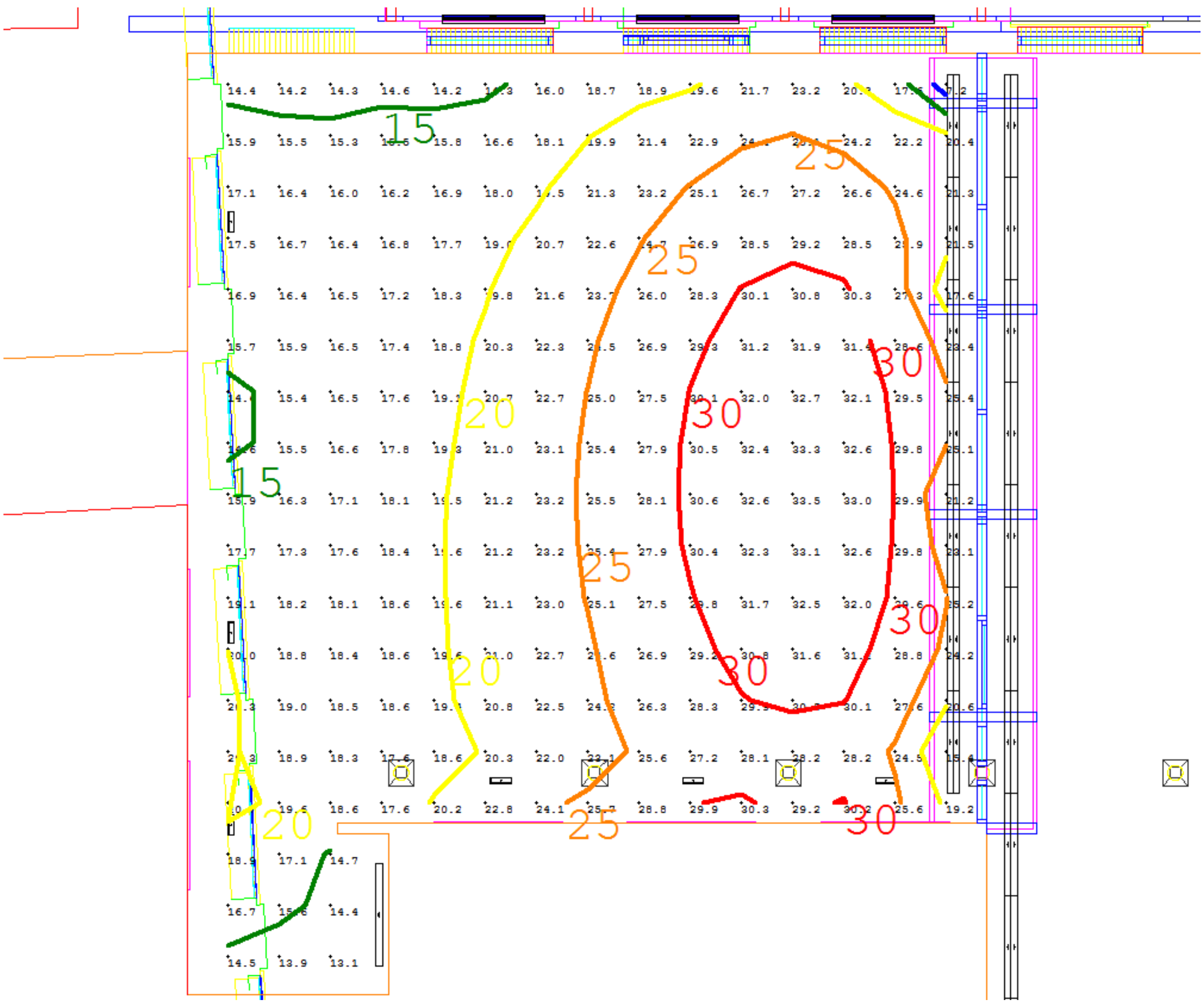
The second image is located from beyond the curtain wall, looking into the lobby.

Design Performance:

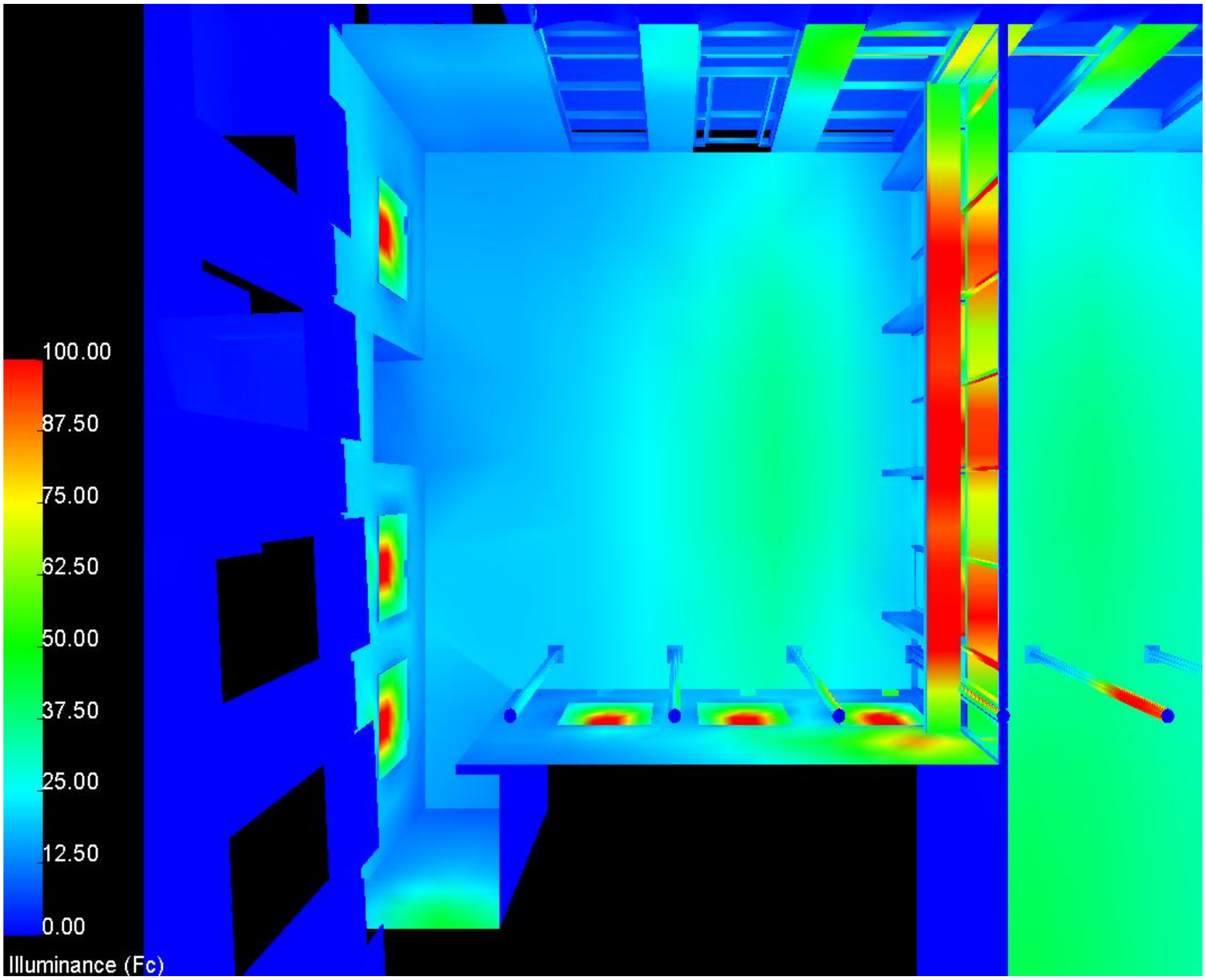
The target illuminance in the lobby is only 10 fc. However, since the lobby is a transitional area between spaces of varying brightness, the illuminance was increased. However, even at full brightness when the design is capable of over 20 fc, it still remains 20% under the 1.3 W/sq ft maximum, as required by ASHRAE 90.1.

Isoline Drawing:

The isolines in the following drawing are in 5 fc increments starting with blue at 10 fc and ending with 30 fc in red.



Pseudo Color Rendering:
The pseudo color rendering graphically displays the illuminances from an overhead view with the ceiling surface set as singles sided. The lack of visual ceiling does not change the performance of the space in any regard.



Energy Code Compliance:

ASHRAE 90.1 Lighting Power Density				
Area	Allowable Power	Size	Allowable Wattage	Designed Wattage
Walkways over 10' wide	1.3 W/sq ft	974	1265	1020

Open Office

Description:
This 3100ft^2 office seats 20 employees, and houses hundreds of documents. There is also large office equipment, such as the full size plotter and scanner. The open office shares the same 13' ceiling as the rest of the first floor. The room is well proportioned. Its large square footage is balanced with its high ceiling height and large windows. The red accents add a splash of interest to the space.

Design Criteria:
Open plan office - Intensive VDT use, Hand written tasks, Printed tasks

Illuminance Values

- Horizontal - 30 fc
- Vertical - 5 fc

Direct Glare- Very Important

- Direct glare can cause visual discomfort and interfere with visibility of the occupants. Its main causes are from luminaire placement and natural light coming in through windows. Because reading and writing will be two tasks being performed by the occupants, it is crucial to control this problem in order for work to be done properly. Considerations to prevent this lie in use of indirect instead of direct light sources, luminaire placement, and placement of seating around fenestrations.

Reflected Glare- Very Important

- Reflected glare can be caused by light refracting off of shiny or glossy surfaces such as magazines. Veiling reflections from such surfaces can cause visual discomfort and reduce contrast on the surface. It is very likely that the occupants will be reading text glossy paper so reflected glare should not be ignored. This problem can be solved in much the same way direct glare can.

Luminances of Surfaces- Very Important

- Luminance values should be uniform on all surfaces; including floor, wall, ceiling, and work plane in order to reduce visual clutter and distractions. However, a slightly higher luminance value may be desired on work surfaces in order to direct focus to the work of the occupants.

Light Distribution on Task Plane (Uniformity) - Very Important

- Uniformity on the task plane is important for visual clarity while performing tasks such as reading and writing. Any type of patterns is undesirable for they will be distracting to the occupants.

Source/ Task/ Eye Geometry- Very Important

- Luminaires should be kept away from the offending zone to reduce reflections. Indirect lighting and luminaires placed to the sides of the desks will help avoid these problems.

Appearance of Space and Luminaires- Important

- It is important that the space be bright and uniformly illuminated to avoid visual distractions and clutter. Areas of circulation should stand out in order to guide foot traffic.

Color Appearance (and Color Contrast) - Important

- Color appearance can affect visibility and aesthetics. Proper color rendering is crucial for producing a pleasant looking space and complementing the appearance of the occupants. Contrast is required for distinguishing text in reading applications.

Daylighting Integration and Controls- Important

- Daylighting integration is important for reduction of lighting load and to provide high quality light or light with exceptional color rendering. The space receives an ample amount of natural light due to the fact that about 50 percent of its walls are exterior glazing. However, measures need to be taken to control the amount of daylighting such as shading in order to reduce glare or excessive solar heat gain.

Modeling of Faces and or Objects- Important

- Within the work environment, it is often important for people to converse with one another and share ideas. Therefore, it is necessary that the occupants' faces are rendered in a pleasant manner in order to optimize social interaction.

Power Allowances and Control Requirements (ASHRAE 90.1):

ASHRAE 90.1 states that the maximum power density for an office space, using the Space-by-Space Method, is 1.1W/ft^2. As for lighting controls, because the building is over 5000 ft^2 "all interior lighting shall be controlled with an automatic control device to shut off building lighting in all spaces."

Lighting Plans:
For a complete list of lighting plans, see Appendix A

Luminaires:
All luminaire schedules are listed in Appendix B

Cut Sheets:
Cut Sheets are located in Appendix C

Controls:
The task-ambient fixtures are integrated with wireless dimming control. The wall washers along the north wall are also to be controllable

Materials and Reflectance:

Floor:
- Dark blue carpet on raised floor.
- Reflectance: 0.2 (assumed)

Ceiling:
- White acoustical tile.
- Reflectance: 0.8 (assumed)

Accents:
- Red paint. Semi-gloss.
- Reflectance: 0.25 (assumed)

Walls:
- White paint on gypsum wall board.
- Reflectance: 0.5 (assumed)

Woodwork:
- Beams and columns.
- Reflectance: 0.5 (assumed)

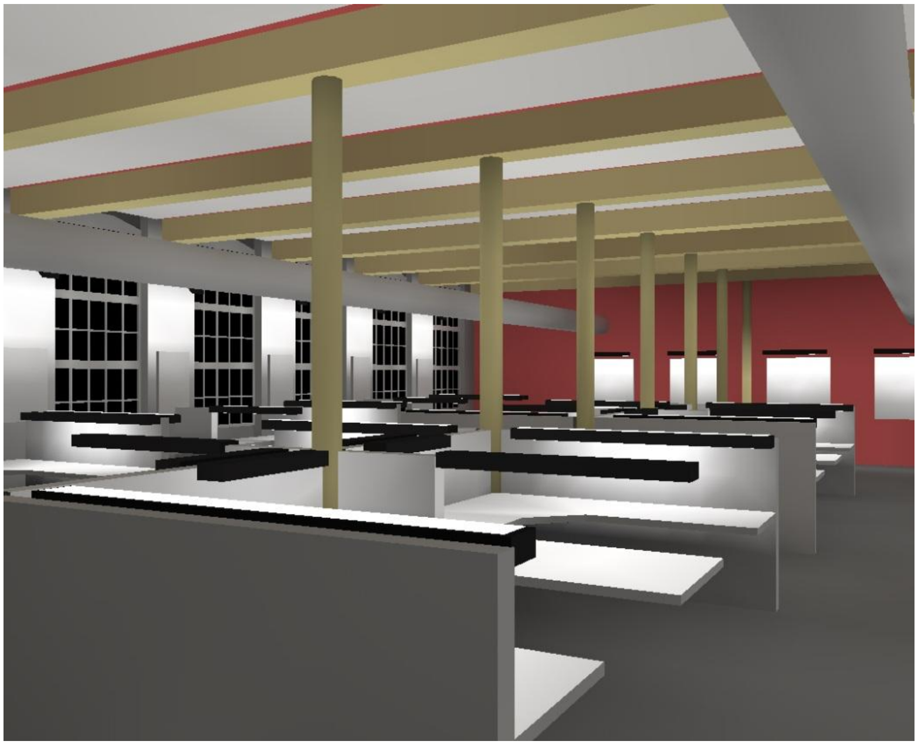
Furniture:
- Cubicles.
- Reflectance: 0.5 (assumed)

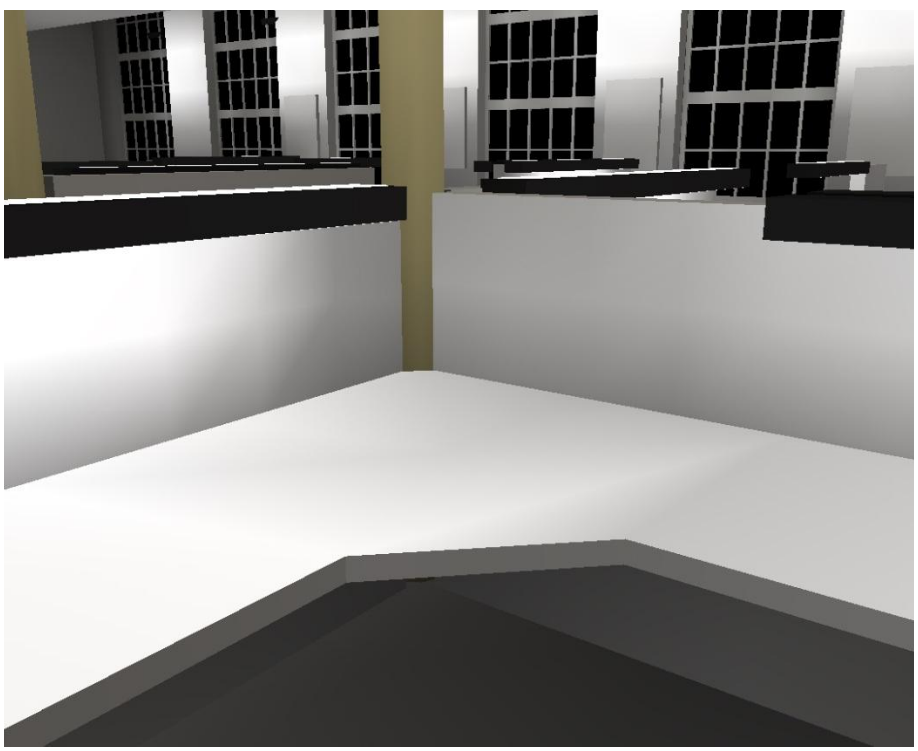
Wall Hangings:
- Paintings and white boards.
- Reflectance: 0.5 (assumed)

Glass:
- Windows.
- Reflectance: 0.15
- Transmittance: 0.85

Lighting Design:
The lighting design can be broken into layers to describe the behavior of each type of luminaire individually. The first layer is the task-ambient system. These luminaires provide the majority of the light in the space. The design consists of a combination of task-only, ambient-only, and task-ambient fixtures.it was necessary is some places to separate the two components to maintain uniformity, whether on the ceiling or on the work plane. The next layer consists of several types of wall washers. Each of the four walls is unique. The south wall is nearly continuous, with the only interruptions being the exposed wood columns. To wash this wall, luminaires were placed in the center of the wall section between the columns. In contrast, the north wall is much the opposite. The north wall has large brick columns rather than the round wood columns, and instead of a wall surface, there are 10’ tall windows. So the resulting surface to wash is the columns, not the walls. The fixtures do not need to be as large as the south wall, since the target surface is much narrower. The east wall is the red accent wall. On this wall are four whiteboards that are grazed with linear fluorescents. The west wall is a small partition that does not connect to the ceiling. Both sides of the partition are illuminated with cantilevered wall washers. As a whole, the wall washers do not add a significant amount of reflected ambient light to the space, but the desks on the bordering wall do see some benefit.

Renderings:

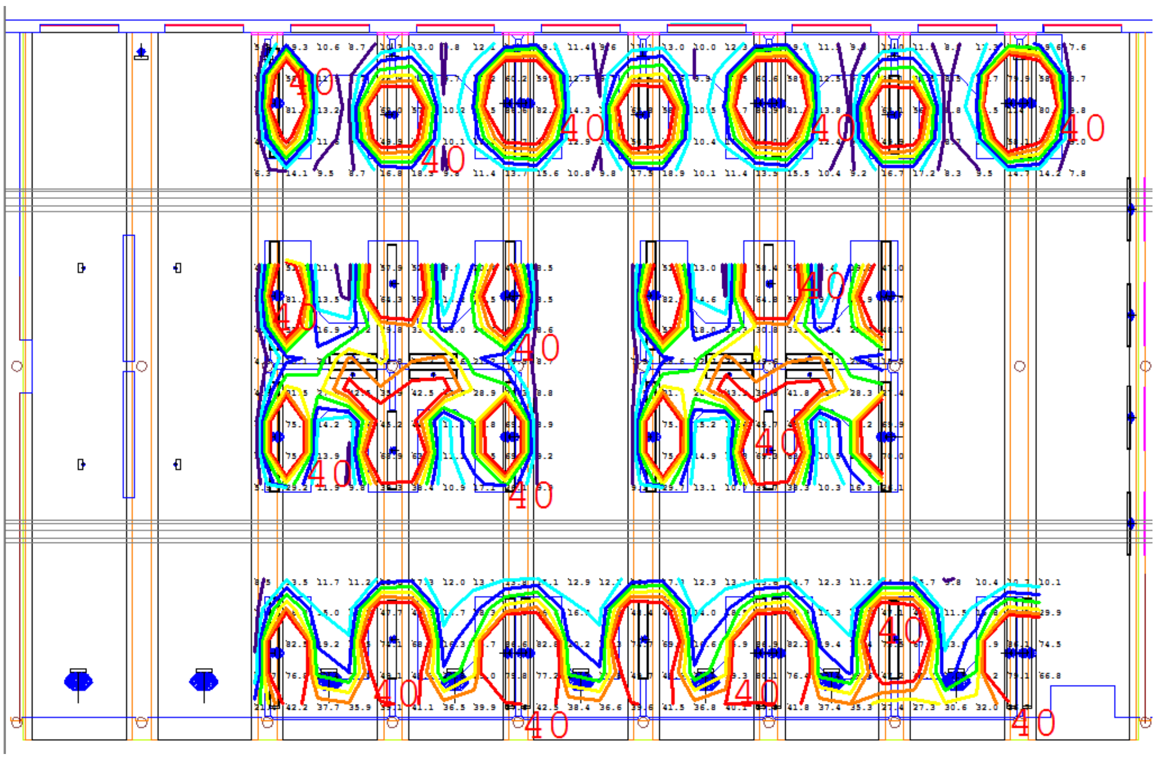




Design Performance:
The target illuminance on the work plane is required to be 30fc. As designed, the average illuminance on the workplane within the cubicle area is 29.25fc. This difference is only 2.5%, and is within the tolerance allowable by IESNA.

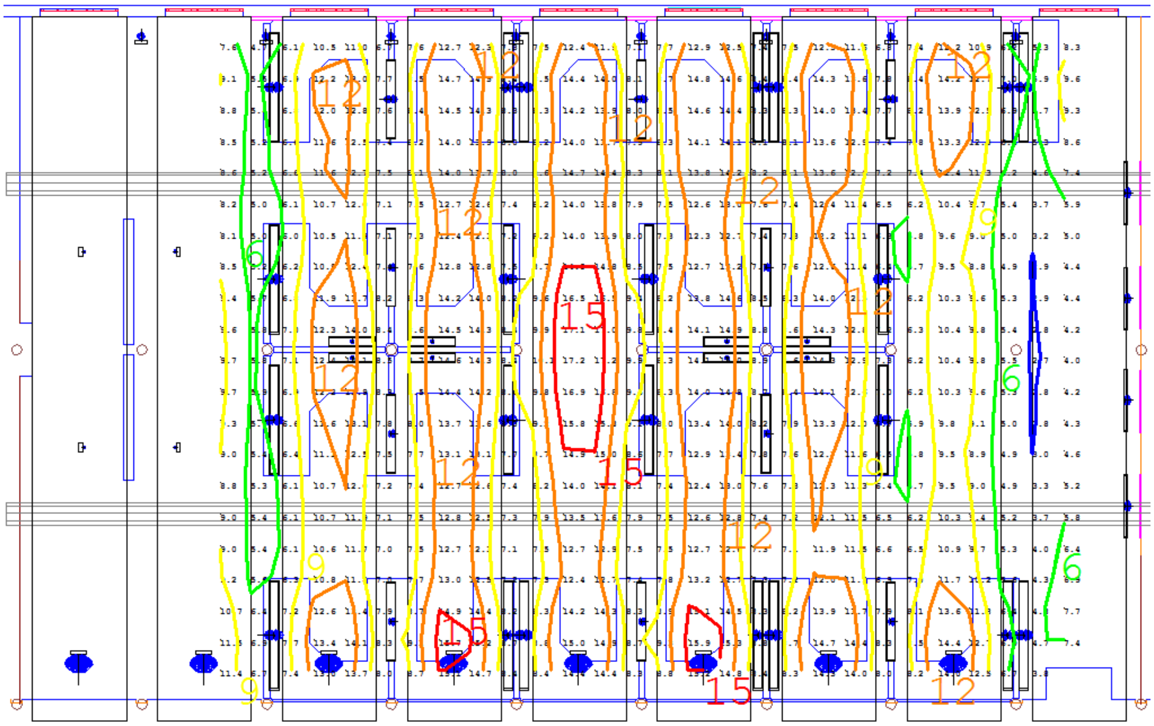
Isoline Drawings:
For the work plane, each isoline is 5 footcandles from the next. The purple isoline represents 10 fc, and the red isoline represents 40 fc.

Work Plane Isolines

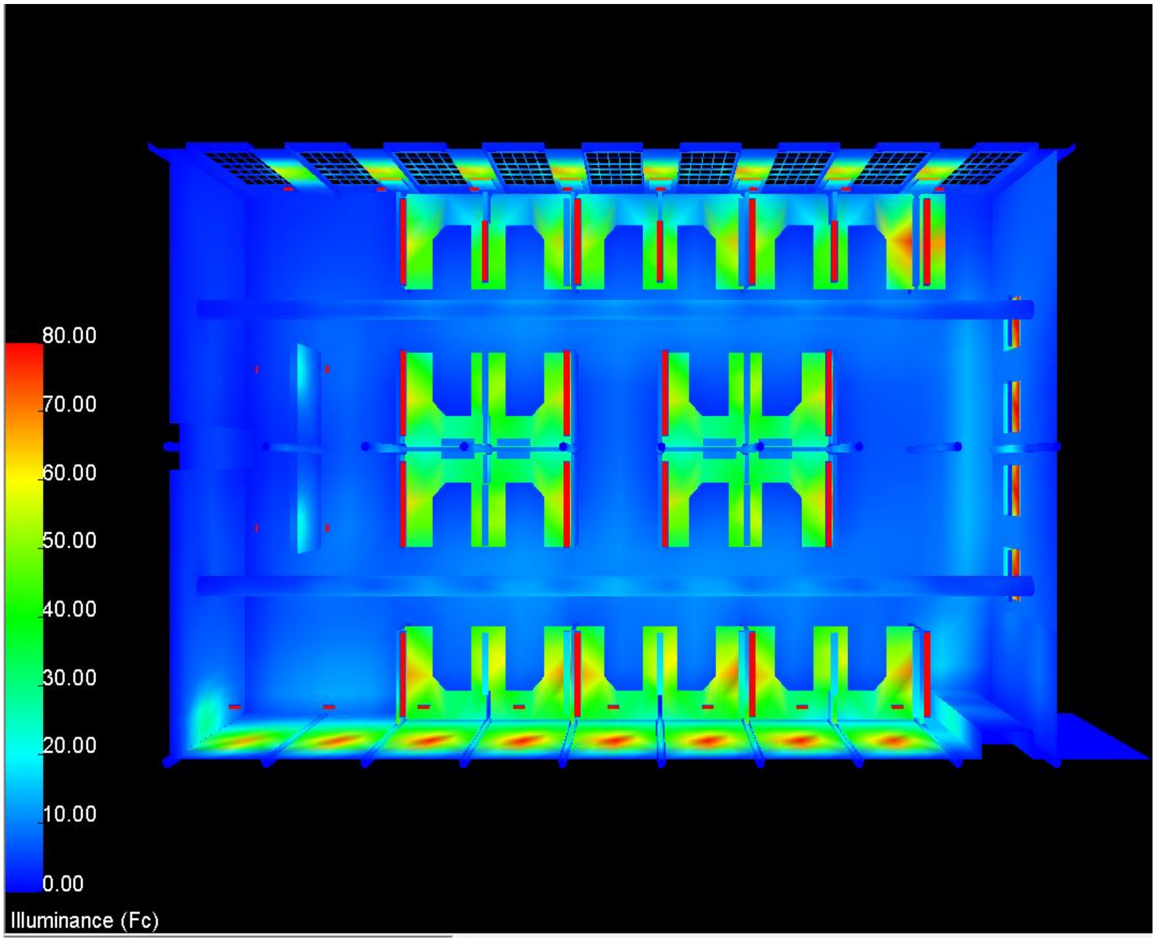


For the ceiling plane, each isoline is 3 footcandles from the next. The blue isoline represents 3 fc, and the red isoline represents 15 fc.

Ceiling Plane Isoline



Pseudo Color Rendering:
The pseudo color rendering graphically displays the illuminances from an overhead view.



Energy Code Compliance:

ASHRAE 90.1 Lighting Power Density					
Area	Allowable Power	Size	Allowable Wattage	Original Wattage	Designed Wattage
Open Office	1.1 W/sq ft	3100 sq ft	3400 W	8580 W	3478 W

Conference Room

Description:
The conference room at The Web Shop caters to a variety of uses. There are frequent staff meetings, product demonstrations, and guest lectures. The room is a simple rectangular shape with no windows. The room must be configurable to accommodate for a variety of points of attention. Often when there is a small department meeting, the tables are configured so that the attendees are facing each other toward the center of the room. When there is an occasion like a product demonstration, the speaker at the front of the room is the center of attention. And often when there is a guest lecturer, the projector screen is the center of attention. All of these assemblies require a different lighting solution, but all of the luminaires must coexist at the same time. The solution to creating different scenes lies in the application of a control system.

Design Criteria: As interpreted from the IESNA Handbook
Conference Rooms – Meeting
Illuminance Values
- Horizontal - 30 fc
- Vertical - 5 fc

Appearance of Space and Luminaires
- IESNA puts great importance on this topic. The interior architecture should speak for itself, yet coincide with the overall theme of the building. The appearance of the luminaires should implement the interior architecture by being simple and not interrupting the task in the space.

Color Appearance (and Color Contrast)
- Though not of the highest importance, IESNA still sees color appearance to be moderately important. Color appearance of this space should be welcoming and warm. Proper color rendering is important for complementing skin tones. As in most meeting spaces, there is a projector screen. Contrast is necessary to distinguish text in reading applications.

Daylight Integration and Control
- Daylight control is only somewhat important in a meeting space. As is the case, many meeting spaces are in the center of a building with no windows. This is generally preferred because there is no extra ambient light from sunlight to take care of when the room has been dimmed.

Direct Glare
- Direct glare is very important. It can result in severe visual discomfort. To avoid direct glare, In a meeting room there is usually a circumstance where the occupants must direct their attention to a particular source for extended periods of time.

Light Distribution on Surfaces
- The beam distribution on the walls is important. The correct fixtures should be chosen and aimed properly to minimize undesirable beam spread.

Light Distribution on Task Surfaces

- Light distribution on the tables should be as uniform as possible. This is important in completing visual tasks such as reading text on a paper.

Modeling of Faces or Objects

- Facial modeling is very important with giving speeches or presentations. Seeing the presenter well aids in the clarity of the presentation. This requires a good combination or direct and indirect light.

Shadows

- The speaker's face, for instance, should not be in shadow. Nor should any other visual task. This can be overcome by the proper placement and aiming of fixtures in the space. If a spotlight on a speaker is directly overhead or behind them, they will be in shadow.

Surface Characteristics

- Surface characteristics are important. If a bright room is desired, the surfaces in a room must convey the goal. All wall surfaces in the room are gypsum wall board, painted white. High luminance can easily be achieved.

Power Allowances and Control Requirements (ASHRAE 90.1):

ASHRAE 90.1 states that the maximum power density for an office space, using the Space-by-Space Method, is $2.6W/ft^2$. As for lighting controls, because the building is over 5000 ft^2 "all interior lighting shall be controlled with an automatic control device to shut off building lighting in all spaces."

Lighting Plans:
For a complete list of lighting plans, see Appendix A

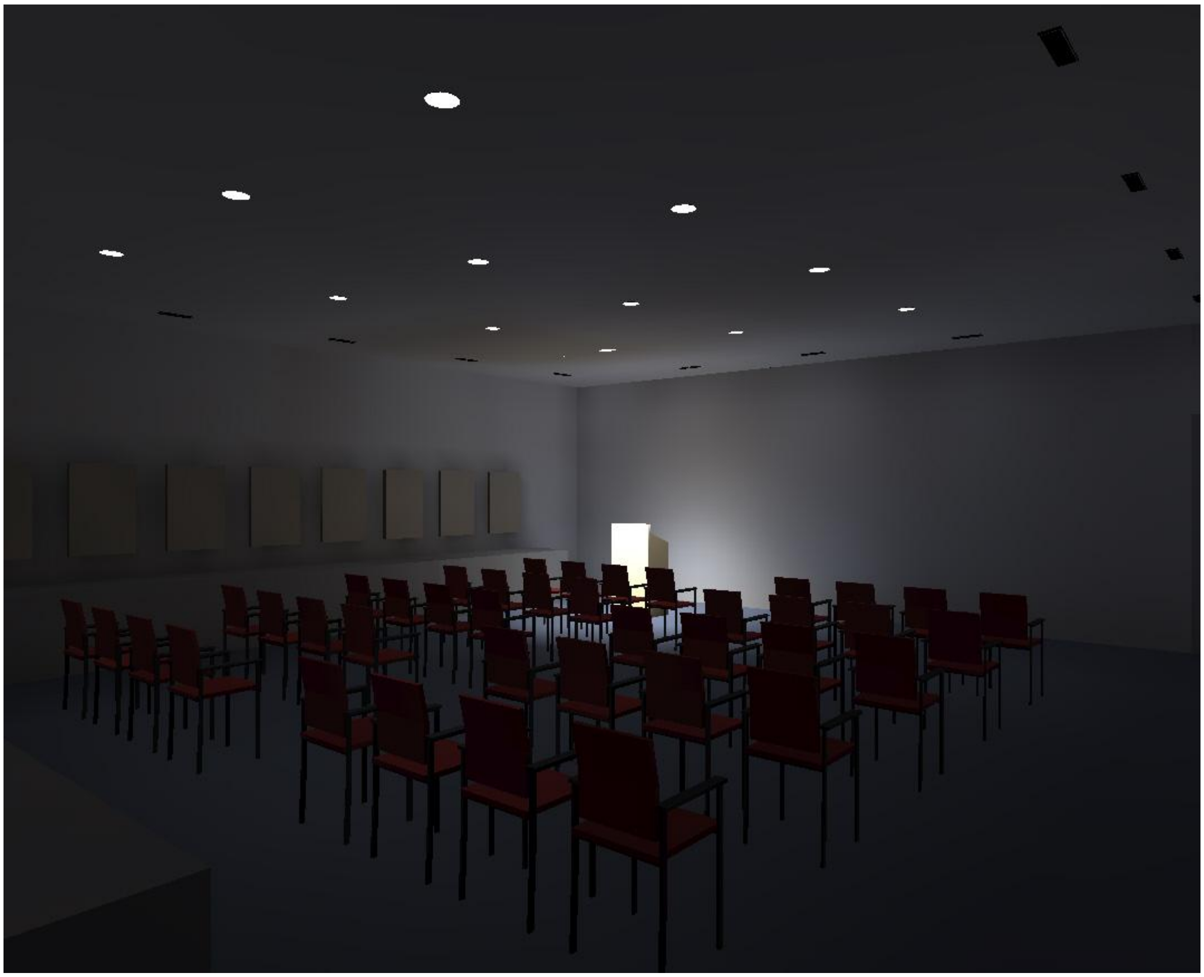
Luminaires:
All luminaire schedules are listed in Appendix B

Cut Sheets:
Cut Sheets are located in Appendix C

Controls:
The controls will be a system with programmable scenes. Since the room has no windows, dynamic daylight control is not necessary.

Materials and Reflectance:
Floor:
  Dark blue carpet.
  Reflectance: 0.2 (assumed)
Ceiling:
  White acoustical tile.
  Reflectance: 0.8 (assumed)
Walls:
  White paint on gypsum wall board.
  Reflectance: 0.5 (assumed)
Furniture:
  Tables.
  Reflectance: 0.5 (assumed)
Elevator doors:
  Silver paint over metal doors.
  Reflectance: 0.4 (assumed)

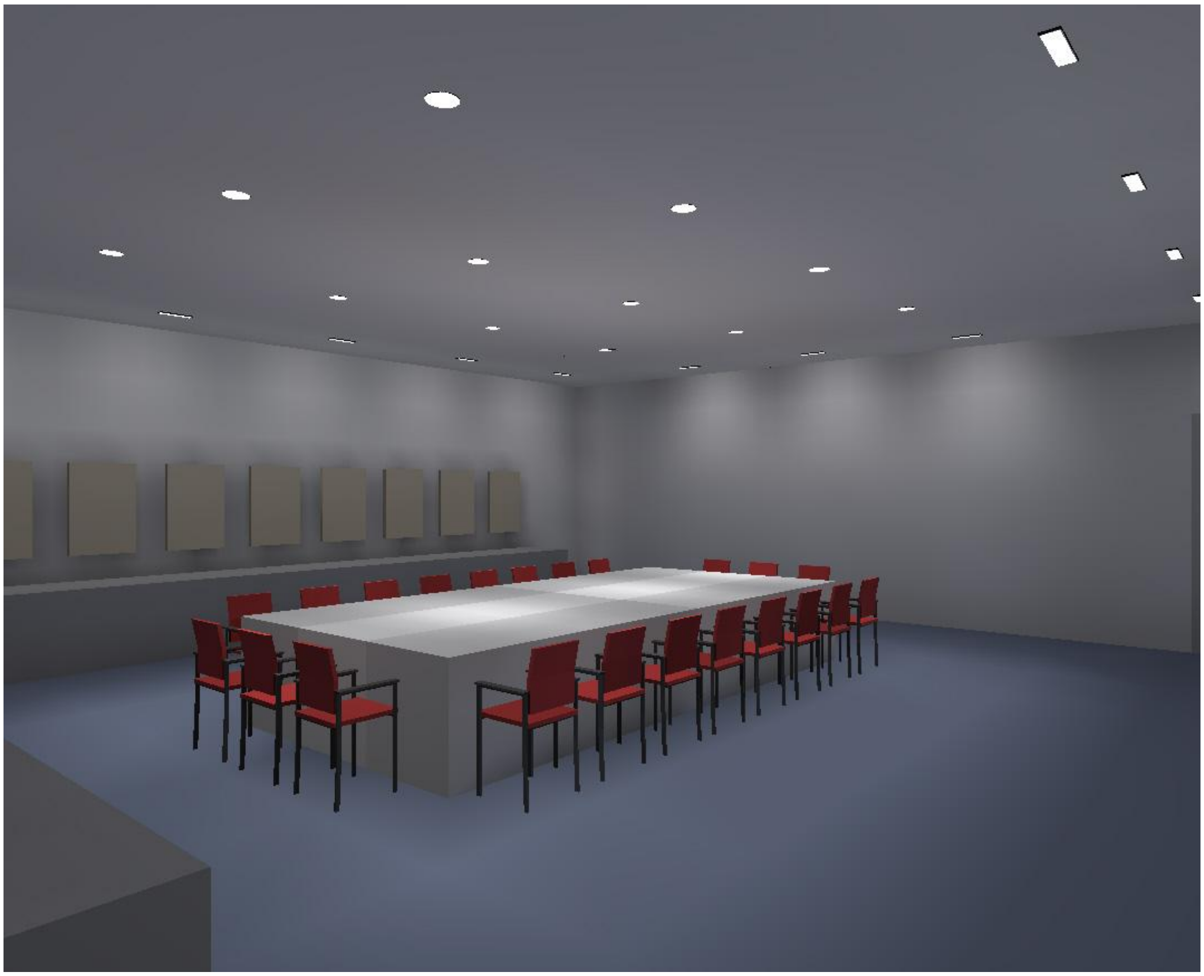
Lighting Design: Speech Scene
The design for this scene is very simple. It consists entirely of recessed downlights. The ambient light is achieved by recessed flood lights dimmed to 5%, and the highlighted podium is lighted by aimed recessed spot lights at full brightness.



Lighting Design: Video Conference Scene
This scene relies on perimeter lighting in the form of wall washing to light the room. By selectively removing light from the center and the front of the room, the audience can feel relaxed as they watch the projection screen.

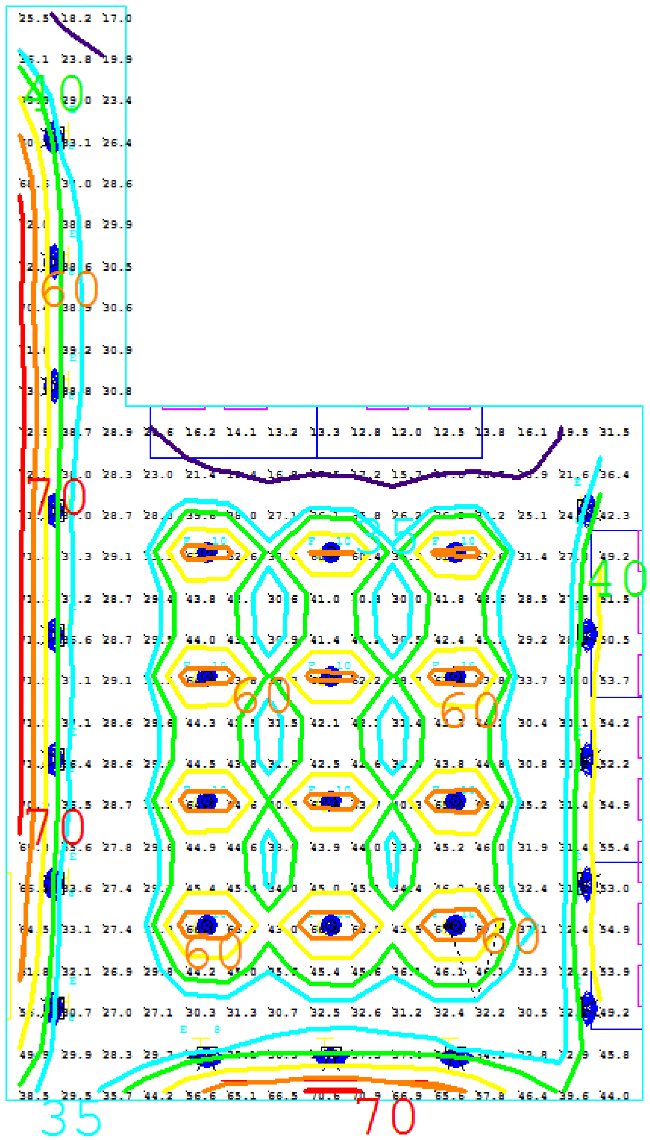
Lighting Design: Group Discussion Scene

During a group meeting when coworkers sit across the table from one another, facial recognition is important. The recessed downlights in the center of the room provide sufficient light to faces and the table surface. To avoid overly high contrast in surface brightness, the perimeter walls are washed at 50% brightness. This also removes a sense of tension associated with dark surroundings. If only the center of the room were lighted, the atmosphere would feel like an interrogation.

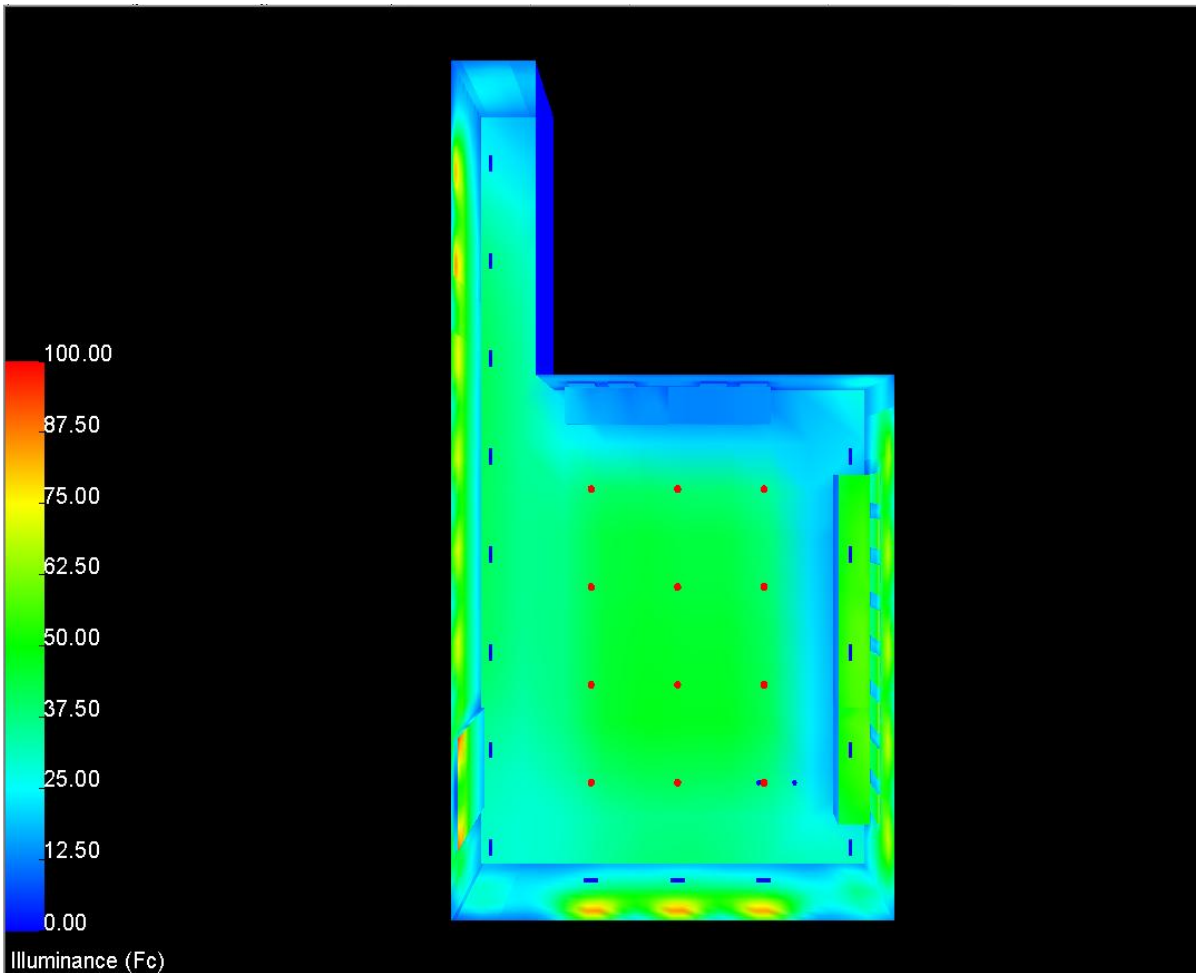


Isoline Drawing:

Each isoline is 10 footcandles from the next. The purple isoline represents 20 fc, and the red isoline represents 70 fc. Note that for this drawing, the lights are at full brightness. This is not part of any of the previous three scenes.



Pseudo Color Rendering:
The pseudo color rendering graphically displays the illuminances from an overhead view.



Energy Code Compliance:

ASHRAE 90.1 Lighting Power Density				
Area	Allowable Power	Size	Allowable Wattage	Designed Wattage
Conference Room	2.6 W/sq ft	1142 sq ft	2969 W	2800 W

ACOUSTICAL BREADTH

Introduction:

Room acoustics are an important quality of a space. In the case of the conference room at The Web Shop, speech intelligibility is a major design consideration. This breadth study contains strategies to develop an acoustically sound space. An analysis of reverberation time in the space shows a baseline of the room as well as suggested adjustments to fine tune the acoustics. In addition to reverberation time, HVAC noise will be taken into consideration in the analysis

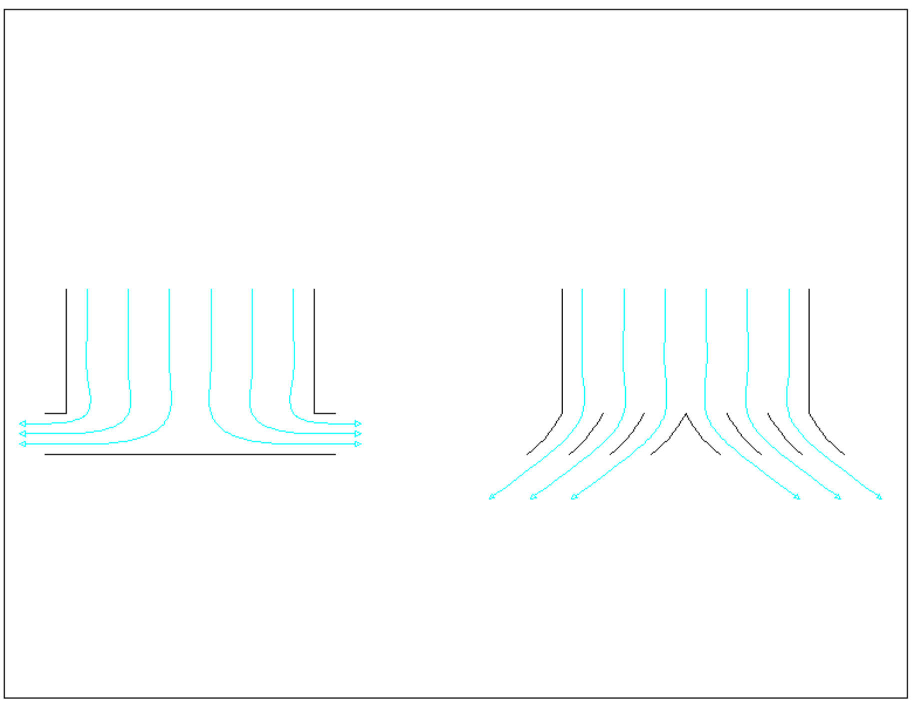
HVAC Noise:

HVAC noise is an inevitable consequence of any building that is ventilated. However the noise it produces is not necessarily a bad thing. In moderation this background noise can provide a sense of normalcy and privacy. On the other hand, in excess it can be distracting to the occupants.

The standard created by ASHRAE to rate noise performance of an HVAC system is referred to as Room Criteria. Room Criteria is calculated by taking the arithmetic average of the 500, 1000, and 2000 Hz octave bands. For a conference room such as the one in The Web Shop, the suggested range is 25 to 30dB.

Unfortunately for the conference room in The Web Shop, the HVAC system suffers from a loud hissing noise. This noise, in the 2000 Hz range, would likely bring the Room Criteria rating above the 30dB maximum. A hissing noise in an HVAC system is most often caused by turbulence in the diffuser. Likely the diffuser is of poor quality or is undersized. In the conference room, the diffusers seem to be both of poor quality and undersized. The diffusers terminate at an abrupt 360 degree T-shape, but also the cross sectional area of the diffuser is reduced to 1/3 the size of the duct.

Above is a photograph of the conference room. Circled in red is a diffuser. Below is a sketch of diffusers. The left represents the existing design, and the right represents a suggested new design. The cyan arrows display the air flow of each method.



Sound Energy Decay:
The way sound decays in a room has a direct correlation with the quality of the acoustics. Within the room, sound energy is reflected off of every surface. Sound energy is also absorbed by these same surfaces.

T60 Reverberation Time:
The standard representation of room absorptivity is referred to as the T60 Time. This figure represents the amount of time it takes for a room to decrease by 60 decibels when the source is turned off. T60 Times can range from less than 0.1 seconds to 2.5 or more seconds. A recording studio, for instance, would fall at the bottom end of the scale, and a concert hall would fall towards the top. Reverberation Time directly impacts speech intelligibility. Lower T60 Time is best for speech quality. For a conference room, the T60 Time is recommended to be between 0.4 and 0.7 seconds. To calculate the T60 Time of the conference room, the Absorption Coefficient must first be determined. This figure represents how much the wall, ceiling, and floor surfaces are absorbing. The average absorption will always be between 0 and 1. 0 is perfectly absorptive, and 1 is completely reflective. Below are the calculations of the Absorption Coefficient and the T60 Time.

Calculating the Absorption Coefficient α:
Let the average room absorption = $\bar{\alpha}$. Let the individual surface absorption = α_n. Let the area of each surface = S_n.

$\bar{\alpha} = (S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + \ldots + S_n\alpha_n) / S_T$
$V = 14846 \text{ ft}^3$
$S_T = 4455$

The assumed values of α, and the areas of each surface type are listed in the table below.

	Frequency (Hz)						
	125	250	500	1000	2000	4000	
Description	**Sabine Abrorptivity α**						**Area (Sq Ft)**
Carpeted Floor	0.08	0.25	0.55	0.7	0.7	0.75	1142
Suspended Acoustic Tile	0.4	0.5	0.6	0.75	0.7	0.6	622
Plaster Ceiling	0.07	0.17	0.4	0.55	0.65	0.65	520
Gypsum on Studs	0.3	0.1	0.05	0.04	0.07	0.09	1338
Painted Brick	0.01	0.02	0.02	0.03	0.04	0.05	689
Wood Door	0.15	0.11	0.1	0.07	0.06	0.07	144
ᾱ Per Octave Band	**0.181**	**0.225**	**0.293**	**0.367**	**0.382**	**0.389**	

Calculating the T60 Time:

$T_{60} = 0.161V / -S_T \ln(1 - \bar{\alpha})$

$T_{60} = 0.161(14846) / -4455 \ln(1 - \bar{\alpha})$

Frequency (Hz)	125	250	500	1000	2000	4000
$\bar{\alpha}$ Per Octave Band	**0.181**	**0.225**	**0.293**	**0.367**	**0.382**	**0.389**
T_{60}	2.69	2.1	1.55	1.17	1.11	1.09

Analysis:

Reverberation time greater than 1 second generally is considered bad for intelligibility of speech. The target T_{60} time for a conference room is somewhere between 0.5 and 0.9 seconds. Since speech lies around the 500-1000Hz range, the T_{60} time for The Web Shop's conference room is between 1.1 and 1.6 seconds. To improve intelligibility for the space, it would be beneficial to get the T_{60} below 0.9 seconds in both the 500 and 1000Hz octave bands. In order to improve the T_{60} time of the conference room, the average absorptivity must increase. The best way to increase the absorptivity of an existing space is to hang highly absorptive materials on the walls. By this method, the reverberation time can be decreased to an appropriate level. This will vastly improve the acoustical quality of the room.

PHOTOVOLTAIC DEPTH

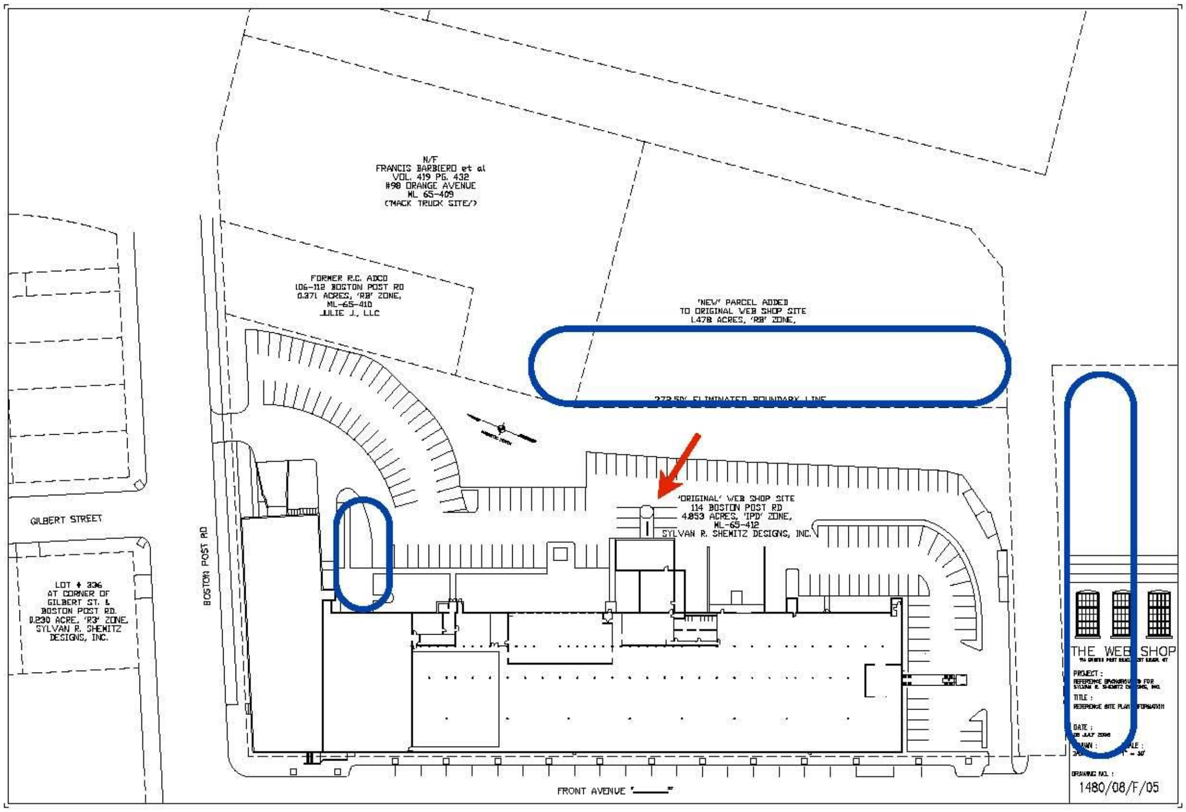
Introduction:
The following Electrical Depth is a study of photovoltaics. This report will present an overview of photovoltaic systems and their advantages. An analysis of the site will be conducted before the design of the system begins. Once design begins, detailed assumptions and calculations will be shown. The results will be analyzed to determine if the PV system was a worthwhile investment.

Why Photovoltaics?
In 2004 the global energy consumption was 130,000 terawatt hours. And in an age where fossil fuels are at a premium, the price of living is only going up. Changes must be made globally to be more efficient. Energy sources must shift to be renewable. The answer to all of the global needs is harnessing the power of the sun. Each year the earth receives about 350,000,000 terawatts of radiation. Even if the efficiency of the solar systems is terrible at first, there is still more than enough solar energy to make a difference.

The advantage of photovoltaics over other renewable energy sources comes down to efficiency. Wind turbines, for instance, rely on temperature differences caused by the sun unequally heating the atmosphere. Photovoltaics, on the other hand, convert the sun's radiation directly to electricity.

Hypothesis:
The geographic location of the site may impact the solar gain. If it were nearer to the equator, the gain would be much higher. This, along with many other factors, will impact whether or not installing a PV system is cost effective. It will likely be very close to breaking even. Hopefully it will be more on the side of a positive investment. With every decision made in the design process, serious consideration will be made to cost effectiveness.

Survey of the Site:
Before the design of the PV system begins, the site must be deemed adequate. One of the major considerations determining the adequacy of the site is shading. Some of the key contributors of shading include, but are not limited to: vegetation such as large trees, surrounding structures, and PV self-shadowing. A shadow on even one of the panels can cripple the net gain, so everything must be thoroughly analyzed.

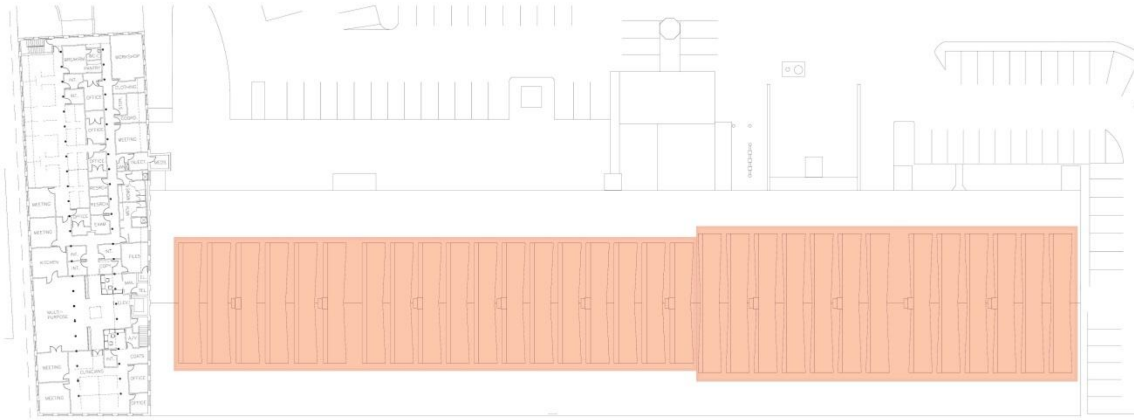


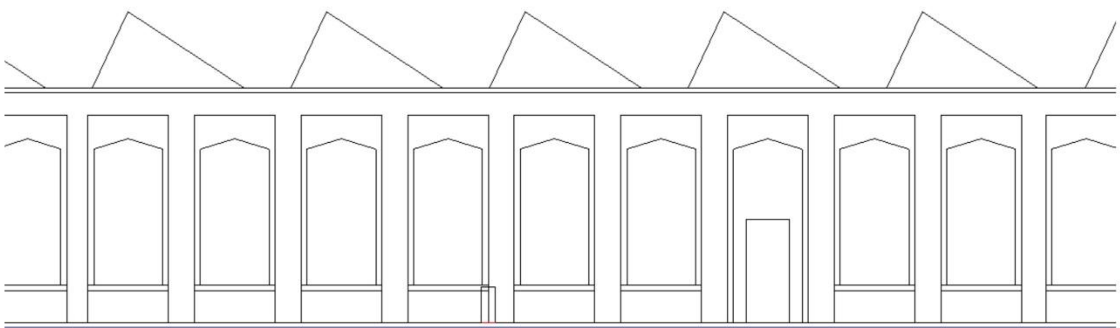
Upon analysis of the site, it has been determined that there are minimal obstructions, and none are of major concern. There are no adjacent buildings taller than The Web Shop. All foliage surrounding the building is sufficiently far away or is small enough to not be a concern. Foliage above 10 feet in height is outlined in blue. The factory cooling tower, as indicated with the red arrow above, may cast a shadow in the early morning. This will be taken into account, however it poses no major threat considering its shadows will generally lay in the parking lot. The only other major consideration is the array self-shadowing. This will be analyzed in detail when designing the array layout.

Determining the Basic Array Layout:
Now that the site has been deemed adequate, possible locations for the PV array can be determined. Since the entirety of the site excluding the building is utilized by parking, the only possibility is a rooftop array. Luckily, the roof of The Web Shop is very large, and should prove to be a viable location for a PV system. Shown below is a bird's eye view of the site. Outlined in purple is the taller office roof, and outlined in green is lower the factory roof.

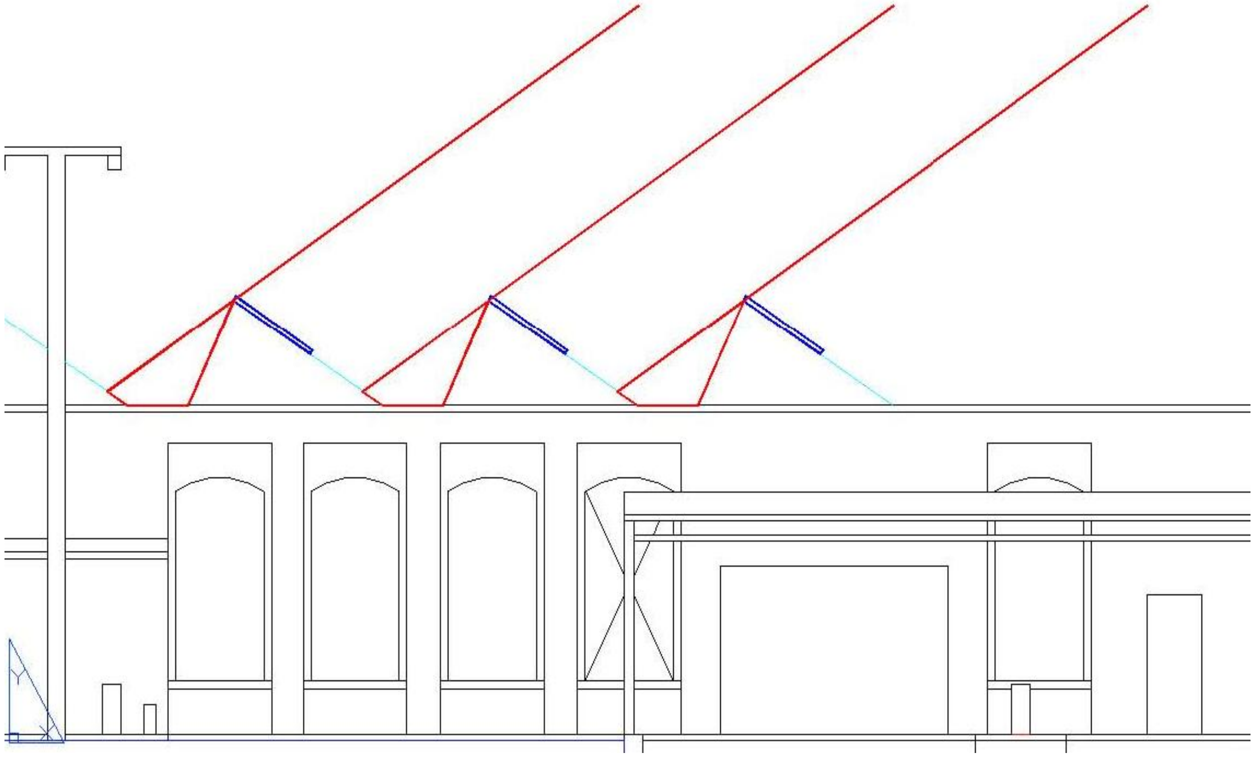
As evident in the image above, the roofs are littered with mechanical equipment. Implementing the design around this equipment would be very difficult, and would also hinder the usability of said equipment. Also, it is necessary to consider a system that someone will be able to pay for. The most extravagant solutions may not be the most practical. By using this mentality, it seems necessary to limit the size of the array to only encompass the sawtooth fenestrations. This method restricts the flexibility of the design. However, the ease of mounting the array is greatly increased due to the convenient design of the fenestrations. In addition, by not stretching the array to the very edge of the roof, it will not be visible to passersby. Thus the building will retain a classic, understated appearance. Below is a plan and an elevation of the factory roof, showing the saw tooth fenestrations. Highlighted in red is the roof area encompassed by the fenestrations.

Preliminary Drawings:



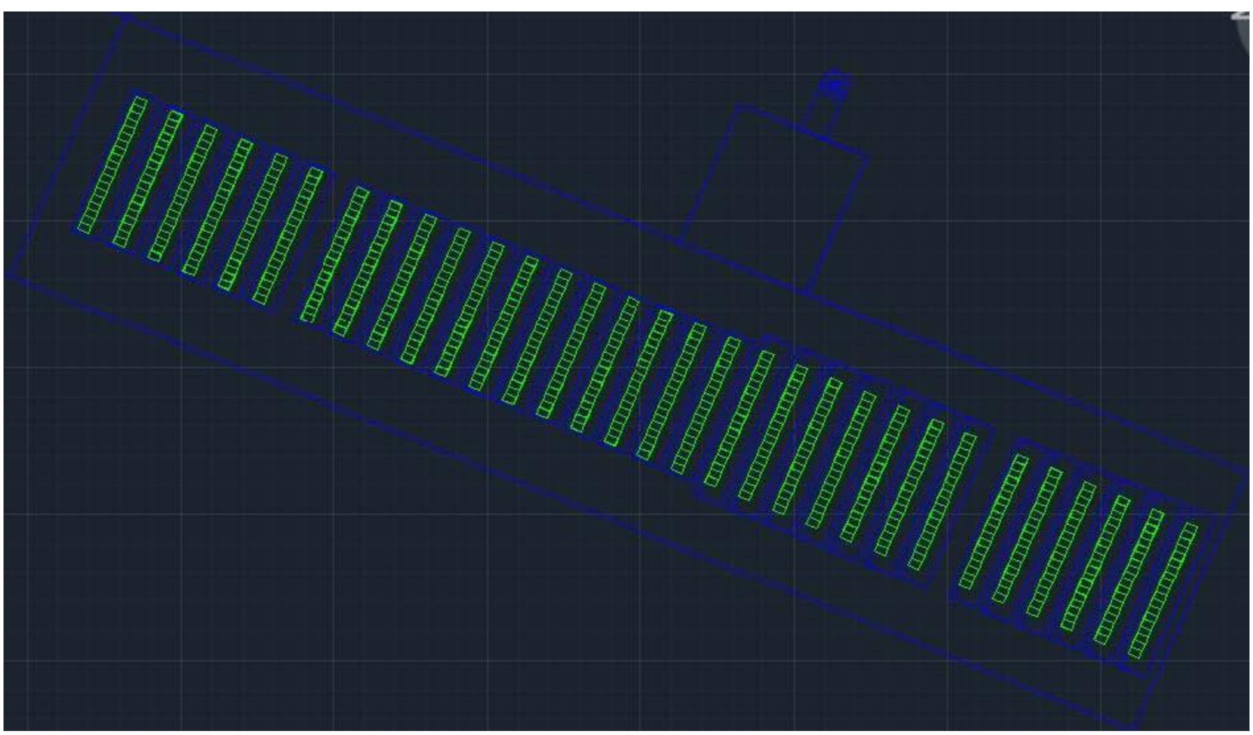


There are so many brands of PV Panels and supporting equipment to choose from. For the purposes of this study, it is impractical to labor over deciding on which to use. Though care will be taken on specifications of products, the brands will be chosen arbitrarily. The first product decision to make is the PV Panels. Sharp Commercial Series Panels were chosen. This series of panels offers many choices of specifications of the same size panel. So for now, only the panel size will be chosen, and the specific model will be chosen later. The chosen panel measures 39.1" x 64.6" x 1.8". This size was chosen based on how well it fits on the back of the rooftop monitors. Filling the entire back slope of the monitors is impractical. Though it would be beneficial in the summer to maximize the size of the panels, in the winter months, the lower portion of the panels would be shaded by the next fenestration to the south. A compromise has to be made so that the panels can be effective all 12 months of the year. To accomplish this, only about half of the monitor is covered in modules. Below is a plan and elevation showing the layout. Please note that all strings contain 18 modules, though the larger monitors are able to fit more. This is done so that the voltage remains the same across all strings, and also so that the microinverters are not overloaded. In total, there are 558 modules.



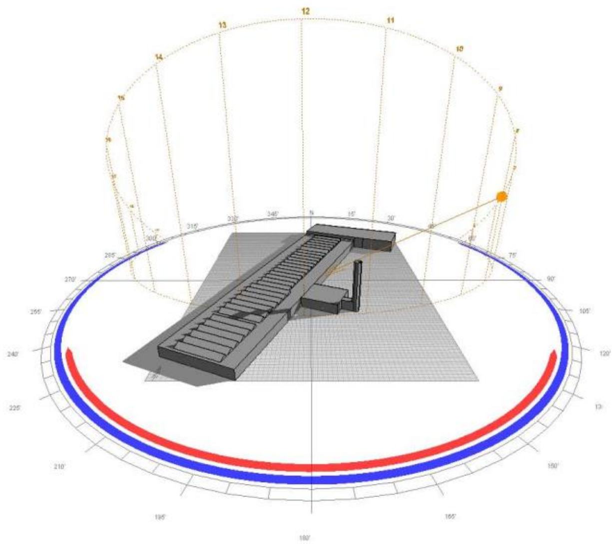
Shown above is a roof elevation with panels in blue on the backs of the monitors. In red shows how

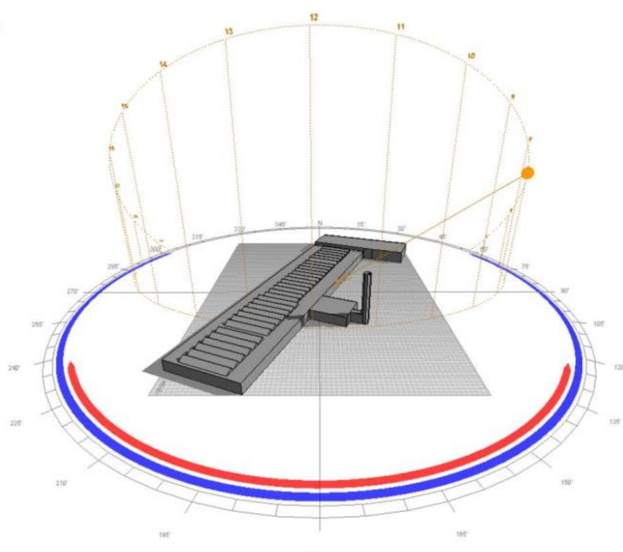
the sun angle affects shadowing. Note that the panels are out of the way of shadows caused by low sun angles. Below is a plan of the layout.

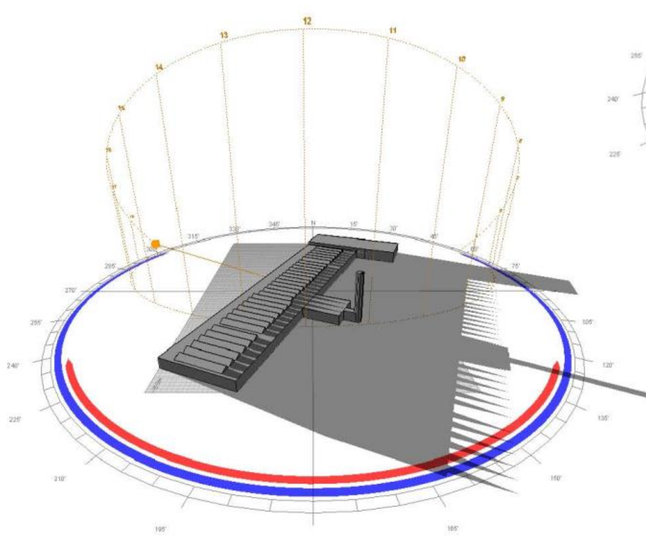


Shading, Revisited:

To take a closer look at the impact of shading, the building was analyzed in Autodesk Ecotect. It is necessary to analyze with this level of detail to calculate the precise times the building shadows itself. The shadows in consideration are the saw tooth fenestration shadows and the shadow caused from the cooling tower. The results show what hours of the day the panels are free of shade, and were analyzed quarterly on the equinoxes and solstices. Shown below is the Summer Solstice as an example. Note that the times do not take into consideration daylight savings, and are rounded to the nearest 15 minutes.







Results from Shading:
The result reveals what duration the PV panels will be free of shadows. In the summer, as shown above in the first image, the Panels are free from shadows caused by the monitors shortly after sunrise at 6:45 AM. However, the panels are not free from the shadow caused by the cooling tower until 7:15 AM. The panels do not see shadows until 7:00 PM when the monitors shade themselves. This yields 11 hours and 45 minutes of uninterrupted gain in the summer. Below is a table showing the summer example, as well as the remaining three quarters of the year. Usable Time 1 represents the total time of uninterrupted shading, and Usable Time 2 represents the total unshaded time, disregarding the cooling tower shadow.

QTR	Sunrise	Out of Shadow	Past Tower	Back In Shadow	Sunset	Usable Time 1	Usable Time 2
Spring	6:53 AM	6:45 AM	8:30 AM	5:30 PM	7:05 PM	9h 00m	10h 45m
Summer	5:19 AM	6:15 AM	7:15 AM	7:00 PM	8:28 PM	11h 45m	12h 45m
Autumn	6:38 AM	6:45 AM	8:30 AM	5:30 PM	6:53 PM	9h 00m	10h 45m
Winter	7:14 AM	7:45 AM	10:30 AM	3:15 PM	4:25 PM	4h 45m	7h 30m

Sizing Inverters:
To optimize solar radiation, it seems necessary to implement microinverters. By doing this, only the individual modules in shade will be affected. This will leave the rest of the system unaffected. The alternative to microinverters is one large inverter. But by using this system, the gain would be crippled in the time that any portion of a module is shaded.

The PV system will be using Sharp 230W modules and an Enphase D380 Twin Microinverter. This microinverter connects to two modules and has a single output. The rated maximum of the microinverter is matched at 230W. The calculations below show that the microinverters are a good

ELECTRICAL CHARACTERISTICS	
Maximum Power (Pmax)*	230 W
Tolerance of Pmax	+10%/-5%
Type of Cell	Polycrystalline silicon
Cell Configuration	60 in series
Open Circuit Voltage (Voc)	37.1 V
Maximum Power Voltage (Vpm)	30.0 V
Short Circuit Current (Isc)	8.48 A
Maximum Power Current (Ipm)	7.67 A
Module Efficiency (%)	14.1%
Maximum System (DC) Voltage	600 V
Series Fuse Rating	15 A
NOCT	47.5°C
Temperature Coefficient (Pmax)	-0.485%/°C
Temperature Coefficient (Voc)	-0.36%/°C
Temperature Coefficient (Isc)	0.053%/°C

Input Data (DC)	D380-72-2LL-S12/3 and D380-72-2LL-S12/3-NA
Recommended input power (STC)	230W
Maximum input DC voltage	56V
Peak power tracking voltage	22V – 40V
Min./Max. start voltage	28V/54V
Max. DC short circuit current	12A
Max. input current	10A

Output Data (AC)	@208 Vac	@240 Vac
Maximum output power	380W	380W
Nominal output current	1.8A	1.6A
Nominal voltage/range	208V/183V-229V	240V/211V-264V
Extended voltage/range	208V/179V-232V	240V/206V-269V
Nominal frequency/range	60.0/59.3-60.5	60.0/59.3-60.5
Extended frequency/range	60.0/59.2-60.6	60.0/59.2-60.6
Power factor	>0.95	>0.95
Maximum units per 20A branch	15	10

match for the modules. First below are the PV module specs. Following is the microinverter specs.

Calculations:
The voltage increase due to temperature must be calculated. The open circuit voltage is calculated at a standard test condition of 25°C. However, the system will experience much lower temperatures. According to ASHRAE, the record low is -32°C.

37.1V + 37.1V*(-0.0036(/°C))*(-26°C-25°C) = 43.91V

This is an increase of nearly 7V due to temperature. However it is still less than the 56V maximum input voltage of the inverter. The maximum power voltage of the modules is 30V. This is between the ranges that are required by the inverter of 22 to 40V. But it is necessary to check that under extreme operating conditions, the system will still work. The record high temperature for the area is 41°C. An additional 30°C is assumed. This represents the additional heat of the roof surface in the summer.

30.0V + 30.0V*(-0.0036(/°C))*(61°C-25°C) = 26.11

This is a decrease of nearly 4V, however is still above the minimum of 22V.

The short circuit current of the module is 8.48A. The NEC requires a 1.25 multiplier.

8.48A * 1.25 = 10.6A

This is below the 12A maximum, as indicated on the microinverter spec sheet.

Also, the maximum number of microinverters per string is 10, as noted in the microinverter specs. Each of the strings in this layout contains 9 microinverters.

It can be concluded that the microinverter is sufficient to output the module.

Determining Array Orientation:
By using the building elevation, the tilt of the panels is 33.5° above horizontal. And by using the site plan, the azimuth is determined to be 20° west of due south.

Analyzing Solar Radiation:
To analyze the solar radiation for the site, a series of online calculators were used from a trusted provider. The PVWatts v.2 online calculator by the National Renewable Energy Laboratory was used for this calculation. By first imputing the zip code, PVWatts pulls data from National Solar Radiation Database.

STATION IDENTIFICATION	
Cell ID:	270369
State:	Connecticut
Latitude:	41.2° N
Longitude:	73.2° W
PV SYSTEM SPECIFICATIONS	
DC Rating	128.3kW
Derate Factor	0.75
AC Rating	96.3kW
Array Type	Fixed Tilt
Array Tilt	33.5°
Array Azimuth	200°
ENERGY SPECIFICATIONS	
Cost of Electricity $0.134/kWh	

RESULTS			
MONTH	SOLAR RADIATION (kWh/m2/day)	AC ENERGY (kWh)	ENERGY VALUE ($)
January	2.79	8559	1143.74
February	3.62	9972	1332.56
March	4.72	13978	1867.88
April	4.93	13855	1851.44
May	5.49	15291	2043.34
June	5.58	14665	1959.68
July	5.48	14712	1965.96
August	5.38	14492	1936.57
September	4.91	12987	1735.45
October	4.14	11809	1578.04
November	2.89	8081	1078.86
December	2.66	7888	1054.07
TOTAL	**4.39**	**146290**	**19584.73**

CALCULATION FOR OVERALL DC TO AC DERATE FACTOR		
COMPONENTS	VALUES	ACCEPTED RANGE
PV Module Nameplate DC Rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and Connections	0.995	0.99 - 0.997
DC Wiring	0.98	0.97 - 0.99
AC Wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System Availability	0.98	0.00 - 0.995
Shading	0.975	0.00 - 1.00
Sun-Tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC to AC Derate Factor	0.75	

Payback:

Though saving nearly $20,000 a year is considerable, it is not as impressive when compared to the monthly bill of the system of over $16,000. The lifetime return is fair, considering the investment that was made; about 19.7%. This return walks the fine line between whether or not it is worth it. So the decision really comes down to what the benefit is. If the company wants no more than an investment to make money off of, then this may not be the safest choice. In the life expectancy, there is always the possibility that something may need to be replaced that isn't covered by the warranty. However, there is much more to energy savings than just money. This is an opportunity to conserve natural resources, reduce carbon emissions, and be a part of a growing technology. In a sense, it seems worth the risk, even though the potential monetary gains are low. In the future, if the price of electricity continues to increase, the return may be much higher. And if the price of PV equipment decreases as the technology improves before the system is implemented, the return would be higher still.

Price Assumptions	
PV Panels	$450,000
Inverters	$90,000
Electrical Systems	$30,000
Labor	$100,000
Shipping	$10,000
Permits	$20,000
TOTAL	$700,000
30% Tax Incentive	($210,000)
TOTAL	$490,000

Investment Payback	
System Cost	$490,000
Annual Cost(over 30 years)	$16,333
Annual Energy Savings	$19,549
Annual Return	$3,216
Total Return(over 30 years)	$96,480
% Payback (over 30 years)	19.70%

TRANSFORMER CONSOLIDATION DEPTH

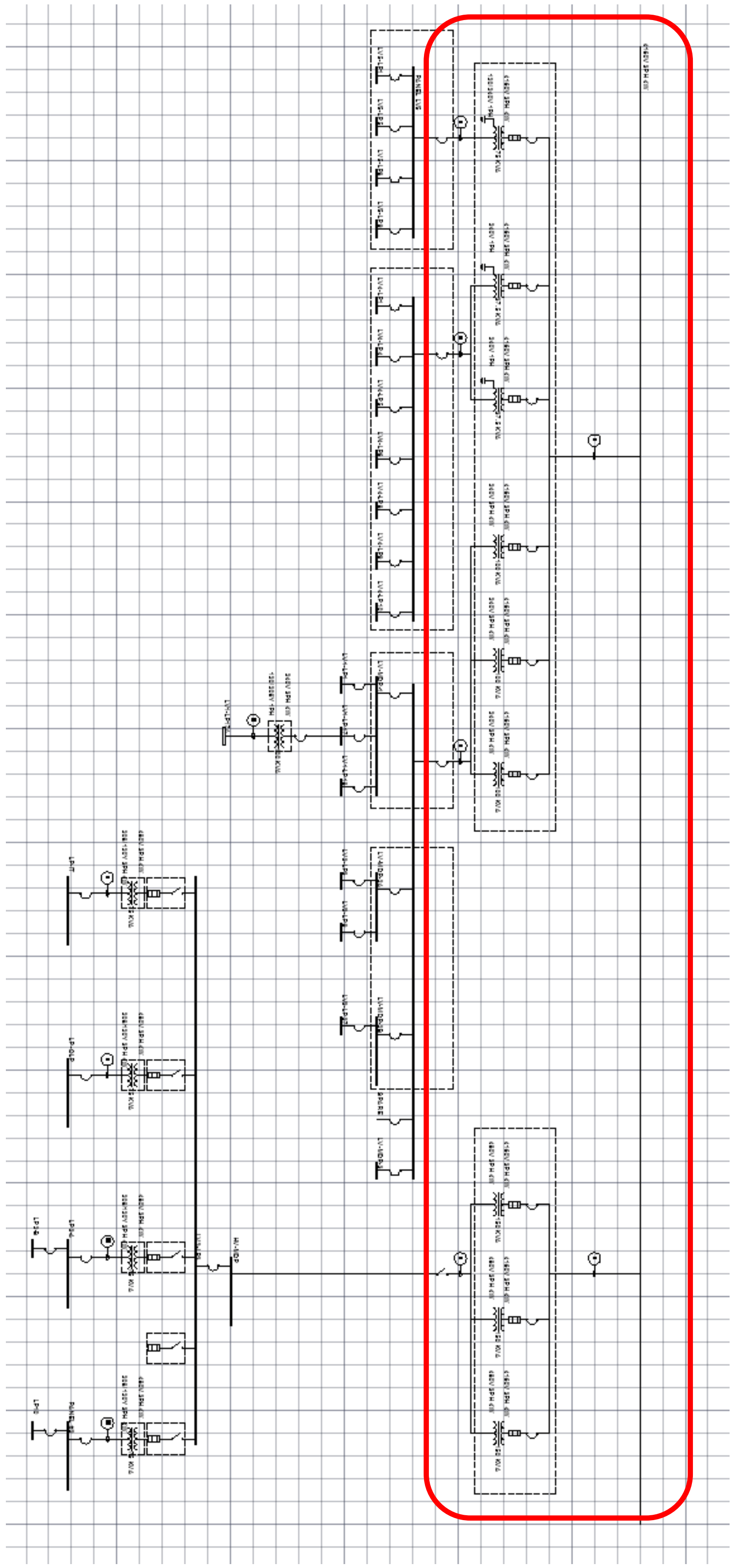
Introduction:

The electrical system at the Web Shop has changed as the needs of the tenants have changed. The Lighting Quotient did not renovate the electrical system when they moved in in the 1980s. They did however add and subtract some equipment as needed. For instance, a previous tenant utilized a bus duct that runs the length of the factory. The Lighting Quotient's manufacturing equipment is primarily pneumatic, with the exception of some large equipment like the powder coating oven. So they now use the bus duct to tie smaller transformers into the grid. This is not the most effective use of a bus. The current electrical system could certainly be redesigned to better meet the current needs of the company, as well as accommodate new equipment.

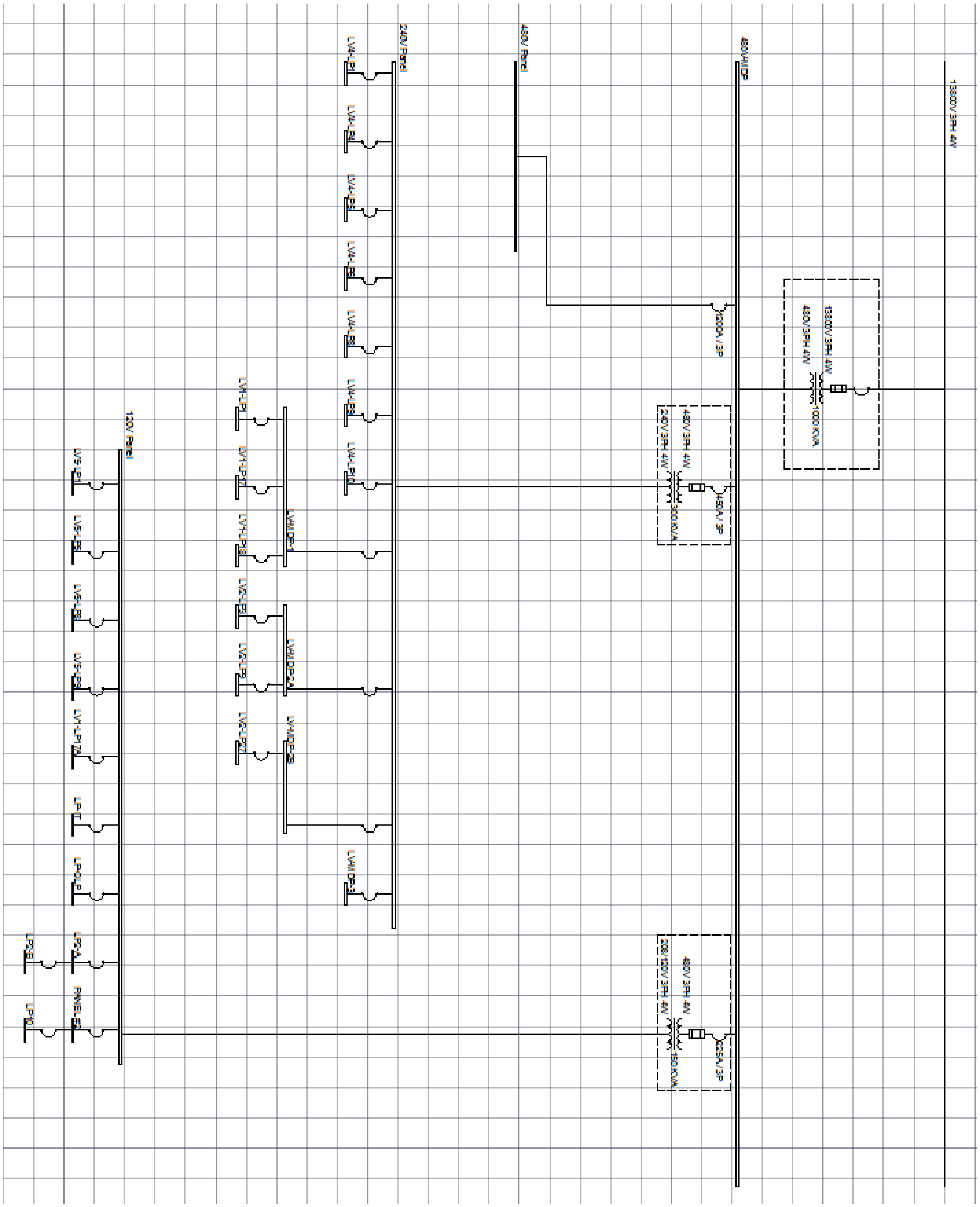
Project Overview:

The following analysis includes a redesign of all transformers and distribution panels. Though the individual panelboards could benefit being reworked, this would be out of the scope of the analysis. The sizing of all equipment and wires leading up to the existing individual panelboards will be documented below. The following drawing displays the scope of the analysis in the red outline.

Scope of Redesign:



Redesigned Transformers and Main Distribution Panels:

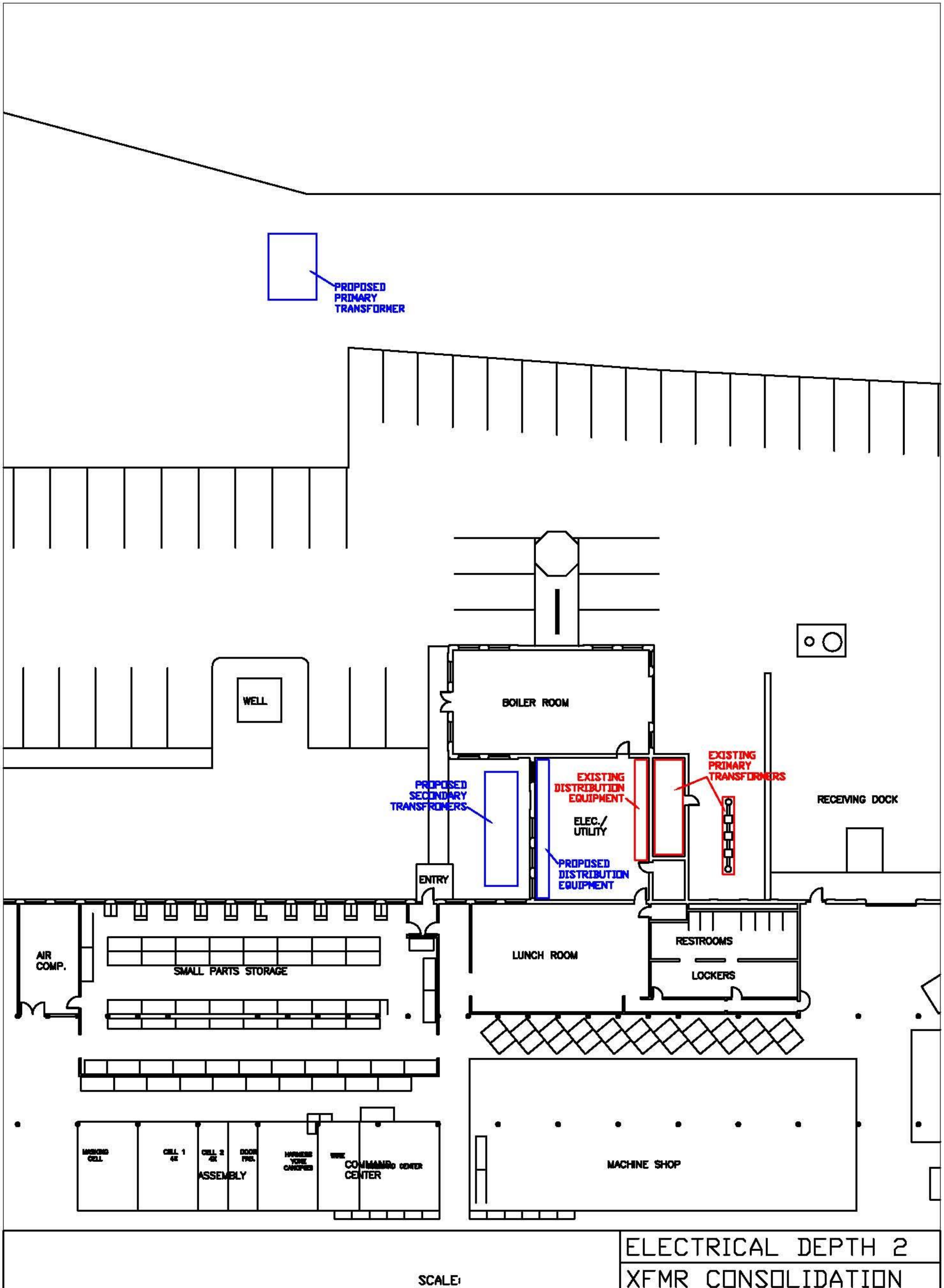


Design Overview:
Whereas the existing design has 9 primary transformers and 5 secondary transformers, the new design utilizes just 1 primary and 2 secondary transformers. By doing so, each of the 3 voltage types in the building essentially has its own transformer. The primary transformer steps the incoming power down to 480V. This transformer feeds the 480V main distribution panel. The 480V main distribution panel serves the 480V loads, including the two secondary transformers. The first of the secondary transformers steps power down from 480V to 240V. The second secondary transformer steps power down from 480V to 120/208V. Each of the secondary transformers then feeds its respective main distribution panel.

There are 3 main distribution panels: one for each voltage type. The existing individual panel boards throughout the building were relocated on the new main distribution panels.

Coordination:
In order to minimize downtime while installing the new system, the building must continue to run on the existing system for as long as possible. It is possible to install the new main distribution panels adjacent to the existing equipment. By doing so, the building can continue to run until the installation is complete. In a short amount of time, the building can be de-energized, and the power can be transferred through the new system. Below is a plan showing the locations of the existing equipment, as well as the proposed locations of the new equipment.

Analysis:



ELECTRICAL DEPTH 2

XFMR CONSOLIDATION

COORDINATION PLAN

SCALE: 1/32"=1'-0"

ADDITIONAL ELECTRICAL REQUIREMENTS

Introduction:
The following section addressed the impact of the new lighting designs on the existing electrical system. Though the individual panelboard schedules were obtained, the connected loads are not known. Therefore an accurate analysis of the existing panelboards is not possible. The compromise made to analyze the impact of the new lighting design is to create an all new panelboard and analyze its attributes. A voltage drop calculation will be conducted to double check that the new panel is sized correctly. Additional analyses consist of a short circuit analysis of one the path leading to one of the existing panels. Trip curves will also be included for this path.

Voltage Drop

The new panel uses a 225A bus.

Feeder:
152.7A → 175A
Use 2/0 AWG

Breaker:
152.7A → 175A
Use a 175A Breaker

Ground Wire:
152.7A → 200A
Use #6 AWG

Conduit:
4x(2/0 AWG) + 1x(#6 AWG) = 1.3455 in^2

Voltage Drop:
Assuming a magnetic conduit and 100% PF, the voltage drop is 0.064V / 1000A-ft
The panel has a 152.7A load and is 360ft from the main distribution panel.
(0.064V / 1000A-ft)(152.7A)(360ft) = 3.52V
3.52V / 208V = 1.7%

Since the voltage drop is below 3%, the feeder does not need to be uprated.

PANELBOARD SIZING WORKSHEET			
Panel Tag------------------------->	LP20	Panel Location:	Mechanical Room
Nominal Phase to Neutral Voltage------->	120	Phase:	3
Nominal Phase to Phase Voltage-------->	208	Wires:	4

Pos	Ph.	Load Type	Cat.	Location	Load	Units	I. PF	Watts	VA	Remarks
1	A	Ltg. Fluorescent	3	Lobby	420	w	0.90	420	467	Uplights
2	A	Ltg. Halogen	5	Lobby	600	w		600	750	Wall Wash
3	B	Ltg. Fluorescent	3	Office	112	w	0.90	112	124	F101 East Wall
4	B	Ltg. Metal Halide	4	Office	560	w		560	700	M101 South Wall
5	C	Ltg. Halogen	5	Office	1200	w		1200	1500	T099 North Wall
6	C	Ltg. Metal Halide	4	Conference	560	w		560	700	North/South Walls
7	A	Ltg. HID	4	Conference	1200	w		1200	1500	Downlights
8	A	Ltg. Metal Halide	4	Conference	210	w		210	263	West Wall
9	B	Ltg. Metal Halide	4	Entrance	520	w		520	650	Ground Lights
10	B	Ltg. Fluorescent	3	Entrance	282	w	0.90	282	313	Uplights
11	C	Ltg. Metal Halide	4	Entrance	360	w		360	450	Wall Wash
12	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
13	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
14	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
15	B	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
16	B	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
17	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
18	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
19	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
20	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
21	B	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
22	B	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
23	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
24	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
25	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
26	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
27	B	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
28	B	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
29	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
30	C	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
31	A	Receptacle	1	Office	1536	w		1536	1920	Tambient Fixtures
32	A				0	w		0	0	
33	B				0	w		0	0	
34	B				0	w		0	0	
35	C				0	w		0	0	
36	C				0	w		0	0	
37	A				0	w		0	0	

38	A				0	w		0	0	
39	B				0	w		0	0	
40	B				0	w		0	0	
41	C				0	w		0	0	
42	C				0	w		0	0	
PANEL TOTAL								36.7	45.8	Amps= 127.3

PHASE LOADING					kW	kVA	%	Amps
PHASE TOTAL	A				13.2	16.4	36%	136.8
PHASE TOTAL	B				10.7	13.3	29%	110.9
PHASE TOTAL	C				12.9	16.1	35%	134.1

LOAD CATAGORIES			Connected			Demand				
			kW	kVA	DF	kW	kVA	PF		
1	receptacles		30.7	38.4		30.7	38.4	0.80		
2	computers		0.0	0.0		0.0	0.0			
3	fluorescent lighting		0.8	0.9		0.8	0.9	0.90		
4	HID lighting		3.4	4.3		3.4	4.3	0.80		
5	incandescent lighting		1.8	2.3		1.8	2.3	0.80		
6	HVAC fans		0.0	0.0		0.0	0.0			
7	heating		0.0	0.0		0.0	0.0			
8	kitchen equipment		0.0	0.0		0.0	0.0			
9	unassigned		0.0	0.0		0.0	0.0			
Total Demand Loads						36.7	45.8			
Spare Capacity			20%			7.3	9.2			
Total Design Loads						44.1	55.0	0.80	Amps=	152.7

Default Power Factor =	0.80	
Default Demand Factor =	100	%

Note:
The receptacle loads were designed to carry two Tambient fixtures each. The total load from the Tambient fixtures is only demand 1816 Watts. However, since the receptacle loads are able to accommodate much larger loads, 1.92A per receptacle was assumed.

Short Circuit Analysis

I_{SC} = Base kVA / (√3)(kV)(Z_U)
$Z_U = \sqrt{(X^2 + R^2)}$
X_U = (X%)(Base kVA) / 100(XFMR kVA)
R_U = (R%)(Base kVA) / 100(XFMR kVA)

Utility:
X_U = 10000kV / 100000kV = 0.1
I_{SC} = 10000 / (√3)(4.16)(0.1) = 138786A

XFMR 1: 450kVA
Z = 5.8%
X/R = 4.33

R = 1.305%
X = 5.65
X_U = (5.65)(10000) / (100)(0.48) = 1.26
$X_{U\text{-}TOTAL}$ = 1.26 + 0.1
R_U = (1.205)(10000) / (100)(0.48) = 0.29
$Z_U = \sqrt{(X_U^2 + R_U^2)}$ = 1.386
I_{SC} = 10000 / (√3)(0.48)(1.386) = 8678A

Wire 1: 2 sets of 4/0
X = (50' / 1000)(0.0326)(1/2 sets) = 0.000815
$X_U = (0.000815)(10000) / (1000)(0.48)^2 = 0.035$
$X_{U\text{-}TOTAL}$ = 1.26 + 0.1 + 0.035 = 1.395
R = (50' / 1000)(0.0614)(1/2 sets) = 0.001535
$R_U = (0.001535)(10000) / (1000)(0.48)^2 =0.067$
$R_{U\text{-}TOTAL}$ = 0.29 + 0.067 = 0.357
$Z_U = \sqrt{(X_U^2 + R_U^2)}$ = 1.44
I_{SC} = 10000 / (√3)(0.48)(1.44) = 8353A

Wire 2: #3 AWG
X = (200' / 1000)(.0367) = 0.00734
$X_U = (0.00734)(10000) / (1000)(0.48)^2 = 0.319$
$X_{U\text{-}TOTAL}$ = 1.26 + 0.1 + 0.035 + 0.319 = 1.714
R = (200' / 1000)(0.247) = 0.0494
$R_U = (0.0494)(10000) / (1000)(0.48)^2 = 2.144$
$R_{U\text{-}TOTAL}$ = 0.29 + 0.067 + 2.144 = 2.501
$Z_U = \sqrt{(X_U^2 + R_U^2)}$ = 3.03
I_{SC} = 10000 / (√3)(0.48)(3.03) = 3967A

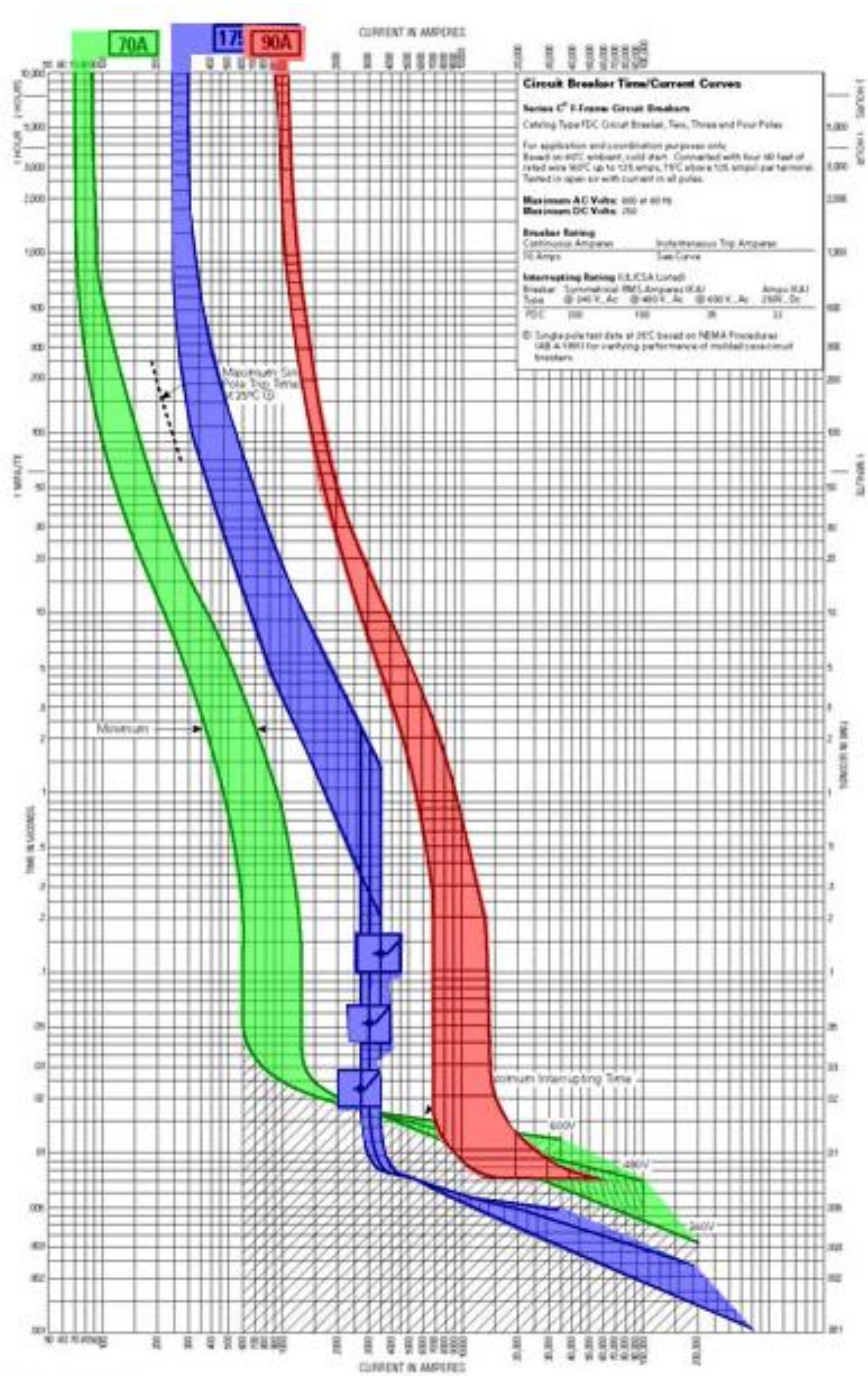
XFMR 2: 75 kVA
Z = 3%
X/R = 0.83

R = 2.308%
X = 1.92
X_U = (1.92)(10000) / (100)(0.208) = 92.31
$X_{U\text{-}TOTAL}$ = 1.26 + 0.1 + 0.035 + 0.319 + 92.31 = 94.02
R_U = (2.308)(10000) / (100)(0.208) = 110.96
$R_{U\text{-}TOTAL}$ = 0.29 + 0.067 + 2.144 + 110.96 = 113.461
$Z_U = \sqrt{(X_U^2 + R_U^2)}$ = 147.35
I_{SC} = 10000 / (√3)(0.208)(147.35) = 188.38A

Wire 3:
X = (100' / 1000)(0.0371) = 0.00371
X_U = (0.00371)(10000) / (1000)$(0.208)^2$ = 0.857
$X_{U\text{-}TOTAL}$ = 1.26 + 0.1 + 0.035 + 0.319 + 92.31 + 0.857 = 94.877
R = (100' / 1000)(0.1553) = 0.01553
R_U = (0. 01553)(10000) / (1000)$(0.208)^2$ = 3.59
$R_{U\text{-}TOTAL}$ = 0.29 + 0.067 + 2.144 + 110.96 + 3.59 = 117.051
$Z_U = \sqrt{(X_U^2 + R_U^2)}$ = 150.67
I_{SC} = 10000 / (√3)(0.208)(150.67) = 184A

Trip Curves

The following image is overlaid trip curves of the equipment analyzed in the previous section.



References and Acknowledgements

Software:
AGi32
Autodesk AutoCAD
Autodesk Ecotect
Adobe Photoshop
PVWatts v.2

Handbooks:
ASHRAE 90.1
IESNA Lighting Handbook

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