THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ARCHITECTURAL ENGINEERING

DESIGNING THE LIGHTING, ELECTRICAL, AND ENERGY GENERATION SYSTEMS FOR A NET-ZERO HIGHRISE IN AN URBAN SETTING

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A thesis
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ABSTRACT

This thesis was completed within the framework of a national student competition. Given a challenging site in an urban setting and the architecture for an office highrise, the design team engineered the systems for a high-performance building. This report details the various steps taken to maximize operating efficiency while minimizing the building's impact on the environment. Special considerations were also taken to ensure the safety of occupants in the event of a natural disaster, as the location is in a seismic region.

Careful research was conducted to determine what building systems most align with the project goals and performance criteria. Major design decisions were not made in isolation, but were a multidisciplinary point of collaboration, as each building system affects the others. Cooperation within the design team was critical to meeting the ultimate goal, which was not only to create efficient building systems, but to create a positive, cohesive working environment for future building tenants.

The final lighting and electrical designs, described in detail throughout this thesis, resulted in a building that responds to the occupants and surroundings. Energy generation is done onsite to avoid the inefficiencies of the electric grid, and offsite generation replaces the entirety of the building's annual energy consumption. The energy is distributed through an advanced electrical network that eliminates many of the conversion inefficiencies that occur in traditional systems. The lighting design meets the needs of an office working environment, maximizing efficiency and optimizing occupant comfort. Behind each building component is the control system, providing the intelligence that allows for sustained, efficient operation. Most importantly, the building sits within a footprint significantly smaller than a standard office highrise and serves as an aesthetic example of multidisciplinary engineering creating an energy-conscious and intelligent design.

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Chapter 1

Project Introduction

Design Competition

This thesis was completed within the guidelines of a national competition sponsored by the Architectural Engineering Institute (AEI) known as the ASCE Charles Pankow Foundation Architectural Engineering Student Competition. This year's competition challenged students to engineer building systems and complete construction planning for a 30-story highrise in San Francisco. The building, known as 350 Mission, is an actual project currently being built. Students were provided the architecture, but the engineering behind it was primarily masked to encourage unique entries. Architectural changes could be made, as long as they were justified and enhanced the building's performance. In addition to the task of designing the building systems for an office highrise, additional criteria added to the project's complexity. 350 Mission must be near-net zero, it must meet stringent seismic design considerations, and it should not interrupt the current flow of traffic in the South of Market neighborhood.

For this competition, I worked in a group of eight students, two representing each discipline within Penn State's architectural engineering department. These disciplines include: lighting/electrical, mechanical, structural, and construction engineering. This group will be referred to hereafter as **AEVITAS**, our design team name. This report, with the exception of Chapter 6, was written in collaboration with my lighting/electrical partner, Lara Kaiserian, and includes a description of our design as well as our supporting analyses.

Executive Summary

The following report details the lighting and electrical systems designs of 350 Mission, San Francisco, CA. **AEVITAS** is an integrated design team, composed of representatives from the construction, structural, electrical, and mechanical disciplines. With the end goal of designing a net-zero high-rise building in the heart of San Francisco, **AEVITAS** developed the overarching attitude of [ZERO**impact**], encompassing four focus areas of [ZERO**interruption**], [ZERO**energy**], [ZERO**waste**], and [ZERO**emissions**]. Through a unified effort, **AEVITAS** achieved the design goals set forth at the beginning of the process. The building systems and components comprising the final design are summarized in Table 1.

System	**Design Summary**
Architectural	Floor Plan Changes, Vestibule Addition, Integrated Public Art Piece
Façade	Natural Ventilation Louvers, Seismic Connections, Electrochromic Glazing
Mechanical	Radiant Floor System, Natural Ventilation Louvers, Dedicated Outdoor Air System
Lighting	LED Lighting, DALI Controls Responsive to Daylighting and Occupancy, Task Lighting
Energy Generation	Onsite Solar Array, Offsite Solar Array, Human Waste to Power Converter
Electrical	AC and DC Distribution, Natural Gas-Powered Fuel Cells, Dual Electrical Risers
Structural	Steel Superstructure, Braced Frame Core, Composite Beams and Deck, Outrigger System, Concrete Substructure
Construction	Production Planning, Matrix Scheduling, Waste Management, BIM Execution Planning, Site Planning

Table 1: System Overview Breakdown

The lighting and electrical design strove to increase efficiency and decrease total energy consumption, and this was achieved through the use of a number of different strategies. The design focused on the lobby and a typical office floor, as well as whole-building systems design.

The desire to optimize daylighting and thermal properties of the glazing led to a façade design that benefitted both the mechanical systems and lighting design. Electrochromic glass is used on the façade of all office floors in place of shades to preserve views to the exterior and offer maximum flexibility to the occupants. Daylight photosensor dimming results in savings for the entire building, exceeding 100,000 kWh annually.

Efficient lighting design decisions, such as task lighting, resulted in a building lighting power density (LPD) of 0.434 W/sf, well below the 0.728 W/sf allowed by California Title 24 and CALGreen space-by-space method.

The building's electrical system features natural gas-powered fuel cells and both AC and DC distribution, designed to minimize conversion losses. The DC system feeds a server room that supports virtual computing on the office floors, saving almost 600,000 kWh of computer loads annually.

Taking the building's location in a seismic region into account, both the lighting and electrical design make special accommodations to ensure the safety of its occupants. The lighting follows guidelines for seismic design laid out by the California Department of General Services. The electrical system features dual emergency risers to give the building an added level of redundancy in a seismic event.

Energy is generated via onsite and offsite solar arrays, as well as an onsite human waste-to-power converter. These systems combined generate 5,544,000 kWh of energy annually, which is more than enough to cover the building's total expected annual consumption of 5,264,570 kWh.

350 Mission adheres to the traditional definition of net-zero by returning as much energy to the grid as it consumes in a year, and it also meets the broader goals defined by **AEVITAS** by minimizing emissions and waste and by creating a design that responds to the earthquake-prone environment to ensure continuity of operation even after a seismic event. Lifecycle cost analyses

determined a payback period of 10.6 years for the mechanical systems and energy generation equipment, as shown in Figure 1 below. The components contributing to the lifecycle analysis are described throughout this report.

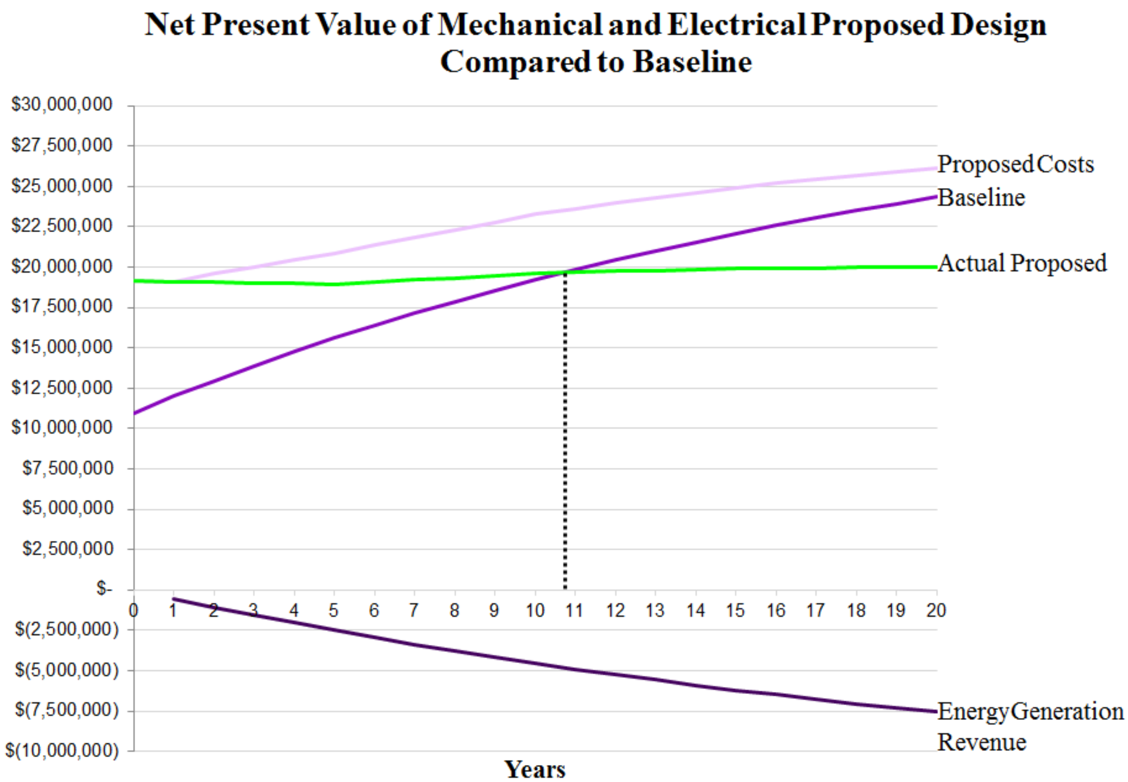


Figure 1: Mechanical and Electrical Lifecycle Cost Analysis

Chapter 2

Team Dynamics

Team Direction: Goals and Attitude

350 Mission is above all else, a collaboration. Through a joint effort, the concept of ‘net-zero building’ has grown to fully encompass the idea of green living and **AEVITAS** is on the forefront of this movement. In order to reach the infinite goals that are stemming from such sustainable building ideas, **AEVITAS** set out to define the way the team would approach 350 Mission. Provided with an established architectural design but a different set of owner goals, the team has been dedicated to making design decisions that reflect the new goals of the owner, as well as the community and future tenants. **AEVITAS** is a talented team comprised of eight individuals with varying educations and diverse experience including backgrounds in structural design, MEP systems design, and construction engineering and management.

For the *2014 ASCE Charles Pankow Foundation Annual Architectural Engineering Student Competition*, teams are challenged to embrace the “development and integration of innovative and original solutions to the design challenge.” With an emphasis placed on “integration of the engineered systems and construction management plan for a high performance building.”

When coming together as a unified design force, the team as a whole was adamant early on about developing something more than a set of goals, something that would enable our interconnected thought process throughout design – our over-arching attitude. This attitude would encompass all team-driven specifications, with the owner profile and competition goals providing direction. From these motives, [ZERO**impact**] was born. [ZERO**impact**] is the way the project team defines the sustainable practices that are driving design decisions and owner goal integration. Within this all-encompassing team attitude and a strong mission statement, there are four focus areas that the goals are derived from, as shown below in Figure 2.

Taking an *integrated approach*, **AEVITAS** strives to *minimize environmental influences* by *engaging our community* with *sustainable* practices in energy conservation and emission reduction.

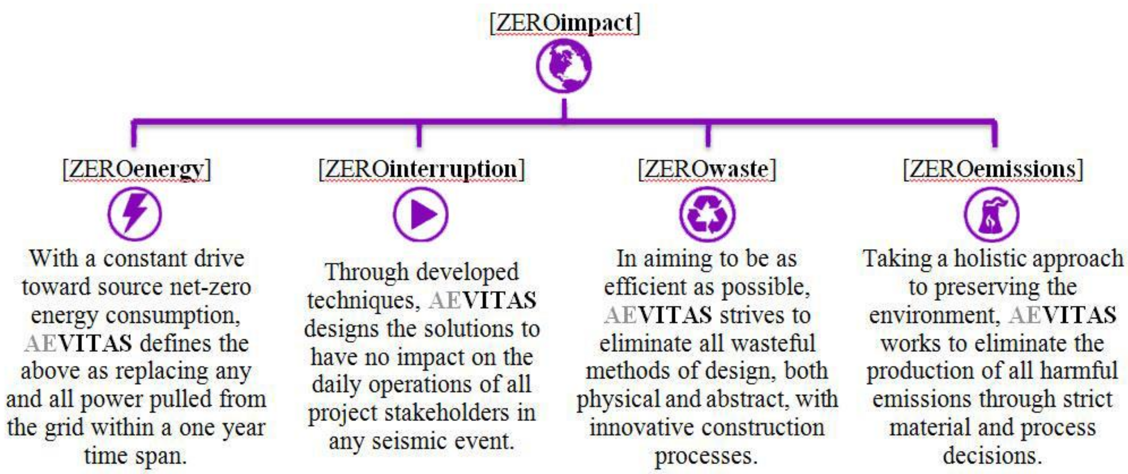


Figure 2: AEVITAS Attitude with Goal Breakout

In the following report, **AEVITAS** has responded to the owner's goals to establish a building that is as close to having zero impact on all project stakeholders when possible. The symbols of the goals appear throughout the report to show the actions **AEVITAS** took to achieve these goals. As one cohesive team – with the project requirements established, the opinion of net-zero defined, mission statement created, and the attitude of [ZERO**impact**] applied – **AEVITAS** created the systems and solutions found in this report to achieve all goals of 350 Mission.

Throughout all design and project decision making, application of the [ZERO**impact**] attitude was the ultimate driving force.

Design Process

All decisions were made using an integrated design process. Each option was weighed based on its impact on the project goals, potential impact on the other disciplines, and its pros and cons related to the lighting and electrical design. Compromises were made in order to make the decisions that were best for the building design as a whole, with no discipline consistently taking priority. Many lighting and electrical decisions were made by working to identify the most efficient option, as the [ZERO**energy**] focus area was a main concern; however, this also had to be balanced with the task of creating an appealing and functional work environment.

Code Analysis

350 Mission was designed to the following codes and standards found within the California Building Standards Code (California Title 24):

- 2010 California Electrical Code and San Francisco Amendments
- 2010 California Energy Code and San Francisco Amendments
- 2010 California Fire Code and San Francisco Amendments
- California Green Building Standards Code (CALGreen)

California Title 24/California Energy Code is used in place of AHSRAE 90.1 for energy standards. The California Green Building Standards Code (CALGreen) requires an additional 15% energy savings beyond the mandatory California Title 24 savings for green buildings.

Program Use

PROGRAM	USES	FILE TYPE	INPUT FROM	OUTPUT TO
AGI32	Lighting Calculations	.agi	AutoCAD	N/A
AUTOCAD	3D Modeling 2D Sections and Details	.dwg & .dxf	Revit	AGI32, Rhino
DAYSIM	Daylight Calculations	.hea	AutoCAD	Excel
DIVA FOR RHINO	Daylight Calculations Radiation Maps	.3dm	AutoCAD	Excel
EXCEL	Data Analysis Load Calculations	.xls	Daysim, DIVA	
PHOTOSHOP	Graphic Development	.psd	Revit, AGI	
PV WATTS	Solar Panel Analysis			
REVIT	Floor Plans, Model Development	.rvt		AutoCAD

Table 2: Lighting/Electrical Computer Program Usage

Table 2 introduces the computer programs used in the lighting and electrical analyses. Revit was the primary design tool used to coordinate between disciplines and produce graphics, but the other programs were used for technical, graphical, and numerical support.

Chapter 3

Energy

As with any ‘net-zero’ building, achieving net-zero energy consumption is one of the most important and challenging aspects. This is done in part by making educated design decisions to select the most efficient equipment and systems and reduce the overall energy consumption of the building, but it also requires the generation of energy to offset what the building must use in order to function properly.

Extensive research was conducted to determine the most viable energy generation tactics, both onsite and offsite. The selected technologies will be presented here. Information about the other systems that were investigated, as well as reasons for their dismissal, can be found in Appendix A on pages 64-65.

Onsite Energy

Due to the location of the site, the relationship with the surrounding buildings, and the limited space, onsite energy generation alone was deemed inadequate to fulfill the needs of the building in a cost-effective manner. Wind, biomass, and geothermal generation, among other systems, were rejected due to findings related to the site. Two systems are being employed onsite, in combination with the offsite source outlined in the next section.

Onsite Solar Array

Even though the building is not in an ideal location for onsite solar generation, analysis of the roof area showed that there is potential for some collection. Figures 3 shows the potential kWh/m^2 values throughout the year, assuming 100% efficient panels and using typical meteorological year (TMY) weather data. An efficiency multiplier of 0.15 and derate factor of 0.77 were applied to these initial values to determine that a roof solar array can produce 194,145 kWh of energy during an average year. Based on the available roof area, a 200kW array was selected.

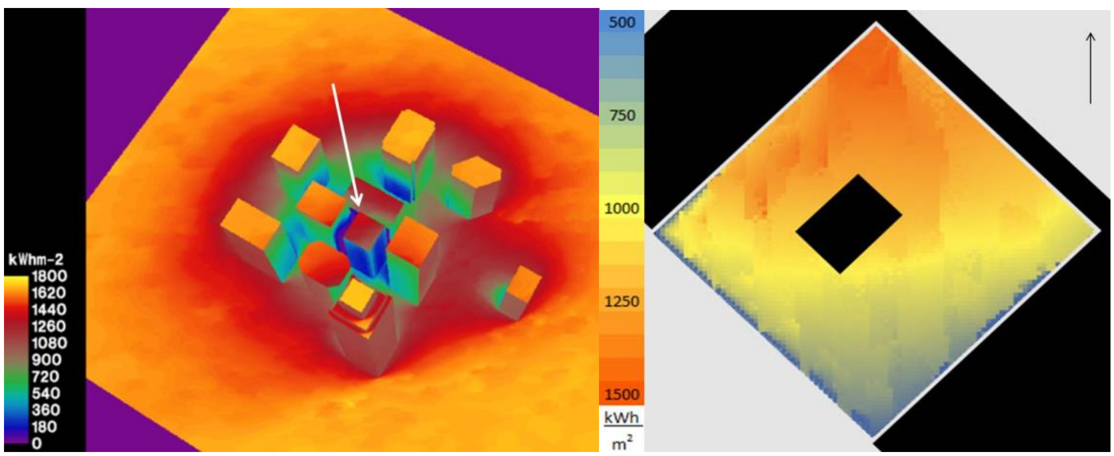


Figure 3: Site and Rooftop Solar Radiation

Through coordination with the mechanical and structural engineers, the mechanical cooling tower was placed below the roof surface in order to minimize possible shading of the panels due to the equipment. There is a hole in the roof above and space around the tower to allow for air flow. The addition of photovoltaic panels required a 4’ parapet wall to be added around the cooling tower opening and building perimeter for safety. The calculations also take into account the amount of space required for maintenance walkways, as the potential kWh value was adjusted to exclude a percentage of the total roof area. Payback will occur in 12.4 years with

30% incentive coverage or 8.8 years with 50% incentive coverage. More information on the calculations and incentives can be found in Appendix A on page 66.

Human Waste-to-Power

Normally, human waste is sent from buildings to a sewage treatment plant, where it can be refined to create fertilizer and water that is sometimes released into rivers and streams. Methane is released into the air, along with other undesirable gases. This is harmful to the environment, as well as being a waste of a potential energy source. 350 Mission will be equipped with a unit that utilizes supercritical water oxidation and gasification (SCWO/SCWG) to convert this waste into usable energy.

The machine heats and pressurizes water to a supercritical phase that oxidizes the sewage and produces a sterile combination of water, carbon dioxide, and inert salts. The resulting steam is used to both sustain the supercritical combustion and operate a steam generator. This process and system are well-suited for use in a building because all of the waste-processing can take place onsite and requires no separation of wastes. SCWO can also process any other materials that find their way into the sewage.

It is estimated that this unit will generate 290,625 kWh per year and will pay back in 26 years on its own; however this period is shorter when combined with the rest of the building systems, and the benefit to the environment cannot be quantified. Calculations and more information can be found in the Appendix A on pages 67-68.

Offsite Energy

After researching a number of offsite generation options, solar power was determined to be the most viable, based on system cost, site procurement, and permit requirements. It was selected over geothermal generation, tidal energy, and wind, as discussed on page 65 of Appendix A. Rather than feeding 350 Mission directly, this solar installation will contribute to Pacific Gas and Electric's (PG&E) utility grid and offset 350 Mission's usage.

The installation will be located in a secured compound in the Mojave Desert. This location is optimal for sunlight exposure and cost. Solar radiation maps of the United States, such as the one in Figure 4, show that it is one of the best locations in the country for harnessing solar power (outlined in red). In order to offset the remainder of the building's energy use, a 3.5 acre tract of land is required. With the addition of some space for maintenance paths and a security enclosure, as well as allowing the possibility of growth, a 10 acre tract of land was chosen. The cost of the selected plot is listed at $13,000. A number of other lots of this size can be found at prices, on average, ranging between $10,000 and $20,000.

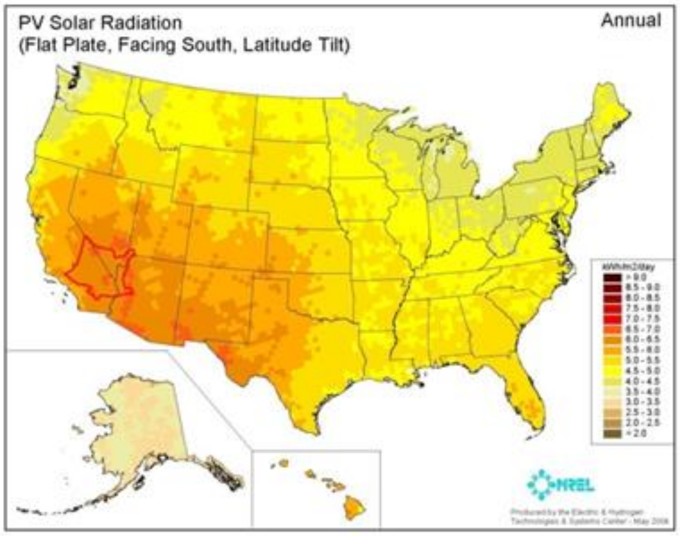


Figure 4: Annual Solar Radiation Map

In order to offset the remainder of the building's energy usage that is not accounted for by onsite generation techniques, a 3000 kW PV array is required. An array of this size will cost about $5,115,000. While the price is steep, generous incentives are available for new installations. Local, state, and federal incentives may cover between 30-50% of the installation.

The fixed-tilt system is expected to generate 5,059,186 kWh of energy annually during an average weather year. This number takes into account site location, array tilt, and derating factors that decrease the efficiency of the system. Fortunately, the size of the array will allow for a large inverter and transformer, which are much more efficient than smaller systems, and reduce the losses of converting DC to AC for the electric grid. While fixed-tilt arrays generate about 20% less energy than axis-tracking systems, the added tracking feature comes with an increased price, maintenance, and potential for malfunction.

Energy can be sold to the utility company for $0.10509/kWh assuming a 20-year contract starting in 2016 (the expected building completion year), and the payback period for the entire 3.5 acre array is 6.7 years with 30% covered by incentives, or 4.8 years with 50% covered by incentives. More information on the site, cost, and calculations can be found in Appendix A on pages 69-71.

Chapter 4

Lighting Design

Daylighting

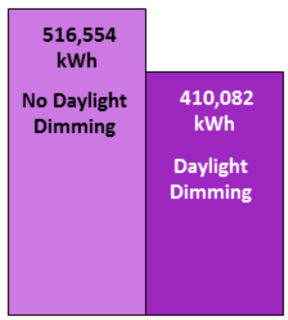


Figure 5: Lighting Energy Use with and without Daylight Dimming

Lobby

The lobby is a four-story, 100% glass, open-air atrium located at the base of the building. Due to the relatively low light levels required in most of the space, daylighting alone can fill the circulation area requirements during the majority of daytime hours. The lobby curtain wall uses double pane, low-e glass with a 55% visible light transmittance and 0.34 solar heat gain coefficient.

Integrating daylighting and electric light through the use of the building control system saves approximately 8,661 kWh annually. Details of the daylight calculations can be found in Appendix A on pages 72-75.

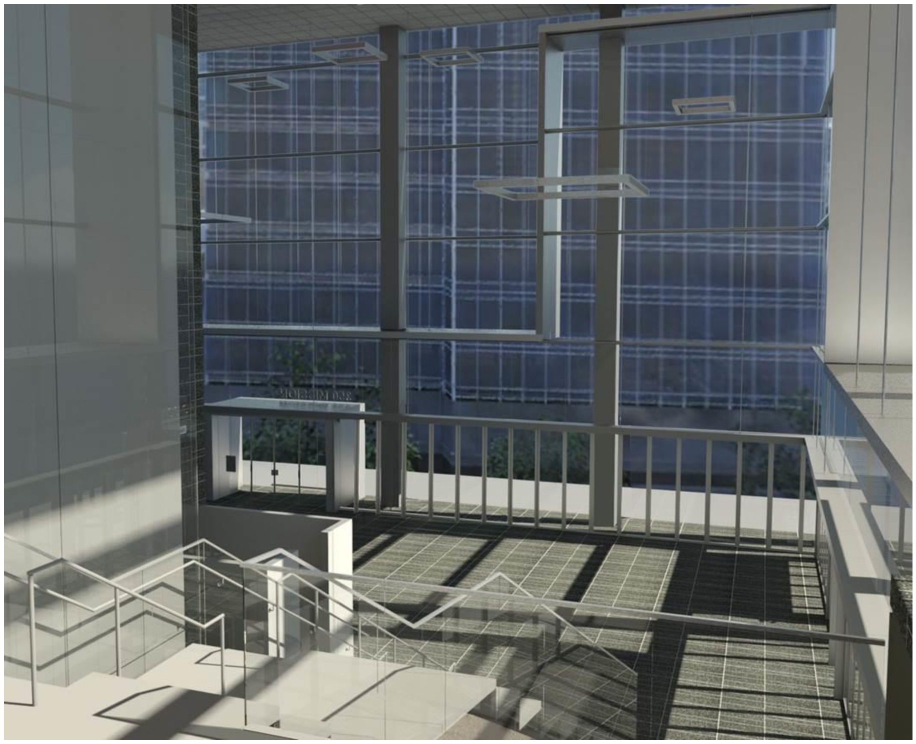


Figure 6: Daylit View of Lobby

Office / Façade Design

The façade design of 350 Mission required an integrated effort in order to engineer a system that would mutually benefit all disciplines. The design focused on making choices that would contribute to the [ZERO**impact**] goal while also maintaining the woven aesthetic of the façade and the vision of the architect.

In collaboration with the mechanical engineers, the decision was made to alter the façade to optimize daylighting and mechanical savings. A daylighting study was conducted in order to determine the glass percentage that would allow a sufficient amount of daylighting without placing an unnecessary thermal burden on the mechanical systems. Figure 7 shows a view of the resulting façade design.

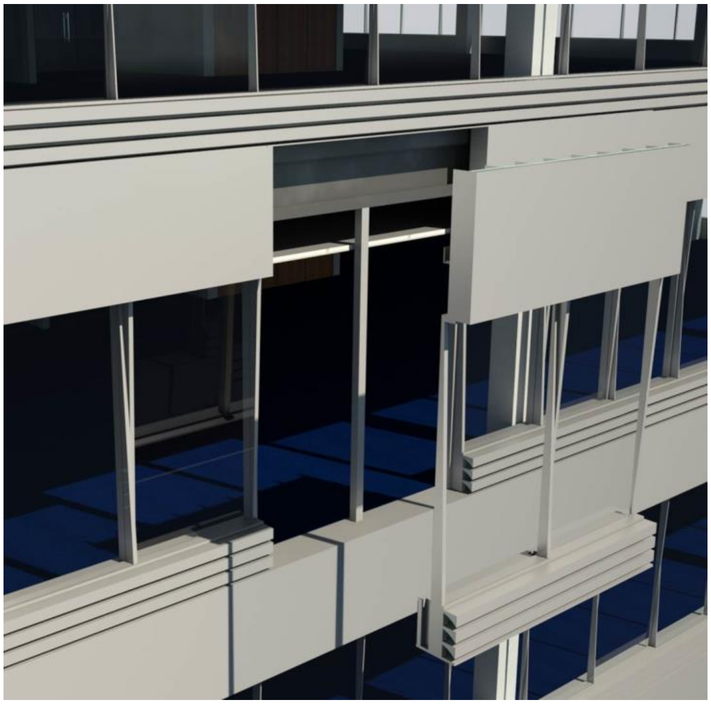


Figure 7: Office Facade with Section Removed

This integration effort resulted in a 60% glass façade on the office floors, which translates to 8’-6” tall windows. Although the site is often shaded by the surrounding buildings, there is still enough direct sunlight and general brightness to warrant the addition of an automatic shading system, described in the next section. This glazing design also allows space for a bulkhead containing natural ventilation louvers to be included on the office floors.

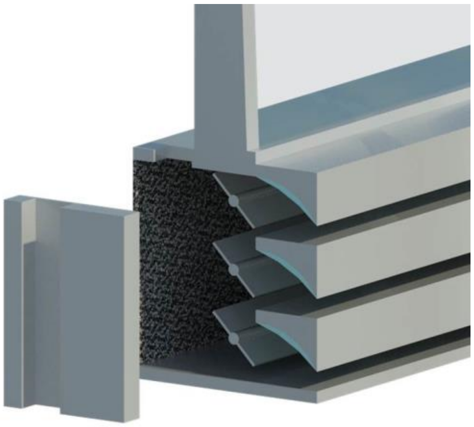


Figure 8: Close-up of Natural Ventilation Louvers

Analysis shows the potential for daylight harvesting to save approximately 97,800 kWh annually on the office floors. These savings, combined with those in the lobby, reduce the expected lighting load by 20%.

Shading

Rather than using traditional window shades, 350 Mission will be equipped with electrochromic glass. This special glass receives an electrical signal that tells it to tint or untint based on environmental conditions. Cost analysis revealed that it is equivalent cost-wise, if not less expensive, than using traditional glass and shades. Estimates assumed that motorized shades would be used in the office as these would have been utilized otherwise.

Traditional shades obscure views to the outside far more than the tinted glass, and preserving these views was a priority for maximizing occupant comfort. When viewing the building from the outside, shades can negatively impact the building aesthetic by drastically taking away from the uniformity of the façade. Electrochromic glass will also lead to some variation on the façade, depending on the level of shading; however it will not be as noticeable from street level as traditional shades. Furthermore, it creates a façade that reacts to the building's surroundings to maximize energy savings. The glass is integrated into the control system and can be automatically tinted due to daylight levels or on command for A/V presentations. The mechanical implications of using electrochromic glazing are expected to be minimal, but the mechanical and electrical equipment have been sized to accommodate fluctuations in the cooling and heating load.

Figure 9: Office Renderings Showing Electrochromic Glass Tinting with Views Preserved

Details of the cost analysis and glass locations, as well as more information about the properties of the glass, can be found on pages 76-79 of Appendix A.

Electric Lighting

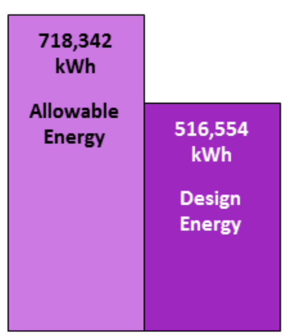


Figure 10: Lighting Energy Use, Baseline vs. Designed

Design Criteria and Concept

Prior to designing the electric lighting for 350 Mission, design criteria and a concept were developed in order to guide design decisions and ensure that each one was made with the project goals in mind. The design criteria for the lobby and office spaces can be found in Tables 3 and 4.

Qualitative
• **Guide visitors to key points**
• **Maximize use of daylight**
• **Integrate with/enhance architecture**
• **Create visual interest**
• **Visually reduce scale of the lobby**
• **Earthquake-conscious design**
• **Separate various functions of the open space**
• **CRI above 80**
• **CCT – 4000K**

Quantitative (values in fc)		
Space Type	*Criteria*	*Actual*
Circulation	10	10.5
Elevator Lobby	10	10.4
Stairs	10	10.9
Security Desk	30	34
Vestibule	15	14.1

Table 3: Lobby Design Criteria

350 Mission is located in the SoMa (South of Market) neighborhood of San Francisco. This area used to be called “South of Slots”, referring to the cable cars that once dominated the streets. Paying tribute to the history of the area, the concept for the lighting design is cable cars.

These represent the innovation of the city, as San Francisco was the first to implement a cable car system. Even now, San Francisco is a leader in energy efficiency and recycling programs. The lighting design for 350 Mission builds on these traditions of innovation and efficiency. Linear forms can be found throughout the design, reminiscent of the cable car tracks and wires that still line the streets of San Francisco.

After developing the design criteria and concept and evaluating the various available light source options, LED lighting was chosen as the primary source for 350 Mission due to its low energy consumption and competitive color rendering and glare control properties. Dimming is an important part of the lighting control system to ensure that energy is not wasted, and is also inherently favorable to LED luminaires by decreasing the amount of heat that needs to be exhausted and contributing positively to luminaire life and resistance to color shift.

In storage rooms and other back-of-house spaces, fluorescent lighting will be used as it is more cost-effective and will not be in use as frequently as the lighting in the public and office spaces.

Lobby

Although the lobby is a big, open space, it has a variety of separate functions. These include circulation, reception, retail, and gathering areas. The lighting design strives to clearly distinguish the separation of these areas.

Linear luminaires configured into squares are suspended from the drop ceiling, providing enough light for general ambiance. The design is decorative to make the lobby visually interesting, even when electric lighting is not needed, and the hollow centers of the luminaires avoid detracting from the architecture. The restaurant and east corner retail area have been left to allow flexibility to the future tenants. Some adjustable ambient lighting is supplied in the east corner retail area, mounted via monorails extending from the partition walls. The rest will be integrated into the displays brought in by the tenants. Receptacles are provided in the floor for this purpose.

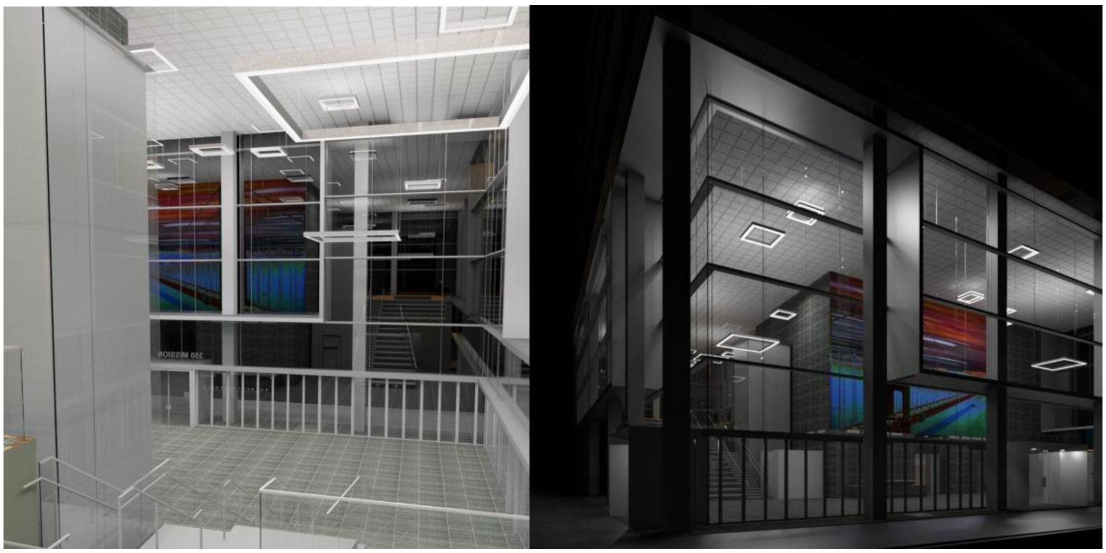


Figure 11: Lobby Lighting Renderings

More information about the special considerations for general circulation area lighting can be found in the "Seismic Design" section on page 51. The lighting plan can be found in Appendix B on page 98. The lobby lighting design resulted in an LPD of 0.41 W/sf, as compared to the 0.97 W/sf allowed by code.

Public Art

The San Francisco Planning Department requires that new construction projects allocate 1% of the total construction cost of the building to publicly displayable art. Originally, the lobby design prominently featured a three-story LED media canvas. While this is a novel way to interact with the public and attract people to the lobby, its operation would require a substantial amount of energy, which is not ideal for a building aiming to be highly energy efficient. The new design transforms the space into a similar public attraction, but one using less energy.

A design competition will be held for local artists to create a mural that incorporates dynamic lighting effects to be installed on the feature wall, and people in the lobby will have the opportunity to interact with the art and the building by using the power of their footsteps. PaveGen tiles are energy-generating floor tiles that use piezoelectric polymer material to convert kinetic energy produced by human foot traffic to electricity. The technology is a new kind of renewable energy, one that directly interacts with humans, but it is not yet a realistic source of building-scale energy generation as the electrical output is too low and the cost too high.

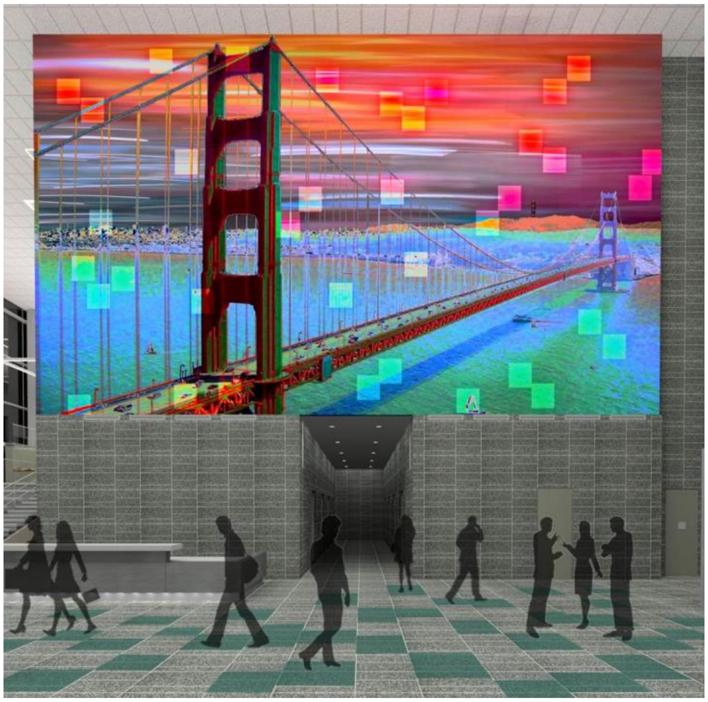


Figure 12: Public Art Example

As an integrated part of the work of art, however, the PaveGen tiles can be purchased under the public art allowance. The tiles will be installed throughout the lobby floor in a pattern determined by the artist, with each tile activating some portion of the lighting in the mural. In this way, people walking across the lobby will interact with the public art using the kinetic energy of their footsteps.

As important as energy efficient building systems are to creating a near net-zero highrise, occupant participation is also critical to minimizing energy use. The interactive art display is intended to make the building occupants more conscious of their role in conserving, and even in this case, creating energy. Since the luminaires used in the wall are only on when triggered by a floor tile, the energy requirements are quite low, and the tiles are sufficient to supply the display.

The electric lighting in the lobby was coordinated with the public art wall to ensure that the view of the wall is not obstructed by suspended luminaires from any location in the lobby from which the wall is visible. Views showing this coordination and other renderings can be found in Appendix B on pages 103-103.

Office

Qualitative
• Create a welcoming, work-friendly environment
• Provide as much controlled daylight as possible
• Prevent glare on computer screens, desks, etc.
• Avoid visual clutter
• CRI above 80
• CCT – 4000K

Quantitative (values in fc)		
Space Type	*Criteria*	*Actual*
Open Office – Desk	30	30.6
Open Office – Circ.	10	15.2

Circulation	10	11.8
Small Conference	30	29.7
Large Conference	30	30.1
Kitchen	30	29.9
Dining/Break Area	10	10.7
Restroom	5	5.5
Copy Room	10	12.0

Table 4: Office Design Criteria

The driving forces behind the lighting design of the office floors were simplicity, energy efficiency, and user flexibility. Energy efficiency on the office floors is especially important because the energy savings resulting from this lighting design are multiplied by 25 (the number of office floors). The primary ambient lighting comes from continuous runs of linear LED fixtures. The fixtures use diffuse lenses and a low lumen package to reduce the risk of glare. They are placed above the partitions between rows of desks to avoid shadowing on the work area and glare on computer screens. Overhead lighting only provides 2/3 of the required maintained illuminance levels, with the other 10 fc provided by dimmable LED task luminaires. These luminaires have adjustable arms for maximum flexibility and are mounted to the front partition on each desk. Employees can choose whether or not they need the task lights after evaluating light levels from daylighting and the overhead lighting. Task lighting is the most efficient means of delivering light to the workplane, and combining this with the overhead lighting reduces the lighting load on the office floors.

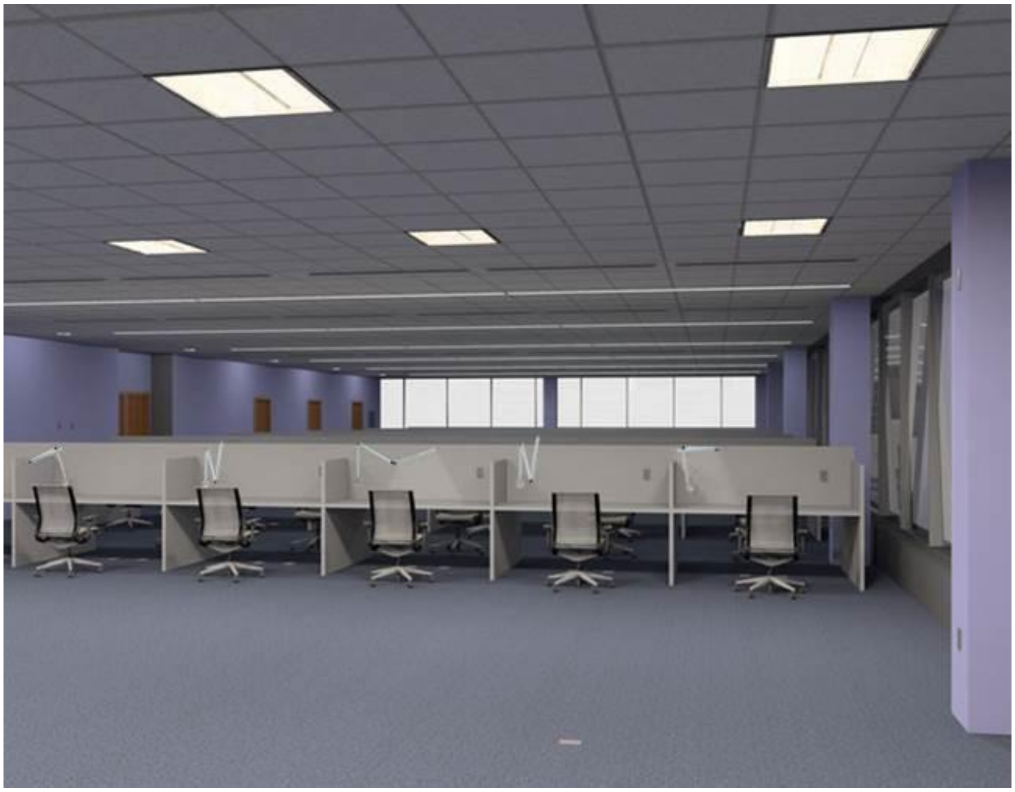


Figure 13: Office Rendering with Task Lighting

The office lighting design resulted in an LPD of 0.42 W/sf, as compared to the code allowable 0.76 W/sf. The lighting plan can be found on page 104 of Appendix B.

Emergency Lighting

The emergency lighting provides one foot-candle of horizontal illuminance at the floor along the path of egress, as required by the California Building Code. This includes all stairwells, corridors, and travel routes that building occupants must take to reach these egress paths, including large partitioned rooms and utility spaces. In both the lobby and office floors, emergency lighting is integrated into the normal lighting design. To accommodate this, the emergency panel is supplied by normal and emergency power supplies and controlled by an automatic transfer switch (ATS). The power server modules (discussed further in the “AC/DC Distribution” section on page 36) that receive the 380VDC and convert it to 24VDC have multiple inputs, one from the normal panel and one from the emergency panel, and are programmed so that only the output channels supporting emergency loads draw power from the emergency panel when the normal feed stops.

Controls

A Digitally Addressable Lighting Interface (DALI) system is used to control the glass tinting and electric lighting in the building. This lighting control system was selected after developing the design criteria listed in Table 5, and is tied into a Building Automation and Control Network (BACnet) that also manages the mechanical systems in the building. The integration of these systems allows the building operations team to view a summary of the building’s energy use, aiding in the identification of systems that are not performing as anticipated and permitting analysis of how the building is performing in regards to the net-zero goal. The offsite solar array is also monitored, sending information back to the main building control system for inclusion in the overall building energy use reports. Both the DALI and BACnet systems feed into the Facilities Integration Model (FIM). The FIM allows the facilities manager to track all building components and have quick access to their cost, location in the building, usage patterns, and product specifications. The control systems are summarized in Figure 14 below.

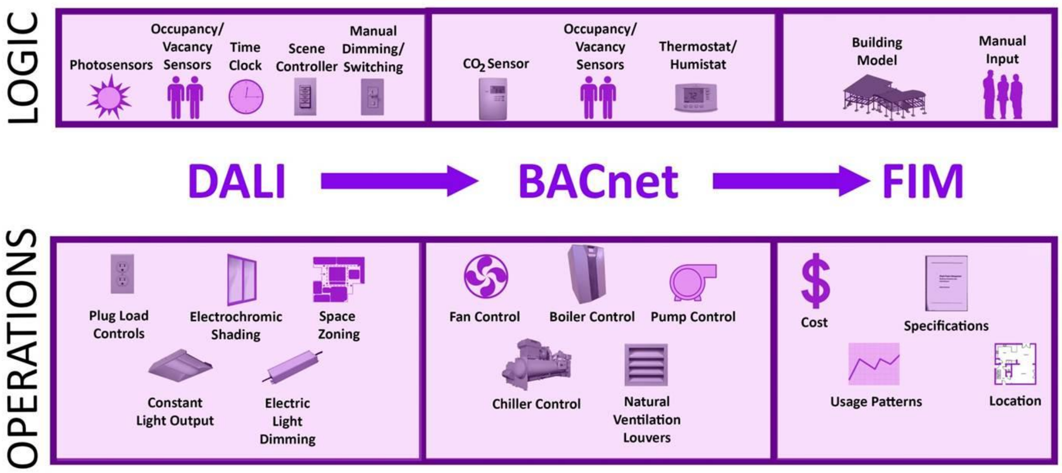


Figure 14: Building Controls Summary

The DALI system for lighting control allows for two-way communication between the central control station and each associated device. The control system can both send signals to the devices, telling the lights to dim or the glass to tint, and receive signals from the devices, informing the operator of failed drivers or motors or of LEDs that have reached the end of useful life. DALI is also an open standard, so a wide variety of manufacturers offer devices and luminaires that are compatible, removing any interoperability limitations.

Qualitative
• Monitor energy use • Minimize energy use • Comply with applicable code • Maximize safety • Seamless integration of daylight and electric lighting • Flexible • Control electric lighting and shading systems • Dimming in daylit spaces • Maximize occupant comfort • Integrate with Building Automation System (BAS)

Table 5: Control System Design

In all locations where LEDs are used, the control system is programmed to adjust power input throughout the LED life to maintain a constant lumen output. Calculations were performed with a 0.7 lumen depreciation factor, and without an adjustment by the control system, areas will be considerably over lit. There is a linear relationship between power input and lumen output, so the initial input for each LED fixture will be 70% of the maximum. Light levels will be monitored via photosensors that tell the control system when the LEDs have depreciated to the point where electric light levels are too low and the power input needs to be increased. Doing this saves energy while also maintaining appropriate light levels, making the spaces more comfortable for the occupants. The complete controls narrative can be found on pages 107-113 of Appendix B.

Lobby

The lobby is divided into separate control areas based on function. These areas are shown in Appendix B on page 107, and a summary of the lobby controls can be found in Table 6 below.

SPACE TYPE	MANUAL ON	MANUAL OFF	DIMMING	OVERRIDE SWITCH	MULTI SCENE CONTROLLER	KEY SWITCH	TIME CLOCK ON	TIME CLOCK OFF	OCCUPANCY	OCCUPANCY SENESOR OFF	PHOTOCONTROL DIMMING
General Circulation Area											X
Reception Desk – task	X	X								X	
Reception Desk – decorative							X	X			
Retail – ambient			X	X			X	X			X
Retail – merchandise			X				X	X			
Elevator Lobby							X	X	X	X	

Table 6: Lobby Lighting Controls Summary

General Circulation

The suspended luminaires in the general circulation area are on from dusk to dawn for security purposes and throughout the day as needed. They are controlled by multiple photosensors attached to the fixtures and calibrated to reflect the approximate ground illuminance levels. The lights dim as daylight levels allow, and when the amount of daylight in the lobby is adequate for general circulation, the lights are turned completely off.

Office

As the office layout is flexible, the lighting controls are described as they would be designed for the typical floor layout that is being used as the standard. Due to the flexibility offered by DALI control systems, any changes made to the floor plan after the initial programming can be reflected in an adjustment of the control system settings to fit the new specifications. A summary of the office floor controls can be found in Table 7 below. The open office is described further in the following section. More information and the control zone layout can be found in Appendix B on page 110-113.

SPACE TYPE	MANUAL ON	MANUAL OFF	DIMMING	OVERRIDE SWITCH	MULTISCENE CONTROLLER	KEY SWITCH	TIME CLOCK ON	TIME CLOCK OFF	OCCUPANCY SENSOR ON	OCCUPANCY SENSOR OFF	PHOTOCONTROL DIMMING
Open Office – overhead	X			X				X			
Open Office – task lighting	X	X								X	
Flex Space	X			X				X			X
Electrical/Mechanical Rooms	X	X								X	
Restrooms									X	X	

Elevator Lobby							X	X	X	X	
Corridors							X	X	X	X	
Copy Room									X	X	
Interview Rooms	X	X								X	
Teleconference Rooms	X	X	X							X	
Conference Rooms	X	X	X		X					X	
Dining/Break Area									X	X	X
Kitchen									X	X	

Table 7: Office Floor Lighting Controls Summary

Open Office

The open office lighting consists of the overhead lights and the task lighting on each workstation. Task lighting is locally controlled, only turning on when switched on by an occupant. These lights can either be switched off manually or a vacancy sensor located under each desk does so automatically after a preset period of time.

The overhead lighting is controlled by a manual "on" at the beginning of each day, with each fixture being assigned to a control zone as designated in Appendix B. At 6:00PM each day, lights blink several times as a five minute shutoff warning. If the override switch is not activated during that time, the lights turn off at 6:05PM. Use of the override causes lights in the specified control area to remain on for an additional 90 minutes, and at the end of this additional time, the same shutoff warning occurs. The override option is available to all employees through the use of the Voice over Internet Protocol (VoIP) phones located at each desk or the physical override switches located in the vicinity of each control zone.

During hours where daylight harvesting is possible, lights dim according to the signals received by closed-loop daylight sensors located in the ceiling. Each control zone is also divided into dimming zones. Though unquantifiable due to uncertainty of end-use and the unpredictability of building users, energy savings from the DALI system that reacts to occupancy can be expected to be significant.

Plug Load Controls

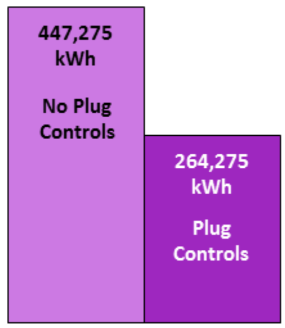


Figure 15: Plug Load Controls Energy Savings

Like most modern office buildings, plug loads comprise more of the overall electrical energy use than any other component or system. Computers, electronics, and appliances that remain plugged in continue to draw small amounts of power, despite the fact that they might be in standby mode or even turned off. Because unplugging everything at the end of the day is impractical, plug load controls help remedy this wasted energy, which is sometimes called a "phantom load." Quantifying the savings from plug load controls is complex and involves many assumptions about future use. In order to quantify these savings, the results of an extensive plug load control study conducted by the California Utilities Statewide Codes and Standards Team in conjunction with PG&E using prototype office spaces was used. The study's recommended plug load control strategies are employed in 350 Mission, with similar energy savings expected.

Plug Load	Control Strategy
Computer monitors Open office task lighting Audio/visual equipment General use receptacles	These devices operate on both time clock controls and occupancy sensors. There is no threat of losing data if the device shuts off due to inactivity in the space. With 120 open office work stations per floor, under-desk occupancy sensors have the potential to save task lighting and computer monitor energy. AV equipment in conference rooms may go unused for long periods of time when the rooms are empty.
Printing, copying, and scanning equipment Kitchen Appliances	Receptacles serving these loads operate solely on a time clock. Most kitchen appliances require operation throughout the work day, even when the kitchen is not occupied, and copy room devices often receive signals when the room is empty.

Table 8: Plug Load Control Strategy

Time switch controls are used to open circuits during non-working hours in order to achieve maximum energy savings. Occupancy sensors also supplement the time clock in some spaces to save energy during working hours when electronics are not in use. Despite potential energy savings, some electronics should always remain in at least a standby power mode, such as continuous-use devices, like refrigerators. Desktops are also considered non-controllable loads, since they might receive updates or be remotely accessed at any time, and VoIP phones must always be capable of receiving messages.

The intelligence behind the plug load system will rely on the DALI system and the established infrastructure of controls that are using for the office lighting. Controlling plug loads comes at a higher capital cost with more complex installation, as circuiting must be done such that loads with similar controls are included on the same circuits, but this quickly pays for itself through energy savings. As with any energy saving system, the occupants must be educated on how the system operates to maximize participation. This control strategy is expected to save 183,000 kWh annually. The calculation for this value is shown in Table 9 below.

Plug Load Savings			
Large Offices	0.61	kwh / year / ft.^{2}	Based on "large" (175,000 ft.^{2} office)
350 Mission Area	300,000	ft.^{2}	Usable office space on 25 office floors
Estimated Energy Savings	183,000	kwh / year	See plug load control section for description of control strategy

Table 9: Plug Load Control Energy Savings

Chapter 5

Electrical Design

AC/DC Distribution

The electrical system in 350 Mission was designed to maximize efficiency, utilizing dual alternating current and direct current (AC/DC) electrical distribution to support building loads. While AC infrastructure is the industry standard, the popularity of DC power distribution is on the rise. Semiconductor-based loads, including LED lighting, computer servers, and low voltage controls inherently require DC voltage, making the standard practice of converting AC distribution to low voltage DC at each device inefficient. Renewable onsite energy generation can also directly interface with DC distribution systems, eliminating the need for an inverter.

As shown in Figure 16, the utility-paralleling AC switchgear is located adjacent to the PG&E vault in the primary electrical space on level B1 and distributes normal and emergency power via a 480VAC bus duct running vertically through the electrical rooms in the core. The DC switchgear, also in parallel with the utility and receiving input from both onsite energy sources, is located in the penthouse. Its distribution runs through a separate 380VDC bus duct also running through the electrical rooms in the core. An additional emergency riser runs vertically through the electrical closet and will be discussed in the "Seismic Design" section on page 52. The bus ducts act as large feeders, allowing power taps using bus plugs to "plug" into the copper runs where power is needed. This offers greater end-use flexibility by eliminating individual feeders and consolidating vertical runs into a large bus accessible at plug locations.

The AC and DC bus ducts are contacted at each office floor and in the lobby spaces to provide power to main circuit breaker (MCB) panels, the AC panel via a small step-down transformer. Panelboards feeding the restaurant and retail areas are separately metered to monitor the energy use of those vendors. AC distribution runs primarily under the floor slab of the floor below and pokes through the slab at receptacle junctions, and DC distribution runs in the ceiling plenum. The AC distribution locations were coordinated with the mechanical radiant floor system, as shown in Appendix B on page 120.

Maintaining AC distribution throughout the building was necessary for receptacles feeding electronics and appliances that have not yet penetrated the DC market. For example, the desktop computer loads at each office floor run on AC distribution because the market is dominated by AC computer power supply units (PSUs). The building's computers are discussed in more detail in the "Server Room" section on page 41. A detailed schematic showing the AC/DC breakdown of building loads and the electrical riser diagram can be found on page 123 in Appendix B.

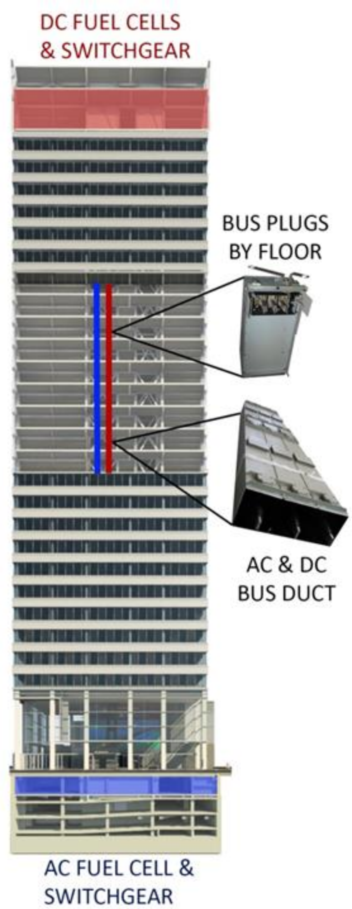


Figure 16: Bus Duct Schematic

Mechanical

350 Mission's approximately 350 kW of connected mechanical equipment requiring power runs on 380VDC. While AC and DC motors have similar efficiencies depending on the size and manufacturer, DC variable frequency drives (VFDs) offer a significant advantage over AC. As shown in Figure 17, a VFD supporting an AC motor and receiving AC input experiences two conversions, AC-DC and then DC-AC, whereas a VFD feeding a DC motor with DC input experiences no conversions. Every device has heat and mechanical losses, but eliminating

conversions is the key to improving system efficiency. The DC motor and VFD combination allows pumps and fans to maintain near-peak efficiency even when running at partial load, which is critical considering that all mechanical equipment is oversized to some degree. Mechanical loads also generally have lower power factors than other equipment, but with DC distribution there are no phases, so this is not an issue.

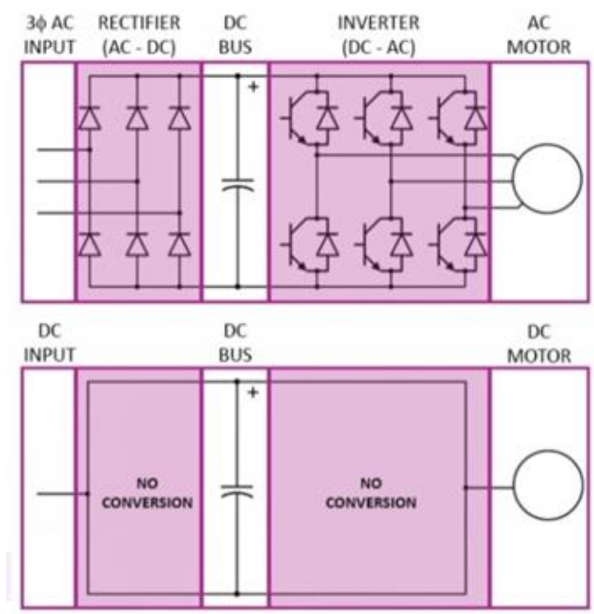


Figure 17: AC vs. DC VFD

Lighting

Before considering energy savings for daylight harvesting and controls, electric lighting is expected to consume 30% of the building's energy use. Therefore, making the electrical system feeding the lighting as efficient as possible was critical. The branch panelboard in the lobby, restaurant and office floor electrical rooms is fed by the 380VDC bus duct and distributes 380VDC to the 2 kW and 123 kW of connected lighting in the lobby and the 25 office floors, respectively. With almost 16,000 ft^2 of office space, the 380VDC is distributed as close to the loads as possible using strategically located power server modules.

With these modules, distribution happens at a higher voltage, preventing voltage drop and allowing the use of the same wire sizes found in a typical AC system. Each module receives the 380VDC distribution voltage and converts it to 24VDC through various output channels for use by the LED DC-DC drivers and DC fluorescent ballasts. From the DC switchgear to each luminaire, the voltage experiences only one 96% efficient conversion at the power server module and minor losses within the DC-DC drivers that regulate the 24VDC current for dimming. The power server module layout and voltage drop calculations can be found in Appendix A on pages 91-93.

Façade

The actuators that adjust and hold the natural ventilation louvers are located every ten feet within the system. They run on 24VDC and are supplied via the 380VDC panelboard on each office floor, with one 90% efficient 380VDC to 24VDC conversion occurring in a small DC-DC converter located at the first actuator on each façade. Only 1 W of power is required for the actuator to hold the louvers in place, and 2.5 W are required to move them, equating to about 25,000 kWh annually for the entire building.

The electrochromic glass also contributes to the total building load very minimally. At most, it will draw 3 kW of power if all of the installed glass is tinted to the maximum level at the same time, a scenario that will never occur. The current required to tint the glass will also be supplied via a DC-DC converter at approximately 4VDC.

Due to the wide range of efficiencies available for both AC and DC power sources, it is impossible to quantify an exact value for anticipated savings resulting from using DC over AC. However, 350 Mission's electrical design minimizes conversions between the two waveforms. It expands upon the idea of configuring localized DC grids within a building and creates a building-scale DC microgrid to complement the traditional AC distribution, from site generation through end use. This brings 350 Mission one step closer to the goal of [ZERO**impact**].

Source Fuel vs. Site Fuel

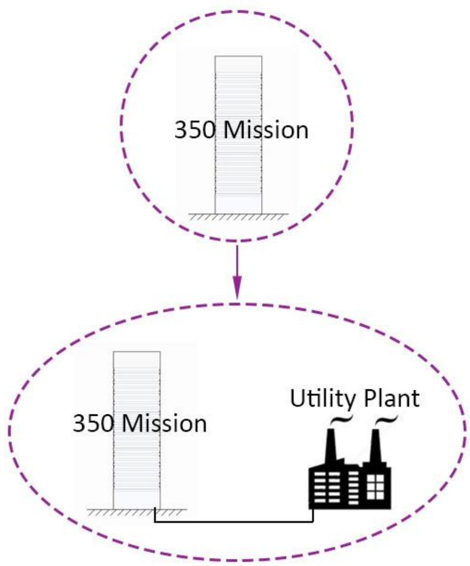


Figure 18: 350 Mission Boundary of Influence

When considering the impact of a building, it should not be viewed as an isolated system. It leaves an energy, waste, and emissions footprint beyond the building site itself. Reliance on the electric grid expands 350 Mission's boundary of influence to include the power plants and transmission lines of PG&E, as shown in Figure 18. On average, the process of utility generation and distribution is only 31% efficient in the United States. In other words, for every unit of energy reaching the building site, three units of primary fuel are consumed. This awareness of the environmental impact of source fuel was the catalyst behind the decision to use fuel cells for onsite energy generation to reduce dependence on the grid and minimize the overall building footprint.

Fuel Cell

Natural gas comprises approximately 25% of the primary fuel that feeds PG&E's electric utility grid, but there is also an extensive existing network of natural gas lines in downtown San Francisco available for use directly at the building site. Onsite natural gas mitigates the inefficiencies associated with the electric grid, as conservative estimates anticipate approximately 10% transmission losses. Like the boilers and service water heating in 350 Mission, the fuel cells use natural gas as their primary fuel.

Three 400 kW units, two DC and one AC, support the expected DC and AC building loads of 535 kW and 393 kW respectively. Rather than using two smaller DC fuel cells, two 400kW units were chosen, first to allow for flexibility of future use with additional onsite DC energy generation and second to maximize efficiency. The additional capacity would be especially useful for an expansion of the server-based virtual computing or added mechanical equipment. The maximum efficiency for these units occurs when operating around 220 kW output, so using two fuel cells to meet the expected DC power demand comes at no efficiency cost.

The standard output of the fuel cell is 480VAC power which directly feeds the AC switchgear. The other two fuel cells require a custom order to remove the inverter within the assembly, resulting in 380VDC output that feeds the DC switchgear and producing an efficiency increase by removing a conversion.

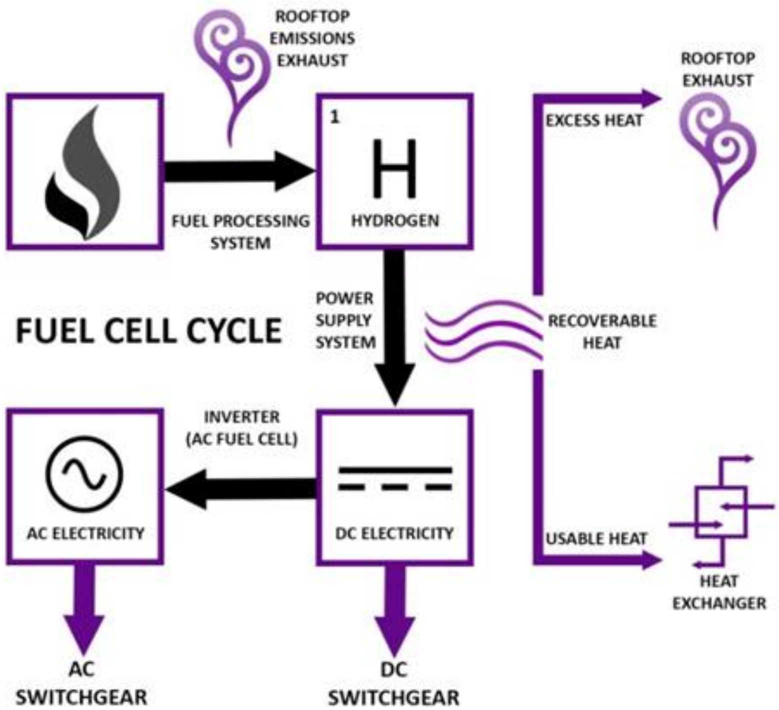


Figure 19: Fuel Cell Cycle Summary

Under normal conditions, 350 Mission can operate free of the electric utility grid. In the event of an unexpected peak in demand power, the fuel cell output can be supplemented by the grid through paralleling switchgear. Also, problems with natural gas infrastructure are uncommon but not unprecedented, making this grid connection a necessary source of redundancy. Paralleling also allows electricity to be supplied back onto the grid if the fuel cells and onsite renewable sources are producing more energy than the building requires, and two-way metering ensures that 350 Mission is credited for this energy.

Using fuel cells rather than the utility grid saves about 1,326,000 kWh of primary energy each year, and they also produce heat that is recovered for use in the building's mechanical system. Approximately 343,563 kWh of recovered heat can be used to heat 350 Mission annually, directly reducing the fuel consumption of the natural gas boilers. When considering the electrical generation and recovered heat together, the fuel cells are 48% efficient as compared to the utility's 31%. Though the building's carbon footprint is not eliminated, as CO_2 is still a byproduct, its quantity is greatly reduced. The CO_2 will be exhausted via a duct running through the core to the roof of 350 Mission and unused heat will be exhausted through the cooling tower.

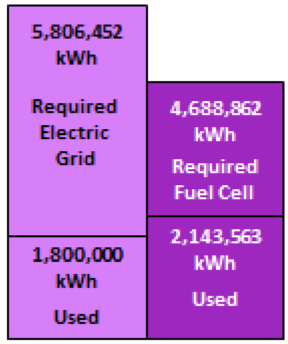


Figure 20: Annual Primary Fuel Consumption, Utility vs. Fuel Cell

The cost of the installation will be approximately $7,000,000, but the capital cost is only $1,000,000 as the system's size qualifies it for over $6,000,000 in self-generation incentives from the federal government and PG&E. Using utility natural gas over electric will also save the building owner $230,000 annually. More information on the fuel cell and calculations can be found in Appendix A on pages 84-87.

Server Room

The building computing loads are supported primarily by a virtual desktop infrastructure. Excess space on the lobby mechanical platform was partitioned into a server room, housing the rack servers that provide the majority of the building's processing power. The servers are accessed by thin client desktops, which require less than 20% of the power of full-capacity desktops.

There are approximately 120 thin client desktops and 12 full-capacity desktops per office floor, included to accommodate employees with very heavy program and application uses. The servers were sized to accommodate medium to heavy computing needs on the thin clients.

Servers save substantial energy for two main reasons. First, they can run directly on 380VDC power, eliminating AC-DC conversion losses that occur in computer power supply units and increasing efficiency by more than 15%. Second, they maximize processor utilization. Energy consumption and processing output in computers and servers are not linearly related, so underutilized or idle devices are consuming wasted energy that does not contribute to any real computing application. The servers in 350 Mission were sized adequately but not oversized, ensuring high processor utilization and energy savings.

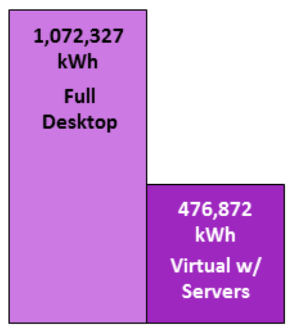


Figure 21: Computer Energy Use, Baseline vs. Designed

Onsite server installation was chosen over cloud-based virtual computing because it offers the tenants of 350 Mission more security and flexibility in creating their own computing infrastructure, and again, considering an energy boundary beyond the building site, cloud-based virtualization simply moves the energy consumption to an offsite data center. Cloud-based computing can be implemented by future tenants if desired, simply by removing the servers.

This virtual server-based infrastructure is expected to save 56% in computing energy use annually. A detailed analysis of server sizing and specification and computing power and energy calculations can be found on pages 88-90 of Appendix A, and a graphic outlining data distribution can be found in Appendix B on page 116.

Emergency Power System

The building's emergency power is supplied by standby batteries to maximize the advantages of using DC distribution. The emergency loads consist of egress lighting and life safety mechanical equipment, such as smoke exhaust fans and fire pumps, and all are fed with 380VDC. The fire alarm system will run on the battery packs within the control panels in the event of an emergency.

The battery units consist of battery packs wired in series to achieve the high voltage distribution necessary to feed the emergency loads. Many of the emergency loads also operate on normal power during standard building operation. Therefore, the emergency panels are served by normal output from the DC switchgear, and the battery packs are placed in parallel. The output from the DC switchgear is always at a slightly higher voltage, so the batteries are never in use until this normal voltage either stops or decreases substantially in the event of a utility outage or emergency. The building control system periodically verifies that the voltage of the batteries is adequate, and the battery packs replace the need for purchasing a generator and supplying and storing its fuel. This increases the reliability of the emergency system because there is no risk of interruption of the generator fuel supply.

Chapter 6

AC/DC Distribution Cost Analysis

A dual alternating current/direct current distribution network is implemented first and foremost for the enhanced performance, as two building-scale microgrids create a more efficient means of distribution. Chapter 5 discusses separated AC/DC distribution advantages in more detail. This chapter explores how such a system impacts the capital cost of the building's electrical infrastructure in comparison to a traditional AC distribution system. Evaluating the exact additional cost of the dual AC/DC system and the resulting expected energy savings requires more detailed product specification than was covered in the scope of this project, which represents a thoroughly developed schematic design. This fact, coupled with limited manufacturer cost information, made it more logical to conduct this analysis based on the quantity of equipment in the traditional AC distribution system versus AC/DC dual distribution and general pricing trends for the equipment.

Table 10 lists the major equipment for both distribution systems. Under the "Impact" column, each component is rated with either a plus, minus, or zero. The plus indicates that the component offers an advantage over the other system, the minus indicates a disadvantage, and the zero means that there is no significant advantage between the two systems.

TRADITIONAL AC SYSTEM		
Equipment	**Impact**	**Justification**
Distribution		
(3) fuel cells	**0**	Both systems use 3 fuel cells
(3) fuel cell inverters	**-**	DC system uses only 1 inverter
(2) onsite renewable energy source inverters	**-**	DC system requires no inverters
(2) switchgears	**0**	Both systems use 2 switchgears
(2) bus ducts	**0**	Both systems use 2 bus ducts
(1) standby generator	**0**	Both need emergency power supply
Generator fuel and fuel storage	**-**	DC system requires no fuel storage
(4) equipment distribution panelboards	**0**	Both use 4 equipment DP's
Typical Office Floor		
(3) branch panelboards	**0**	Both use 3 branch panelboards
(1) Lighting and Equipment (480/277)		
(1) Receptacles (208/120)		
(1) Emergency (208/120)		
(1) step-down transformer	**0**	Both need step-down transformer
(1) ATS for the emergency panelboard	**0**	Lighting in both would run on emergency and normal
(1) Uninterruptible power supply (UPS)	**-**	Stanby batteries have no warm-up time
(125) AC-DC drivers	+	More common, cheaper
(15) AC ballasts	+	More common, cheaper
(> 4200 ft.) 12 AWG conductors	**-**	DC load centers save on material
(600 ft.) underfloor conduit	**0**	Same AC underfloor distribution
DUAL AC/DC SYSTEM		
Equipment	**Impact**	**Justification**
Distribution		
(3) fuel cells	**0**	Both systems use 3 fuel cells
(1) fuel cell inverters	+	DC system uses only 1 inverter
(1) grid-paralleling inverter	**-**	DC system requires no inverters
(1) grid-paralleling rectifier	**-**	AC system does not need this
(2) grid-paralleling ATS	**-**	AC system does not need this
(2) switchgears	**0**	Both systems use 2 switchgears
(2) bus ducts	**0**	Both systems use 2 bus ducts
(3) standby battery packs	+	More reliable and fits into DC circuit easily
(4) equipment distribution panelboards	**0**	Both use 4 equipment DP's
Typical Office Floor		
(3) branch panelboards	**0**	Both use 3 branch panelboards
(1) Lighting and Equipment (380VDC)		
(1) Receptacles (208/120)		
(1) Emergency (380VDC)		
(1) step-down transformer	**0**	Both need step-down transformer
(1) ATS for the emergency panelboard	**0**	Lighting in both would run on emergency and normal
(125) DC-DC drivers	**-**	Less common, more expensive
(15) DC ballasts	**-**	Less common, more expensive
(6) power server modules	**-**	Additonal necessary purchase
(4200 ft.) 12 AWG conductors	+	DC load centers save on material
(600 ft.) underfloor conduit	**0**	Same AC underfloor distribution

Table 10: Major Electrical Equipment, AC vs. AC/DC Distribution

Similar Equipment

The primary justification for the AC/DC system is that most of the equipment required for dual distribution already needs to be in place for the traditional AC system. Rather than adding components to accommodate the DC grid, it is instead replacing equipment that would run on the AC grid. Many of the largest, most expensive pieces of equipment would remain the same in both scenarios. Three fuel cells are required to meet the building's expected energy demand, and two switchgears are necessary to handle this load. While the dual AC/DC system utilizes one switchgear for the DC grid and one for the AC grid, an entirely AC system of this scale would likely also have two switchgears. This builds an extra level of redundancy into the system. In the event that one switchgear fails, the other can still supply critical building loads. Additionally, two switchgears allow for more flexibility and reduce the size of the units. Rather than having one unit with a 10,000A main bus, the 6000A unit and 4000A unit are smaller and can be placed in different locations if that is more optimal for the design. The switchgear considered for this project, which can run on AC or DC and interfaces with the utility grid and multiple onsite generation methods, has a maximum bus duct size of 6000A. Therefore, two bus ducts would be required, even in the traditional AC system. The AC/DC system employs two 4000A bus ducts, one at 380VDC and one at 480VAC, to meet the entire building load. Both systems would also require four equipment distribution panels, as these are determined by mechanical equipment location and emergency/normal power designation. Three branch panelboards would be required at each typical office floor in both cases, assuming that there is room for mechanical equipment on the lighting panel. These panelboards are rated for both AC and DC use, ensuring that there is no additional cost for DC panelboards.

AC Distribution Advantages

The traditional AC system parallels easily with the utility electric grid in the event that the fuel cells malfunction or are not producing enough electricity. Because it is anticipated that 350 Mission will remain off of the electric grid during standard operation, the transformers belong to the utility rather than the building owner. Therefore, taking electricity off of the grid or returning it to the grid if production is too high simply requires that the 480V distribution voltage goes through one of the two utility transformers. On the DC grid, a rectifier and inverter are required to change the waveform to take and return energy from the grid. The AC system also has the advantage of being the standard in the building industry. Most importantly, fluorescent ballasts and LED drivers are much more commonly found in AC and AC-DC forms. The lesser demand makes DC ballasts and DC-DC drivers less common, and therefore more expensive. The products are available, but at a greater cost. Along these lines, the cost of the DC installation could be higher, as most electrical contractors have experience with AC wiring. Running two distributions would require more coordination and a higher level of expertise, thus increasing the capital cost of the AC/DC system. DC motors will also increase the capital cost. While there is variance across the industry, DC motors for pumps and fans are generally more expensive, as they tend to be more robust. This will likely pay back, as they generally have a longer life and offer improved performance running mechanical equipment at partial loads, but they still represent an increase in the capital cost. Power server modules, in this case costing about $2,000 apiece, are also not necessary with the AC system. These modules ensure that voltage drop in the low voltage DC wires does not exceed 3% on branch circuits, but they are not necessary in an AC system that delivers 277VAC to the drivers and ballasts. This greatly limits voltage drop concerns, but also comes at the cost of much lower conversion efficiencies.

AC/DC Distribution Advantages

Onsite generation makes the AC/DC system more competitive with the traditional AC system when considering capital cost. Because the fuel cells, human waste to power turbine, and onsite photovoltaic array produce direct current, these systems can tie directly into the DC switchgear without first going through an inverter. This step not only saves energy by minimizing conversion losses but also saves money by requiring four fewer inverters. One of the primary reasons that the AC/DC system was considered for this project in the first place was the ability to tie directly into onsite generation. The material cost of wiring AC/DC is also less than the traditional AC system. Ceiling power distribution and floor distribution are both necessary to meet the demands of the office floors. Distribution in both locations was not a result of the dual AC/DC system, but rather to supply power to the luminaires and other electrical devices in the ceiling plenum and to supply power to the receptacles in the floor that serve the workstations. A voltage drop analysis determined that the AC/DC system could use size 12 AWG conductors to supply the DC loads, making it directly comparable to an AC system. While primary distribution is through the bus ducts in the core, all panelboard feeders running on the DC grid will save copper. AC feeders are five-wire, three phase, while DC feeders are three-wire, single phase. This means that replacing feeders that would originally be on an AC grid results in 40% material savings. Along these lines, the power server modules acting as load centers throughout the typical office floor will also save in conductor material costs. Lighting will be single phase, three-wire on either an AC or DC circuit. However, by providing power to load centers that then distribute low voltage DC through various output channels on the DC grid, less copper is required than if each luminaire was served directly from the lighting panelboard. Using a standby battery unit instead of a generator to serve emergency loads also saves money and reduces maintenance by eliminating the need for onsite generator fuel and fuel storage.

Summary

While this analysis does not provide an exact number for the additional capital cost of the dual AC/DC distribution network, it places the cost on a relative scale alongside the traditional AC system. AC distribution will be the cheaper of the two options, primarily due to some of its components being more common and less expensive. Money dictates many aspects of the building industry, and the AC system would probably not be the standard if it was not the cheapest. However, by using equipment that can operate on both an AC and DC grid where possible, such as the switchgear and panelboards, the AC/DC system can keep additional costs down. Fewer inverters in the AC/DC system help offset the additional grid-paralleling equipment necessary for the DC grid. Less conductor copper per office floor is also a substantial source of cost savings because these typical floor savings will apply to all 25 office floors.

By generating energy onsite with the natural gas fuel cells and renewable sources, the total energy cost comes from utility natural gas because the fuel cells have the capacity to meet the expected building load. This greatly reduces the total energy cost, as utility natural gas is significantly cheaper than utility electric. The $230,000 saved annually by using utility natural gas will contribute to paying for the offsite solar array. However, the cheaper cost of fuel lessens the return on the investment of the dual distribution system. Table 11 summarizes the annual cost and energy savings for three different efficiency improvements. Based on data collected by the Emerge Alliance, anticipated efficiency improvement from using both AC and DC distribution is expected to fall somewhere between 10% - 30%, with the actual value dependent upon the equipment specified. [2]

Efficiency Improvement	Annual Cost Savings	Annual Energy Savings
10% improved DC efficiency	$6,500	100,000 kWh
20% improved DC efficiency	$13,000	200,000 kWh
30% improved DC efficiency	$19,500	300,000 kWh

Table 11: Annual Expected Cost and Energy Savings

Ultimately, the owner established the goal of creating a near net zero highrise, and decreasing 350 Mission's energy footprint becomes more important than capital cost. There is always an additional cost associated with enhanced performance. Analysis of the equipment involved in the dual AC/DC system versus the traditional AC system reveals that their required infrastructure is similar and that each option offers cost advantages over the other. Given the low annual cost savings due to lower energy prices, a payback period could be longer than would normally be justified. The justification for using this system in 350 Mission is found in the overarching attitude of [ZERO**impact**], as dual distribution offers potential for significant energy savings.

Chapter 7

Seismic Design

Lobby Lighting

One of the challenges with the design in the lobby was the conflict between the criteria of visually reducing the scale of the lobby and creating an earthquake-conscious design. The scale reduction was achieved through the use of suspended luminaires; however, these can be dangerous in earthquake scenarios. Neither criterion could be discarded as each was developed for a reason, one for occupant comfort and the other for occupant safety. In order to address both of these concerns, the initial conceptual design using suspended luminaires was maintained, and the design for the lobby follows the guidelines set forth by the Federal Emergency Management Agency (FEMA) and the California Department of General Services (DGS) for the support of pendant mounted light fixtures in earthquake-prone areas. The design addresses concerns about swing radius of the fixtures and the strength of cable connections and supports. More information about how the design follows these guidelines can be found in Appendix A on pages 80-81.

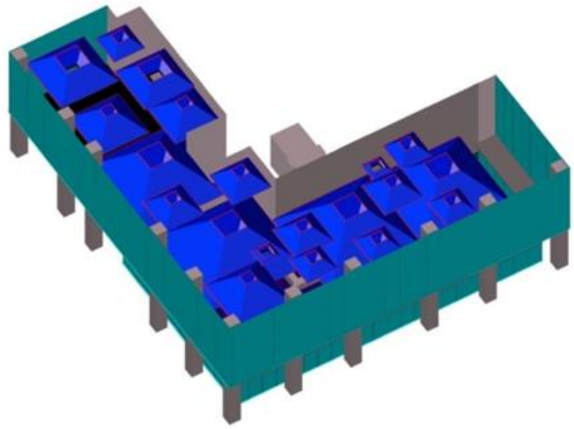


Figure 22: Isometric View of Lobby with Luminaire Swing Areas Defined

Dual Electrical Risers

As San Francisco is located in a seismic region, the electrical system was designed with an extra emphasis on safety and redundancy. In the event of an earthquake or other emergency, it is important for the emergency lighting and other important electrical loads to be maintained. While most buildings have a single set of electrical risers carrying power to the entire building, the electrical design for 350 Mission contains two sets of electrical risers, one being the bus duct located in the main electrical room and the other located in the electrical closet, as shown in Figure 23. Multiple electrical risers have been utilized in other buildings in earthquake-prone areas, such as Taipei 101 in Taiwan. The rooms are located on opposite sides of the core, decreasing the likelihood that risers located in both locations would be damaged in the event of an earthquake.

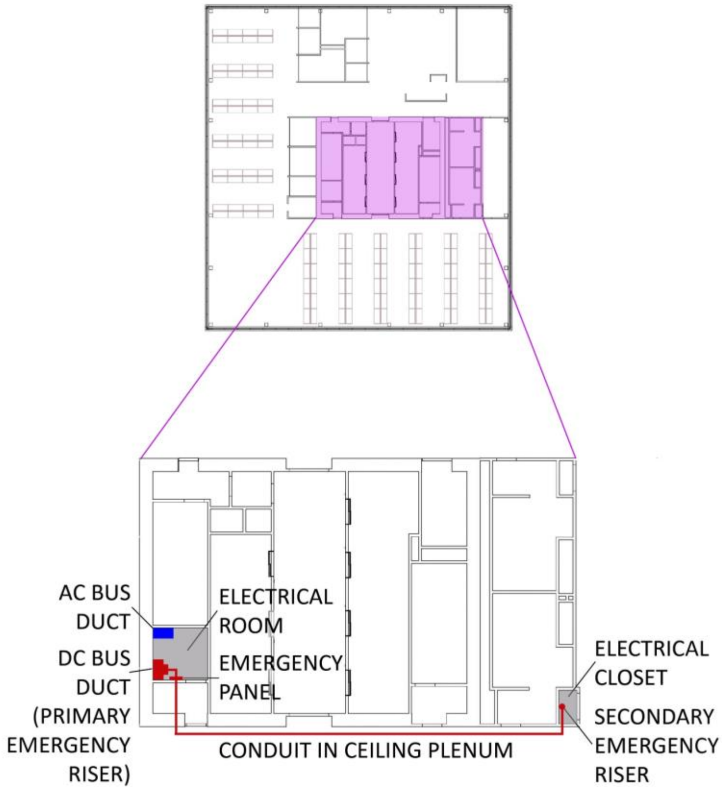


Figure 23: Electrical Riser Locations

As shown in Figures 23 and 25, the electrical room contains the normal power electrical risers, both AC (blue) and DC (red), and a DC emergency riser. During normal building operation, the entire electrical load is served by the electrical room. If the utility fails during an emergency, the building will switch to battery power and feed the emergency loads, which are all on DC power, through the electrical room emergency riser.

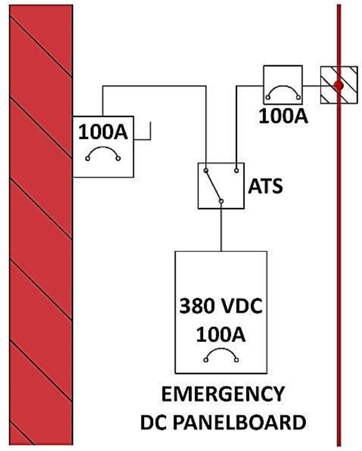


Figure 24: Dual Riser Electrical One-Line

If the electrical risers in the main electrical room are damaged, the building clearly will have undergone serious structural damage, and occupant safety during egress will be of paramount importance. In this situation, getting power to the emergency loads would be impossible with a traditional single riser. 350 Mission has a secondary emergency riser that serves the life safety loads. If the primary riser is damaged, an ATS switches the emergency battery feed to this secondary emergency riser, supplying power to the most vital building loads. All of the emergency loads are on DC power, and as a result, the electrical closet will only contain a DC riser. The riser diagram showing the redundant system layout in its entirety can be found in Appendix B on pages 124-125.

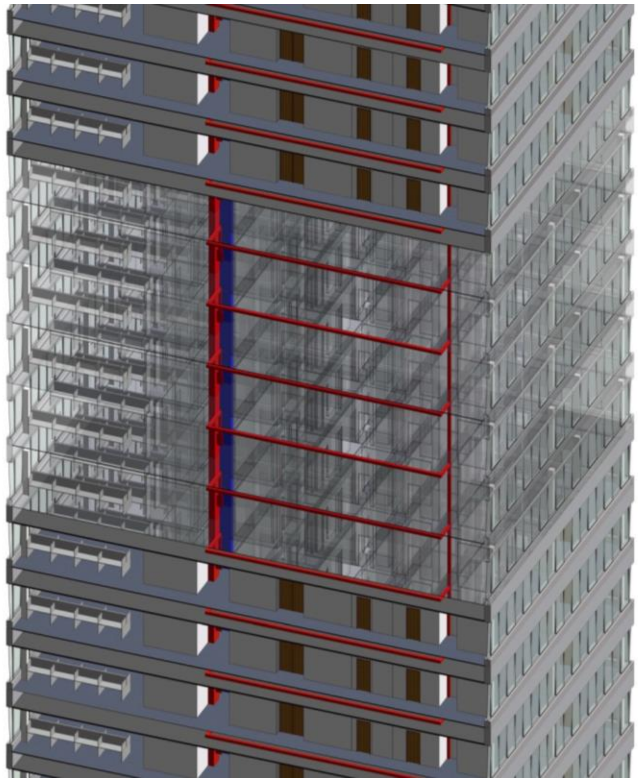


Figure 25: Isometric Section of Dual Risers

Chapter 8

Systems Design and LEED

Fire Alarm Design

The primary fire alarm control panel is located in the fire command room on the first floor of the lobby. This panel contains the logic of the fire alarm system by interfacing with the BACnet system's duct smoke detectors and receives input from smaller panels located on each level of the building. These two control panels are located in the electrical room and systems closet on each floor. While the fire alarm circuits run on 24VDC, these panels are fed by 208Y/120VAC with integral rechargeable battery backup in accordance with National Fire Protection Association mandates.

Each panel has two 24VDC initiating device circuits that supply the smoke detectors and manual pull stations. The 20' radius smoke detector coverage of the open spaces and corridors is shown, and each separately partitioned space has its own dedicated smoke detector. Manual pull stations are located in the primary egress path at the entrances to the stairways. Stair vestibules contain rescue intercom stations for two-way communication with a central station to dispatch the fire department.

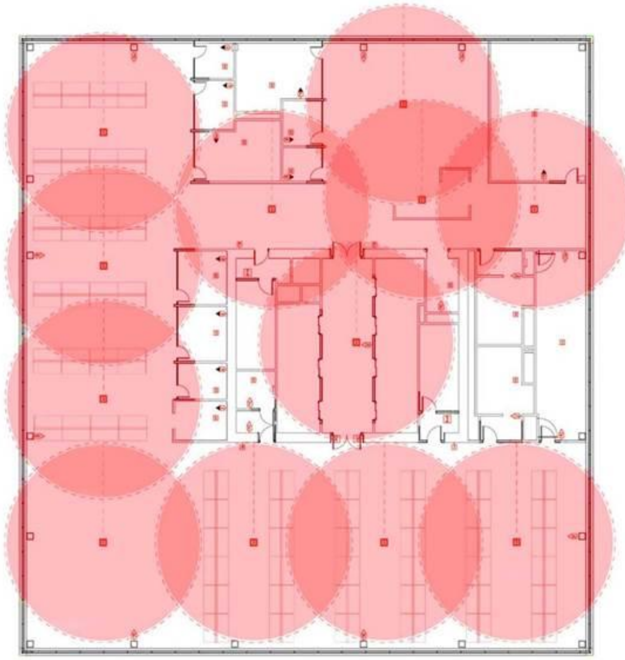


Figure 26: Open Office and Corridor Fire Alarm Smoke Detection Coverage

After receiving a signal from the alarm initiation devices, notification appliances alert occupants to the potential emergency. Speaker-strobe devices are located in open spaces, corridors, and utility spaces, and their coverage is shown in Figure 27 below. Visual strobes are located in all of the conference rooms. Automatic door operators automatically close (but do not lock) the doors to the elevator lobby in the event of an emergency to discourage elevator use and prevent the spread of fire through the core.

Figure 27: Open Office and Corridor Fire Alarm Annunciation Coverage

The complete fire alarm coverage plan can be found on page118 of Appendix B.

Data/Telecommunications Design

The data and telecom infrastructure provides the flexibility for future building occupants to create a building area network (BAN) or multiple local area networks (LANs) to allow data sharing between network users. The servers providing computing power and the telecom equipment loads are served by the 380VDC distribution and converted using a highly efficient 380VDC-48VDC power supply designed for data and telecom applications. The complete data/telecom plan and riser can be found in Appendix B on pages 116-117.

LEED (Leadership in Energy and Environmental Design)

Under the LEED 2009 for New Construction and Major Renovations Checklist, 350 Mission can achieve LEED Platinum Accreditation, accumulating 93 points out of a possible 110 points, as summarized in Figure 28 below. Receiving Daylight & Views credits, along with other points associated with lighting and electrical design, contributed to achieving this level of certification. For a complete list of the credits and points received, see pages 94-95 of Appendix A.

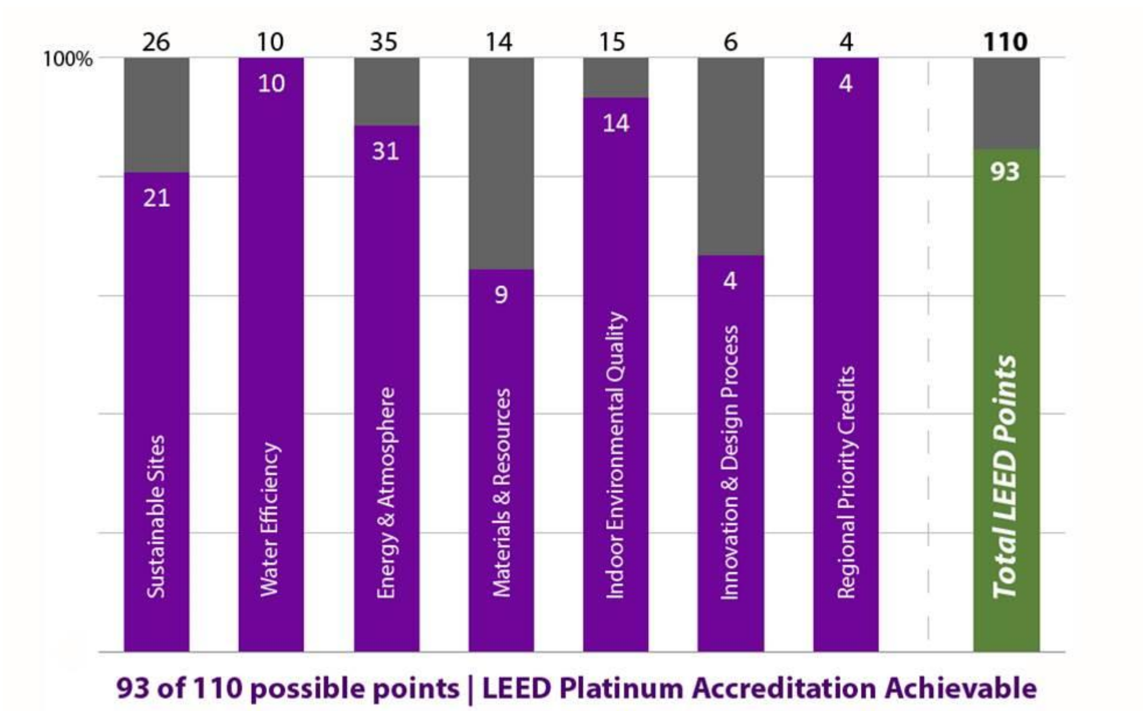


Figure 28: LEED Summary

Chapter 9

Conclusion

The underlying attitude of [ZERO**impact**] has guided the approach of the project through the four design emphases of [ZERO**energy**], [ZERO**interruption**], [ZERO**waste**], and [ZERO**emissions**]. In conjunction with other building systems, the lighting and electrical system design effectively contributes to all four areas while remaining economically feasible. The approach has culminated in a design that is beneficial to the environment, building occupants, and owner.

The lighting design features a daylighting and control system and energy efficient lighting that result in over 100,000 kWh of savings annually and a building LPD of 0.434 W/sf, as compared to the code-allowed value of 0.728 W/sf.

The innovative electrical system fully embraces DC distribution, using it to power computer servers, LED lighting, VFDs, motors, low voltage controls, and other devices. Virtual computing eliminates the need for full-sized desktop computers at every workstation, saving almost 600,000 kWh each year.

Fuel cells supply energy to the building and save over $230,000 in energy costs annually by allowing the owner to purchase natural gas rather than electricity from the utility grid, and their exhaust heat is sufficient to cover the heating needs of the building 87% of the time.

Energy is generated via onsite and offsite solar arrays, as well as an onsite human waste-to-power converter. These systems combined generate 5,544,000 kWh annually, which is more than enough to cover the building's overall annual consumption of 5,264,570 kWh.

350 Mission adheres to the traditional definition of net-zero by returning as much energy to the grid as it consumes in a year, and it also meets the broader goals defined by **AEVITAS** by minimizing emissions and waste and by creating a design that responds to the earthquake-prone environment to ensure continuity of operation even after a seismic event. Lifecycle cost analyses determined a payback period of 10.6 years when compared to the code-minimum baseline building.

The final building design successfully responds to the project requirements and achieves the project goals through the use of innovative and efficient design techniques. The graph shown below in Figure 29 highlights 350 Mission's energy use and energy savings in various shades of purple versus the baseline building shown in gray. Aside from plug load and systems and shading, which were approximately equal to the baseline, the other categories saw a drastic reduction in energy use, and the systems as designed introduced various energy savings measures.

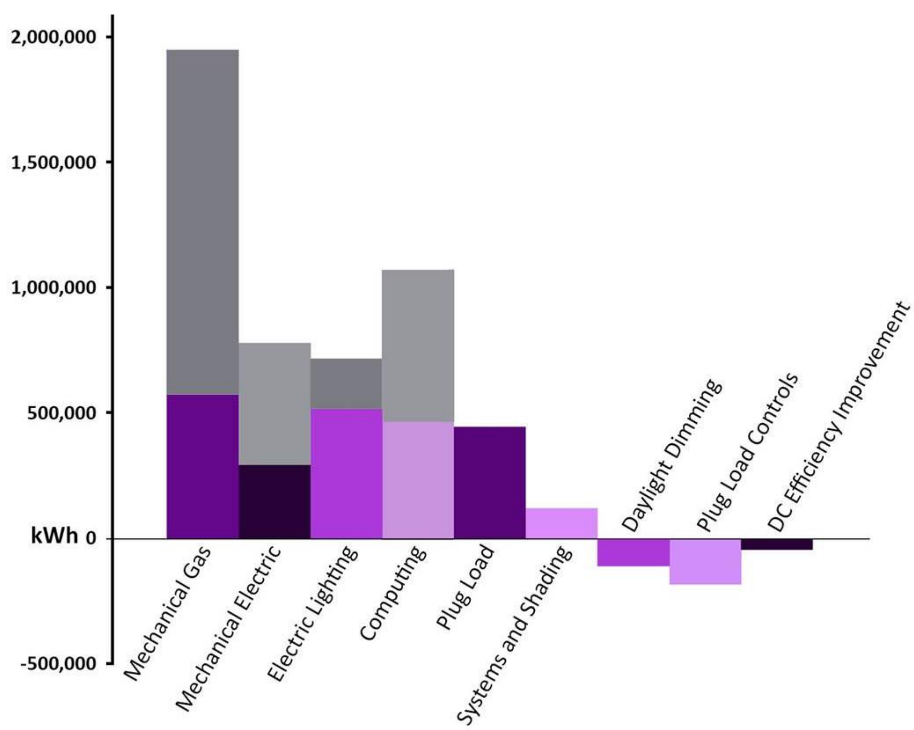


Figure 29: Comparison of Baseline Energy vs. As Designed Energy

Figure 30: Rendered View of 350 Mission within the context of San Francisco

Appendix A

Supporting Documents

Decision Point System

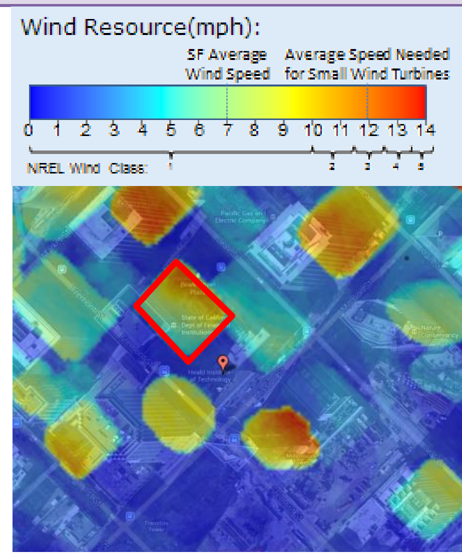
		ZERO IMPACT GOALS				OWNER DRIVEN EVALUATION CRITERIA														
	SYSTEM DESCRIPTION	ENERGY	INTERRUPTION	WASTE	EMISSIONS	ENERGY QUANTITY	COST	SUSTAINABILITY	PHASEABILITY	INNOVATION	COMPLEXITY	SPACE NEEDED	MAINTENANCE	INTEGRATION	SITE/CLIMATE ISSUES	TEACHING	PRACTICALITY	LIFECYCLE	EFFECTIVENESS	RECOMMENDED?
ONSITE ENERGY	Solar Power	++	0	0	+	+	-	++	0	0	0	++	+	0	-	+	++	-	-	YES
	Wind Power	++	0	0	+	0	-	++	0	0	0	+	0	0	--	++	++	-	--	NO
	Geothermal Power	++	0	0	+	+	--	++	0	+	--	--	--	--	--	+	--	--	--	NO
	Fuel Cells	++	0	-	+	+	-	+	0	+	-	-	-	+	-	++	+	++	+	YES
	Human Waste to Power	++	0	++	++	+	-	++	0	++	-	+	-	+	0	++	+	+	+	YES
	Municipal Waste to Power	++	0	++	++	+	-	++	0	++	-	+	-	0	0	++	0	0	0	NO
	Algae Biomass	++	0	0	+	+	--	++	0	+	--	-	-	0	-	++	-	-	-	NO
	PaveGen Tiles	++	0	+	+	+	--	++	0	++	0	++	-	+	+	++	+	-	0	YES
OFFSITE ENERGY	Tidal Power	++	0	0	+	0	--	++	0	++	--	-	--	0	-	+	-	-	+	NO
	Solar Power	++	0	0	+	++	-	++	0	0	-	-	0	0	0	+	++	+	++	YES
	Geothermal Power	++	0	0	+	++	--	++	0	+	--	--	--	0	-	+	--	--	+	NO
	Wind Power	++	0	0	+	++	--	++	0	0	--	--	-	0	-	+	-	-	+	NO
ELECTRICAL SYSTEM	AC/DC Distribution	+	+	++	0	+	-	+	0	++	-	-	-	0	0	+	+	+	++	YES
	Dual Risers	0	++	-	0	0	--	0	0	+	-	-	-	-	-	0	+	0	+	YES
	Paralleling Switchgear	-	++	-	0	0	--	0	0	0	-	0	-	0	0	0	0	-	0	YES
	Double Ended Substation	-	++	-	0	0	--	0	0	0	-	0	-	0	0	0	-	--	++	NO
DAYLIGHTING	Shades	++	0	+	0	0	-	+	0	0	-	-	-	0	0	0	+	+	+	NO
	Electrochromic Glass	++	0	+	0	0	-	+	0	++	0	+	+	++	0	++	0	+	+	YES
ELECTRIC LIGHTING	LED Lighting	++	0	++	0	+	-	++	0	0	0	0	0	0	0	0	++	++	++	YES
	DALI Control System	++	+	++	0	+	-	++	0	0	+	0	+	+	0	++	++	++	++	YES
	Task Lighting	++	+	++	0	+	-	++	0	+	-	-	0	0	0	0	++	++	++	YES

Figure 31: Decision Point Matrix

This decision point system was used throughout the design process to ensure that design decisions were being made with consideration for the [ZERO**impact**] goals. This table shows a summary of the technologies considered and their positives and negatives.

Rejected Energy Generation Matrix

Onsite:

Alternative Energy Technology	Reason(s) for Rejection	Details
Geothermal electrical generation	Feasibility, threat of induced seismicity	While geothermal heating is possible, ground water temperatures hot enough to power steam turbines for electricity generation require drilling more than 1 mile into the earth. This scale of drilling would not reasonably occur under a highrise in downtown San Francisco. Drilling at that scale for geothermal wells in a highly seismic region also runs the risk of induced seismic events, events that could be catastrophic in a highly developed area.
Wind	Building site	The average wind speed required for building-scale wind turbines is about 12 mph, and San Francisco's average wind speed is 7 mph. However, the effect of wind funneling through the downtown buildings also had to be considered. In general, tall buildings to the northwest of Market Street tend to obstruct and redirect the flow of wind, decreasing the downwind resource southeast of Market. In the figure to the right, the building outlined in red is 35' taller than 350 Mission and only has potential on a portion of its roof. Even this potential is not present on the roof of 350 Mission, as it is blocked by the red building.[7] 
PaveGen	Cost, lack of useful production	PaveGen floor tiles use piezoelectric polymers to convert kinetic energy in the form of footsteps to mechanical energy. This technology was explored due to the anticipated high foot traffic in the building lobby and circulation spaces and because it is highly renewable by harnessing the movement of occupants. While PaveGen is a unique feature, the energy generated is difficult to quantify based on its existing installations (several have been installed in past testing phases) and the initial cost is unreasonable for a large installation. Instead, PaveGen will be used as a teaching tool in the public art installation and not relied upon as a substantial source of energy.
Algae and Plant Biomass	Issue of scale, location	While algae and plant biomass has been successfully implemented in buildings, the scale of onsite biomass that could be achieved in an urban setting for a highrise would not provide enough electrical power to justify the additional costs and maintenance associated with it. Successful building installations of algae have taken place on sites with a great deal of sun exposure, which is necessary to cultivate the biomass. Instead of creating biomass fuels onsite, the goal is to utilize byproducts of occupancy, namely human waste, to create energy.

Municipal Waste to Power Converter	Inadequate volume of input materials	The city of San Francisco is on a mission to become the greenest city in America, with the ultimate goal of diverting 100% of its waste from landfills by the year 2020. The city is currently diverting about 80% of its waste due to composting and recycling programs. The conversion process takes non-recyclable and non-compostable waste and turns it into usable power through a gasification process. While this technology was found to be very useful, with the small amount of applicable waste produced by the 350 Mission, it is not worth the investment and will not produce a useful amount of power.

Table 12: Rejected Onsite Energy Generation Methods

Offsite:

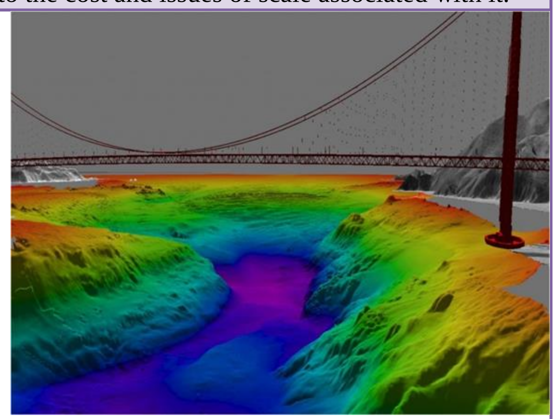
Alternative Energy Technology	Reason(s) for Rejection	Details
Geothermal electrical generation	Cost, issue of scale, procurement of land	San Francisco lies within California's "Pacific Ring of Fire," which makes it a prime location for geothermal energy generation. PG&E receives some of its utility capacity from The Geysers, a large complex of geothermal plants located 72 miles north of San Francisco. Creating a geothermal electrical generation site to offset the energy usage of one building becomes impractical due to the cost and issues of scale associated with it.
Tidal energy	Infancy of technology, lack of suitable locations, permits	 San Francisco Bay was identified as a potential site for tidal energy because it has strong currents, minimal turbulent flow, and areas with appropriate depths. An extensive study was conducted jointly by PG&E, the City of San Francisco, and Golden Gate Energy Company on the potential use of tidal power as a renewable energy source in San Francisco Bay. The study found that the only locations in the generally shallow bay that were deep enough for tidal turbines and had high enough water velocity to move them were located in shipping lanes. The bathymetry can be seen in the figure above. As of May 2011, after pumping millions of dollars into the study, PG&E abandoned its efforts, saying that tidal power is still too new for practical use in the Bay.[5]
Wind	Issue of scale, procurement of land	Most wind energy in California is concentrated at three utility-scale wind farms. The closest one is located at Altamont Pass, lying 40 miles east of San Francisco. The use of wind energy has seen large increases in California over the past decade, and offshore wind has even been explored by the city of San Francisco. However, much like geothermal electrical generation, creating a large-scale wind farm to offset the electrical use of one building is an ambitious pursuit. Not to mention, PG&E already uses the wind energy at Altamont Pass as one of its renewable sources.

Table 13: Rejected Offsite Energy Generation Methods

Onsite Solar Array

	Cost
Solar Panels	$360,000

Table 14: Onsite Solar Costs

	Amount
Incentives	$108,000
Annual Energy Generation	194,144 kWh
Annual Income	$20,400

Table 15: Onsite Solar Income/Incentives

With the minimum 30% incentives, the array will cost $3,580,500 and will pay back in 12.4 years. With 50% covered by incentives, this payback period is reduced to 8.8 years.

Onsite Solar Potential Analysis									
Area represented by each point			3.861225	ft^2	=	0.358719	m^2		
Sensor Point			Sensor Orientation			Annual	Daily	Annual	Daily
x	y	z	x	y	z	kwh/m2	kwh/m2	kwh	kwh
-92.9875	-0.27729	440.1	0	0	1	663.74	1.82	238.10	0.65
-92.9875	1.687739	440.1	0	0	1	789.08	2.16	283.06	0.78
-91.0225	-2.24232	440.1	0	0	1	713.62	1.96	255.99	0.70
-91.0225	-0.27729	440.1	0	0	1	946.03	2.59	339.36	0.93
87.79528	3.652769	440.1	0	0	1	1078.48	2.95	386.87	1.06
89.76031	-0.27729	440.1	0	0	1	1058.49	2.90	379.70	1.04
89.76031	1.687739	440.1	0	0	1	1065.26	2.92	382.13	1.05
							Sum	1769374	
							Efficiency	265406.03	
							Derate	204362.65	
							Walkways	194144.51	

Table 16: Portion of Onsite Solar Array Analysis Spreadsheet

The spreadsheet shown in Table 16 was used to calculate the potential for onsite solar harvesting. A simulation was conducted using Diva for Rhino, and the output was imported into Excel for analysis. The data has been cropped, but 4278 calculation points were used with each representing a 1.965' x 1.965' area of the roof. Solar radiation numbers were converted to kWh values and summed, and efficiency values were applied to get the final number outlined in red.

Human Waste to Power

10 dry tons generates 18,868 kWh → 1 pound generates 0.93 kWh
The average person will generate about 0.25 dry pounds per day.

$$0.25 \frac{dry\,pounds}{person} * 5000\ people = 1250\ dry\,pounds$$

$$1250\ dry\ lbs * 0.93\ kWh = 1163 \frac{kWh}{day}$$

$$1163 \frac{kWh}{day} * 250 \frac{working\,days}{year} = 290{,}625 \frac{kWh}{year}$$

$$\$0.13\ per\ kWh * 290{,}625 \frac{kWh}{year} = \$37{,}781\ annually$$

Simple Payback:

$$\frac{\$1{,}000{,}000\ approximate\ initial\ cost}{\$37{,}781\ per\ year} = 26\ years$$

A system being developed at Duke University's Pratt School of Engineering is one of the first to make building-scale sewage treatment a viable option. The research focus is on neighborhood-scale solutions in third world countries; however the same technology can be utilized in a building. [9]

Figure 32: Duke University Sewage Treatment Project Summary Graphic

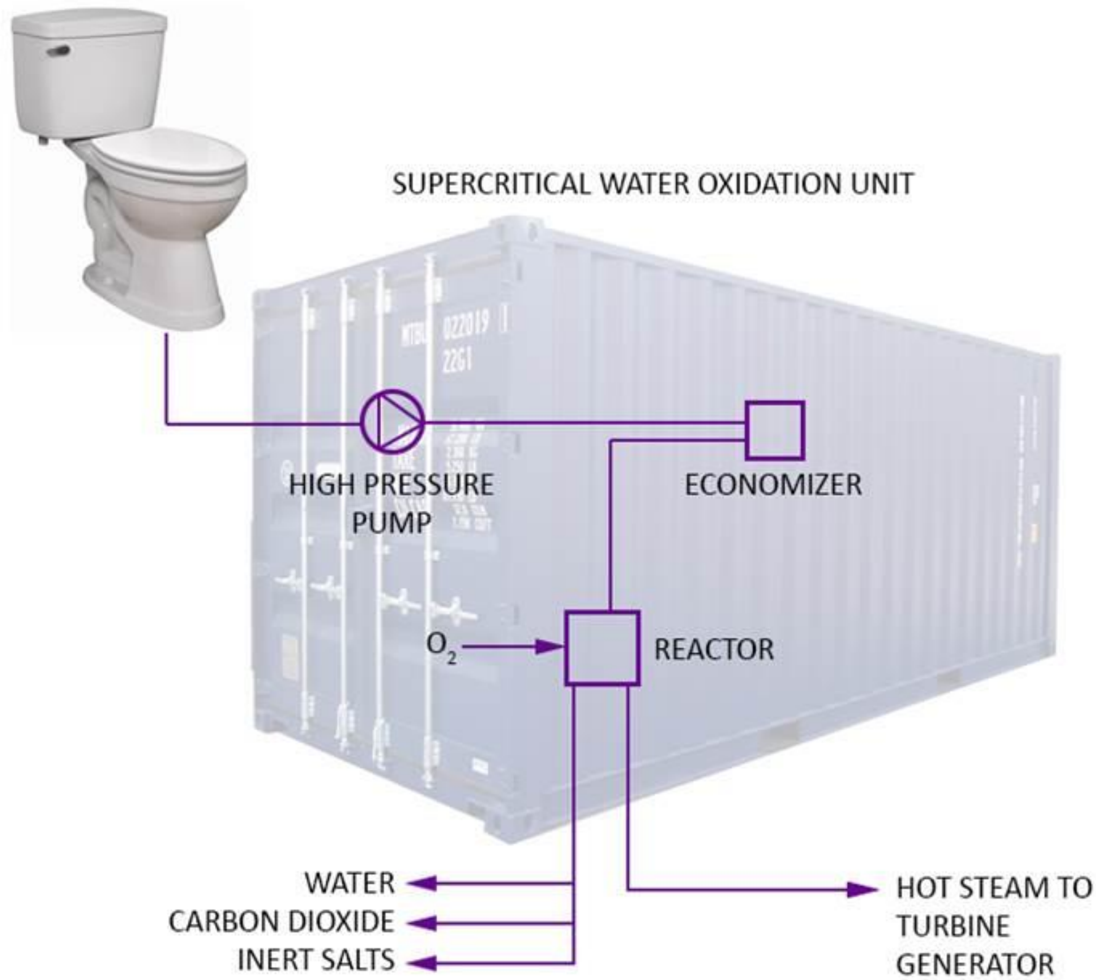


Figure 33: Human Waste to Power Schematic

The human waste to power unit follows the process shown above in Figure 33 to create hot steam that powers a turbine generator. A building-scale unit, which is the size that is installed in 350 Mission, would be similar in size to a shipping container. Though it offsets only a portion of the building's energy consumption, it reduces emission by turning human waste into useful energy and decreasing the amount of waste entering San Francisco's sewer system.

Offsite Photovoltaic Array

With the site in the Mojave Desert selected, The National Renewable Energy Laboratory's (NREL) PVWatts calculator to determine the required array size and its generation potential, seen in Table 17. The PG&E power purchase agreement shown in Table 18 lists the sell-back amount as $0.10509/kWh, assuming a 20-year contract and building completion in 2016.

Station Identification	
Cell ID:	0176359
State:	California
Latitude:	34.9 ° N
Longitude:	118.1 ° W
PV System Specifications	
DC Rating:	3000.0 kW
DC to AC Derate Factor:	0.750
AC Rating:	2250.0 kW
Array Type:	Fixed Tilt
Array Tilt:	34.9 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	14.4 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	5.27	348266	50031.89
2	5.98	358230	51463.32
3	6.78	440047	63217.15
4	7.24	450080	64658.49
5	7.52	468484	67302.41
6	7.71	452164	64957.88
7	7.62	454446	65285.71
8	7.88	471687	67762.56
9	7.56	447211	64246.33
10	7.09	448603	64446.31
11	6.12	386421	55513.24
12	5.13	333546	47917.22
Year	6.83	5059186	726802.67

Table 17: PVWatts Offsite Solar Analysis

The array is 3000kW and covers 3.5 acres of the 10 acre array shown in Figure 34. It costs approximately $5,115,000, but at least 30% of this is covered by federal incentives, as shown in Figure 35. Additional incentives from PG&E are possible, but they require an application and waiting list and are not definite. 30% was assumed as a minimum.

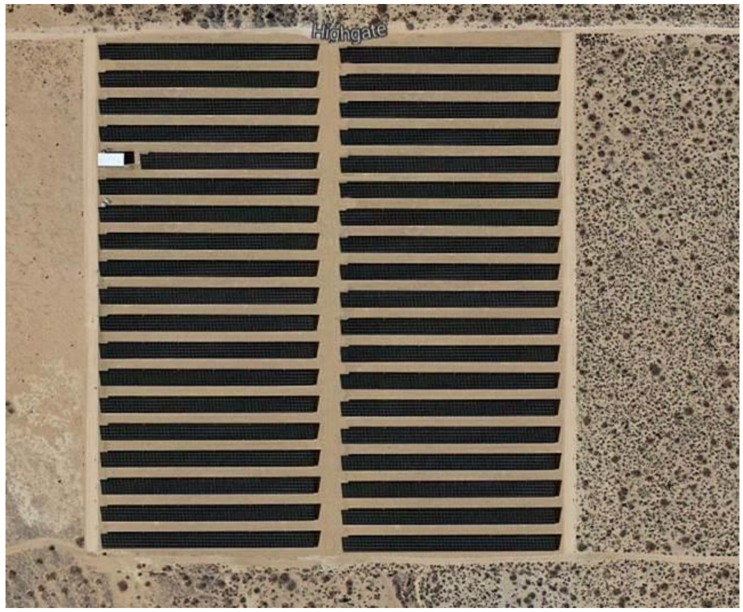


Figure 34: Sample Layout of Solar Modules on the Site

Cost:

Pacific Gas and Electric Company
San Francisco, California
U 39

	Revised	*Cal. P.U.C. Sheet No.*	28701-E
Cancelling	Original	*Cal. P.U.C. Sheet No.*	28031-E

ELECTRIC SCHEDULE E-SRG Sheet 3
SMALL RENEWABLE GENERATOR PPA

SPECIAL CONDTIONS: (cont'd)

6. The Market Price Referent (MPR) is stated in the table below, which the Commission approved in Resolution E-4442, effective December 6, 2011. (T) (T)

Adopted 2011 Market Price Referents (N)
(Nominal - dollars/kWh)

Resource Type	10-Year	15-Year	20-Year
2012 Baseload MPR	0.07688	0.08352	0.08956
2013 Baseload MPR	0.08103	0.08775	0.09375
2014 Baseload MPR	0.08454	0.09151	0.09756
2015 Baseload MPR	0.08804	0.09520	0.10132
2016 Baseload MPR	0.09156	0.09883	0.10509
2017 Baseload MPR	0.09488	0.10223	0.10859

Advice Letter No: 3965-E-A		*Issued by*	*Date Filed*	February 10, 2012
Decision No.		***Brian K. Cherry***	*Effective*	January 3, 2012
		Vice President	*Resolution No.*	E-4442
3C0		*Regulatory Relations*		

Table 18: PG&E Renewable Energy Credit Purchase Price

Figure 35: FEDERAL Solar Panel and Fuel Cell Installation Incentives

	Cost
Land	$13,000
Solar Panels	$5,115,000

Table 19: Offsite Solar Costs

	Amount
Incentives	$1,534,500
Annual Energy Generation	$5,059,186 kwh
Annual Income	$531,670

Table 20: Offsite Solar Income/Incentives

With the minimum 30% incentives, the array will cost $3,580,500 and will pay back in 6.7 years. With 50% covered by incentives, this payback period is reduced to 4.8 years.

Daylight Autonomy Analysis

Daylight autonomy shows the percent of occupied hours that the illuminance due to daylight at a certain point in a space exceeds the target illuminance. This can also be summarized for a space in a single number as the percent of points that have an illuminance exceeding the target for at least 50% of occupied hours. Daylight autonomy numbers were used to estimate the energy savings due to daylighting in the 1st floor lobby, 2nd floor lobby, open office, and break room. The results are shown below, along with the analysis spreadsheet used to estimate the energy savings. Also shown is a useful daylight illuminance (UDI)) analysis. The minimum was placed at 10 fc as that is the required illuminance in many of the transition spaces and the maximum at 500 fc as that is the upper limit set by the U.S. Green Building Council (USGBC) in the Leadership in Energy and Environmental Design (LEED) 2009 guidelines.

Lobby:

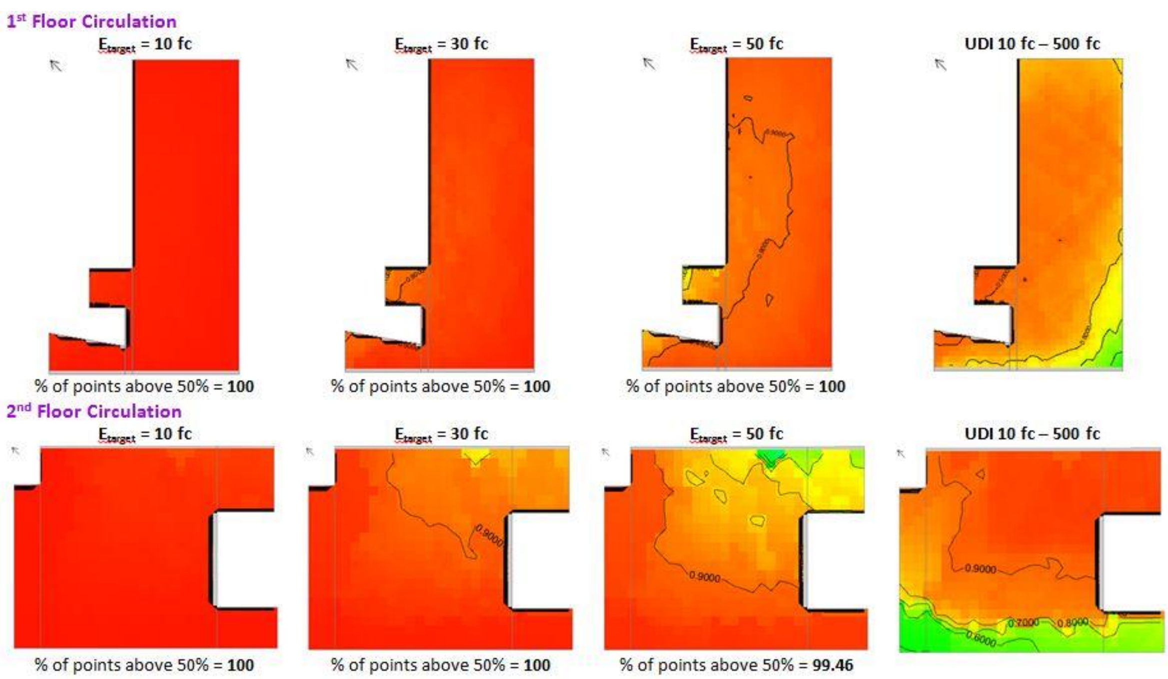


Figure 36: Lobby Daysim Daylight Autonomy Analyses

Office:

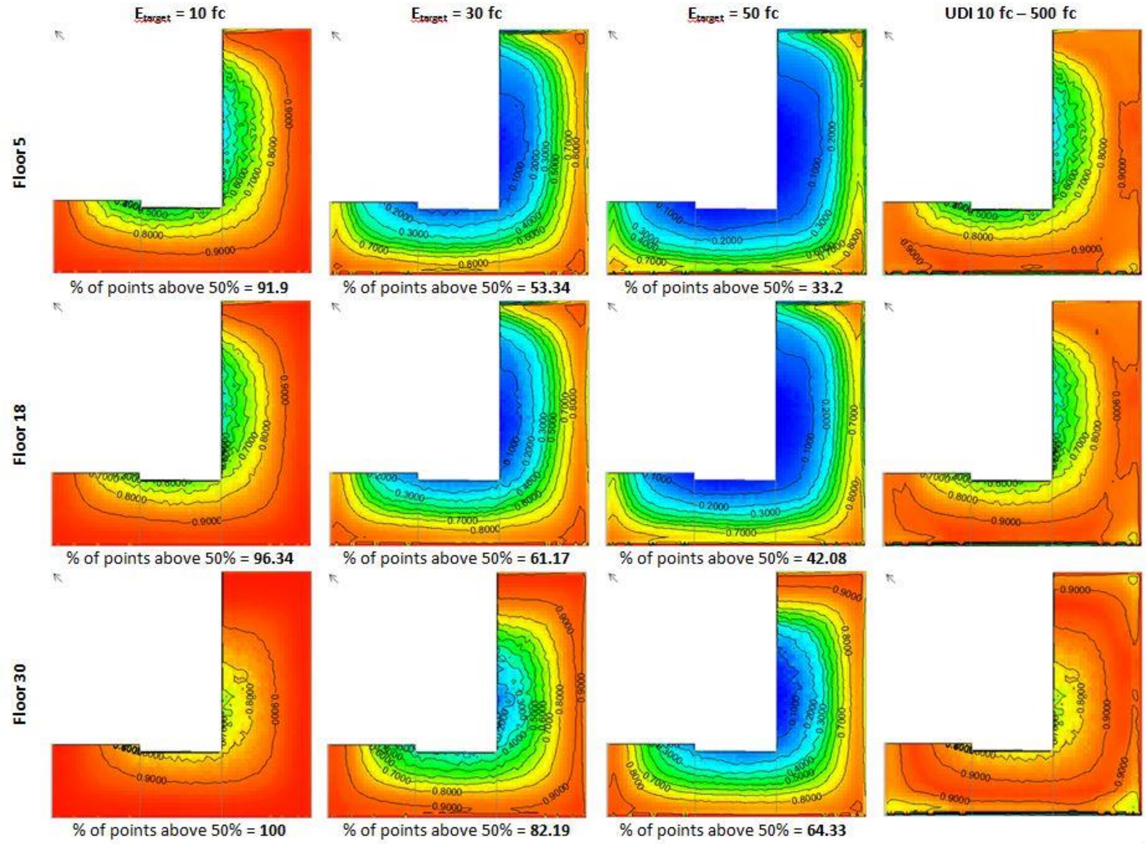


Figure 37: Office Daysim Daylight Autonomy Analyses

Calculations:

DAYLIGHT AUTONOMY ENERGY SAVINGS ANALYSIS

Daylight Autonomy Summary			
Space	Floor	Threshold	DA Value
Lobby	1st Floor	50 lux	100.0
		100 lux	100.0
		200 lux	100.0
		300 lux	100.0
	2nd Floor	50 lux	100.0
		100 lux	100.0
		200 lux	100.0
		300 lux	100.0
Open Office	Low	50 lux	100.0
		100 lux	91.9
		200 lux	68.1
		300 lux	53.3
	Middle	50 lux	100.0
		100 lux	96.3
		200 lux	75.5
		300 lux	61.2
	High	50 lux	100.0
		100 lux	100.0
		200 lux	95.2
		300 lux	82.2
Dining/ Break	Low	50 lux	100.0
		100 lux	97.4
	Middle	50 lux	100.0
		100 lux	100.0
	High	50 lux	100.0
		100 lux	100.0

Daylight Autonomy Definition

Percentage of the floor area that exceeds 300 lux for at least 50% of the time

Daylight Autonomy Energy Savings Equation

$$kwh\ saved = (\%\ floor\ area\ met\ 50\%\ of\ time)x(LPD\ of\ space)x(total\ hours\ of\ lighting\ use)x\frac{0.5}{1000}$$

Energy Savings Calculation General Information		
Lobby 1st Floor Area	4700	$ft.^2$
Lobby 2nd Floor Area	2167	$ft.^2$
Open Office Area	8350	$ft.^2$/floor
Dining/Break Area	1347	$ft.^2$/floor
Lobby Design LPD	0.290	$W/ft.^2$
Open Office Design LPD	0.387	$W/ft.^2$
Dining/Break Design LPD	0.145	$W/ft.^2$
Lobby Annual Lighting	4015	hrs
Open Office Annual Lighting	2800	hrs
Dining Break Annual Lighting	2800	hrs

Daylight Hour Assumptions
7:00 am - 6:00 pm, 365 days
7:00 am - 6:00 pm 250 days, 5 hours on another 10 days

Annual Lighting Hours of Use Assumptions
Assume that all lighting is at full output (no dimming)
11 hours per day (daylight hours), 365 days per year
11 hours of use per workday, 250 workdays, 5 hours of use on 10 additional days
11 hours of use per workday, 250 workdays, 5 hours of use on 10 additional days

Daylight Automony Approximated by Floor					Daylight Automony Difference				Daylight Automony Approximated by Floor			Daylight Automony Difference	
Open Office					Open Office				Dining/Break			Dining/Break	
Floor	50 lux	100 lux	200 lux	300 lux	Floor	50 - 100	100 - 200	200 - 300	Floor	50 lux	100 lux	Floor	50 - 100
5	100.0	91.9	68.1	53.3	5	8.1	23.8	14.7	5	100.0	97.4	5	2.6
6	100.0	92.3	68.7	54.0	6	7.7	23.6	14.7	6	100.0	97.7	6	2.3
7	100.0	92.6	69.3	54.6	7	7.4	23.3	14.7	7	100.0	97.9	7	2.1
8	100.0	93.0	69.9	55.3	8	7.0	23.1	14.6	8	100.0	98.1	8	1.9
9	100.0	93.4	70.6	56.0	9	6.6	22.8	14.6	9	100.0	98.3	9	1.7
10	100.0	93.8	71.2	56.6	10	6.2	22.6	14.6	10	100.0	98.5	10	1.5
11	100.0	94.1	71.8	57.3	11	5.9	22.3	14.5	11	100.0	98.7	11	1.3
12	100.0	94.5	72.4	57.9	12	5.5	22.1	14.5	12	100.0	98.9	12	1.1
14	100.0	94.9	73.0	58.6	14	5.1	21.8	14.5	14	100.0	99.1	14	0.9
15	100.0	95.2	73.6	59.2	15	4.8	21.6	14.4	15	100.0	99.4	15	0.6
16	100.0	95.6	74.3	59.9	16	4.4	21.3	14.4	16	100.0	99.6	16	0.4
17	100.0	96.0	74.9	60.5	17	4.0	21.1	14.4	17	100.0	99.8	17	0.2
18	100.0	96.3	75.5	61.2	18	3.7	20.8	14.3	18	100.0	100.0	18	0.0
19	100.0	96.6	77.1	62.9	19	3.4	19.5	14.2	19	100.0	100.0	19	0.0
20	100.0	97.0	78.8	64.7	20	3.0	18.2	14.1	20	100.0	100.0	20	0.0
21	100.0	97.3	80.4	66.4	21	2.7	16.8	14.0	21	100.0	100.0	21	0.0
22	100.0	97.6	82.1	68.2	22	2.4	15.5	13.9	22	100.0	100.0	22	0.0
23	100.0	97.9	83.7	69.9	23	2.1	14.1	13.8	23	100.0	100.0	23	0.0
24	100.0	98.2	85.4	71.7	24	1.8	12.8	13.7	24	100.0	100.0	24	0.0
25	100.0	98.5	87.0	73.4	25	1.5	11.5	13.6	25	100.0	100.0	25	0.0
26	100.0	98.8	88.7	75.2	26	1.2	10.1	13.5	26	100.0	100.0	26	0.0
27	100.0	99.1	90.3	76.9	27	0.9	8.8	13.4	27	100.0	100.0	27	0.0
28	100.0	99.4	92.0	78.7	28	0.6	7.4	13.3	28	100.0	100.0	28	0.0
29	100.0	99.7	93.6	80.4	29	0.3	6.1	13.2	29	100.0	100.0	29	0.0
30	100.0	100.0	95.2	82.2	30	0.0	4.8	13.1	30	100.0	100.0	30	0.0

Table 21: Daylight Autonomy Energy Savings Calculations

Daylight Autonomy Energy Savings [kwh]		
Floor	Open Office	Dining/Break
5	3278	270
6	3300	270
7	3322	271
8	3344	271
9	3366	271
10	3388	271
11	3410	272
12	3432	272
14	3454	272
15	3476	273
16	3498	273
17	3519	273
18	3541	273
19	3595	273
20	3648	273
21	3702	273
22	3755	273
23	3809	273
24	3863	273
25	3916	273
26	3970	273
27	4023	273
28	4077	273
29	4130	273
30	4184	273
Totals	90998	6813

Daylight Autonomy Energy Savings [kwh]	
1st Floor	2nd Floor
5928	2733

Daylight Autonomy Savings Summary			
Lobby 1st Floor	5928	kwh	annually
Lobby 2nd Floor	2733	kwh	annually
Open Office	90998	kwh	annually
Dining/Break	6813	kwh	annually
Total	106473	kwh	annually

Table 22: Daylight Autonomy Energy Savings Summary

Data from the daylight autonomy analyses was interpolated to find values for each floor, and these were combined with the space LPDs to find approximate daylight savings for each daylit area. Those savings are summarized in Table 22 above.

Lobby Glass:

Sungate® 600 Glass Performance

Glass Type	Transmittance: Ultra-violet %	Transmittance: Visible %	Transmittance: Total Solar Energy %	Reflectance: Visible Light %	Reflectance: Total Solar Energy %	U-Value (Imperial): Winter Night-time	U-Value (Imperial): Summer Day-time	European U-Value	Shading Coeffi-cient	Solar Heat Gain Coeffi-cient	Light to Solar Gain (LSG)
Insulating Vision Unit Performance Comparisons 1-inch (25mm) units with 1/2-inch (13mm) airspace and two 1/4-inch (6mm) lites; interior lite clear											
SUNGATE® 600 Low-E Glass (4)											
SOLARBAN 60 (2) Clear + *SUNGATE* 600 (4) Clear	14%	63%	29%	12%	30%	0.23	0.21	1.25	0.41	0.36	1.77
SOLARBAN 70XL (2)' + *SUNGATE* 600 (4) Clear	5%	58%	22%	13%	53%	0.23	0.20	1.22	0.30	0.26	2.23
SOLARBAN z50 (2) *OPTIBLUE* + *SUNGATE* 600 (4) Clear	11%	46%	23%	8%	24%	0.23	0.21	1.25	0.34	0.29	1.55
SOLARBAN R100 (2) Clear + *SUNGATE* 600 (4) Clear	9%	37%	17%	32%	41%	0.23	0.21	1.25	0.25	0.22	1.73
SUNGATE® 600 Low-E Glass											
CLEAR + *SUNGATE* 600 (3) Clear	38%	71%	48%	17%	15%	0.33	0.32	1.76	0.75	0.65	1.09
ATLANTICA + *SUNGATE* 600 (3) Clear	10%	54%	23%	12%	7%	0.33	0.32	1.76	0.40	0.35	1.55
AZURIA + *SUNGATE* 600 (3) Clear	26%	55%	23%	12%	7%	0.33	0.32	1.76	0.39	0.34	1.62
GRAYLITE II + *SUNGATE* 600 (3) Clear	1%	7%	5%	4%	4%	0.33	0.32	1.76	0.18	0.16	0.46

Table 23: Lobby Curtain Wall Glass Properties - PPG Catalog

Electrochromic Glazing

Benefits

Electrochromic glass is an alternative method of controlling the daylight that enters a space, as opposed to using traditional glass and fabric shades. It uses an electrical current to tint or untint based on commands sent by the control system. As the glass tints, it also adjusts its solar heat gain properties, ranging between 0.42 when clear and 0.09 when fully tinted. The visible light transmission can range from 60% in its clear state to 2% when fully tinted. Depending on the size of the glass panels, desired tint level, and temperature, the tinting process takes between three and ten minutes. Aside from controlling daylight, it can be used in conference rooms and other spaces where A/V presentations may take place. It can be integrated into the building control system and programmed to react to different environmental conditions or lighting scenes in a space. Traditional shades, when lowered, severely limit views to the outdoors. Electrochromic glass optimizes daylight, views, glare control, heat gain, and energy use.

Cost

Cost data for this analysis was drawn from two sources: numbers for the traditional solution are from a Lutron cost comparison study [16], and the electrochromic glass numbers are from the Sage Glass cost data sheet shown in Figure 38. If a price range was given, the lower numbers were used for the traditional solution and the higher numbers were used for the electrochromic glass. These numbers are for materials alone; they do not include any labor costs. However, with traditional shades, there are labor costs for both the window installation and shade installation. With electrochromic glass, installations are hardly more complex than installing normal glass, and there is no additional shade installation.

The cost comparison prices shown in Table 24 are for a line voltage AC shading system. The windows are the same size as those found in 350 Mission. The “per square foot” numbers were found by dividing the total price by the quantity shown in the table. This was then divided by the area of each shade represented by that number. For shade material, this was the area of one shade (5' x 8'). For motors, this was the area of four shades, as the Lutron study assumed four shades per controller. Only the glass, shade fabric, and motors were included in the study as the controls, wiring, etc. were assumed to be comparable for the two scenarios.

Traditional Windows/Shades	Price	SF value (5'x8' windows)
Low e, double pane glass	$40-55/sf	$40
Shade fabric	$28/sf	$28
Automatic shade motor	$370 per unit	$2.50
Total		**$70.50**

Electrochromic Glazing	Price	SF value (5'x8' windows)
Glass	$50-65/sf	$65
Total		**$65**

Table 24: Electrochromic Glass Cost Comparison

			Qty	Total Price (USD)
Labor	Window Treatment Contractor	Administrative Charges	-	$1,950.00
		Keypad Cable Labor	-	$400.00
		Shades Installation and Programming	-	$11,518.00
	Electricical Contractor	Line voltage wiring and circuit installation	-	$10,172.19
	Total Labor			$24,040.19
Wiring	Breakers & Electrical Materials	20 A Breakers	6	$157.15
		Miscellaneous Materials	-	$2,099.59
	Cable (Qty. in feet)	#12/3 MC Cable (Shades Wiring)	2300	$3,878.69
		#12/2 MC Cable (Breaker Wiring)	300	$301.34
		Low Voltage 4 Conductor Keypad Cable	400	$193.60
	Total Wiring			$6,630.37
Components	Shades, Brackets and Lineals	Open Office Sheer Shade Pairs	17	$18,464.15
		Conference Rooms & Executive Office Dual Shade Pairs	6	$6,950.94
	Keypads	Group A, B, A+B Keypads	4	$369.81
	Power and Control	Group Controllers	6	$2,207.55
	Total Components			$27,992.45
Total Installed Cost				**$58,663.01**

Table 25: Lutron Cost Comparison Study Price Summary

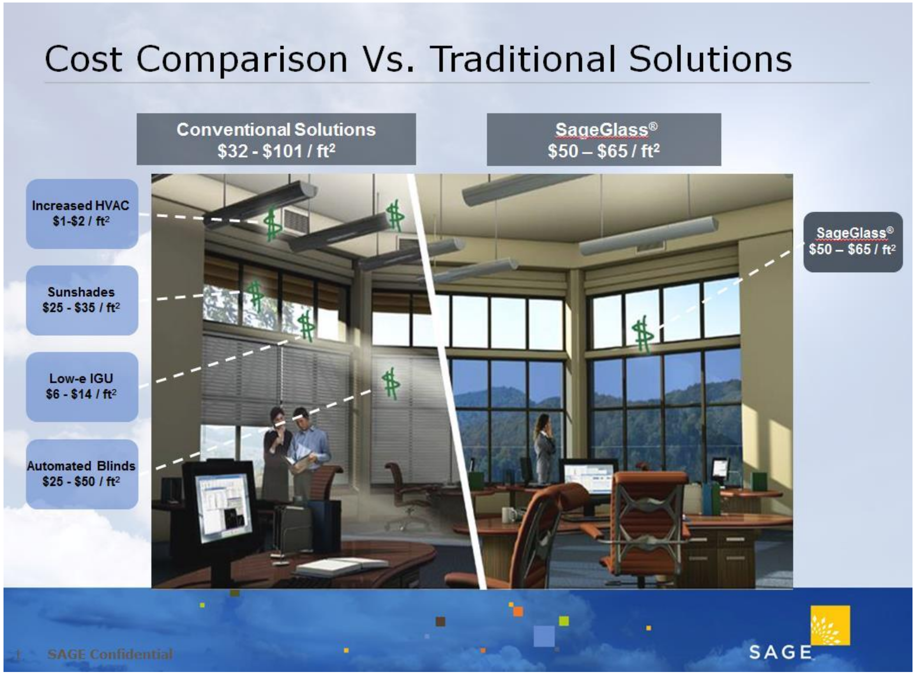


Figure 38: Electrochromic Glass Cost Comparison - Sage Electronics

Façade Locations

Electrochromic glass is placed on the majority of the façade, as the cost analysis determined that it is more cost effective than traditional glass/shade solutions. It is not used in the lobby, as this is a transitional space where occupants will not be as intolerant of direct sun and glare. It is also not used in the mechanical penthouse and along the mechanical rooms than border the windows on the northeast façade. Figure 39 shows the annual solar radiation that each façade receives. Every façade receives some solar radiation throughout the year, and applying glass to all facades ensures that regardless of how the functions of the spaces and floor layouts may change, all interior spaces will remain functional and comfortable for the occupants. It also eliminates the risk of surrounding buildings causing glare inside the building, as glass panes can be tinted as needed to maximize comfort.

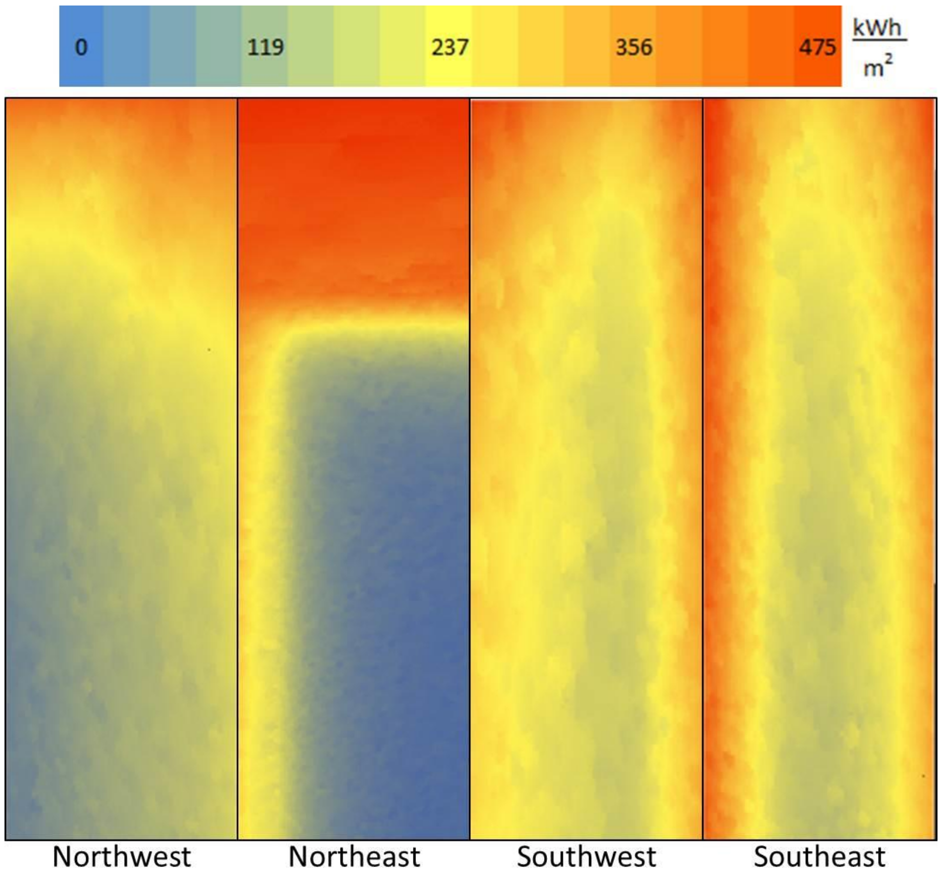
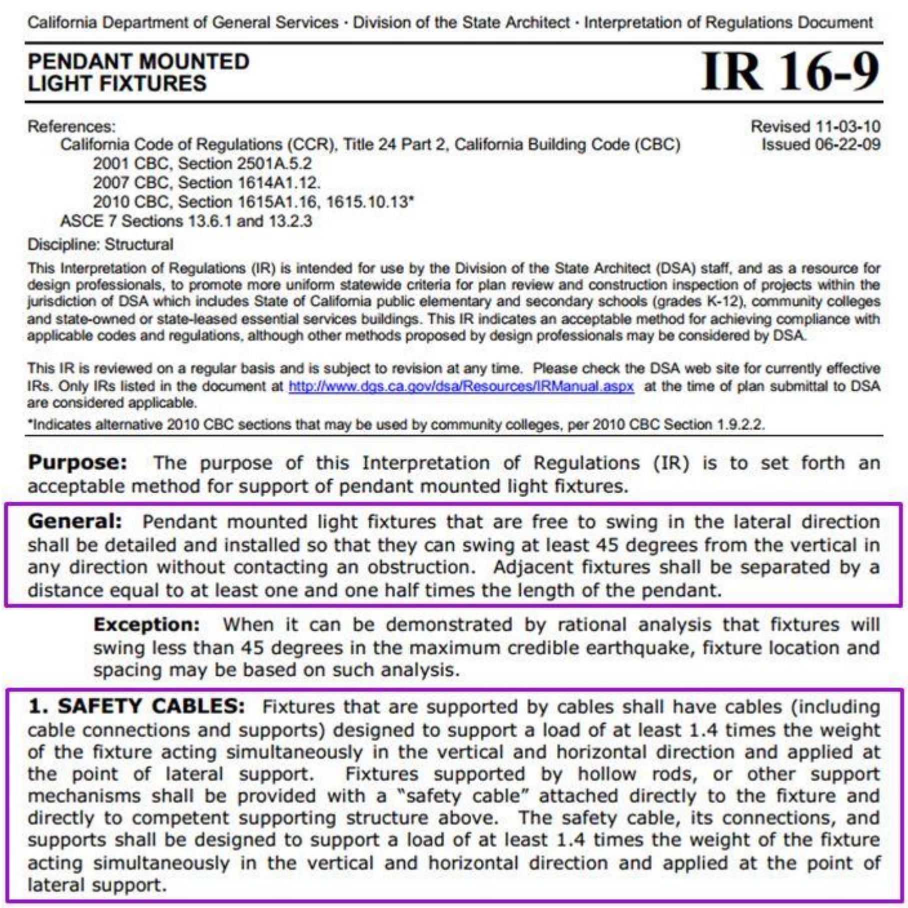


Figure 39: Electrochromic Glass Locations and Facade Annual Solar Radiation

The shaded areas will have normal glass with no shades, and while this will lead to some variation on the façade, the northeast in particular, this will not be noticeable from street level. The northeast façade faces another building that is only about 35' away. Glass colors will be manufactured to match, but a difference will be seen, especially when the electrochromic glass is tinted. Approximately 73,000 ft^2 of the building's glass will be electrochromic in place of traditional glass and shades.

Seismic Lighting Design

The document shown in Figure 40, created by the California Department of General Services (DGS), outlines the requirements for the use of pendant mounted light fixtures in earthquake-prone areas. The sections outlined in purple are those that specifically relate to 350 Mission. Figure 41 below addresses the swing area requirement. The fixture support cables and connections to the ceiling are designed to carry 1.4 times the weight of the fixtures they are supporting. Connections allow movement in all directions, as required by both the California DGS and the Federal Emergency Management Agency (FEMA).


California Department of General Services · Division of the State Architect · Interpretation of Regulations Document

PENDANT MOUNTED LIGHT FIXTURES **IR 16-9**

References:
California Code of Regulations (CCR), Title 24 Part 2, California Building Code (CBC)
2001 CBC, Section 2501A.5.2
2007 CBC, Section 1614A1.12.
2010 CBC, Section 1615A1.16, 1615.10.13*
ASCE 7 Sections 13.6.1 and 13.2.3

Revised 11-03-10
Issued 06-22-09

Discipline: Structural

This Interpretation of Regulations (IR) is intended for use by the Division of the State Architect (DSA) staff, and as a resource for design professionals, to promote more uniform statewide criteria for plan review and construction inspection of projects within the jurisdiction of DSA which includes State of California public elementary and secondary schools (grades K-12), community colleges and state-owned or state-leased essential services buildings. This IR indicates an acceptable method for achieving compliance with applicable codes and regulations, although other methods proposed by design professionals may be considered by DSA.

This IR is reviewed on a regular basis and is subject to revision at any time. Please check the DSA web site for currently effective IRs. Only IRs listed in the document at http://www.dgs.ca.gov/dsa/Resources/IRManual.aspx at the time of plan submittal to DSA are considered applicable.

*Indicates alternative 2010 CBC sections that may be used by community colleges, per 2010 CBC Section 1.9.2.2.

Purpose: The purpose of this Interpretation of Regulations (IR) is to set forth an acceptable method for support of pendant mounted light fixtures.

General: Pendant mounted light fixtures that are free to swing in the lateral direction shall be detailed and installed so that they can swing at least 45 degrees from the vertical in any direction without contacting an obstruction. Adjacent fixtures shall be separated by a distance equal to at least one and one half times the length of the pendant.

Exception: When it can be demonstrated by rational analysis that fixtures will swing less than 45 degrees in the maximum credible earthquake, fixture location and spacing may be based on such analysis.

1. SAFETY CABLES: Fixtures that are supported by cables shall have cables (including cable connections and supports) designed to support a load of at least 1.4 times the weight of the fixture acting simultaneously in the vertical and horizontal direction and applied at the point of lateral support. Fixtures supported by hollow rods, or other support mechanisms shall be provided with a "safety cable" attached directly to the fixture and directly to competent supporting structure above. The safety cable, its connections, and supports shall be designed to support a load of at least 1.4 times the weight of the fixture acting simultaneously in the vertical and horizontal direction and applied at the point of lateral support.

Figure 40: DGS Regulations for Pendant-Mounted Luminaires in Earthquake Areas

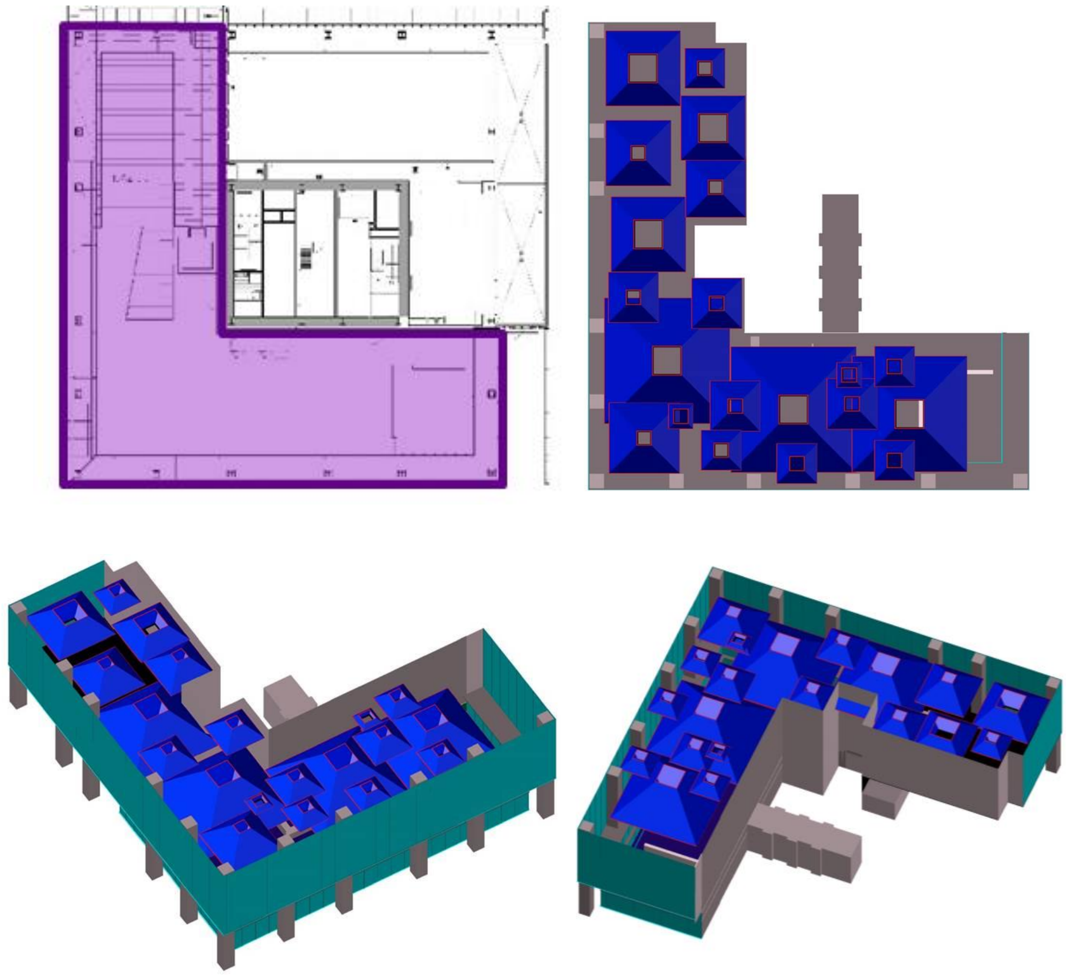


Figure 41: Plan and Isometric Views of Luminaires with Swing Area

Figure 41 show various views of the model that aided in the lobby design. The blue planes define the interference space for each. Fixtures can swing 45^0 in any direction without the risk of colliding with another luminaire or its support cables. The edges of the swing areas are lined in red to improve visibility. These figures prove that the lobby lighting design follows the requirements set by the California DGS. FEMA has less explicit instructions for design, simply stating that “care must be taken to avoid seismic interactions with adjacent objects when the suspended component swings.” This lighting layout satisfies all of the required earthquake safety measures.

Lighting Power Density

Space	Total Area [ft.^{2}]	Code Category	Code LPD [W/ft.^{2}]	Code LPD with CalGreen Reduction (15%)	Allowable Watts [W]	Watts as Designed [W]	LPD as Designed [W/ft.^{2}]
SPACE BY SPACE LIGHTING POWER DENSITY ANALYSIS							
Typical Office Floor							
Open Office DC	5600	Office (>250 ft.^{2})	0.9	0.77	4284.0	2166	0.39
Flexible Space	1100	Office (>250 ft.^{2})	0.9	0.77	841.5	709.5	0.65
Break/Dining	1040	Dining	1.1	0.94	972.4	151.2	0.15
Kitchen	100	Kitchen/Food preparation	1.6	1.36	136.0	100.8	1.01
Large Conference	600	Conference	1.4	1.19	714.0	277.2	0.46
(2) Small Conference	455	Conference	1.4	1.19	541.5	361.2	0.79
(4) Video Conference	405	Office (<250 ft.2)	1.1	0.94	378.7	378.4	0.93
(3) Interview Room	205	Office (<250 ft.2)	1.1	0.94	191.7	151.2	0.74
Printer/Copy	92	Support	0.6	0.51	46.9	25.2	0.27
Southwest Corridor	620	Corridor	0.6	0.51	316.2	120	0.19
Southeast Corridor	500	Corridor	0.6	0.51	255.0	120	0.24
Northwest Corridor	1025	Corridor	0.6	0.51	522.8	400	0.39
Elevator Lobby	400	Lobby/Waiting Area	1.1	0.94	374.0	105.2	0.26
Men's Restroom	200	Restroom	0.6	0.51	102.0	30.8	0.15
Women's Restroom	205	Restroom	0.6	0.51	104.6	30.8	0.15
(2) Stair and Vestibule	300	Stair	0.6	0.51	153.0	134	0.45
Service Lobby	75	Support	0.6	0.51	38.3	67	0.89
Electrical and Electrical Closet	80	Electrical room	0.7	0.60	47.6	68	0.85
Telecom and Telecom Closet	50	Telephone room	0.7	0.60	29.8	34	0.68
Mechanical	425	Mechanical room	0.7	0.60	252.9	268	0.63
Lobby							
General Illumination	5359	Lobby	1.1	0.94	5010.7	1545.6	0.29
Retail Area	922	Retail	1.6	1.36	1253.9	979.8	1.06
Feature Stairs	558	Stair	0.6	0.51	284.6	10.5	0.02
Elevator Lobby	383	Lobby/Waiting Area	1.1	0.94	358.1	200	0.52
Vestibule	196	Lobby/Waiting Area	1.1	0.94	183.3	160	0.82
Reception Desk	212	Office	0.9	0.77	162.2	72	0.34
Feature Art Wall	55 ft long	Wall Display	3.5	2.975	163.6	163.6	2.97
Undesigned Spaces (Assume design utilizes maximum LPD)							
Restaurant Dining	3800	Dining	1.1	0.94	3553.0	-	-
Restaurant Kitchen	500	Kitchen	1.6	1.36	680.0	-	-
Restaurant Restrooms	120	Restroom	0.6	0.51	61.2	-	-
Restaurant Corridor	460	Corridor	0.6	0.51	234.6		
Lobby Support Space	1700	Support	0.6	0.51	867.0		
Locker rooms below grade	1200	Locker room	0.6	0.51	612.0	-	-
Stairs below grade	1050	Stair	0.6	0.51	535.5		
Elevator Lobby below grade	800	Lobby/Waiting Area	1.1	0.94	748.0		
Parking Garage Parking	10920	Parking area	0.2	0.17	1856.4	-	-
Parking Garage Ramps	26800	Parking ramps	0.6	0.51	13668.0		
Mechanical penthouse and below grade spaces	5730	Mechanical room	0.7	0.60	3409.4	-	-
Electrical below grade spaces	2300	Electrical room	0.7	0.60	1368.5	-	-
Telcom Room below grade	600	Telephone room	0.7	0.60	357.0		
Below grade support spaces (water storage, pump room)	2875	Support	0.6	0.51	1466.3	-	-
Below grade storage	3650	Storage	0.6	0.51	1861.5		

Table 26: Light Power Density using the Space by Space Method

Lighting Power Summary				Note about Expected Load
Total Connected DC Load [kW]	Total Connected AC Load [kW]	Total Expected DC Load [kW]	Total Expected AC Load [kW]	Apply a diversity factor of 0.10 to all support, storage, electrical, mechanical, and telecom space. This assumes that no more than 10% will ever be in use simultaneously. The lighting in these spaces is controlled by occupancy sensors.
156.2	20.5	138.0	20.5	
Total Lighting LPD		0.434	W/ft^2	
Lighting Energy Summary				**Note about Energy Calculations**
Connected DC Energy Use [kwh]	Connected AC Energy Use [kwh]	Expected DC Energy Use [kwh]	Expected AC Energy Use [kwh]	Energy calculation use assumes maximum light output (no dimming), 12 hours of use per workday, 250 workdays per year, and 5 hours of use on 10 additional days on office floors. The lobby general illumination is on 24 hours, 365 days a year, the restuarant and retail is considered to be in use 14 hours a day, 360 days of the year. Parking areas are in use 16 hours a day.
505,314	62,282	454,273	62,282	

Lighting Comparison to Maximum LPD (Baseline)				
	Connected Load [kW]	Expected Load [kW]	Connected Energy [kwh]	Expected Energy [kwh]
As Designed	176.7	158.5	567,596	516,554
Allowable by Code	296.3	278.6	763,259	718,342
Baseline Reduction	119.6	120.2	195,663	201,788

Table 27: Lighting Power Density Summary

Fuel Cell Analysis

After considering several fuel cell manufacturers, the PureCell Model 400 system from ClearEdge Power was selected. Its electrical efficiency is slightly lower than other major manufacturers, but this model is rated for indoor use, is compact, and three 400 kW units support the expected 1,000 kW building load without under or over sizing.

Table 29 analyzes the impact of using fuel cells to produce enough energy to meet the entirety of the building's electrical loads. Each fuel cell has an electrical output of 400 kW, making them capable of supplying 800 kW of DC power and 400 kW of AC power simultaneously to cover the expected 540 kW DC load and 393 kW AC load. The connected AC load (1,110 kW) exceeds the capacity of the AC fuel cell, but the fuel cell was sized to the expected load. The connected load includes the maximum receptacle loads, even though this capacity will not be reached.

The expected energy is calculated from this value using assumptions about when equipment will be used throughout the year. It also accounts for potential energy savings. The expected natural gas consumption was calculated using the expected AC and DC energy usage and the electrical efficiency of the fuel cells. It is important to note that the increase in efficiency of the DC fuel cells comes as a result of the inverter being eliminated from the system. On average, industrial inverters operating at partial load will have efficiency at or below 95%.[4] Heat can also be recovered from the process, and mechanical simulations anticipate that it will meet the heating load 87% of the time. Extra heat is exhausted through a duct to the rooftop along with the carbon dioxide that is produced as a byproduct. From a maintenance standpoint, the fuel cell stacks will require replacement after 10 years of use.

Due to the low price of PG&E's natural gas compared to its electric grid, which continues to increase rates, using the fuel cells to supply the building's electrical loads will save approximately $230,000 annually. The capital cost of the fuel cells is also low, as the self-generation incentives shown in Figures 35 and 43 provide over 80% of the initial cost. Most importantly, as 350 Mission aims to be net-zero, the comparison of primary fuel usage between onsite generation with the fuel cells and the electric grid is shown in Table 29. The natural gas fuel cells save over 100,000 kWh annually and lead to a 15% efficiency increase.

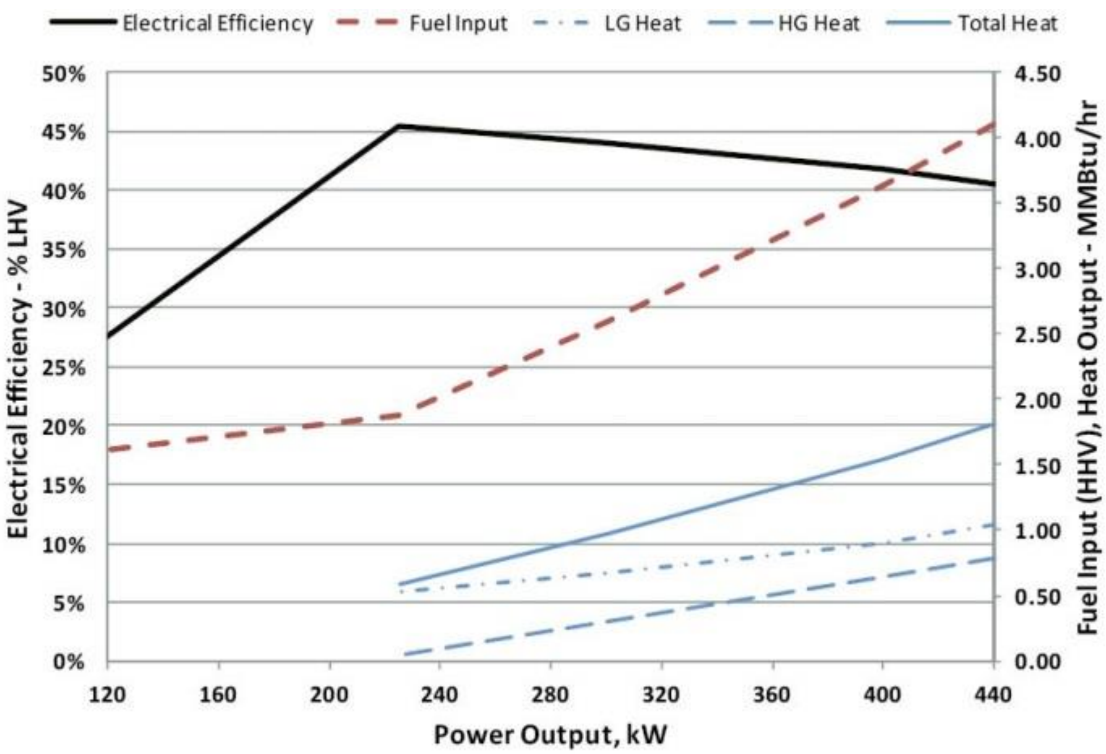


Figure 42: ClearEdge Model 400 PureCell Electrical Characteristics Graph

Characteristic	Units	Maximum Power Mode*	Baseload Power Mode*
Electric Power	kW/kVA	440/440	400/471
Electrical Efficiency	%, LHV	41%	42%
Peak Overall Efficiency	%, LHV	90%	90%
Gas Consumption	MMBtu/h, HHV	4.11	3.63
High-Grade Heat Output @ up to 250ºF	MMBtu/h	0.78	0.65
Low-Grade Heat Output @ up to 140ºF	MMBtu/h	1.04	0.90

Table 28: ClearEdge Model 400 PureCell Operating Characteristics

$33.4 million per year in available incentives	75 percent renewable and emerging/25 percent nonrenewable	
Incentive levels	Technology	Incentive ($/watt)
Renewable, waste heat capture technologies	Wind turbines	$1.13/W
	Waste heat to power	$1.13/W
	Pressure reduction turbine	$1.13/W
	Renewable microturbine (on-site or directed biogas)	$2.08/W*
	Renewable internal combustion engine (on-site or directed biogas)	$2.08/W*
	Renewable gas turbine (on-site or directed biogas)	$2.08/W*
	Renewable fuel cells (on-site or directed biogas)	$3.45/W*
Emerging technologies	Advanced Energy Storage (AES)	$1.62/W
	Fuel cells: combined heat and power (CHP) or electric	$1.83/W

Figure 43: PG&E Self-generation Incentives

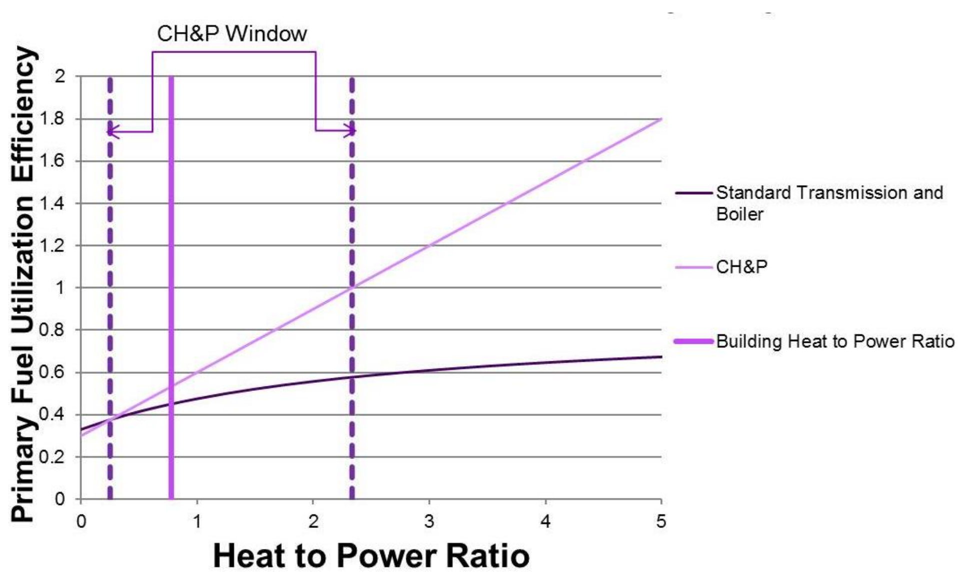


Figure 44: 350 Mission CH&P Feasibilty Analysis

Analysis of 350 Mission's heat to power ratio determines that it falls within the optimal combined heat and power window a majority of the time.

FUEL CELL ANALYSIS

Fuel Cell	Max Output	Output Voltage	Electrical Efficiency	Natural Gas Consumption	Heat for Recovery	CO_2 Emissions	Space Required (Dimen. & Area)
ClearEdge Model 400 PureCell	400 kW	480 VAC	42%	3,630,000 Btu/h	1,550,000 Btu/h at 140°F	1059 lb/MWh no recovery	27'4" x 8'4" x 10'
		380 VDC	47%			497 lb/MWh w/ recovery	

Expected AC Energy	800,000	kwh	Annually
Expected DC Energy	1,000,000	kwh	Annually

Natural Gas Fuel Usage

Fuel Cell	Electrical Energy Use	Hours of Use	Total Energy Consumption [using electrical efficiency]	Cas Consumption in kBtu	Gas Consumption in Therms	Monthly Therms
ClearEdge AC	800000 kwh	2000 hr	1904762 kwh	6499048 kBtu	64990 therms	5416 therms
ClearEdge DC1	500000 kwh	1250 hr	1063830 kwh	3629787 kBtu	36298 therms	3025 therms
ClearEdge DC2	500000 kwh	1250 hr	1063830 kwh	3629787 kBtu	36298 therms	3025 therms
Total	1800000 kwh	4500 hr	4032421 kwh	13,758,622 kBtu	137586 therms	11466 therms

Heat for Recovery

	Heat Recovery from Fuel Cell	Actual Heat to Mechanical Equ.	Annual Energy Used in Recovery Heat
ClearEdge Model 400	6975000 kBtu	4185000 kBtu	1226553 kwh

Carbon Footprint (CO_2)

ClearEdge Model 400	1906200 lb	864637 kg	Annually, no recovery
	894600 lb	405783 kg	Annually, with recovery

Cost Analysis

Summer $/Month	Winter $/Month	Flat $	Total $	
Cost using natural gas				
$9,239.83	$9,815.10	$1,808.64	$116,138.22	Annually
Cost using grid electricity				
$35,259.50	$22,458.50	-	$346,308.00	Annually
Monetary Savings from using Fuel Cells			$230,169.78	Annually

Primary Fuel Comparison

Energy Source	Annual Primary Fuel Energy Consumption		Assumptions
Grid Natural Gas with Fuel Cells	4,480,468	kwh	Natural gas tranmission results in 10% losses from source to site
Grid Electric	5,806,452	kwh	Electric grid is 33% efficient from source to site after generation and tranmission
Savings	1,325,983	kwh	

Primary Fuel Utilization Comparison

Energy Source	Energy Use	Energy Consumption	
Fuel Cell	Total Required	4,480,468	kwh
	Electricity	1,800,000	kwh
	Recovery Heat	343,563	kwh
	Percent of total	48%	kwh
Electric Grid	Total Required	5,806,452	kwh
	Electricity	1,800,000	kwh
	Percent of Total	31%	kwh

Table 29: Fuel Cell Analysis Summary

Server Room Sizing

VMware is an industry leader in cloud and virtualization software. The following method for sizing 350 Mission's server room is derived from a VMware publication entitled "Server and Storage Sizing Guide for Windows 7 Desktops in a Virtual Desktop Infrastructure." The results were then verified with actual rack server technical specification sheets and server sizing guides from Dell, HP, and IBM. The comparison found the results of this method to be an accurate estimate of server sizing.

Equation:

$$(Virtual\ Machines\ per\ Server) = \frac{Cores\ Available\ on\ Server}{vCPUs\ Needed\ per\ Virtual\ Machine} x\ (Overcommit\ Ratio\ of\ vCPUs\ per\ pCPU)$$

$$(Virtual\ Machines\ per\ Server) = \frac{Cores\ Available\ on\ Server}{vCPUs\ Needed\ per\ Virtual\ Machine} x\ (Overcommit\ Ratio\ of\ vCPUs\ per\ pCPU)$$

Vocabulary:

pCPU = physical central processing unit

vCPU = virtual central processing unit

USER/WORKER TYPE	APPLICATIONS (OPEN SIMULTANEOUSLY)	VIRTUAL MACHINE CONFIGURATION
Task-based worker (light)	Limited (1-5 applications, light use)	1 virtual CPU 1GB memory
Knowledge worker (medium)	Standard office (1-5 applications, regular use)	2 virtual CPUs 2GB memory
Power user (heavy)	Compute-intensive (5+ applications, regular use)	2 virtual CPUs 4GB memory
Power user plus (heavy)	Compute-intensive (5+ applications, intense use)	2+ virtual CPUs 4GB memory

Table 30: Required Processing Power for Various Applications [14]

It is assumed that most employees would not require more intensive power requirements than the category highlighted in the table above. This is likely a conservative estimate that will result in more processing power than will be required, but it is not excessive to the point that processing power is being wasted. To accommodate users with heavy processing demands, 12 non-virtual desktops are planned for each office floor.

Conservative overcommit ratio = 6:1 (vCPUs:pCPU)

Rack servers are available in countless configurations with various packages of processing cores, internal memory, storage, and other options. For these calculations, a server with 24 available cores was chosen, as it offered an adequate balance between performance, power consumption, and cost (based on Dell, HP, and IBM servers). The Eltek Flatpack2 DC/DC converter for data center applications operates at an industry-leading 98% efficiency and is specified for the 350 Mission server room. IBM and HP manufacture 380VDC server power supplies as well.

Calculation:

$$Virtual\ Machines\ per\ Server = \frac{24}{2} x\ 6 = 72\ Virtual\ Machines\ per\ Server$$

Based on this calculation, a server with 24 cores can serve approximately 70 thin client virtual desktops. Therefore, it would require two servers per office floor to accommodate the necessary computing capacity. Again, this value is on the conservative side, as these servers will accommodate about 140 virtual desktops, which exceeds the demand of each office floor.

On average, with the technology available, a server of this capacity consumes a maximum of 700 Watts. The resulting reduction in demand power using the server room arrangement compared to full-capacity, non-virtual desktops is summarized in Table 31 below.

COMPUTING POWER DEMAND										
Average rack server	Max Power [W]	700	Avg. Power [W]	600	Idle Power [W]	420	Sleep Power [W]	200	Off Power [W]	5
Average thin client	Max Power [W]	30	Avg. Power [W]	15	Idle Power [W]	10	Sleep Power [W]	4	Off Power [W]	2
Average full-capacity desktop	Max Power [W]	175	Avg. Power [W]	120	Idle Power [W]	85	Sleep Power [W]	5	Off Power [W]	3
Average LED or LCD monitor	Max Power [W]	30	Avg. Power [W]	30	Idle Power [W]	20	Sleep Power [W]	2	Off Power [W]	1

Computing Method	Rack Servers	DC Power [kW]	Thin Client Desktops	AC Power [kW]	Full-Capacity Desktops	AC Power [kW]	Monitors (Backlit LED)	AC Power [kW]	Total Maximum Power	
Maximum Power Per Office Floor										
Virtual Computing	2	1.4	120	3.6	12	2.1	132	4.0	11.1	kW
Traditional Computing	-	-	-	-	132	23.1	132	4.0	27.1	kW
Maximum Power for the Entire Building										
Virtual Computing	50	35	3000	90	300	52.5	3300	99	276.5	kW
Traditional Computing	-	-	-	-	3300	577.5	3300	99	676.5	kW

Computing Maximum Power Demand Summary		
Virtual Computing Connected Power	276.5	kW
Traditional Computing Connected Power	676.5	kW
Connected Power Reduction	400	kW
Connected Power Reduction	59%	-

Note about Computing Power Demand Analysis

The AC computer loads (every load except the servers) is supplied by receptacles and are included in the receptacle table and load summaries. This analysis was completed for two reasons, the first being a method of quantifying estimated energy savings over traditional computing methods. The second was to evaluate whether the computing loads could be met by the fuel cells when using actual loads, and not receptacles loads that conservatively overestimate power demand.

Estimated Energy Usage					Energy Assumptions
Virtual Computing Connected Power	1865.4	kwh per workday	476,872	kwh annually	Assume an average of 7 hours of active use, 1.5 hours of idle use, 1 hours of sleep use, and 14.5 hours of off use per workday. 'Off' status on weekends and holidays. Assume 255 annual workdays.
Traditional Computing Connected Power	4199.3	kwh per workday	1,072,327	kwh annually	Assume an average of 7 hours of active use, 1.5 hours of idle use, 1 hours of sleep use, and 14.5 hours of off use per workday. 'Off' status on weekends and holidays. Assume 255 annual workdays.
Connected Power Reduction	2333.9	kwh per workday	595,454	kwh annually	-
Connected Power Reduction	56%	kwh per workday	56%	kwh annually	-

Table 31: Computing Power Demand Comparison - Virtual vs. Traditional Computing

Voltage Drop Calculations

The prospect of using low voltage DC distribution throughout the office floor caused concerns about voltage drop. Power server modules (PSMs) are used distribute 380VDC as close each load as possible. The modules then convert 380VDC to 24VDC at an efficiency of over 96%, with the 24VDC distribution reaching the lighting, controls, and other low voltage loads through one of the sixteen 95W output channels.

Each output channel operates independently, so the power to several luminaires can be turned off without disrupting the others. Control wires for the DALI system run separately from the power wiring. The modules can also receive more than one input, allowing emergency circuits to also be connected to a module serving normal loads. Under normal operating conditions, all loads in the module are served by normal power, and only the emergency channels are served by the emergency feed if necessary.

Six PSMs supply all of the 24VDC loads on each office floor, aside from the actuators in the façade, which have their own DC-DC converters. In order to verify that the voltage drop on each branch circuit does not exceed 3%, as recommended by the National Electrical Code (NEC), the placement of the power server modules and wiring to the lighting fixtures was anticipated for the typical office layout. Figure 45 shows the layout and wiring of the circuits, and Table 32 proves that the voltage drop on all branch circuits, from DC panel to PSM to load, remains under 3%. 12 AWG conductors were used; the same size that is typically found on AC lighting circuits.

Equation: $V_{drop} = \frac{K(I)(L)(2)}{cmils}$

K = resistance (ohms/cmil-ft)
 11 for copper loaded to less than 50% ampacity
 12 for copper loaded to greater than 50% ampacity
I = load in amps
L = one-way distance

Figure 45: Typical Office Wiring Diagram

A typical wiring diagram from the load centers to the end use devices was created to ensure that voltage drop would not be an issue. The results showed that no circuit had a voltage drop above 3%, thereby meeting NEC recommendations. The calculations are shown in Table 32.

TYPICAL OFFICE FLOOR POWER SERVER MODULE LOAD AND VOLTAGE DROP															
380VDC Distribution							24VDC Distribution								
Circuit	Load Type	Max Load [A]	Actual Load [A]	Breaker on Panel [A]	Max Distance	V_{drop} Panel - PSM	PSM	Load [VA]	Load [A]	Channel	Load [VA]	Load [A]	Max Dist.	V_{drop} PSM - Luminaire	Max Total Branch Circuit V_{drop}
1	Lighting, controls	4.00	1.87	15	64	0.2%	1 (Flex)	662.2	27.6	1	94.6	3.9	24	1.4%	1.6%
										2	94.6	3.9	24	1.4%	
										3	94.6	3.9	16	0.7%	
										4	47.3	2.0	12	0.3%	
										5	47.3	2.0	12	0.3%	
										6	94.6	3.9	16	0.7%	
										7	94.6	3.9	24	1.4%	
										8	94.6	3.9	24	1.4%	
								47.3	2.0	9 E	47.3	2.0	<1	0.0%	
2	Lighting, controls	4.00	2.50	15	60	0.2%	2 (Open Office)	819.2	34.1	1	40	1.7	56	1.3%	2.8%
										2	40	1.7	56	1.3%	
										3	92.4	3.9	47	2.6%	
										4	92.4	3.9	47	2.6%	
										5	92.4	3.9	47	2.6%	
										6	92.4	3.9	47	2.6%	
										7	92.4	3.9	33	1.8%	
										8	92.4	3.9	33	1.8%	
										9	92.4	3.9	18	1.0%	
										10	92.4	3.9	18	1.0%	
								132.4	5.5	11 E	66.2	2.8	40	1.6%	
										12 E	66.2	2.8	40	1.6%	
3	Lighting, controls	4.00	2.47	15	54	0.2%	3 (Open Office)	806.8	33.6	1	40	1.7	41	1.0%	2.8%
										2	40	1.7	41	1.0%	
										3	92.4	3.9	47	2.6%	
										4	92.4	3.9	47	2.6%	
										5	92.4	3.9	18	1.0%	
										6	92.4	3.9	18	1.0%	
										7	46.2	1.9	18	0.5%	
										8	46.2	1.9	18	0.5%	
										9	94.6	3.9	31	1.7%	
										10	94.6	3.9	39	2.1%	
										11	75.6	3.2	57	2.6%	
								132.4	5.5	12 E	66.2	2.8	50	2.0%	
										13 E	66.2	2.8	50	2.0%	
4	Lighting, controls	4.00	2.84	15	114	0.4%	4 (Dining/ Break)	941	39.2	1	50.4	2.1	57	1.7%	2.8%
										2	94.6	3.9	43	2.3%	
										3	79.8	3.3	46	2.1%	
										4	67.2	2.8	56	2.2%	
										5	50.4	2.1	30	0.9%	
										6	94.6	3.9	32	1.8%	
										7	79.8	3.3	46	2.1%	
										8	67.2	2.8	56	2.2%	
										9	50.4	2.1	26	0.8%	
										10	75.6	3.2	38	1.7%	
										11	92.4	3.9	36	2.0%	
										12	46.2	1.9	42	1.1%	
										13	92.4	3.9	45	2.4%	
								138.6	5.8	14 E	71.4	3.0	30	1.3%	
										15 E	67.2	2.8	58	2.3%	
5	Lighting, controls, systems	4.00	1.79	15	98	0.3%	5 (Corridor)	576.8	24.0	1	60	2.5	49	1.7%	3.0%
										2	80	3.3	34	1.6%	
										3	60	2.5	18	0.6%	
										4	87.2	3.6	26	1.3%	
										5	73.6	3.1	35	1.5%	
										6	80	3.3	58	2.7%	
										7	52.6	2.2	24	0.7%	
										8	52.6	2.2	42	1.3%	
										9	30.8	1.3	56	1.0%	
								101.7	4.2	10 E	66.3	2.8	62	2.4%	
										11 E	35.4	1.5	78	1.5%	
6	Telecom devices, controls	4.00	-	15	-	-	6	Location and loads based on low voltage device placement and wiring.							

Table 32: Voltage Drop Calculations

LEED Checklist

Under the LEED 2009 for New Construction and Major Renovations Checklist, 350 Mission can achieve LEED Platinum Accreditation, accumulating 93 points out of a possible 110 points. [12]

Sustainable Sites (21/26 Points)

Prereq 1	Construction Activity Pollution Prevention	
Credit 1	Site Selection	1 Point
Credit 2	Development Density and Community Connectivity	5 Points
Credit 4.1	Alternative Transportation – Public Transportation Access	6 Points
Credit 4.2	Alternative Transportation – Bicycle Storage and Changing Rooms	1 Point
Credit 4.3	Alternative Transportation – Low-Emitting and Fuel-Efficient Vehicles	3 Points
Credit 4.4	Alternative Transportation – Parking Capacity	2 Points
Credit 6.1	Stormwater Design – Quantity Control	1 Point
Credit 7.1	Heat Island Effect – Non-roof	1 Point
Credit 8	Light Pollution Reduction	1 Point

Water Efficiency (10/10 Points)

Prereq 1	Water Use Reduction – 20% Reduction	
Credit 1	Water Efficient Landscaping | No Potable Water Use or Irrigation	4 Points
Credit 2	Innovative Wastewater Technologies	2 Points
Credit 3	Water Use Reduction | Reduce by 40%	4 Points

Energy and Atmosphere (31/35 Points)

Prereq 1	Fundamental Commissioning of Building Energy Systems	
Prereq 2	Minimum Energy Performance	
Prereq 3	Fundamental Refrigerant Management	
Credit 1	Optimize Energy Performance| Improve by 48%+ for New Buildings	19 Points
Credit 2	On-Site Renewable Energy | 72% Renewable Energy	7 Points
Credit 3	Enhanced Commissioning	2 Points
Credit 5	Measurement and Verification	3 Points

Materials and Resources (9/14 Points)

Prereq 1	Storage and Collection of Recyclables	
Credit 2	Construction Waste Management | 75% Recycled or Salvaged	2 Points
Credit 3	Materials Reuse | Reuse 10%	2 Points
Credit 4	Recycled Content | 20% of Materials	2 Points
Credit 5	Regional Materials	2 Points
Credit 7	Certified Wood	1 Point

Indoor Environmental Quality (14/15 Points)

Prereq 1	Minimum Indoor Air Quality Performance	1 Point
Prereq 2	Environmental Tobacco Smoke (ETS) Control	1 Point
Credit 1	Outdoor Air Delivery Monitoring	1 Point
Credit 2	Increased Ventilation	1 Point
Credit 3.1	Construction IAQ Management Plan – During Construction	1 Point
Credit 3.2	Construction IAQ Management Plan – Before Occupancy	1 Point
Credit 4.1	Low-Emitting Materials – Adhesives and Sealants	1 Point
Credit 4.2	Low-Emitting Materials – Paints and Coatings	1 Point
Credit 4.3	Low-Emitting Materials – Flooring Systems	1 Point
Credit 4.4	Low-Emitting Materials – Composite Wood and Agrifiber Products	1 Point
Credit 5	Indoor Chemical and Pollutant Source Control	1 Point
Credit 6.1	Controllability of Systems – Lighting	1 Point
Credit 6.2	Controllability of Systems – Thermal Comfort	1 Point
Credit 7.1	Thermal Comfort – Design	1 Point
Credit 7.2	Thermal Comfort – Verification	1 Point
Credit 8.2	Daylight and Views - Views	1 Point

Innovation and Design Process (4/6 Points)

Credit 1.1	Innovation in Design: Acoustics Pilot Credit	1 Point
Credit 1.2	Innovation in Design: Interior Lighting – Quality Pilot Credit	1 Point
Credit 1.3	Innovation in Design: Sustainable Wastewater Management Pilot	1 Point
Credit 2	LEED Accredited Professional	1 Point

Regional Priority Credits (4/4 Points)

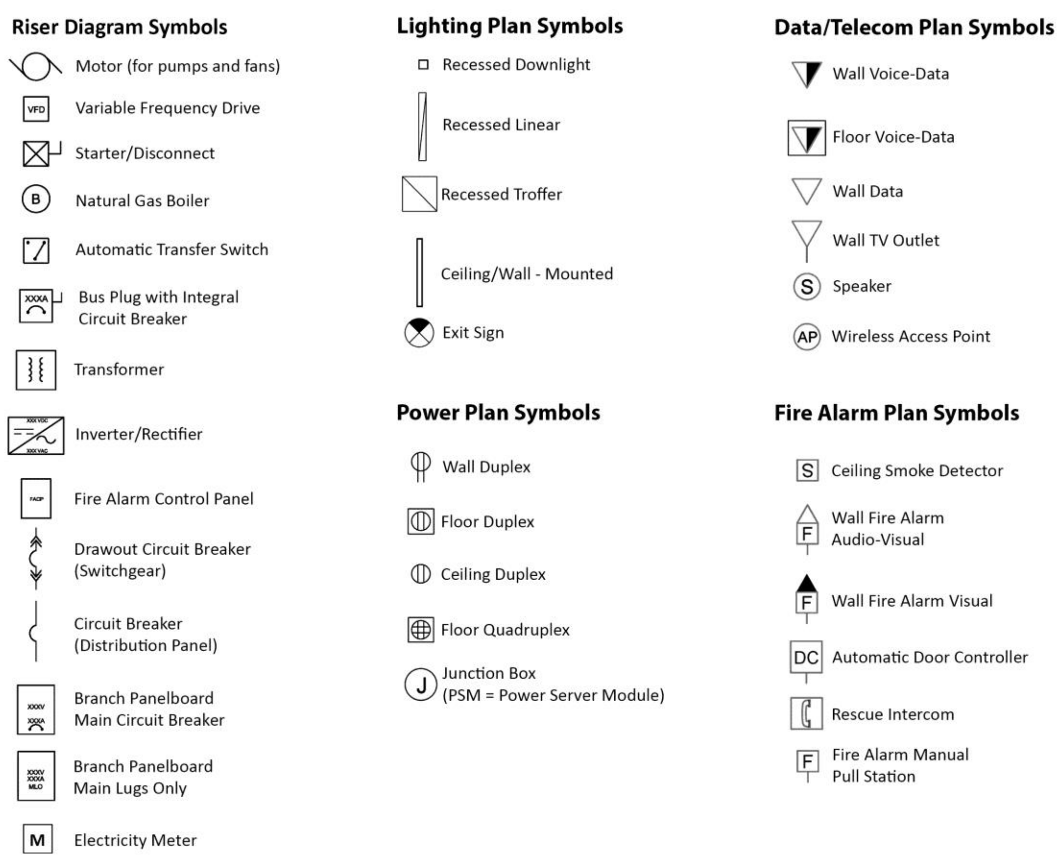
Credit 1.1	Regional Priority: On-site Renewable Energy	1 Point
Credit 1.2	Regional Priority: Daylight & Views - Daylight	1 Point
Credit 1.3	Regional Priority: Innovative wastewater technologies	1 Point
Credit 1.4	Regional Priority: Water use reduction	1 Point

Total LEED Points 93/110

Appendix B

Drawings

The following symbols are referenced throughout Appendix B, as they will appear on the floor plans for each building system.



Schedules

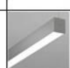
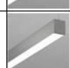
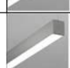
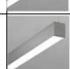
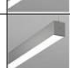
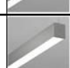
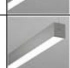
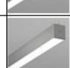
LUMINAIRE SCHEDULE																
Luminaire Symbol	Image	Luminaire Type	Manufacturer and Series	Light Source	Correlated Color Temperature (K)	Color Rendering Index (CRI)	Wattage [W] at Full Output	Initial Lumens [lm] (lumen package)	Luminaire Efficacy [lm/W]	Luminaire Efficiency	Voltage	Mounting	Height into Plenum [inches]	Notes	Lumen Maintenance
C		1" x 7.6" LED undercabinet strip	Feelux Diva 2	LED	4000	> 80	2.4	146	60.8	-	24VDC	Surface-mounted	-	Square diffuser	L_{70} at 40,000
DA		6" x 6" downlight	Gotham EVO	LED	4100	83	20.0	1125	56.3	-	24VDC	Recessed	6 3/4	Open	L_{70} at 50,000
DB		6" x 6" downlight	Gotham EVO	LED	4100	83	26.3	1590	60.5	-	24VDC	Recessed	6 3/4	Open	L_{70} at 50,000
DC		6" x 6" downlight	Gotham EVO	LED	4100	83	33.6	2150	64.0	-	24VDC	Recessed	6 3/4	Open	L_{70} at 50,000
DD		4" x 4" downlight	Gotham EVO	LED	4100	83	20.0	1016	50.8	-	24VDC	Recessed	6 3/4	Open	L_{70} at 50,000
I1		1-lamp industrial strip	Philips Day-Brite	F32T8	4100	90	34.0	2900	72.5	85.0%	24VDC	Surface-mounted	-	Open	-
I2		2-lamp industrial strip	Philips Day-Brite	F32T8	4100	90	67.0	5800	71.0	82.0%	24VDC	Surface-mounted	-	Open	-
L12		12' x 4" linear	Axis Beam 4	LED	4000	> 80	46.2	4800	104.0	-	24VDC	Recessed	4 3/4	Lensed	L_{70} at 50,000
L4		4' x 4" linear	Axis Beam 4	LED	4000	> 80	15.4	1600	104.0	-	24VDC	Recessed	4 3/4	Lensed	L_{70} at 50,000
M		Monorail mounted, aimable LED MR16 head	LBL Lighting Orbit Swivel	LED	4000	80	6.0	360	60.0	-	120VAC	Monorail	-	MR16 LED lamp	L_{70} at 30,000
O		Adjustable task light	Koncept Z-Bar Mini	LED	4500	85	6.5	230	53.0	-	120VAC	Desk-braced	-	Lensed	L_{70} at 50,000
PDA		4' x 4" linear direct pendant	Axis Beam 4	LED	4000	> 80	11.0	1200	104.0	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
PDB		4' x 4" linear direct pendant	Axis Beam 4	LED	4000	> 80	14.7	1600	104.0	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
PDC		4' x 4" linear direct pendant	Axis Beam 4	LED	4000	> 80	19.0	2000	100.6	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
PDD		4' x 4" linear direct pendant	Axis Beam 4	LED	4000	> 80	30.7	3000	93.4	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
PUA		8' x 4" linear direct/indirect pendant	Axis Beam 4	LED	4000	> 80	22.0	2400 up/ 2400 down	104.0	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
PUB		8' x 4" linear direct/indirect pendant	Axis Beam 4	LED	4000	> 80	25.7	2400 up/ 3200 down	104.0	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
PUC		8' x 4" linear direct/indirect pendant	Axis Beam 4	LED	4000	> 80	30.0	2400 up/ 4000 down	102.0	-	24VDC	Pendant	-	Lensed, configured into squares of 4 fixtures	L_{70} at 50,000
ST		2-lamp stairwell	Philips Day-Brite	F32T8	4100	90	67.0	5800	65.5	75.7%	24VDC	Surface-mounted	-	Lensed	-
TA		2' x 2' troffer	Axis Day 2x2	LED	4000	> 80	25.2	2500	99.3	-	24VDC	Recessed	3 7/8	Lensed	L_{70} at 50,000
TB		2' x 2' troffer	Axis Day 2x2	LED	4000	> 80	47.3	4400	93.1	-	24VDC	Recessed	3 7/8	Lensed	L_{70} at 50,000
X1		Edge-lit green LED exit sign	Philips Chloride	LED	-	-	3.5	-	-	-	24VDC	Ceiling mounted	-	Double or single faced with chevrons as indicated on plan	-

Figure 46: Luminaire Schedule

Lobby Lighting

Figure 47: Lobby Lighting Plan

The lobby lighting layout shows the suspension lengths of the decorative pendant squares, as well as the locations of the recessed, monorail mounted, and undercounter luminaires. Creative solutions were required due to the scale and layout of the space.

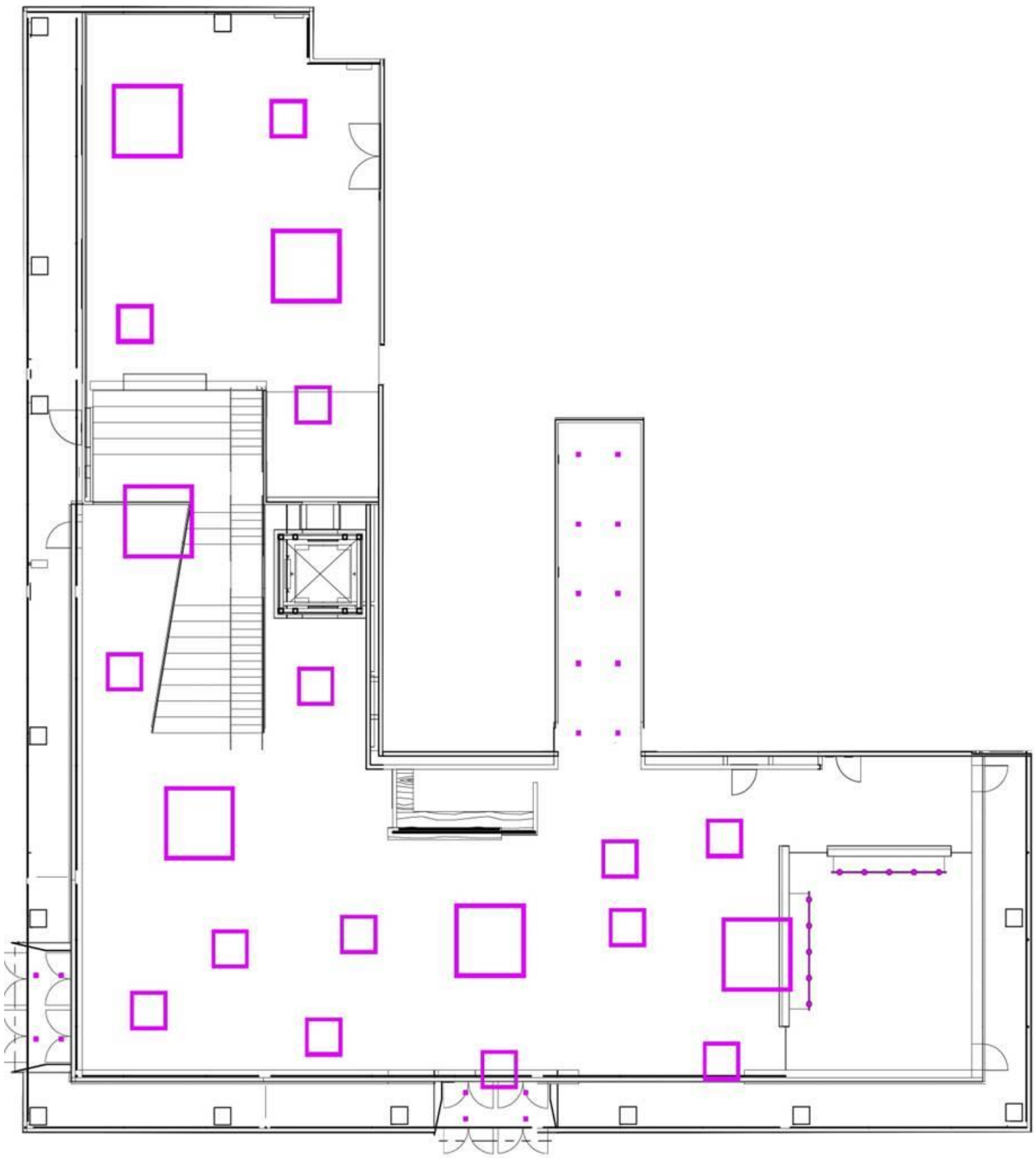


Figure 48: Lobby Lighting, Schematic with Luminaires Highlighted

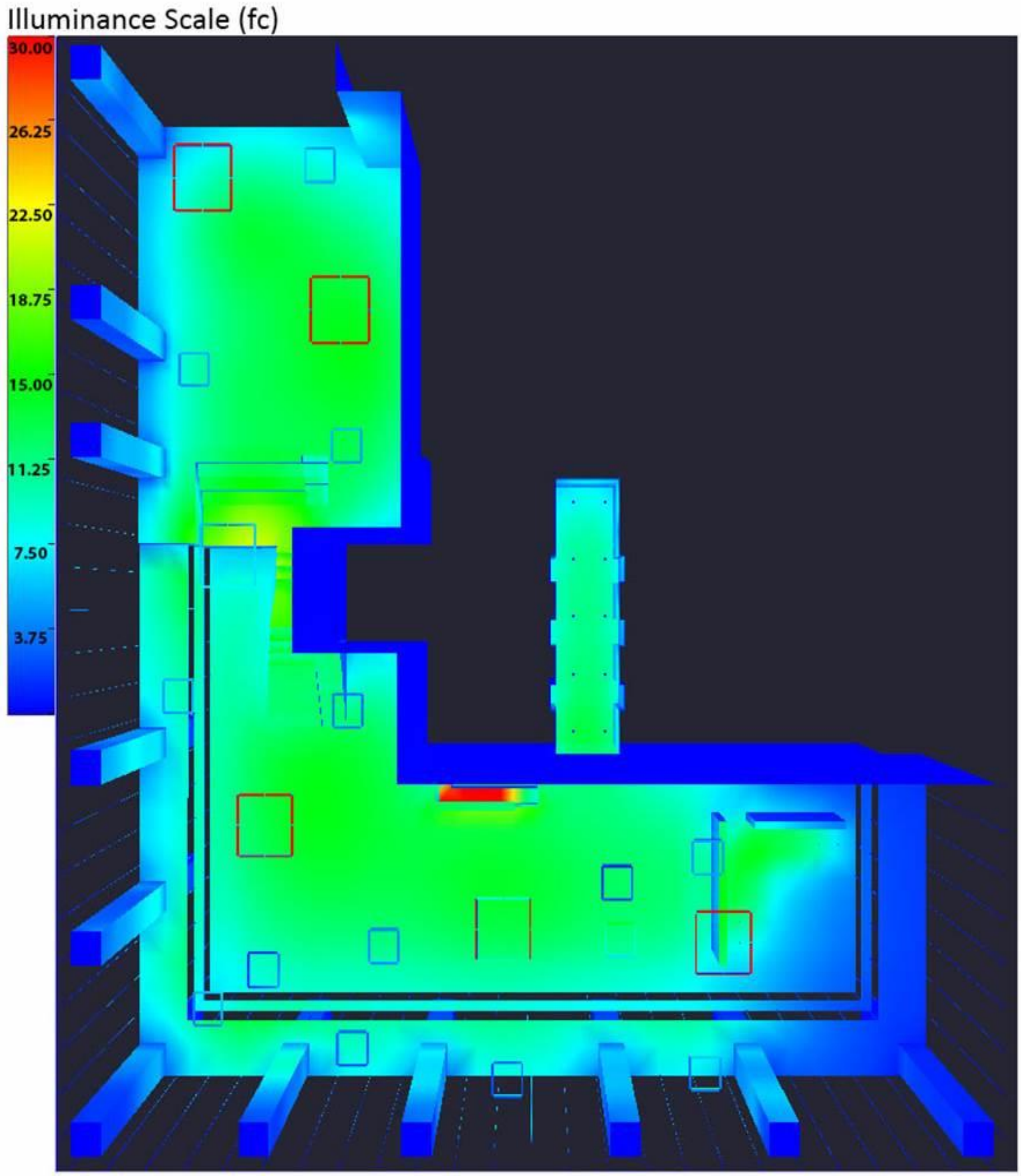


Figure 49: Lobby Lighting Pseudocolor Rendering

This image shows a visual representation of the lobby illuminance levels due to electric lighting. Most of the circulation areas are at 10 fc, shown by the green. The reception desk has higher illuminance levels to accommodate reading and writing.

Space	Average Illuminance [fc]	Workplane Height [ft.]
General Circulation 1	10.34	Floor
General Circulation 2	10.68	Floor
Retail	8.09	Floor
Reception Desk	33.23	3' - 0"
Elevator Lobby	10.37	Floor
Stairs 1	10.63	Stair Surface
Stairs 2	11.07	Stair Surface
Stairs 3	10.90	Stair Surface

Figure 50: Lobby Average Maintained Illuminance Calculations

The calculation points used to check the lobby illuminance levels are shown in this image, and the average values are recorded in the color-coordinated table. All calculations planes were set at floor level for circulation, with the exception of the reception desk where calculation points were placed on the workplane.

Public Art Wall

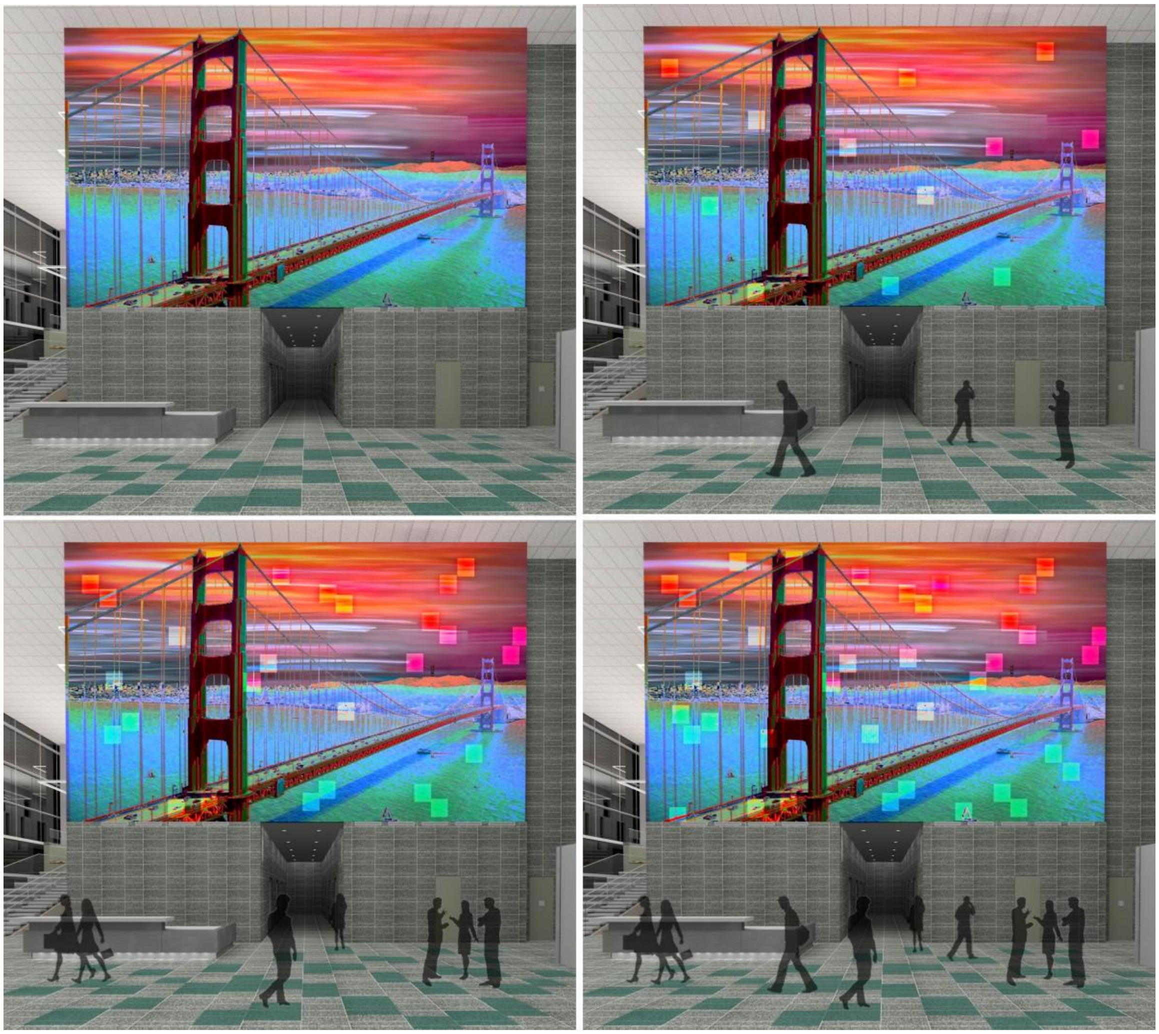


Figure 51: Public Art Wall Example Renderings

These four renderings are examples of the art wall activating based on the amount of foot traffic in the lobby. The placement of luminaires and tiles will ultimately be decided by the artist, but the intent is to create a dynamic feature that interacts with building visitors and teaches them that they can contribute to a form of renewable onsite energy.

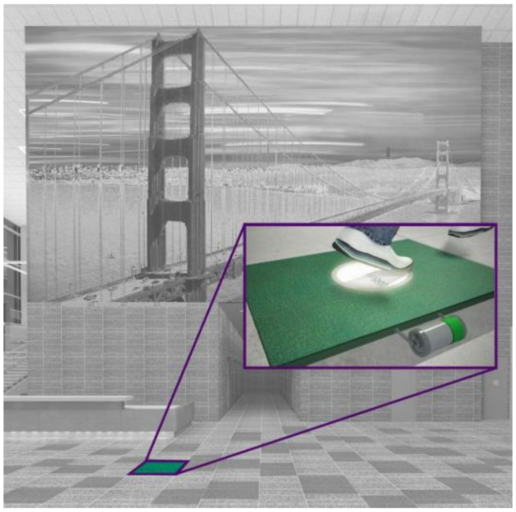


Figure 52: Callout of PaveGen Floor Tiles

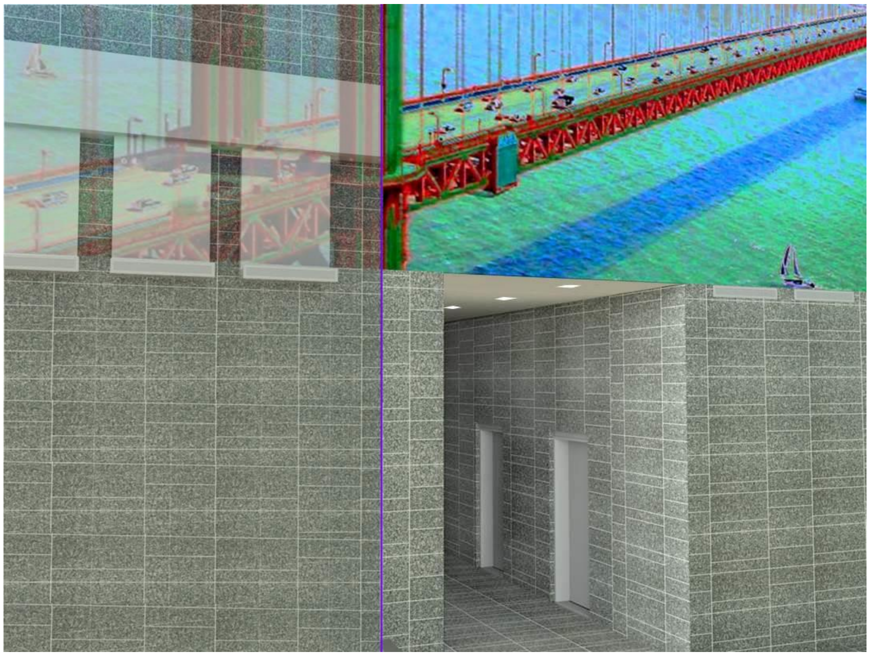


Figure 53: Public Art Wall Mechanical Coordination

The mural will be placed on a gypsum dummy wall that extends 20” beyond the core wall. This creates a vertical plenum that will house the luminaires used in the art installation, and it also creates space to conceal the mechanical ducts serving the lobby with ventilation. The diffusers terminate just below the mural. In this way, the art wall became a multidisciplinary point of collaboration.

Office Lighting

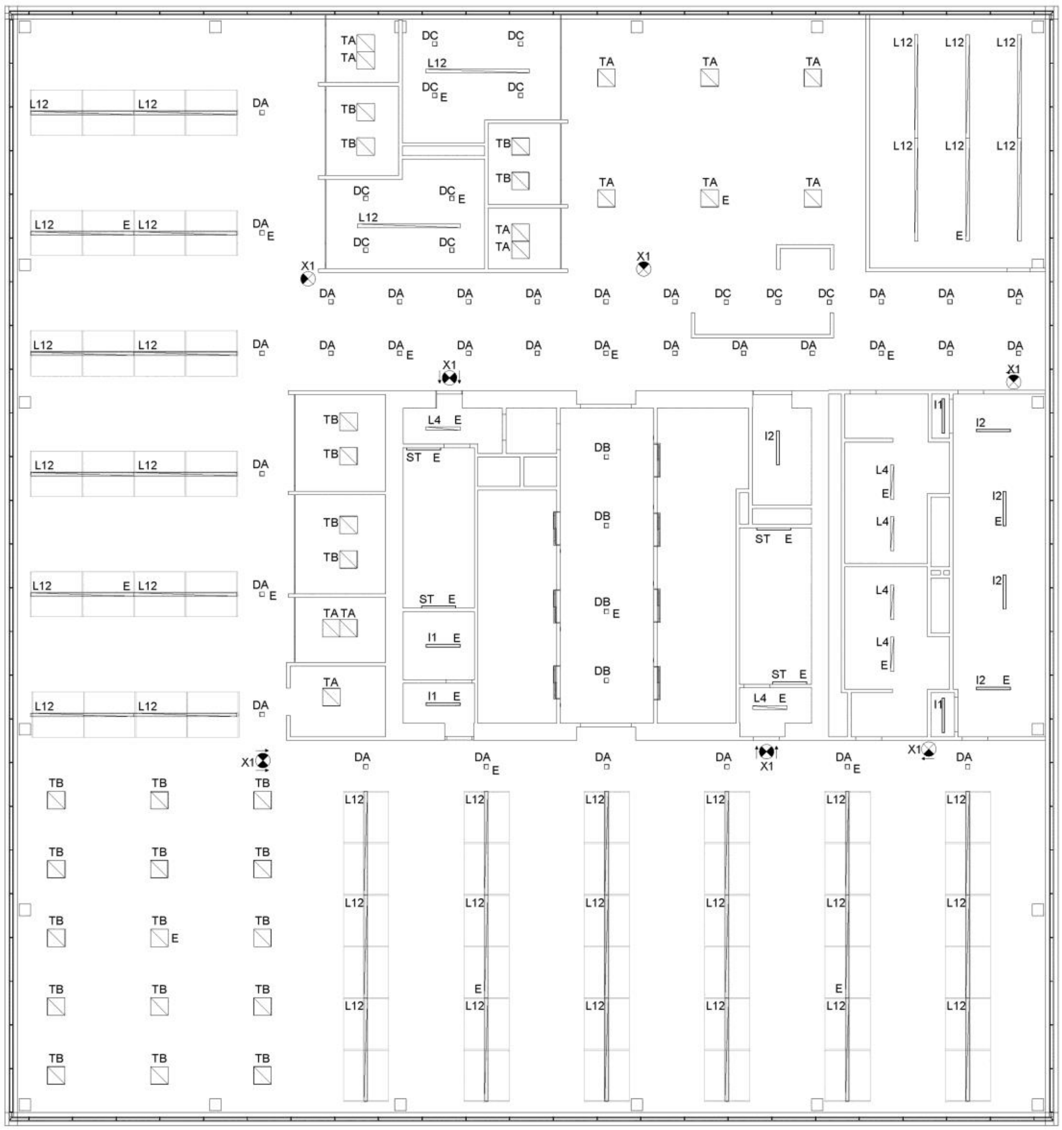


Figure 54: Office Lighting Plan

The office lighting is shown above, with the exception of the task lighting located at each workstation. Exit signs are provided to mark the paths of egress, and emergency lighting, which also operates under normal conditions, provides 1 fc for egress circulation in the event of a power outage.

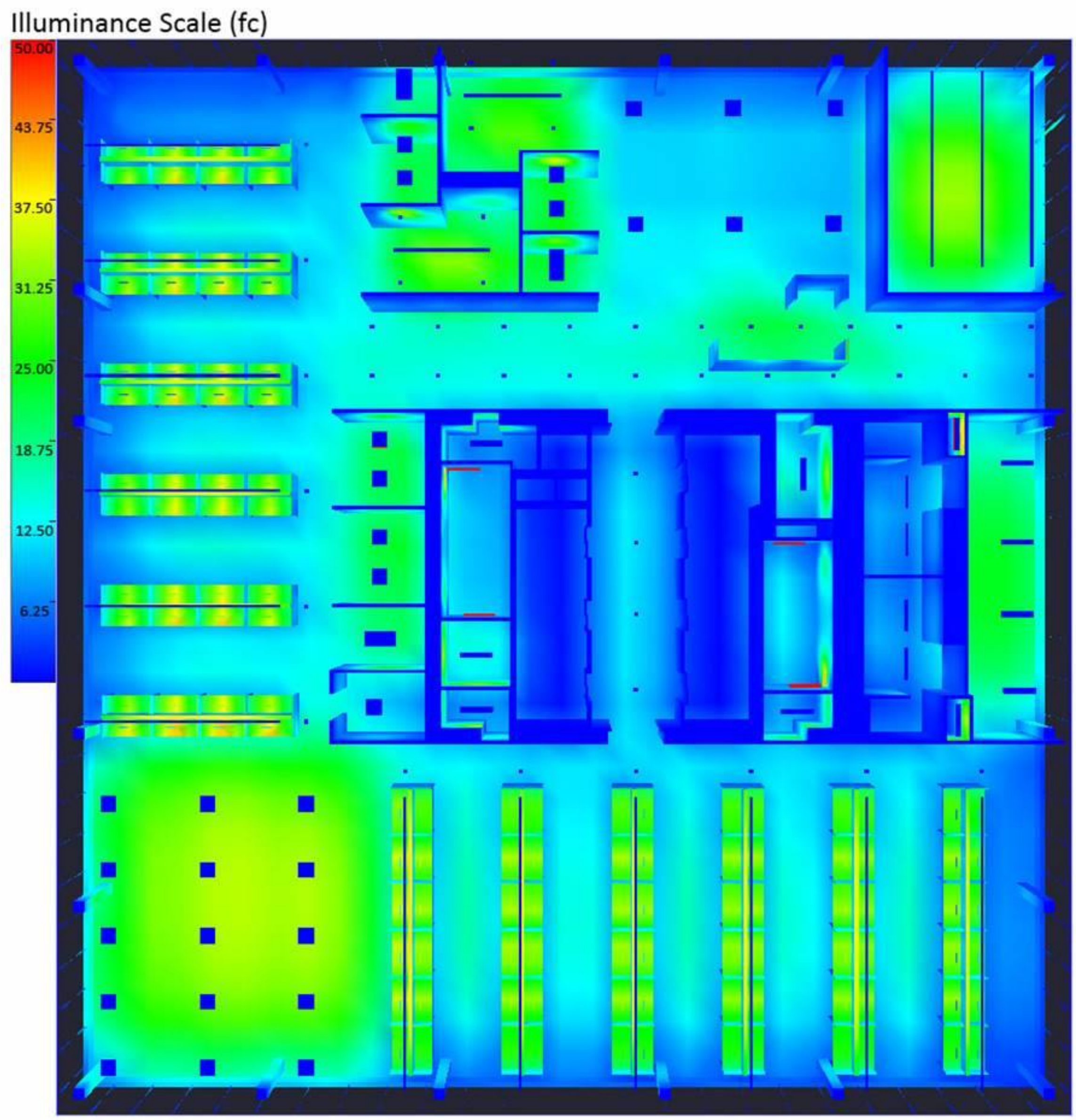


Figure 55: Office Pseudocolor Rendering

This image shows a visual representation of the office illuminance levels due to electric lighting. Most of the circulation areas are at 10 fc, shown by the light blue. The circulation areas around the desks are only at about 15 fc, with the additional illuminance on the workplane being supplied by task lighting. The flex area, in the absence of task lighting, has an even distribution of 30 fc across the space.

Space	Average Illuminance [fc]	Workplane Height [ft.]
Desk 1	30.94	2' - 6"
Desk 2	32.02	2' - 6"
Desk 3	30.31	2' - 6"
Desk 4	29.05	2' - 6"
Flexible Use	30.91	2' - 6"
Large Conference	30.06	2' - 6"
Small Conference	29.69	2' - 6"
Video Conference	29.76	2' - 6"
Interview	30.23	2' - 6"
Print/Copy	11.98	2' - 6"
Dining/Break	10.72	3' - 0"
Kitchen	29.92	3' - 6"
Restroom	5.49	Floor
Corridor - Northwest	12.58	Floor
Corridor - Southwest	11.80	Floor
Corridor - Southeast	11.09	Floor
Open Office Circulation 1	16.13	Floor
Open Office Circulation 2	14.26	Floor
Elevator Lobby	9.90	Floor

Figure 56: Office Average Maintained Illuminance Calculations

The calculation points used to check the office illuminance levels are shown in this image, and the average values are summarized in the color-coordinated table. Calculation planes were set at floor level for circulation and at the workplane in other areas including the open office, conference rooms, and break room.

Lobby Lighting Controls

Figure 57: Lobby Lighting Control Plan

General Circulation Area CZ1

The suspended luminaires in the general circulation area are on from dusk to dawn for security purposes and throughout the day as needed. They are controlled by multiple photosensors attached to the fixtures and calibrated to approximate the ground illuminance levels. The lights dim as daylight levels allow, and when the amount of daylight in the lobby is adequate for general circulation, the lights are turned completely off. Each luminaire is controlled individually due to the size and layout of the lobby, ensuring that the entire space will have adequate light levels regardless of the time of day or exterior conditions.

Reception Desk CZ2

The reception desk lighting is divided into two groups – task lighting on the desktop area and decorative lighting underneath the desk. The task lighting is controlled by a manual on/off and occupancy sensor off. Throughout much of the day, this lighting will likely not be necessary as the daylight values in the space are more than adequate. However, it is available if needed. The decorative lighting is time clock controlled, turning on at 6AM and off at 7PM each day.

Retail CZ3-CZ4

There are two retail areas, one underneath the stairs to the second floor and the other at the east corner of the building. The stair retail area has ceiling recessed fixtures that are switched together and have manual on/time clock off controls, with the time clock set based on store operating hours. The east corner retail area has two levels of lighting – ambient and merchandise lighting. The ambient lighting has time clock on/off controls, set to remain on during operating hours. These lights can be dimmed based on the tenant requirements, and there is an override switch in case of housekeeping or other after-hours usage. Due to the store's location, ambient luminaires are also controlled by a photosensor and are dimmed/switched off when daylight levels allow. The merchandise lighting in this area is also controlled by a time clock on and off; however this can be set separately from the ambient lighting to allow the tenant to light merchandise during closed hours for advertising and security purposes. This lighting is flexible and can be dimmed as desired by the tenant.

Elevator Lobby CZ5

The elevator lobby is controlled by a time clock for the majority of the work day, turning all lights on at 6AM and off at 7PM. Outside of these hours, occupancy sensors are responsible for the on/off controls.

Vestibule CZ6-CZ7

Vestibule lighting is controlled primarily via a time clock that switches the lights on when the building opens in the morning and off when it closes at night. During the day, it is also controlled by a photosensor that dims and switches the lights when there is enough daylight to do so. All of the lights in each vestibule are controlled together.

Office Lighting Controls

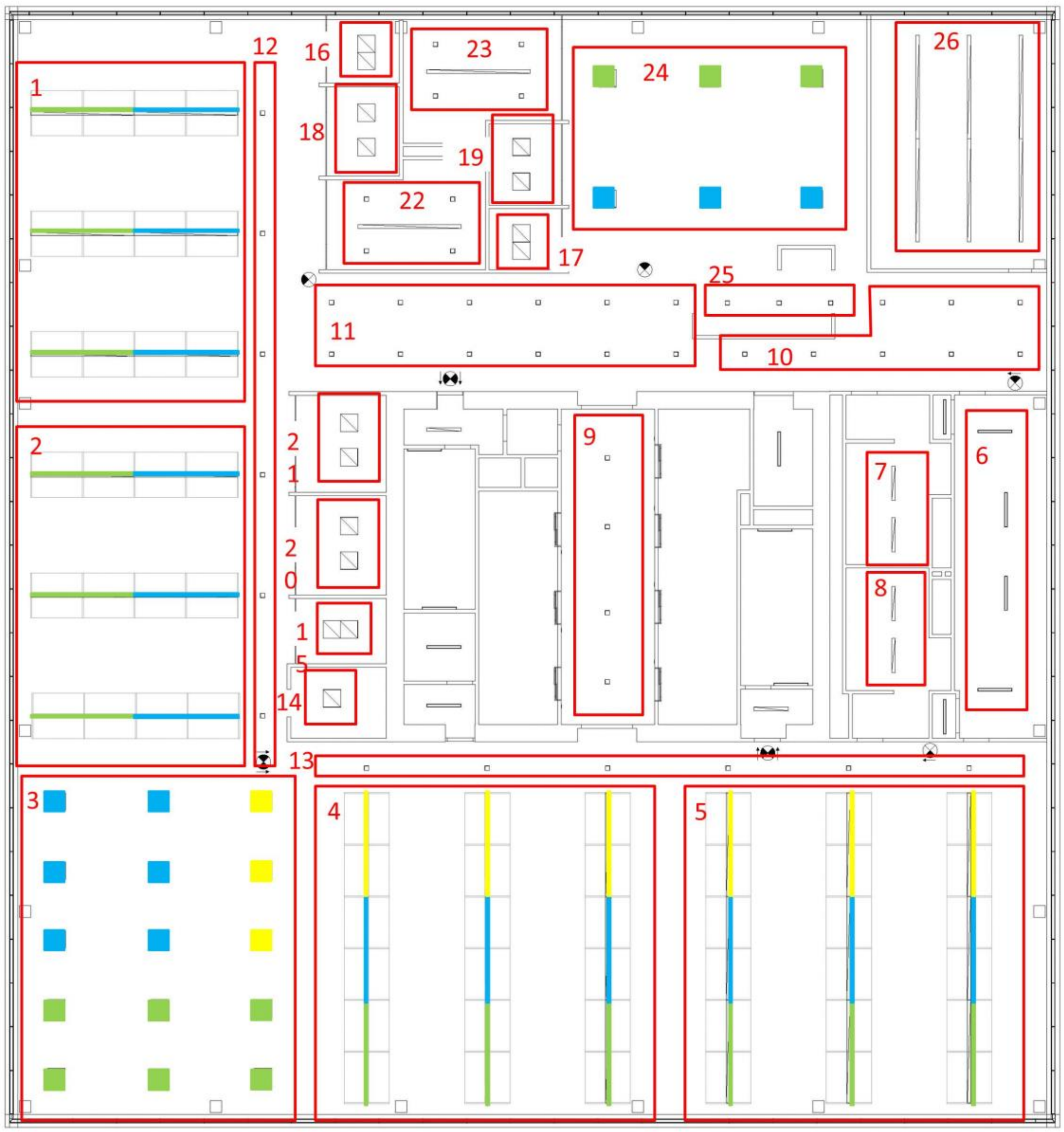


Figure 58: Office Lighting Control Plan

Open Office/Flex Space CZ1-CZ5

The luminaires in these areas are grouped into control zones, as designated by the red outlines. Within each control zone, luminaires are divided into dimming zones. Luminaires of the same color in the same control zone are controlled by one photocell to prevent each fixture from dimming to a different level, as occupants generally prefer dimming to occur in groups rather than each fixture dimming individually. An override switch is also provided for housekeeping. CZ1 and CZ2 are controlled by the same housekeeping switch, and CZ3-CZ5 are controlled together. When the housekeeping override is activated, lights in the designated zones will turn on for 30 minutes. These are the only spaces in which a housekeeping override is required, as most other areas on the office floor are occupancy sensor controlled.

Mechanical Room CZ6

These fluorescent luminaires are controlled with a manual on/off as well as occupancy sensor off. The controls for the rest of the electrical/telecom/etc. spaces (unmarked on the plan) are the same as this room. Switches are located at the entrances to each room and control all of the lights in the area.

Restrooms CZ7-CZ8

The restrooms are controlled solely by occupancy sensors. There is a wall switch sensor at the entrance to the room, as well as ceiling mounted occupancy sensors in the stall area to ensure that the lights do not turn off while occupants are in the restroom.

Elevator Lobby CZ9

The elevator lobby is controlled by a time clock for the majority of the work day, turning all lights on at 7AM and off at 6PM. Outside of these hours, occupancy sensors are responsible for the on/off controls.

Corridors CZ10-CZ13

Similar to the elevator lobby, the corridors are controlled by time clock to constantly remain on from 7AM-6PM. At other times, occupancy sensors assume control, and lights only turn on when a sensor is triggered. The luminaires located in each control zone are controlled as a group, and occupancy sensors are located as required to ensure that lights turn on when the corridor area is occupied.

Copy Room CZ14

The copy room uses an occupancy sensor for on/off control at all hours.

Interview Rooms CZ15-CZ17

Interview rooms utilize a manual on/off switch located at the door, as well as a vacancy sensor to prevent lights from staying on and wasting energy while the room is unoccupied.

Teleconference Rooms CZ18-CZ21

Similar to the interview rooms, the teleconference rooms have a manual on/off controller at the door and a vacancy sensor. In addition, the wall controller allows for dimming to accommodate the various light level needs depending on the current function of the room.

Conference Rooms CZ22-CZ23

Conference rooms are equipped with scene controllers to accommodate the variety of activities that may occur in these spaces. They can be used for formal and informal meetings, brainstorming sessions, audio/visual presentations, etc. The lighting requirements for each of these scenarios are different, and scenes are programmed for each. A/V presentation mode turns off the majority of lights, excluding the two rear downlights, and the electrochromic glass on the façade will tint to allow for better screen visibility. Meeting mode consists of all lights turned on. Other scenes can be programmed into the controller as the needs of the tenants require. There is also a vacancy sensor to ensure that lights are off when the room is not being used.

Dining/Break Area CZ24

Occupancy sensors located in the break area control on/off switching of the luminaires. The control zone also contains two photosensor dimming zones, shown by the luminaire colors in the control diagram.

Kitchen CZ25

The kitchen is controlled by occupancy sensors that switch the lights on and off.

Large Conference Room CZ26

This conference room also has a scene controller to accommodate the variety of activities that may take place, including meetings, presentations, training sessions, etc. A/V presentation mode turns off the front lights, dims the middle, and leaves the front lights on. It also shades the glass. Normal presentation mode has the same luminaire controls, but the glass does not tint. Other scenes can be programmed into the controller as the needs of the tenants require. There is also a vacancy sensor to ensure that lights are off when the room is not being used.

Office Power

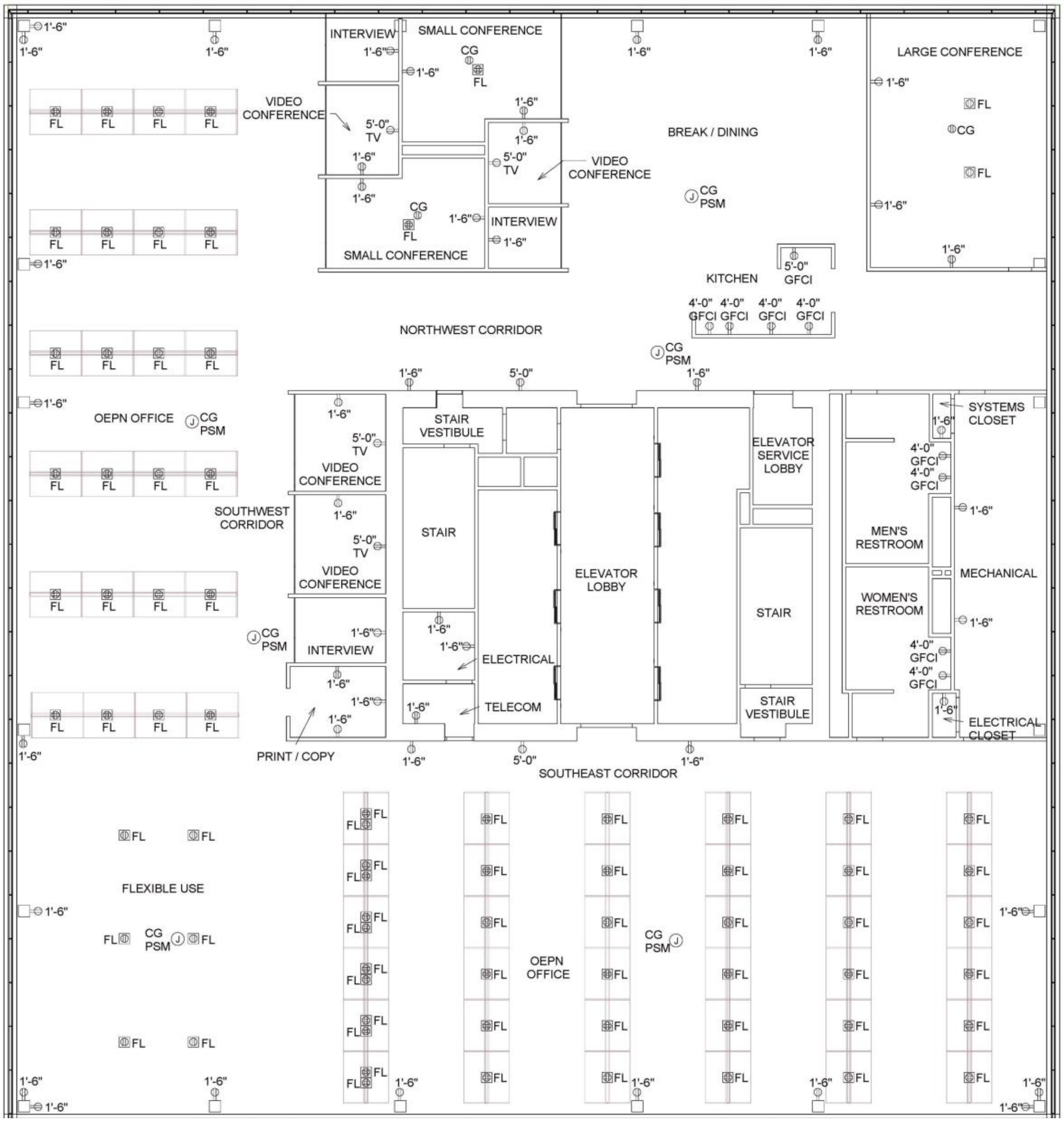


Figure 59: Office Power Plan

Quadruplex receptacles are provided at workstations to provide power to the thin client computers. Other receptacles are located throughout the space to accommodate less consistent loads. Junction boxes in the ceiling show the locations of the DC power supply modules.

TYPICAL OFFICE FLOOR														
Type	Location	Purpose	Quantity	Maximum Power per		Connected Power per floor		Connected Power for Building		Demand Power for Building		Expected Demand Power for		Notes and Assumptions about Expected Demand Power
General Use Receptacles														
Duplex	Column covers	General use	18	180	VA	3.24	kVA	81	kVA	45.5	kVA	4.55	kV	Assume 10% are in use at any given time
Open Office														
Quadruplex	Open office floor, under desk partitions	Thin client desktops, computer monitors	66	360	VA	23.8	kVA	594	kVA	594	kVA	222	kV A	Thin client desktop = 30W, LED backlit monitor = 30W, full desktop = 175W (Max power) Assume 10% full desktop
Hard-wired	At each open office desk	Task light	120	6.5	VA	0.78	kVA	19.5	kVA	19.5	kVA	12.19	kV A	Assume that 50% of task lights will be at full output and 25% at half output simultaneously
Flexible Space														
Duplex	Floor	Thin client desktops, computer monitors	6	180	VA	1.1	kVA	27	kVA	27	kVA	10.5	kV A	Thin client desktop = 40W, LED backlit monitor = 30W (Max power)
Large Conference Room														
Duplex	Walls	General use of additional electronics	3	180	VA	0.5	kVA	13.5	kVA	11.8	kVA	5.88	kV A	Assume that 50% of conference rooms are simultaneously in use
Duplex	Ceiling	Video projector	1	180	VA	0.2	kVA	4.5	kVA	7.25	kVA	3.63	kV A	Assume that 50% of conference rooms are simultaneously in use
Duplex	Floor	For use at central conference table	2	180	VA	0.4	kVA	9	kVA	9	kVA	4.50	kV A	Assume that 50% of conference rooms are simultaneously in use
Small Conference Rooms														
Duplex	Walls	General use of additional electronics	4	180	VA	0.7	kVA	18	kVA	14	kVA	7	kV A	Assume that 50% of conference rooms are simultaneously in use
Duplex	Ceiling	Video projector	2	180	VA	0.4	kVA	9	kVA	9.5	kVA	4.75	kV A	Assume that 50% of conference rooms are simultaneously in use
Quadruplex	Floor	For use at central conference table	2	360	VA	0.7	kVA	18	kVA	18	kVA	9	kV A	Assume that 50% of conference rooms are simultaneously in use
Video Conference Rooms														
Duplex	Near TV screen	Operation of TV and video conference equipment	4	180	VA	0.7	kVA	18	kVA	18	kVA	2.23	kV A	TV, LCD = 60W, speakers = 30W Assume that 33% of video conference rooms are simultaneously in use
Duplex	Adjoining wall	General use of additional electronics	4	180	VA	0.7	kVA	18	kVA	14	kVA	4.62	kV A	Assume that 33% of video conference rooms are simultaneously in use
Interview Rooms														
Duplex	Wall	General use of electronics	3	180	VA	0.5	kVA	13.5	kVA	11.8	kVA	2.35	kV A	Assume that 20% of interview rooms are simultaneously in use
Printer/Copier Room														
Duplex	At equipment locations	(1) laser printer, (1) inkjet multifunction printer	1	180	VA	0.2	kVA	4.5	kVA	4.5	kVA	2.34	kV A	Laser printer = 130W, Inkjet MFD = 26W Assume 60% of units are in use simultaneously
Duplex	Opposite walls of current equipment	General purpose recetacles for growth	2	180	VA	0.4	kVA	9	kVA	9	kVA	0.9	kV A	Assume 10% are simultaneously in use
Northwest and Southeast Corridors														
Duplex	around building core	General use	4	180	VA	0.7	kVA	18	kVA	14	kVA	1.4	kV A	Assume 10% are simultaneously in use
Duplex	Entrance to elevator corridor	TV's showing energy use on office floor	2	180	VA	0.4	kVA	9	kVA	9.5	kVA	3	kV A	TV, LCD = 60W
Kitchen														
Duplex (special purpose) GFI	At equipment locations	Coffee maker	1	464	VA	0.5	kVA	11.6	kVA	11.6	kVA	5.59	kV A	Equipment on standby = 2W Assume 50% of coffee makers are on standby, 50% active
Duplex (special purpose) GFI	At equipment locations	Microwave oven	1	1620	VA	1.6	kVA	40.5	kVA	40.5	kVA	11.39	kV A	Equipment on standby = 3W Assume 75% of microwaves are on standby, 25% active
Duplex GFI	At equipment locations	Water dispenser	1	180	VA	0.2	kVA	4.5	kVA	4.5	kVA	0.65	kV A	Water dispenser = 90W, standby = 1W Assume 75% of dispenser are on standby, 25% active
Duplex (special purpose) GFI	At equipment locations	Hot beverage dispenser	1	1650	VA	1.7	kVA	41.3	kVA	41.3	kVA	12.90	kV A	Equipment on standby = 75W Assume 75% of dispensers are on standby, 25% active
Duplex (special purpose) GFI	At equipment locations	Refrigerator	1	650	VA	0.7	kVA	16.3	kVA	16.3	kVA	16.25	kV A	Always in use
Restrooms														
Duplex GFI	Above sinks	Miscellaneous use	4	180	VA	0.7	kVA	18	kVA	14	kVA	0.70	A	Assume 5% are simultaneously in use
Utility Spaces (Electrical, Mechanical, Telecom)														
Duplex	Walls	Miscellaneous use	7	180	VA	1.3	kVA	31.5	kVA	20.8	kVA	1.04	kV	Assume 5% are simultaneously in use
OFFICE FLOORS TOTAL								Connected		Demand		Expected		
								1034	kVA	968	kVA	341	kV	

Table 33: Office Receptacles showing Connected, Demand, and Expected Electrical Loads

Office Data/Telecom

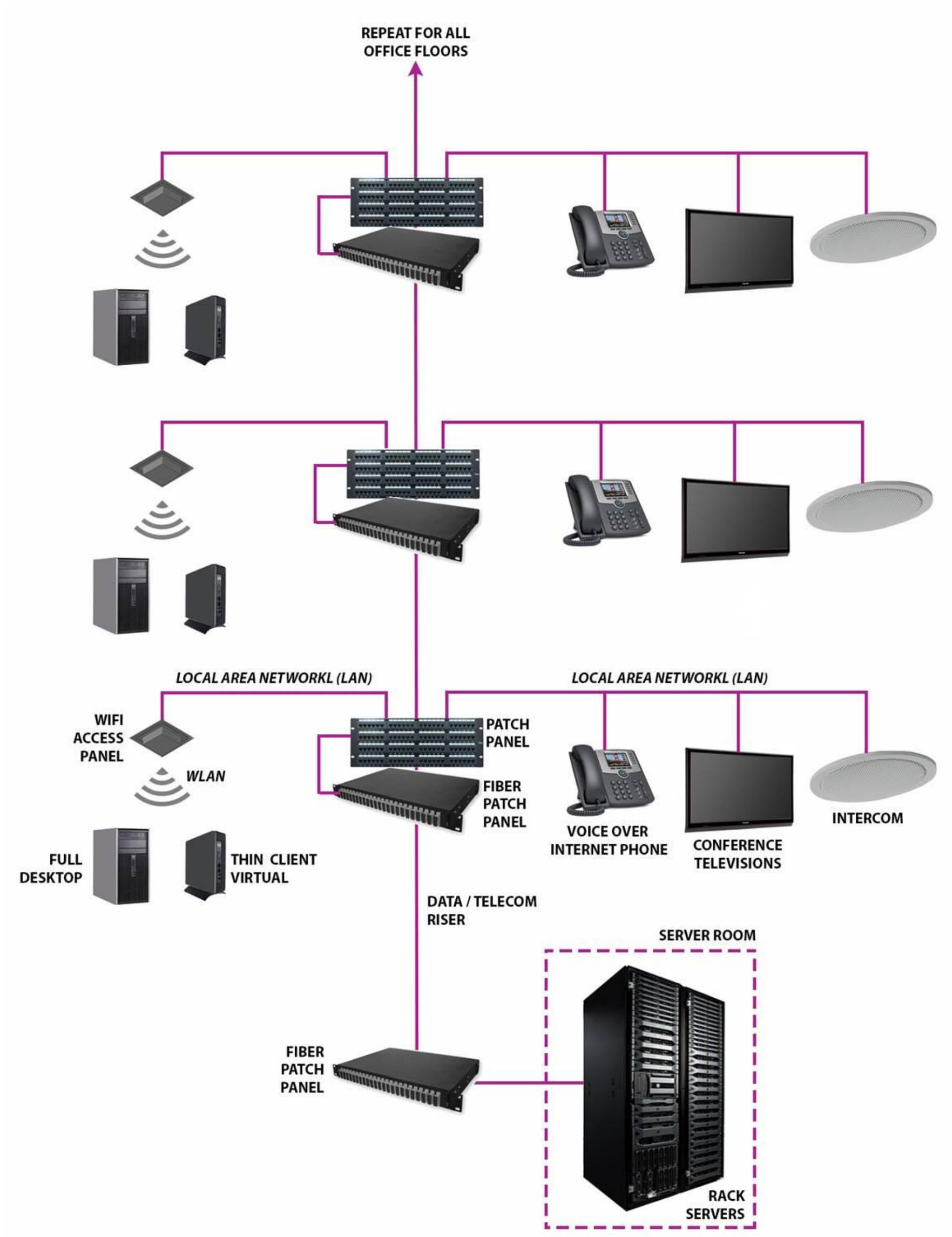


Figure 60: Data/Telecom Riser Schematic

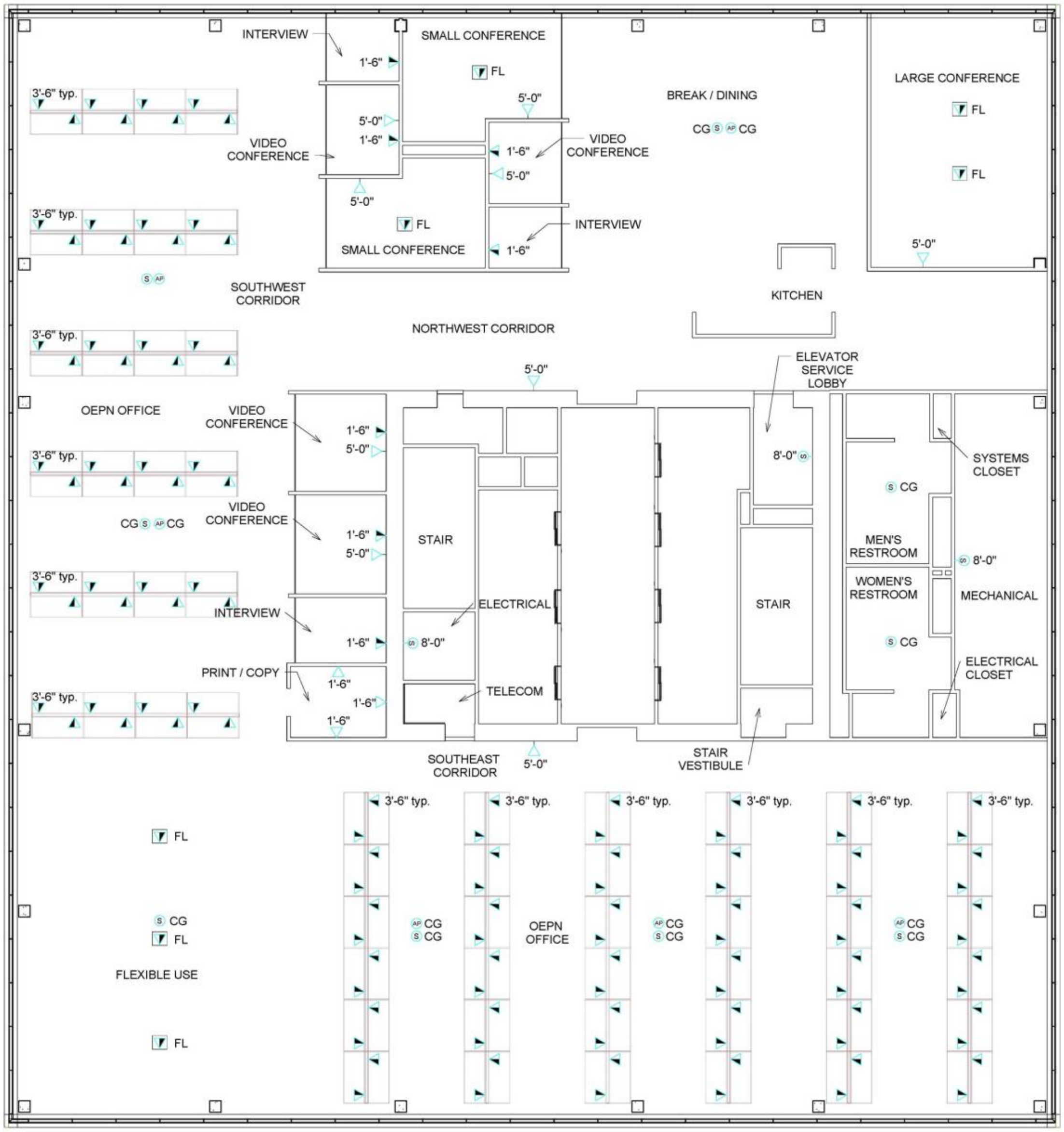


Figure 61: Office Data/Telecom Plan

At each floor, the data and telecom services are supplied through a fiber patch panel and patch panel. Six hardwired access panels provide WiFi, and open office workstations are equipped with a voice/data outlet for voice over internet protocol (VoIP) phones. Conference rooms have a TV outlet and voice/data outlet. TV outlets/TVs are also provided near the elevator lobby to make occupants aware of their monthly energy usage.

Office Fire Alarm

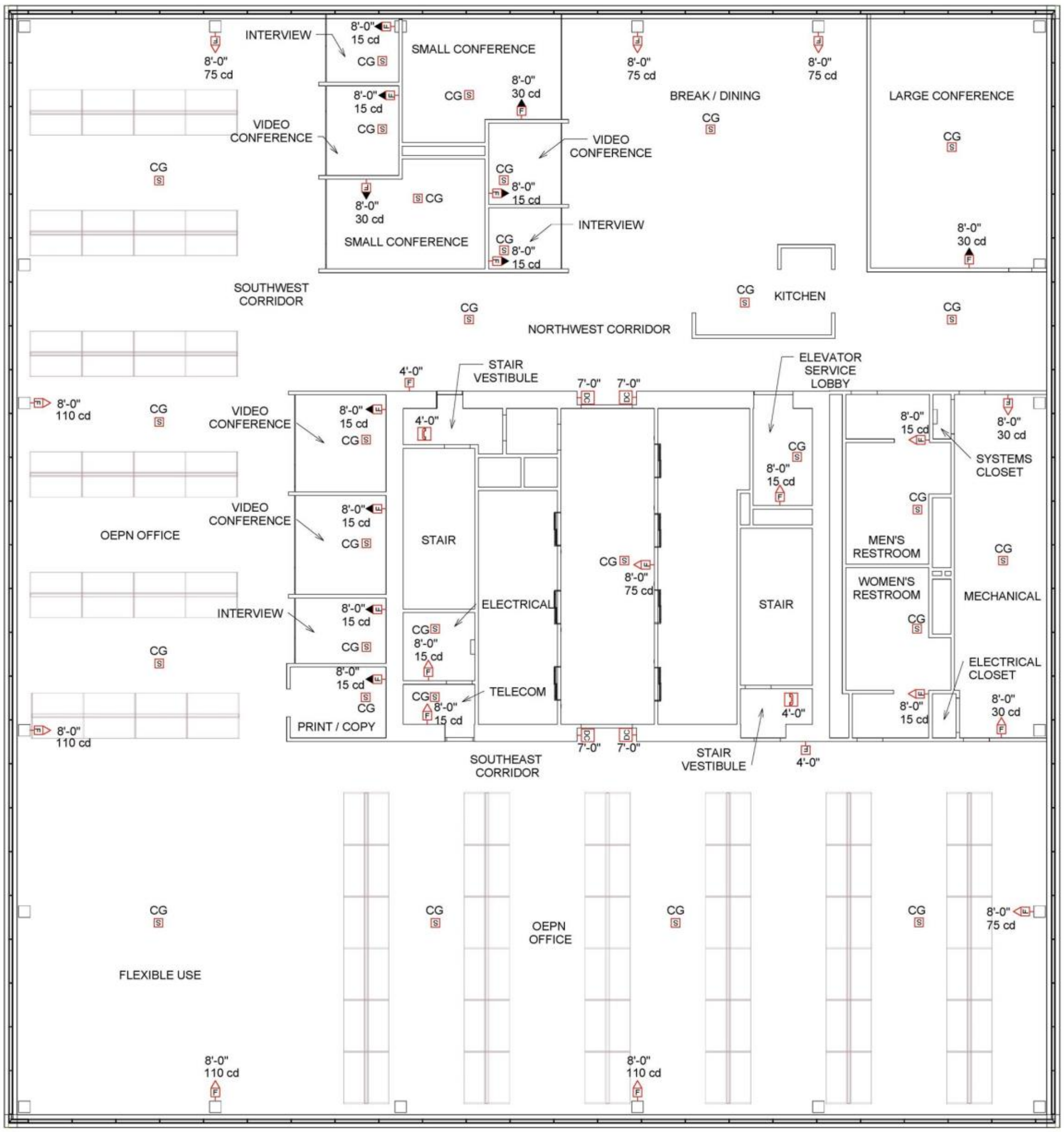


Figure 62: Office Fire Alarm Plan

Electrical and Mechanical Coordination

Shown in the ceiling coordination diagram in Figure 63 below, the 1’-7” ceiling plenum beneath the 22” structural beams is shared by the mechanical and lighting/electrical systems. All recessed luminaires extend into the plenum less than seven inches to create more space for mechanical ductwork and dampers. The DC electric distribution runs through the plenum and feeds all of the ceiling recessed lighting, low voltage controls, and telecom devices. Linear mechanical diffusers are installed to match the linear luminaires over the open office workstations.

System coordination in the floor unit is shown in the floor coordination diagram. The AC electrical distribution feeding the open office work stations runs through conduit in the 4.5” concrete topping. Radiant piping is distributed in a 4” raised subfloor. While the conduit and radiant piping run in separate parts of the floor, their placement is coordinated for floor receptacle terminals and in case maintenance is required.

In the core, the double story X-braced frame allows more flexibility than a concrete system. The conduit holding the branch circuit conductors that run from the panelboards to the loads can simply travel through one of the openings in the steel frame, rather than requiring a penetration through the concrete.

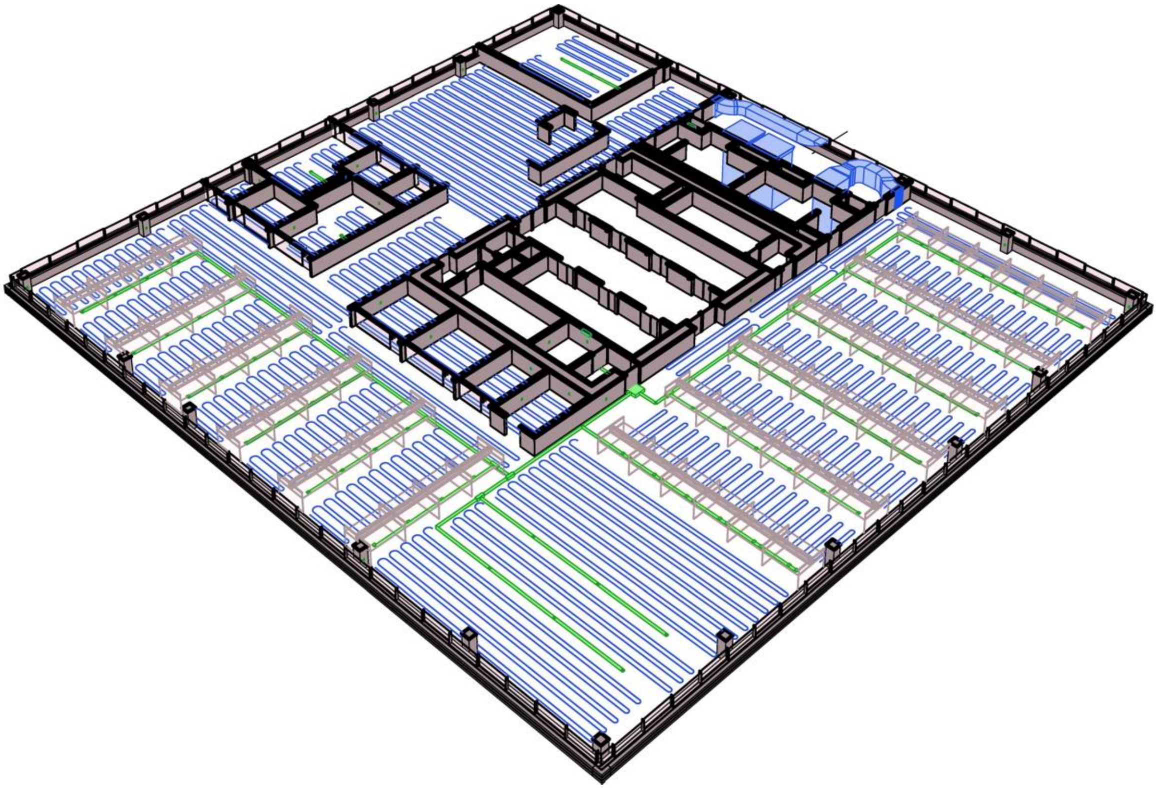


Figure 63: Office Floor Coordination

Electrical conduit is highlighted in green and the mechanical radiant heating/cooling tubing is highlighted in blue. Conduit runs horizontally beneath the floor slab of the floor below and pokes vertically through the concrete floor slab and radiant floor plenum at each floor receptacles. Floor receptacles run on the AC grid and serve the computer and task lighting loads at each workstation. Coordination between the mechanical and electrical disciplines ensured that the AC conduit and radiant system do not clash at any point.

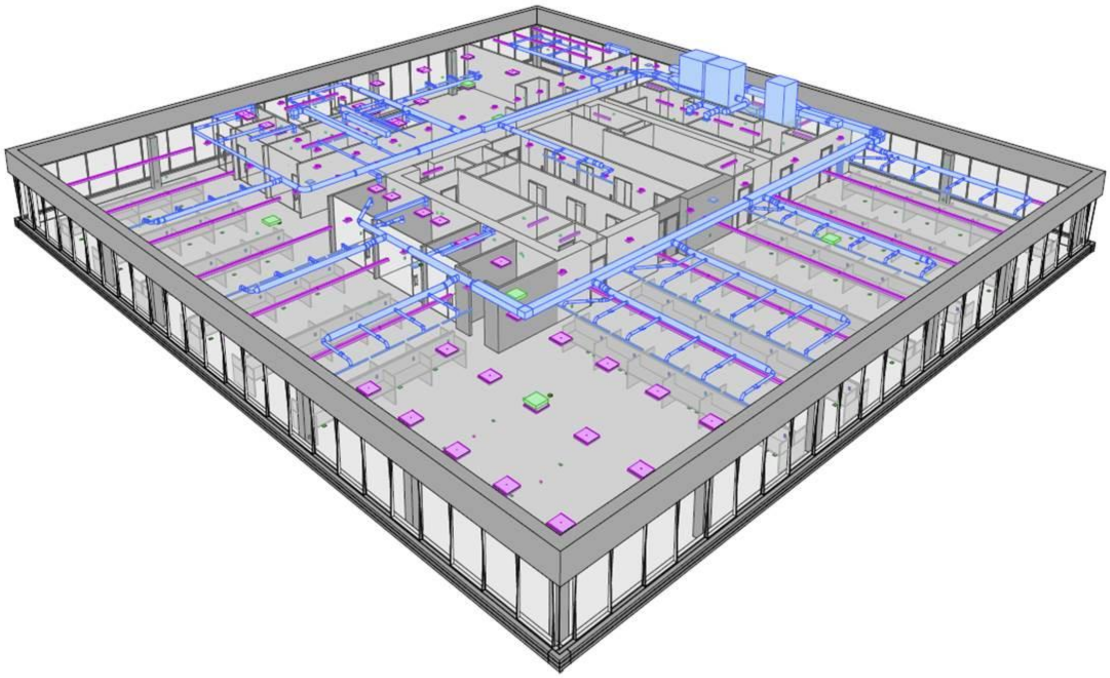


Figure 64: Office Ceiling Coordination

Mechanical ductwork is shown in blue, luminaires in pink, and power supply units in green. These three systems share the portion of the plenum beneath the structural beams. Working in linked Revit models allows for constantly updating coordination views between disciplines. This early identification of potential problems saves time when clash detection is run.

Electrical Distribution

DC DISTRIBUTION			
INPUT			
380VDC	DC FUEL CELL	NO CONVERSIONS	
	ONSITE PHOTOVOLTAICS		
	HUMAN WASTE TO POWER		
	BACKUP UTILITY ELECTRIC	*VIA*	*UTILITY XFMR AND RECTIFIER*
OUTPUT			
380VDC BUILDING RISER			
380VDC	MECHANICAL VFDS, MOTORS	NO CONVERSIONS	
48VDC	RACK SERVERS	VIA	380VDC TO 48VDC POWER SUPPLY
	DATA/TELECOM POWER SUPPLIES		
24VDC	LIGHTING	VIA	380VDC TO 24VDC POWER SERVER MODULE
	DALI CONTROL POWER SUPPLY		
	LOW VOLTAGE DEVICES		
	FAÇADE ACTUATORS	VIA	380VDC TO 24VDC CONVERTER
< 4 VDC	ELECTROCHROMIC GLASS	VIA	380VDC TO <4VDC CONVERTER

AC DISTRIBUTION			
INPUT			
480VAC	AC FUEL CELL	VIA	FUEL CELL INVERTER
	BACKUP UTILITY ELECTRIC	*VIA*	*UTILITY TRANSFORMER*
OUTPUT			
480 VAC BUILDING RISER			
208Y/120 VAC	RECEPTACLES	VIA	480Δ TO 208Y/120V STEP-DOWN TRANSFORMER & DEVICE POWER SUPPLY AND DRIVER AC-DC RECTIFIERS
	DESKTOPS, MONITORS		
	TASK AND RETAIL LIGHTING		
	FIRE ALARM CONTROL PANELS		

Figure 65: Electrical Component Operating Voltages

The dual AC/DC system greatly minimizes the number of voltage conversions because these are the most inefficient portion of any electrical distribution system. This table indicates what voltage every electrical component runs on and how necessary conversions are made.

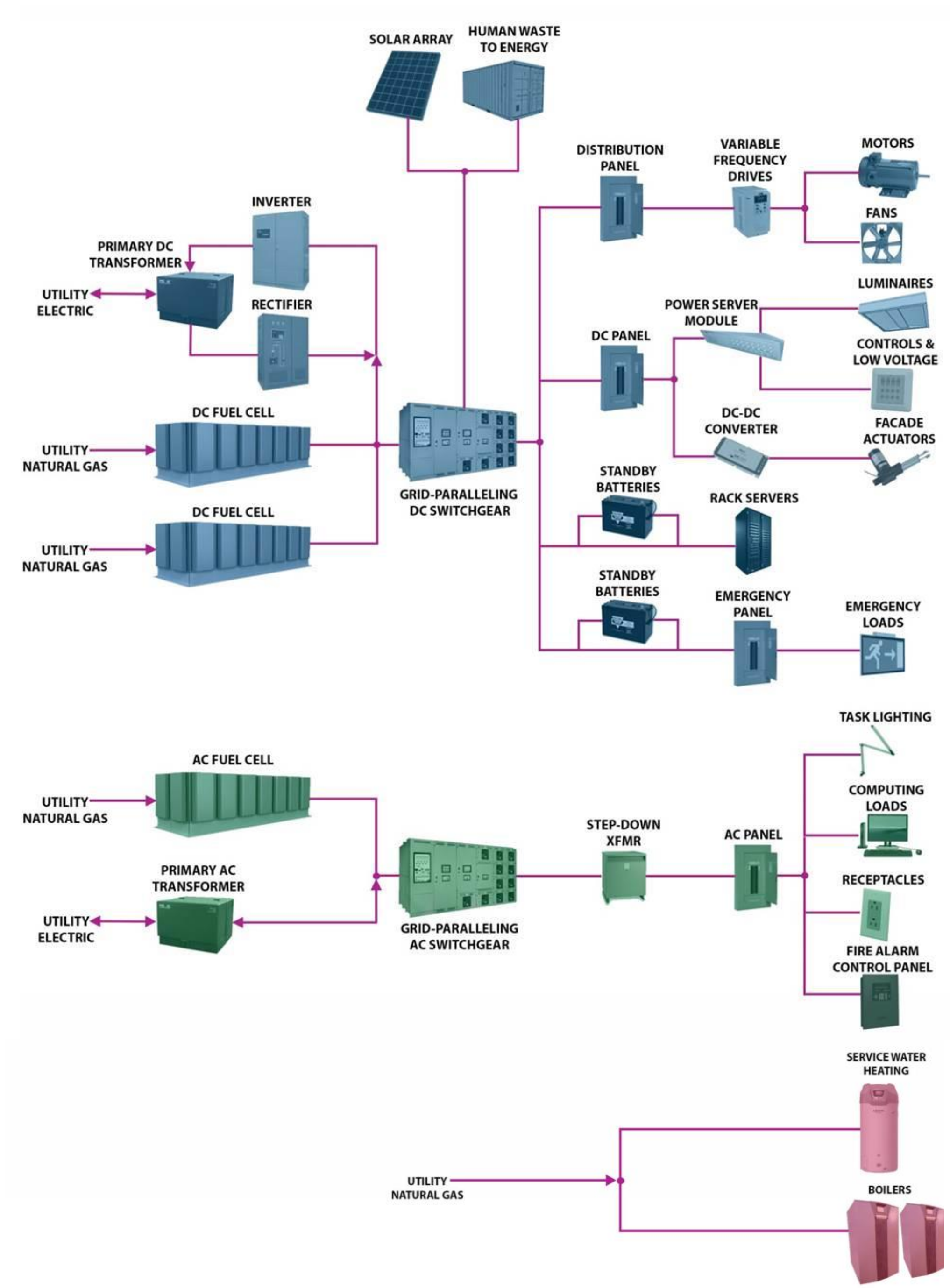


Figure 66: Electrical AC/DC Building Microgrid Schematic

This schematic details the building's AC and DC distribution systems and their associated loads. All DC equipment and components are shown in blue, AC in green, and natural gas-powered equipment is shown in red.

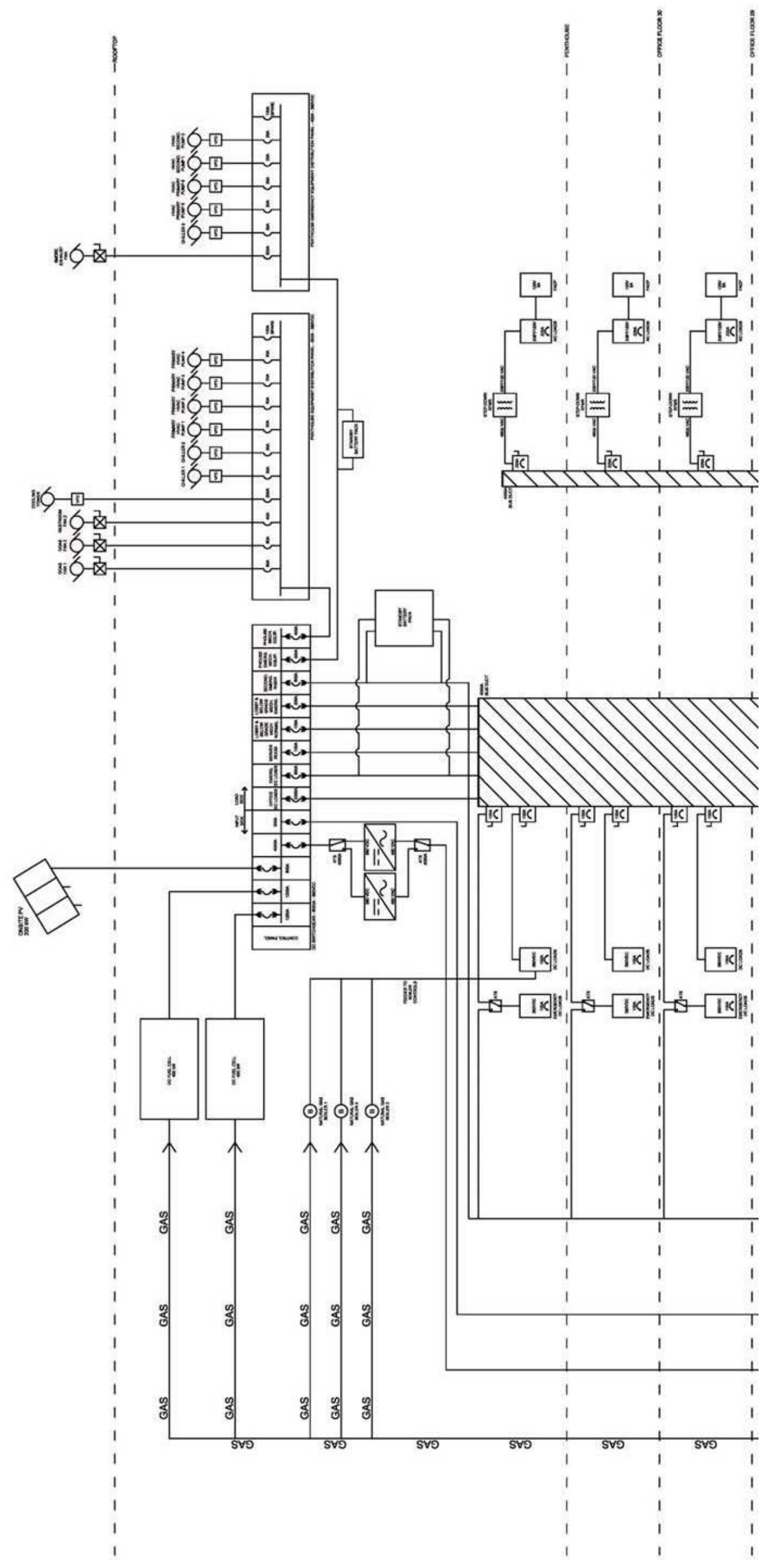


Figure 67: Riser Diagram - Top Half

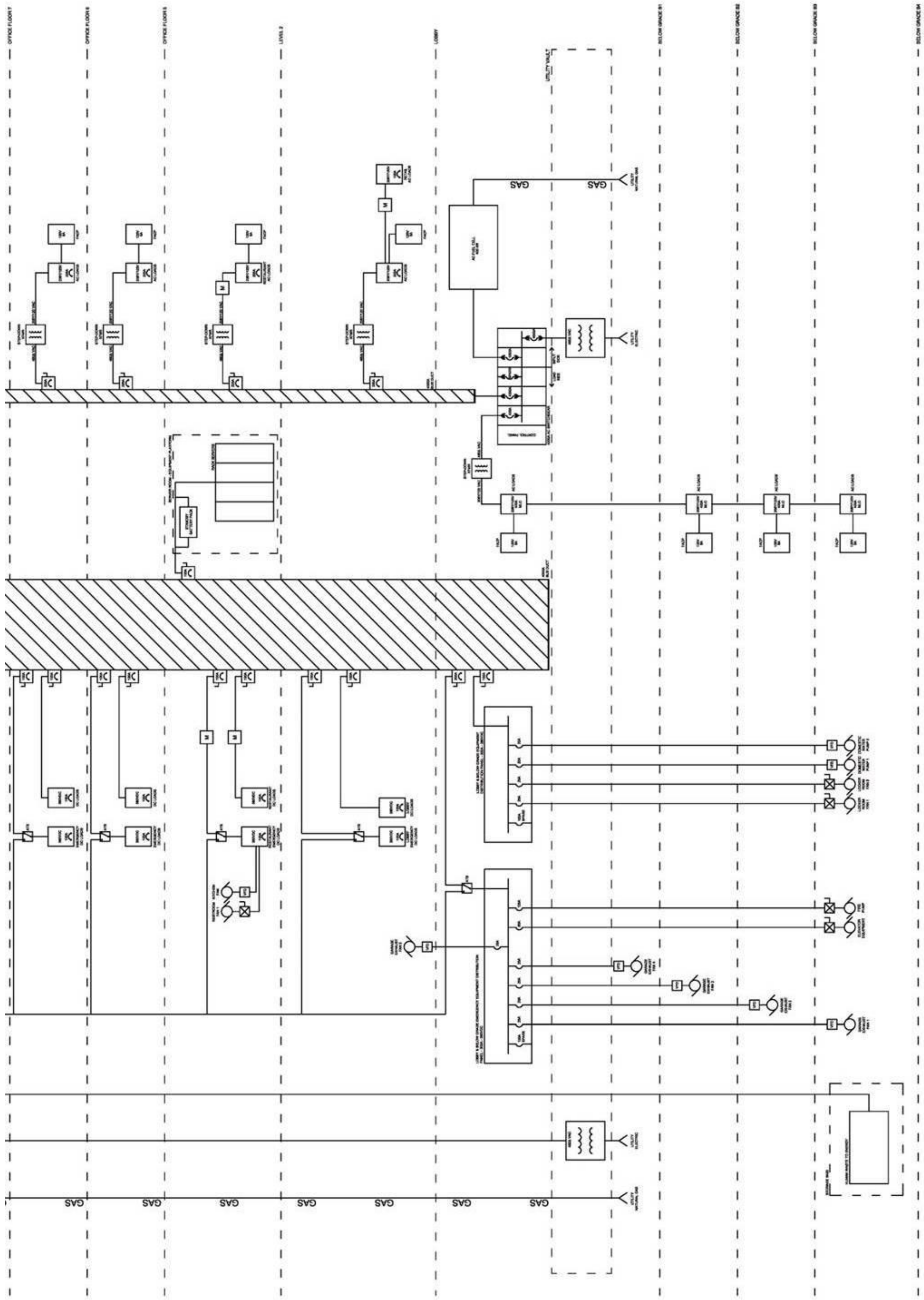


Figure 68: Riser Diagram - Bottom Half

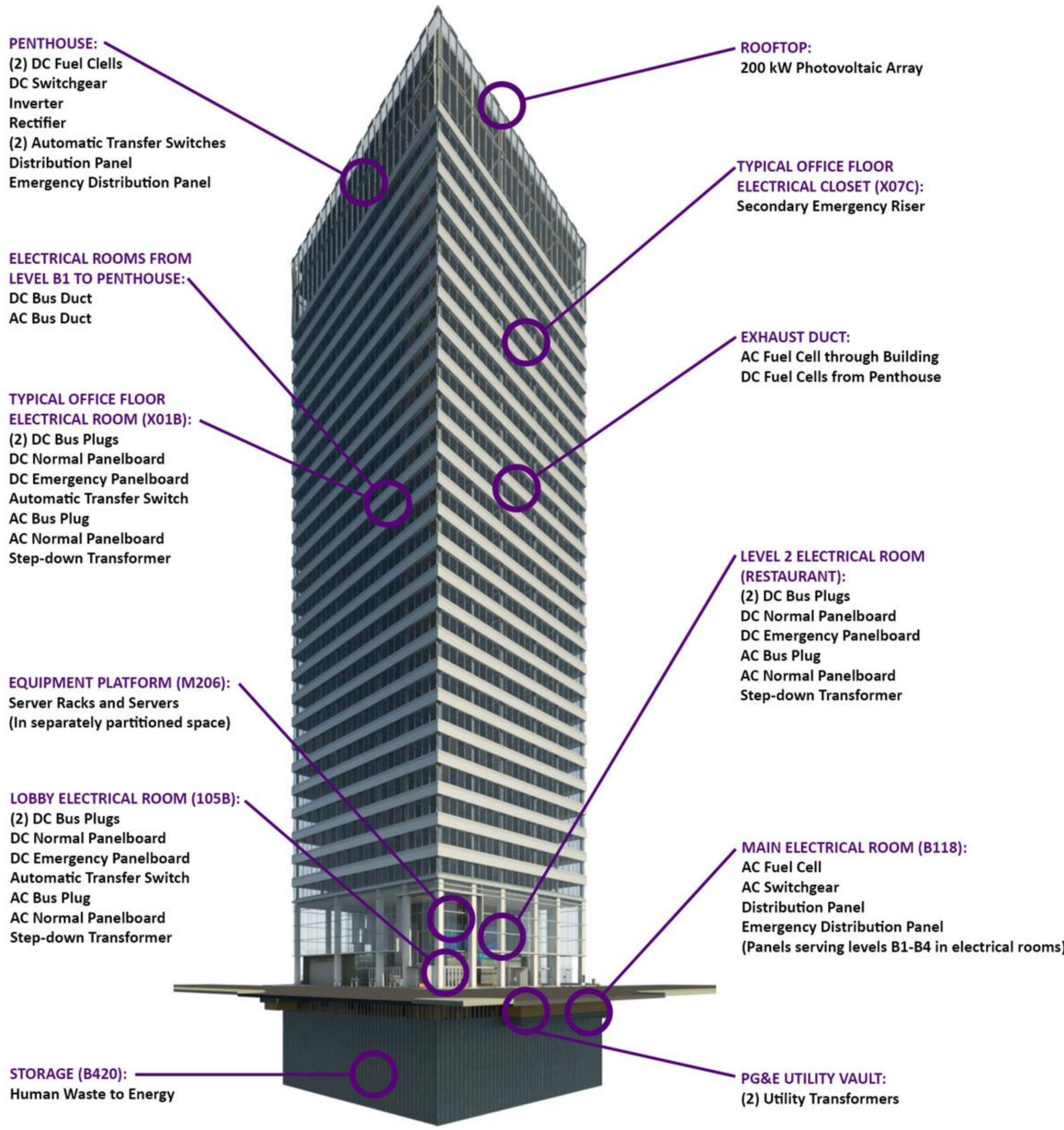


Figure 69: 350 Mission Electrical Space Layouts

This diagram details the locations of the various equipment and system components and gives a clearer picture of how all of the various parts work together to create the final overall lighting and electrical system.

Energy Summary

BUILDING ELECTRIC POWER DEMAND AND ENERGY SUMMARY

Location	DC Loads						AC Loads					
	Connected Load		Demand Load		Expected Load		Connected Load		Demand Load		Expected Load	
Interior Lighting												
Office	123.0	kW	123.0	kW	112.6	kW	19.5	kW	19.5	kW	19.5	kW
Lobby	2.0	kW	2.0	kW	2.0	kW	1.0	kW	1.0	kW	1.0	kW
Undesigned Spaces	31.3	kW	31.3	kW	22.4	kW	-	kW	-	kW	-	kW
Total	156.2	kW	156.2	kW	137.0	kW	20.5	kW	20.5	kW	20.5	kW

	DC Energy Use		AC Energy Use		Savings Source	Reference or Assumptions
Total Energy	454,273	kwh	62,282	kwh		See LPD analysis
Energy Savings	95,825	kwh	10,647	kwh	Daylight harvesting	See DA analysis
Energy Savings	17,922	kwh	-	kwh	5% efficiency increase for DC	
Expected Energy	340,525	kwh	51,634	kwh		

Location	DC Connected Load		DC Demand Load		DC Expected Load		AC Connected Load		AC Demand Load		AC Expected Load	
Receptacles (Plug load - not including desktops and monitors or lighting)												
Office	-	kW	-	kW	-	kW	393	kW	328	kW	105	kW
Lobby	-	kW	-	kW	-	kW	20	kW	17	kW	6	kW
Undesigned Spaces	-	kW	-	kW	-	kW	19	kW	14	kW	11	kW
Total	-	kW	-	kW	-	kW	432	kW	359	kW	121	kW

	DC Energy Use		AC Energy Use		Savings Source	Reference or Assumptions
Total Energy	-	kwh	447,275	kwh		See office power plan
Energy Savings	-	kwh	183,000	kwh	Plug load controls	See plug load in support
Expected Energy	-	kwh	264,275	kwh		

Location	DC Connected Load		DC Demand Load		DC Expected Load		AC Connected Load		AC Demand Load		AC Expected Load	
Computing Loads (Desktops and monitors on receptacles)												
Rack Servers	35	kW	35	kW	35	kW	-	kW	-	kW	-	kW
Desktops & Monitors	-	kW	-	kW	-	kW	621	kW	621	kW	242	kW
Total	35	kW	35	kW	35	kW	621	kW	621	kW	242	kW

	DC Energy Use		AC Energy Use		Savings Source	Reference or Assumptions
Total Energy	64,983	kwh	403,764	kwh		See computing power
Energy Savings	3,249	kwh	-	kwh	5% efficiency increase for DC	
Expected Energy	61,734	kwh	403,764	kwh		

Location	DC Connected Load		DC Demand Load		DC Expected Load		AC Connected Load		AC Demand Load		AC Expected Load	
Mechanical Equipment												
Office	15	kW	15	kW	15	kW	-	kW	-	kW	-	kW
Below Grade	36.5	kW	36.5	kW	36.5	kW	-	kW	-	kW	-	kW
Mechanical Platform	37.4	kW	37.4	kW	37.4	kW	-	kW	-	kW	-	kW
Penthouse	68.3	kW	45.3	kW	45.3	kW	-	kW	-	kW	-	kW
Rooftop	95	kW	95	kW	95	kW	-	kW	-	kW	-	kW
Total	252.2	kW	229.2	kW	229.2	kW		kW		kW		kW

	DC Energy Use		AC Energy Use		Savings Source	Reference or Assumptions
Total Energy	295,769	kwh	-	kwh		See mechanical loads
Energy Savings	14,788	kwh	-	kwh	5% efficiency increase	
Expected Energy	280,980	kwh	-	kwh		

Location	DC Connected Load		DC Demand Load		DC Expected Load		AC Connected Load		AC Demand Load		AC Expected Load	
Systems												
Fire Alarm	-	kW	-	kW	-	kW	37	kW	37	kW	9	kW
Telecom/Data	130	kW	130	kW	130	kW	-	kW	-	kW	-	kW
Total	130	kW	130	kW	130	kW	37	kW	37	kW	9	kW

	DC Energy Use		AC Energy Use		Savings Source	Reference or Assumptions
Total Energy	39,000	kwh	78,840	kwh		
Energy Savings	1,950	kwh	-	kwh	5% efficiency increase	
Expected Energy	37,050	kwh	78,840	kwh		

Location	DC Connected Load		DC Demand Load		DC Expected Load		AC Connected Load		AC Demand Load		AC Expected Load	
Miscellaneous												
Electrochromic glass	3	kW	3	kW	3	kW	-	kW	-	kW	-	kW
Total	3	kW	3	kW	3	kW		kW		kW		kW

	DC Energy Use		AC Energy Use		Savings Source	Reference or Assumptions
Total Energy	3,000	kwh	-	kwh		
Energy Savings	150	kwh	-	kwh	5% efficiency increase	
Expected Energy	2,850	kwh	-	kwh		

Table 34: Building Loads by System

Electric Power Demand Summary											
DC Loads						AC Loads					
Connected Load		Demand Load		Expected Load		Connected Load		Demand Load		Expected Load	
576.4	kW	553.4	kW	534.2	kW	1,110.1	kW	1,037.5	kW	392.4	kW

Expected Energy Use					
DC Energy			AC Energy		
Before Savings	857,024	kwh	Before Savings	992,161	kwh
After Savings	723,139	kwh	After Savings	798,514	kwh

Conservative Energy Estimate					
DC Energy			AC Energy		
1,000,000	annual	kwh	800,000	annual	kwh
Fuel cell analysis conducted assuming additional DC load as a conservative estimate in the event that projected DC energy savings are lower than expected. Server or mechanical expansion may result in larger DC energy use.					

Table 35: Building Load Summary

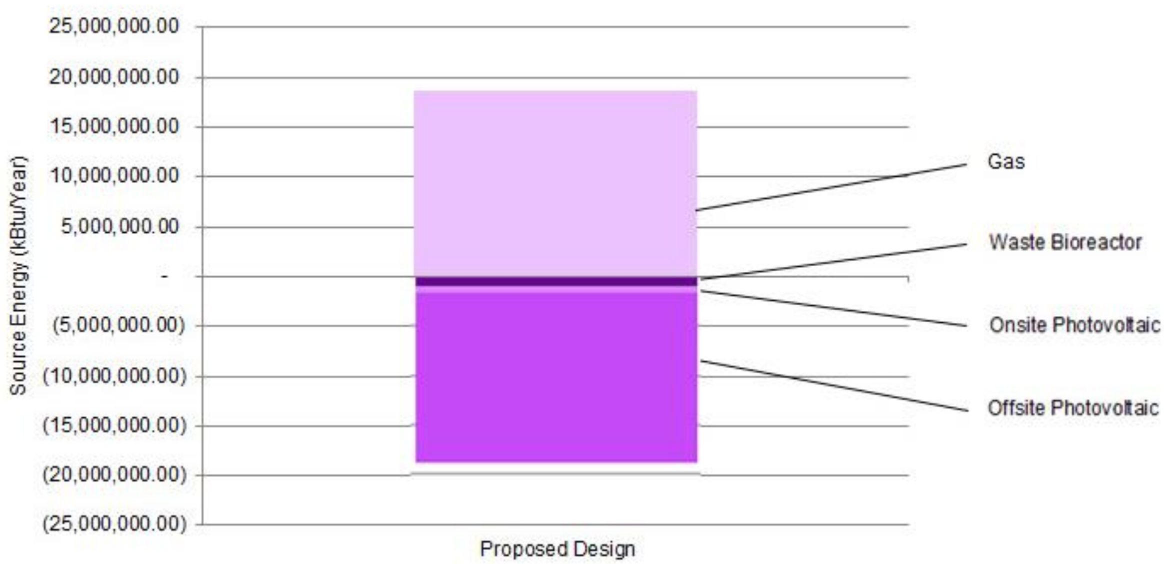


Figure 70: Energy Used and Generated

The table at the top of the page displays the annual expected AC and DC electrical energy use. These numbers were increased prior to conducting the fuel cell analysis to account for future increased use of the DC grid, primarily through the computing servers or mechanical equipment. The chart at the bottom shows that the building's annual energy use is returned to the grid through the three renewable energy generation sources.

BIBLIOGRAPHY

Websites

[1] "Commercial Flat Roof Grid-Tie Solar Panel Systems." Solar Electric Supply, Inc. http://www.solarelectricsupply.com/commercial-solar-systems/flat-roof

[2] "EMerge Alliance." EMerge Alliance. http://www.emergealliance.org/

[3] "Federal Business Energy Investment Tax Credit (ITC)." DSIRE USA. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F

[4] "List of Eligible Inverters per SB1 Guidelines." Go Solar California. http://www.gosolarcalifornia.ca.gov/equipment/inverters.php

[5] "Mapping California's Seafloor." California Ocean Protection Council. http://www.opc.ca.gov/

[6] "Power Supply System." Taipei 101. http://www2.taipei-101.com.tw/en/Tower/buildind_07-1.html

[7] San Francisco Department of the Environment and CH2M HILL. "San Francisco Urban Wind Map." San Francisco Energy Map. http://www.sfenergymap.org/

[8] "Self-Generation Incentive Program (SGIP)." PG&E. http://www.pge.com/en/mybusiness/save/solar/sgip.page

[9] "Supercritical Sanitation Systems: Neighborhood-Scale Sewage Treatment." Duke University, Pratt School of Engineering. http://sanitation.pratt.duke.edu/home

Publications/Books

[10] "A Practical Guide to Fire Alarm Systems." Central Station Alarm Association. http://www.csaaintl.org/2011FireAlarmBookONLINE.pdf

[11] DiLaura, David, Kevin Houser, Richard Mistrick, and Gary Steffy. The Lighting Handbook: Reference and Application. 10th ed. New York, NY: Illuminating Engineering Society, 2011.

[12] "LEED 2009 for New Construction and Major Renovations Rating System." U.S. Green Building Council. http://www.usgbc.org/Docs/Archive/General/Docs5546.pdf

[13] "Plug Load Circuit Controls: 2013 California Building Energy Efficiency Standards ." California Utilities Statewide Codes and Standards Team. http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Lighting_Controls_Bldg_Power/2013_CASE_NR_Plug_Load_Circuit_Control_Oct_2011.pdf

[14] "Server and Storage Sizing Guide for Windows 7 Desktops in a Virtual Desktop Infrastructure." VMware. https://www.vmware.com/files/pdf/view/Server-Storage-Sizing-Guide-Windows-7-TN.pdf

[15] Shalva, Anthony. "The ABC's of Fire Alarm Systems." IMSA Journal, May/June (2009): 42-45.

[16] "Total installed cost comparison study of motorized shading systems." Lutron Electronics, Inc.. http://www.lutron.com/TechnicalDocumentLibrary/367-1548.pdf

[17] Ryu, Myung-Hyo , Ho-Sung Kim, Jong-Hyun Kim, Ju-Won Baek, and Jee-Hoon Jung. "Test Bed Implementation of 380V DC Distribution System Using Isolated Bidirectional Power Converters ." *Energy Conversion Congress and Exposition* 2013 (2013): 2948-2954. http://ieeexplore.ieee.org/Xplore/home.jsp (accessed April 5, 2014).

Academic Vita

ROBERT J. LIVORIO

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Education:

Integrated Master/Bachelor of Architectural Engineering ~ Lighting/Electrical Option 2009 – 2014
The Pennsylvania State University ~ Schreyer Honors College University Park, PA
EIT Upon Graduation

Professional Experience:

Employer: HGA Architects and Engineers Milwaukee, WI
Electrical Engineering Department Intern: Electrical Design Focus Summer 2013

- Worked extensively in RevitMEP completing tasks such as placing, adjusting, and tagging lighting, electrical and telecommunication devices while coordinating locations with architecture and other engineering disciplines.
- Created and linked equipment schedules and updated one-line diagrams to accurately reflect the electrical loads and flow of power between substations, switchgear, distribution panels, and branch panels, taking into consideration multiple power branches.
- Performed various electrical project responsibilities, some of which included: power circuiting, mechanical load calculations and mechanical-electrical equipment coordination, wire sizing, voltage drop calculations, and panelboard phase load balancing

Employer: Astorino Architecture, Engineering, Interior Design, Design Build Pittsburgh, PA
Electrical Engineering Department Intern: Lighting Design Focus Summer 2012

- Used Revit, AutoCAD, and AGi32 to create and export 3D models for lighting calculations and space visualization and subsequently to adjust plans to reflect necessary changes.
- Searched manufacturer catalogs and online databases and worked with lighting agency representatives to find and customize suitable luminaires.

Associated Employment:

Penn State AE Lighting Lab Research Assistant Spring 2013 – Fall 2013

- Assisted in developing a prototype living space for the Pennsylvania Housing Research Center (PHRC) to test architectural light therapy systems and their effects on the aging of seniors.
- Included in the scope of work: addressing light sources to interface with a control system, creating the luminaires to house the light sources, wiring power and control cables from junction boxes to luminaires, testing software control capabilities throughout the process, and establishing the physical surroundings of the space.

Highlighted Coursework:

Interdisciplinary Collaborative Building Information Modeling (BIM) Studio Spring 2013

- Worked as the lighting/electrical engineer in a studio group that included one student from each of the following disciplines: architecture, landscape architecture, and mechanical, structural and construction engineering.
- Collaborated with each discipline to implement an energy efficient lighting and electrical system, including responsible daylighting, into a complete and cohesive building design.

Study Abroad:

Participant in the AE Department's "Sede di Roma" Program Summer 2011

- Satisfied credits to earn a minor in Architectural Studies
- Explored structural, daylighting, and design features of Roman and Italian architecture

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Skills: Proficiency: Revit Design Suite ~ AutoCAD ~ AGi32 ~ Microsoft Office ~ Adobe Photoshop
Familiarity: EQUEST and Energy Plus (By Spring 2013) ~ 3ds Max ~ Daysim ~ Photopia

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Involvement:

Project CANDLE Outreach Ambassador, Student Society of Architectural Engineers Mentor Member (2011 Executive Board), Penn State IFC/Panhellenic Dance Marathon organization executive board (2010-2012) and 2012 dancer, Illuminating Engineering Society Student Member, Engineering Orientation 2012 Mentor, Various Intramural Sports

Accolades:

Schreyer Honors College Academic Excellence Scholarship, Tau Beta Pi Engineering Honor Society Inductee and Scholarship Recipient, Herbert Wheeler Memorial Scholarship, Philadelphia Section of IES Scholarship