Final Report:

Architectural Engineering Senior Thesis

Sarah Miller
Lighting + Electrical Option

with advisors: Shawn Good & Leslie Beahm
9 April, 2014
University of Maryland: Prince Frederick Hall

PRINCE FREDERICK HALL
university of maryland

SARAH MILLER
lighting & electrical

BUILDING STATISTICS

function: University Housing
size: 185,522 GSF
number of stories: 7 floors + ground floor
construction dates: May 2012-August 2014
project cost: $66.8 million
delivery method: design-build

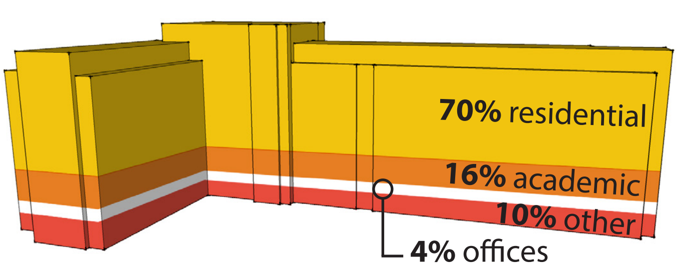
PROJECT TEAM

architect: WDG Architecture, PLLC
general contractor: Clark Construction
structural engineer: Cagley & Associates, Inc.
mep consulting: WFT Engineering, Inc.
civil engineer: Site Resources Inc.
landscape architect: Parker Rodriguez Inc.

ARCHITECTURE

Prince Frederick Hall is a new building located on the University of Maryland campus. The building programming provisions space for **academic rooms** on the ground and first floors of the building. Part of the first floor and all of the second through seventh floors are used for **dormitory rooms**. A combination of single, double occupant, and suites provide housing for a little over 450 students.

Red brick dominates the most surface area of the building and is is laid in a traditional running bond pattern. The first floor of the building is wrapped in a **limestone**-colored, special finish masonry unit. **Metal** is also used on the facade; it is used primarily to accent the curtain walls.



LIGHTING & ELECTRICAL

daylighting: Provided to spaces through numerous glazed openings. The lobby and social areas feature large, glass curtain walls. Classrooms are equiped with blackout shades.

lighting: Interior lighting is mostly fluorescent. Many troffers and recessed downlights are applied throughout the building. Exterior lighting is LED.

electrical: Power feeds into the building from the north side. Two 3000 kVA transformers, outside the building, provide 480/277V to the main electrical room. Power is transformed to 208Y-120V for all receptacles and lighting.

MECHANICAL

air distribution: Six air handling units and two roof top units circulate air throughout the building.

central systems: Prince Frederick Hall is connected to the campus' central steam distribution system.

academic spaces: Variable air volume (VAV) boxes are located throughout the ground and first floors. Separate heating and cooling coils provide extra control to individual spaces.

dormitory spaces: Each dormitory room is equipped with its own fan coil unit (FCU) that connects to the building's chilled water and hot water systems.

STRUCTURAL

foundation: Concrete columns carry the load of the building below grade to footings.

superstructure: The structure of the building is mostly steel-reinforced concrete. Typical 18x30 columns carry 8" concrete decks. Cantelievers on the 2nd floor are supported by post-tensioned concrete beams.

lateral system: Shear walls around stairwells and elevator cores resist lateral loads.

trellis: Located at the north and south entrances, this feature of the building is constructed mainly of hollow steel sections.

Executive Summary

The following studies pertain to Prince Frederick Hall, a new LEED Gold building for The University of Maryland. A major focus of this project is to promote sustainability for the campus. Programming for the building provisions space for academic rooms on the ground and first floors where the second through seventh floors, along with part of the first floor, are used for student housing. This thesis consists of four main studies: lighting, electrical, architectural, and mechanical. Both lighting and electrical are depth studies. The two breadths are integrated with these lighting and electrical studies for a cohesive report.

The first depth study conducted on this building is a lighting redesign for four spaces. To fully represent the gradient of public and private spaces, the four that were selected are: the entry plaza, the lobby, a seminar room, and a typical dormitory suite. Despite this variation in function, the binding factor between these spaces is the need for each to provide an effective learning environment for its occupants. Therefore, the concept used for the lighting design is discovery, where this is utilized in a unique way for each of the four spaces. To promote the LEED aspect of Prince Frederick Hall, part of the lighting studies involved more strictly adhering to IES recommendations to ensure maximum reduction of the lighting power density within each space. The power used by the existing lighting systems in these four spaces was 22,100 watts. After optimizing the lighting, this was reduced to 10,700 watts in the redesign, for a successful power reduction of 51%.

Three electrical studies comprised the second depth study. In the first of these, the effects of the lighting design changes were determined for the lighting branch circuits. By reducing the power usage by lighting, a few circuits were able to be converted into spares. However, the lighting changes were dispersed over enough circuits that they did not affect any major changes to the electrical system. The main portion of this electrical depth was used to determine that savings could be created by switching to a distributed transformer system, in place of the existing centralized transformers. RSMeans data was used to compare the materials cost difference for equipment and wiring. By using several smaller transformers, instead of two large ones, and reducing the necessary wire sizes, the materials cost savings is approximately $71,000. Finally, a seven-level short circuit calculation was conducted to check the available fault current at critical points along this redesigned dormitory riser.

To reinforce the LEED goal for Prince Frederick Hall, the two breadth studies are focused on increasing sustainability. Architectural features have been applied to provide passive solar shading; this reduces the requirements on the mechanical system by a net 83,500 BTUs per year. To accomplish this, shading was applied to the most typical dormitory room at each orientation of the building. A different shading system was used at each orientation to maximize the unshaded area of each window in the winter and minimize the unshaded area of each window in the summer. This highly visible architectural system was then integrated into the facade. This is a practical addition to the building in that it provides mechanical system savings, but it also very visibly communicates the sustainable goals of Prince Frederick Hall and for The University of Maryland.

Table of Contents

Acknowledgments

I would like to thank the following individuals who helped make this thesis possible:

Justin Hollier | Senior Project Manager, Clark Construction Group
Lee Brandt | Associate Principal, HLB
Lee Waldron | Principal, GWA Lighting
Dr. Kevin Houser | Academic Advisor, Professor, Penn State University

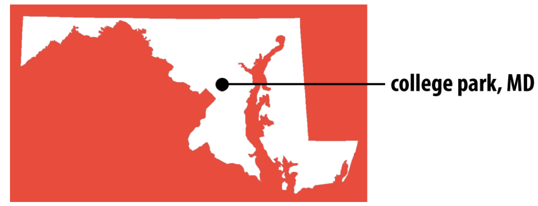
Shawn Good | Thesis Advisor, Lighting Department Head, Brinjac Engineering
Leslie Beahm | Electrical Advisor, Senior Electrical Engineer, Reese Engineering

My family and friends for their support.

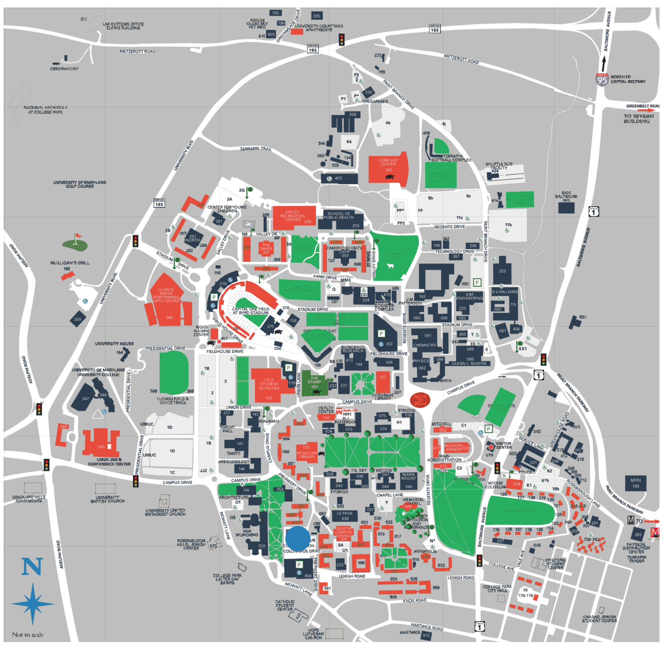
-SARAH

Introduction

Prince Frederick Hall is a new building located on The University of Maryland's campus, in College Park, Maryland. This sustainable addition to campus is targeting a LEED Gold certification. Some sustainable features of the building include: bike racks, recycling on every floor, efficient plumbing and mechanical equipment, and sustainable construction practices.



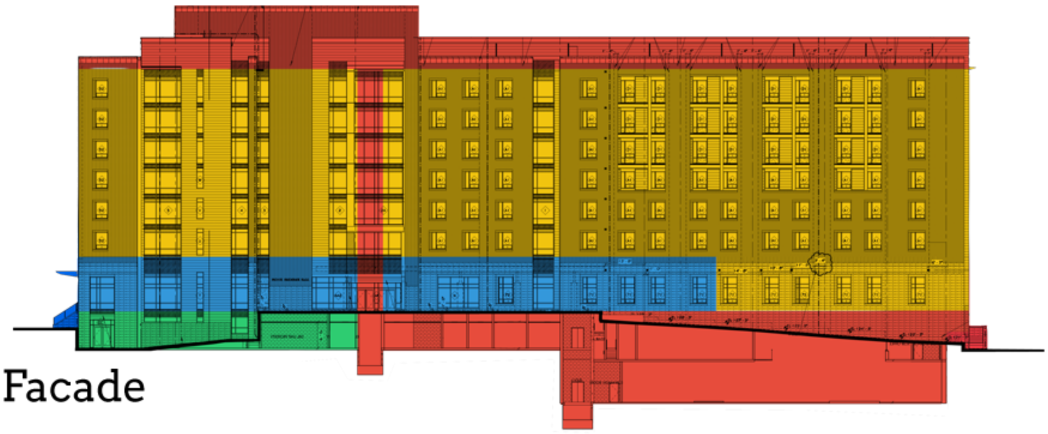
This building is comprised of 7 stories and is located on the southwest side of the campus, as shown on the campus map below. The primary function of the building is for housing for students of the University of Maryland. Housing for 464 students is provided by a combination of dormitory suites, double-occupancy bedrooms, single-occupancy bedrooms, and staff apartments. Building residents have access to amenities such as: study spaces, social lounges, laundry rooms on every floor, and air conditioning. Several classrooms are also located throughout the building: 3 on the first floor, and 2 on the lower floor. The lower floors, however, are primarily used for administrative offices and mechanical space.



Below is an exterior rendering, from the architect, of the South facade. This demonstrates the architectural form of the building. Materials have been selected to coordinate with nearby buildings, where the georgian red brick is the standard used throughout campus. Surfaces of brick and glass curtain walls are mixed to create visual interest across the facade and give the building a hint of modern design.

rendering of South facade (WDG Architecture)

The building can be broken into the following categories: **academic** which includes classrooms and the main lobby, **residential** spaces are the dormitory rooms that make up most of the upper floors, **administrative** offices are located in the basement, and **other** spaces such as mechanical rooms and elevators.



South Facade

1st Floor

2nd - 7th Floors

Building Statistics

GENERAL DATA
building name: Prince Frederick Hall
location & site: University of Maryland
occupancy & function: University Housing
size: 185,522 GSF
number of stories: 7 floors + ground floor
construction dates: May 2012-August 2014
project cost: $66.8 million
delivery method: design-build

PROJECT TEAM
owner: University of Maryland
architect: WDG Architecture, PLLC
general contractor: Clark Construction
structural engineer: Cagley & Associate, Inc.
mep & fire protection: WFT Engineering, Inc.
civil engineer: Site Resources Inc.
landscape architect: Parker Rodriguez Inc.

Sustainability Features

"Planned LEED Gold Certification as a 'green' building which will include many sustainable and energy efficient design features."

-University of Maryland's Department of Residence Life website

Features of the building include:

- heating and cooling systems designed to perform 22% better than baseline performance
- bike locker on ground floor & additional bike racks for visitors
- recycling facilities located on each floor
- water-efficient plumbing fixtures save more than 30% over conventional fixtures
- energy-efficient windows, occupancy sensor lighting controls, and elevators with regenerative braking
- recycled content is around 10% overall of the building cost
- 10% of building materials and fixtures from within 500 miles of project site
- use of low-emitting materials that off-gas fewer harmful compounds
- more than 75% of all construction debris will be diverted from landfills and processed by recyclers for use in other future construction projects in the region
- construction site surrounded by fencing to prevent erosion and storm water runoff into local storm drains

Engineering Systems

The following a summary of the existing conditions within the building. This is to give a brief understanding of building systems, construction methods, and design concepts.

STRUCTURAL

substructure: Concrete columns carry the load of the building below grade to footings.
superstructure: The structure of the building is mostly steel-reinforced concrete. Typical 18x30 columns carry 8" concrete decks. Cantilevers on the 2nd floor are supported by post-tensioned concrete beams.
lateral system: Shear walls around stairwells and elevator cores resist lateral loads.

MECHANICAL

Prince Frederick Hall is connected to the campus' central steam distribution system. Six air handling units and two roof top units circulate air throughout the building. Air flow is regulated locally by VAV boxes, and separate heating and cooling coils provide extra control to individual spaces.

ELECTRICAL & LIGHTING

Medium voltage is provided to the building from the university's grid. Two 3000 kVA transformers, outside the building, provide 480/277V to the main electrical room for mechanical loads and outdoor lighting. Power is transformed to 208Y-120V for receptacles and interior lighting. Interior lighting is mostly fluorescent. Many troffers and recessed downlights are applied throughout the building. Exterior lighting is LED.

CONSTRUCTION

The general contractor on this project is Clark Construction. The building began construction in May of 2012 and is projected to finish in August of 2014. The cost of Prince Frederick Hall is approximately $360/SF.

FIRE PROTECTION

The main FACP is located on the first floor, in the fire alarm control room. The fire alarm control room is within the envelope of the building, but separated by a firewall and only accessible from a door on the outside. A FATC is located on each dormitory floor, and on the ground floor, in an electrical closet. Each dorm room is equipped with a alarm speaker, strobe, and smoke alarm.

TRANSPORTATION

Circulation is provided to the residential floors via three elevators. Two additional elevators provide service access throughout the building.

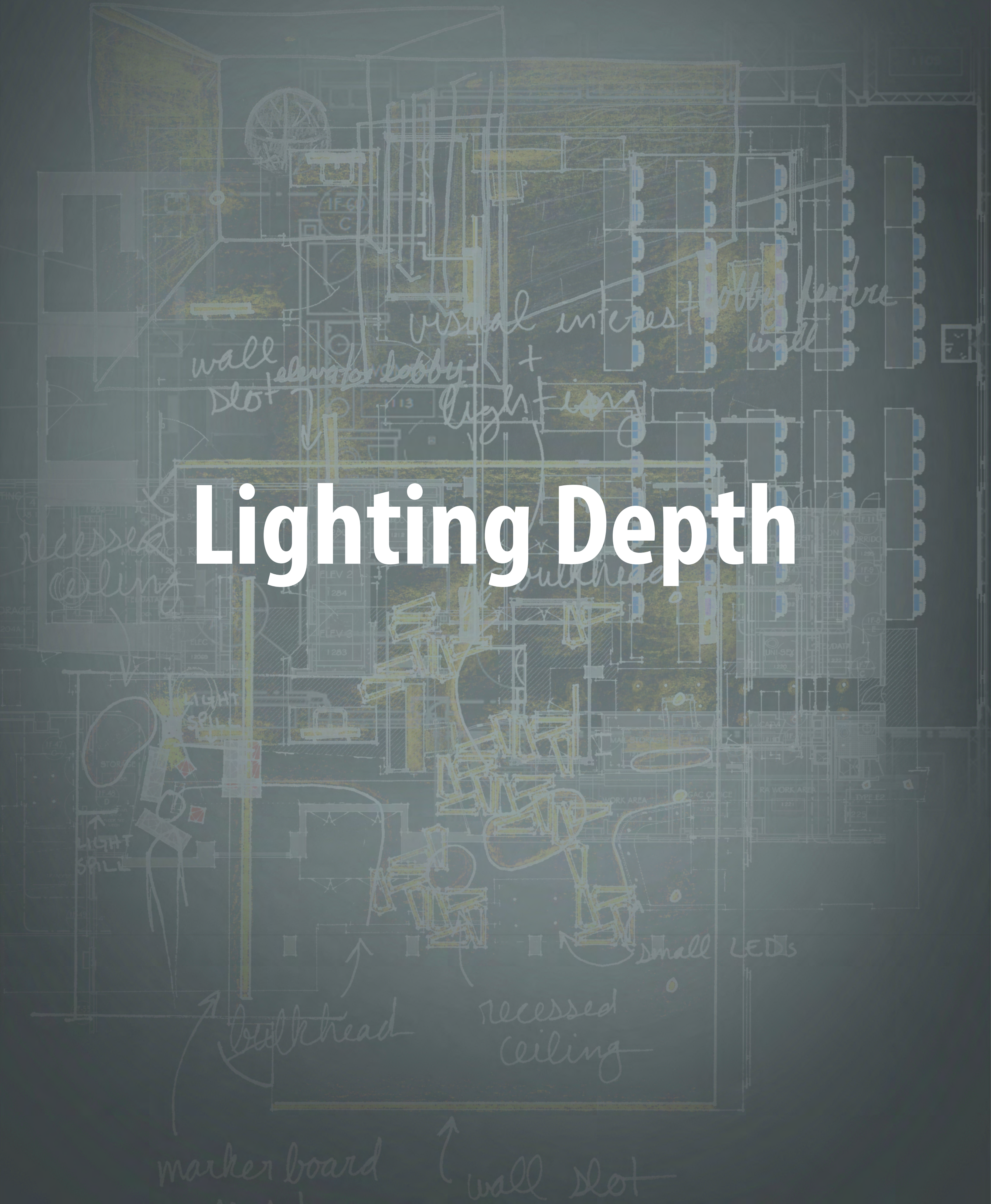
TELECOMMUNICATIONS

Telecom service is provided by the university. Main service enters the building at the northwest corner. Most outlets are dual tel/data outlets wired with Cat5e. All classrooms, first floor corridors, and study lounges have their own wireless access point. Data is distributed throughout the upper residential floors through two tel/data risers that feed each floor. Dormitory rooms have coax connections and data connections, no telephone connections are provided in these areas.

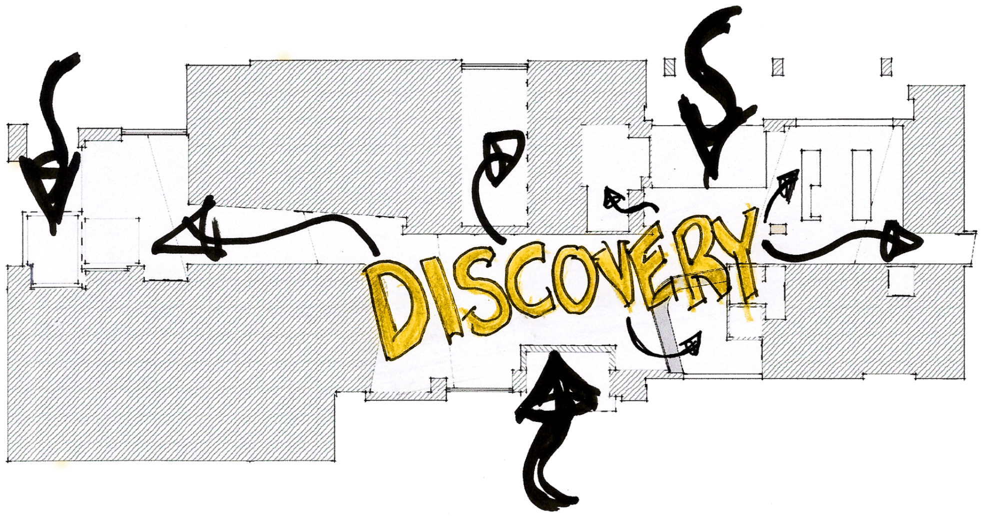
SPECIAL SYSTEMS

Security and access control is an important aspect of this building that requires additional systems. The main form of access control is through magnetic door contacts and card readers. Areas protected with this system are: mechanical and electrical rooms, tel/data rooms, all elevators, all access points on the first and ground floors, and all dormitory rooms. Residential floors have RF readers installed above the ceiling. Security protection outside the building occurs in two forms. Three blue-light emergency phones are located around the outside, not more than 600 feet away, and six exterior CCTV cameras are mounted around the perimeter, on the roof level.

Lighting Depth



Lighting Introduction

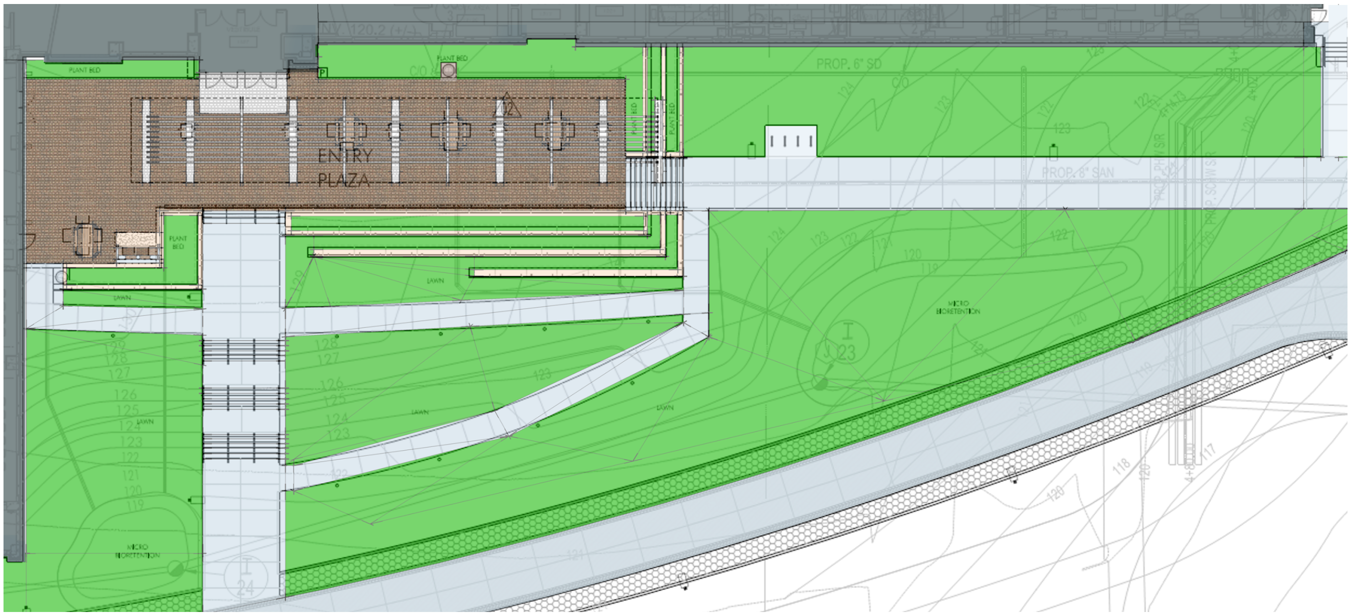


This building's composition represents a gradient of public to private spaces. But the one binding factor across this variation is that the primary function of every space is to provide a good learning environment. This can be summarized into the singular concept of **DISCOVERY**. This concept is the driving force behind the lighting designs completed for this report. Through this concept, the lighting is able to express the building's function in multiple ways. In that occupants must literally be able to navigate through the building to discover new spaces, and discovery in sense that the lighting must provide an effective learning environment. Discovery is applied in a unique way to each of these four spaces: an outdoor entry plaza, the lobby, a seminar room, and a dormitory suite.

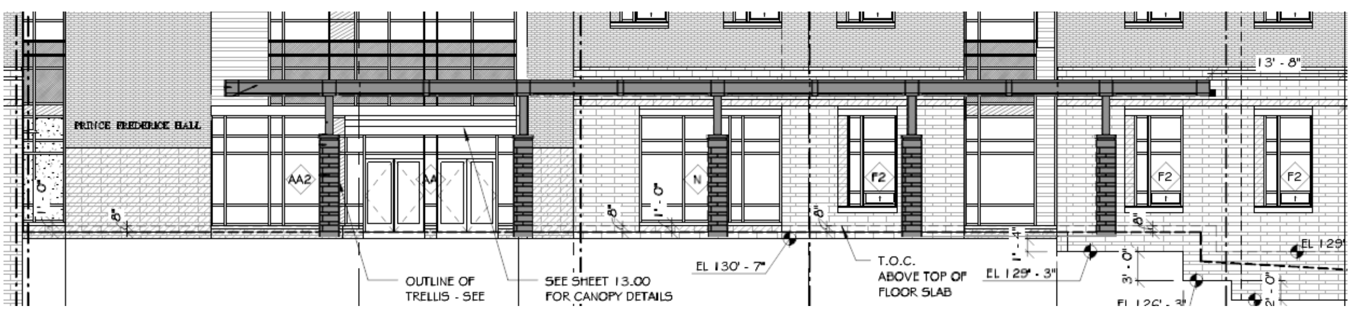
Entry Plaza

This is the most public of the four spaces. It is located on the south side of the building, and functions as both a circulation space and an outdoor social space with seating. Therefore, the lighting design for this space must apply the concept of discovery in two different layers. Safe levels of light must be provided for occupants transitioning through the plaza. This is in contrast to the casual atmospheric lighting that is well-suited to social areas. Both layers must work in concert to achieve the ultimate goal for this space: discovery of the building.

Spatial Environment



This brick patio serves as a transition space and as a social gathering space. A trellis provides shade and visual interest close to the building. But for the most part, this space is unprotected from the elements. Under the trellis is where the main seating area is located. Adjacent to these tables is a high traffic area with access to the front doors of the building. It is important to note that the building facade adjacent to the entry plaza is largely comprised of glass curtain walls, where light from the interior of the building will affect this outdoor space. This portion of the building's south facade is shown below.



Design Approach

The entry plaza's lighting is important to help visitors discover the building via wayfinding and guidance.

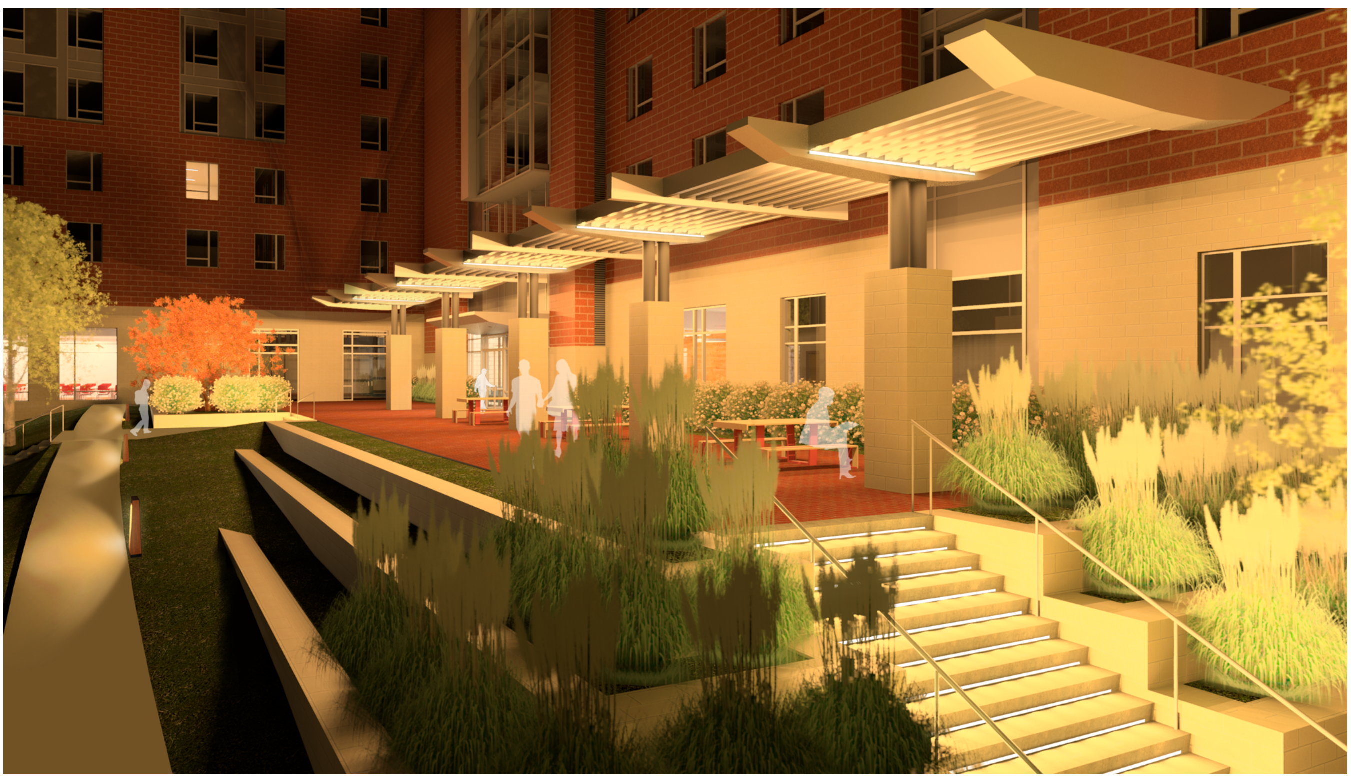
> **WELCOMING ENTRANCE:** This is the best opportunity to provide a welcoming entrance to help visitors discover the building at night. One factor of this is to increase the safety around the building after dark by providing adequate lighting. The entry vestibule on the south facade is mostly glass that will allow light from the lobby to clearly indicate the main doors. Therefore lighting is integrated into the stairs and trellis to help direct visitors to the entrance. A tertiary entrance, located on the west

side of the plaza does not need its own lighting system, as this is a daytime classroom entrance only.

SOCIAL GATHERING: The architect has provisioned space for some seating on the plaza, which is addressed by this lighting design. In this area, social discovery is reinforced by the semi-indirect, ambient lighting in the seating area. The architectural form of the trellis is both highlighted and utilized by this integrated lighting.

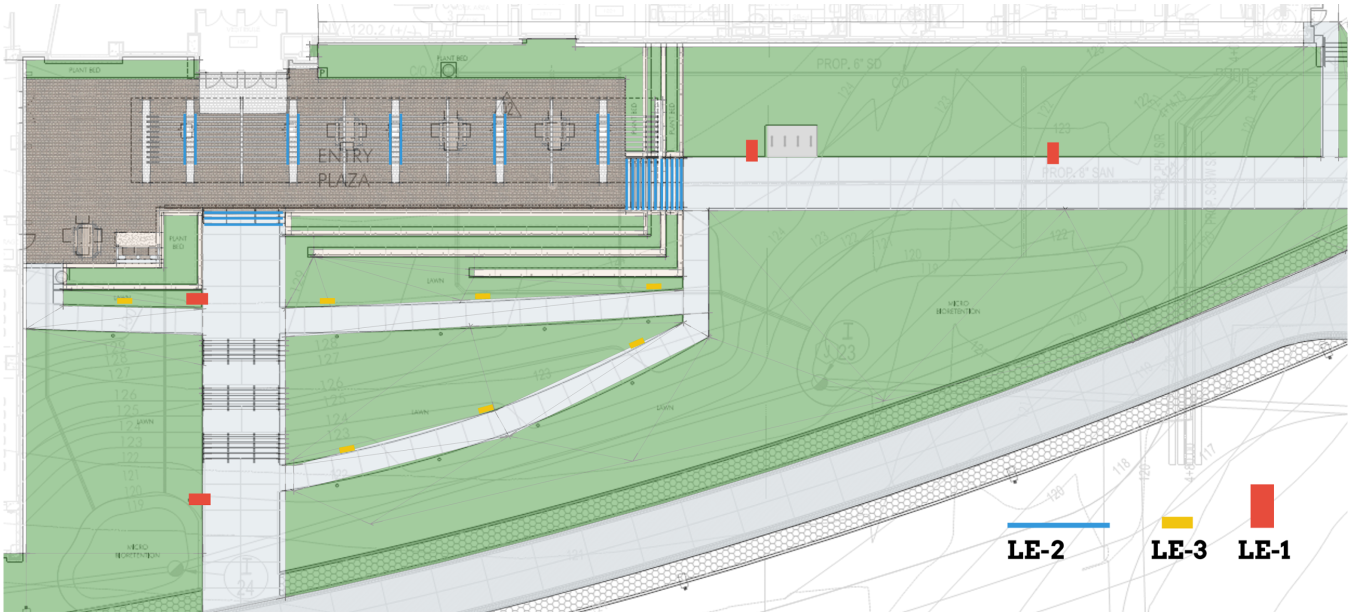
URBAN SKY GLOW: As a targeted LEED Gold project, this lighting design also focuses on reducing the uplight used on the exterior of the building. This is important because as a LEED building, every part of the design should help achieve its sustainability goals. Also due to the high occupancy density of the dormitory floors at night, there is little need to illuminate the facade of the upper floors. Glow from the interior will reveal the building's form; where exterior lighting will only add to surrounding urban sky glow, along with installation and maintenance costs. Therefore, on the entry plaza, no fixtures are used that direct light upwards.

Lighting Layout



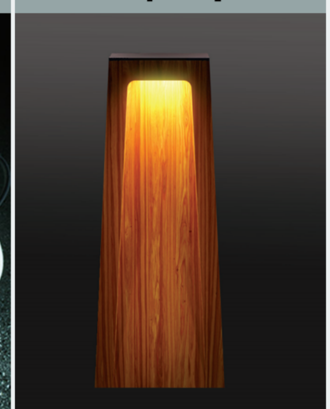
east side of entry plaza

University standard pole fixtures, labeled on the plan as LE-1, are applied outside of the main plaza area to provide safe levels of lighting from the building to the curb. Along the handicap ramp that traverses this distance, bollards, LE-3, are used for extra illumination. There are two main steps up onto the plaza, and these feature integrated LED strips, LE-2. These bright stairs clearly indicate where the main entrance of the building is located. Finally, the same LED strips are also integrated into the trellis, for an indirect lighting effect at the seating areas.



entry plaza lighting plan

Lighting Equipment*

LE-1: by LSI Industries	**LE-2:** by LED Linear	**LE-3:** by Cooper
		
Input: 138 watts	**Input:** 1.4 watts/ft	**Input:** 8 watts
Output: 1000 lumens	**Output:** 124 lumens/ft	**Output:** 57 lumens
Lamp: LED	**Lamp:** LED	**Lamp:** LED

LE-1: The University of Maryland's standard 15' pole fixture
LE-2: fully encapsulated IP67 protected flexible LED light, for outdoor applications
LE-3: exterior rated linear LED module in a 30" tall wood bollard

*see Appendix B: Lighting for complete schedule of equipment and LLF calculations

Calculations and Metrics

Criteria for lighting levels are based on IES recommendations[3]. All lighting levels are given in units of lux. The first two criteria are for canopied building entries/exits, and paths to curb with a high activity level. To promote use of the outdoor seating area, the illuminance criteria list here are intended for lobby seating areas, distant from entries. This ensures that there will be enough light for students to use this area at night for socialization. The existing values shown in the table below are for the lighting designed for the existing building; these are used for a comparison to this lighting redesign.

ASHRAE 90.1 gives power use requirements for outdoor spaces of this type. However, it was more important for this space to show that the existing system could be improved. Therefore the power density is not compared to ASHRAE values, but to the existing system's power density. Using this comparison, the new lighting system uses 10% less watts.

LIGHTING LEVELS

	General Illumination			Paths to Curb			Seating Areas		
	Criteria	Existing	Thesis	Criteria	Existing	Thesis	Criteria	Existing	Thesis
E (horizontal)	30	30	50	4	11	30	50	31	81
E (vertical)	15						15	3	31
Avg:Min							4:1	1.8:1	2.5:1

POWER USE

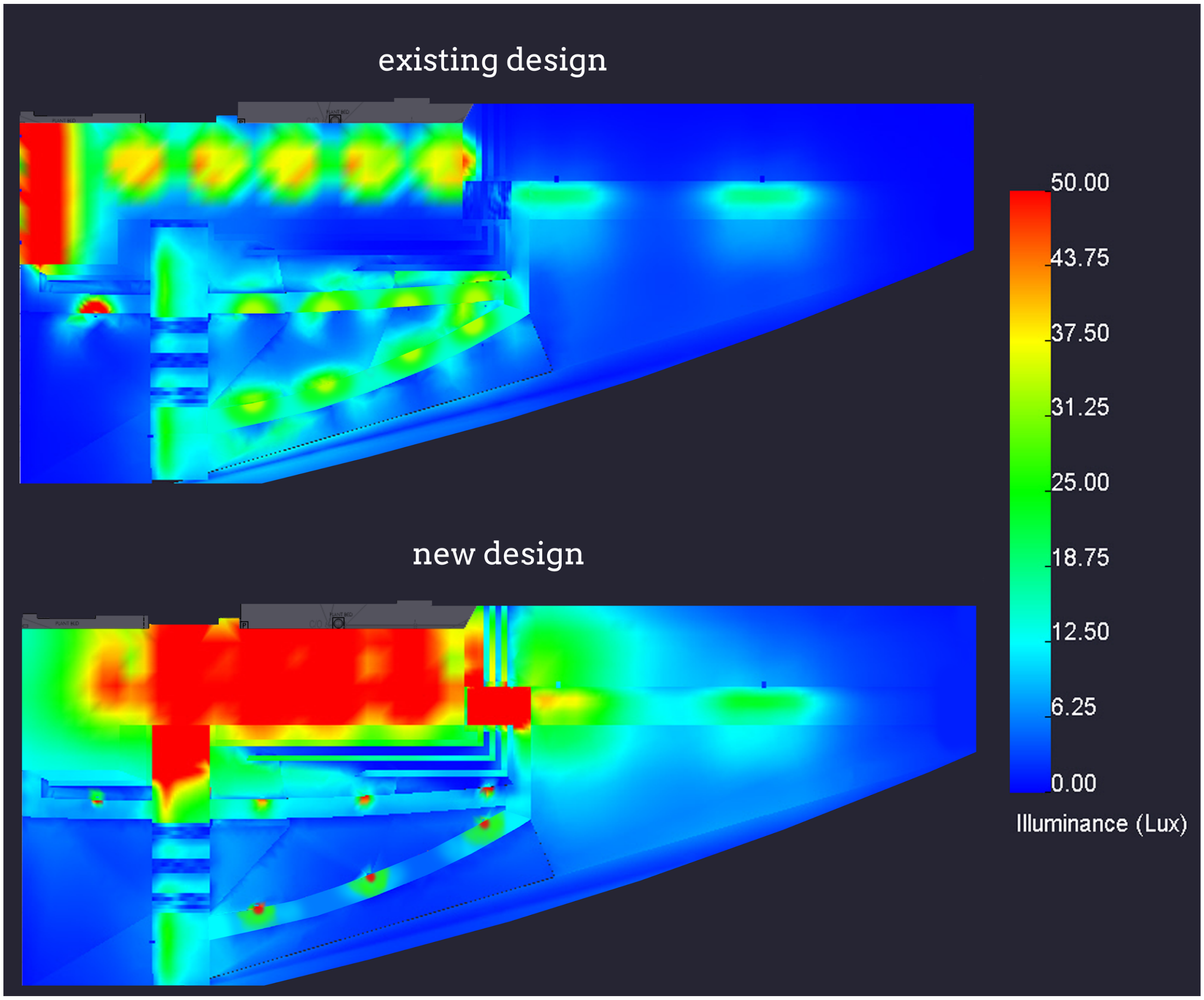
Existing LPD	Area (SF)	Total Watts	LPD	Target LPD	% Difference
0.09	12,300	987	0.08	0.09	10.80%

Criteria Evaluation

This is an important opportunity to provide a welcoming entrance to Prince Frederick Hall. Part of this involves maintaining safe light levels throughout the circulation areas of the plaza, as per IES Recommendations[3]. But there are also seating areas on the plaza that need to be addressed with higher light levels and more indirect lighting for a comfortable atmosphere.

QUANTITATIVE

To determine energy savings of this new lighting design, the total watts used was compared to the watts used in the existing design. As shown in the above tables, the new design is more effective at meeting IES recommendations for light levels and also uses 10% less energy than the existing design. In this new design, the grazing light applied to the underside of the trellis bounces semi-indirect light down onto the seating area for a brighter and more evenly illuminated space. This is shown in the following diagram, where the scale is set to 50 lux, the IES recommendation for an outdoor seating area. This means that areas shown in red are bright enough to meet this recommendation for horizontal illuminance of outdoor seating areas.



QUALITATIVE

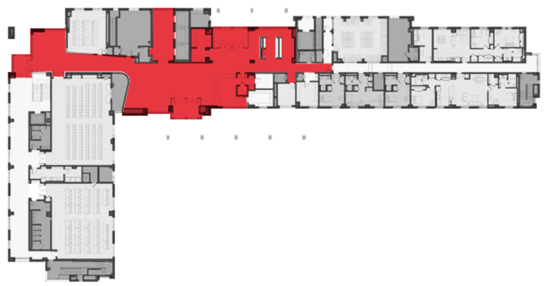
The above pseudo-color diagram shows a comparison of these two lighting schemes. In the new design, lighting is focused where it is needed most: on the main entrance and seating areas. This means that a clear delineation is made between the main entrance on the plaza and the tertiary entrances, located on the far west of the plaza.

SUSTAINABILITY

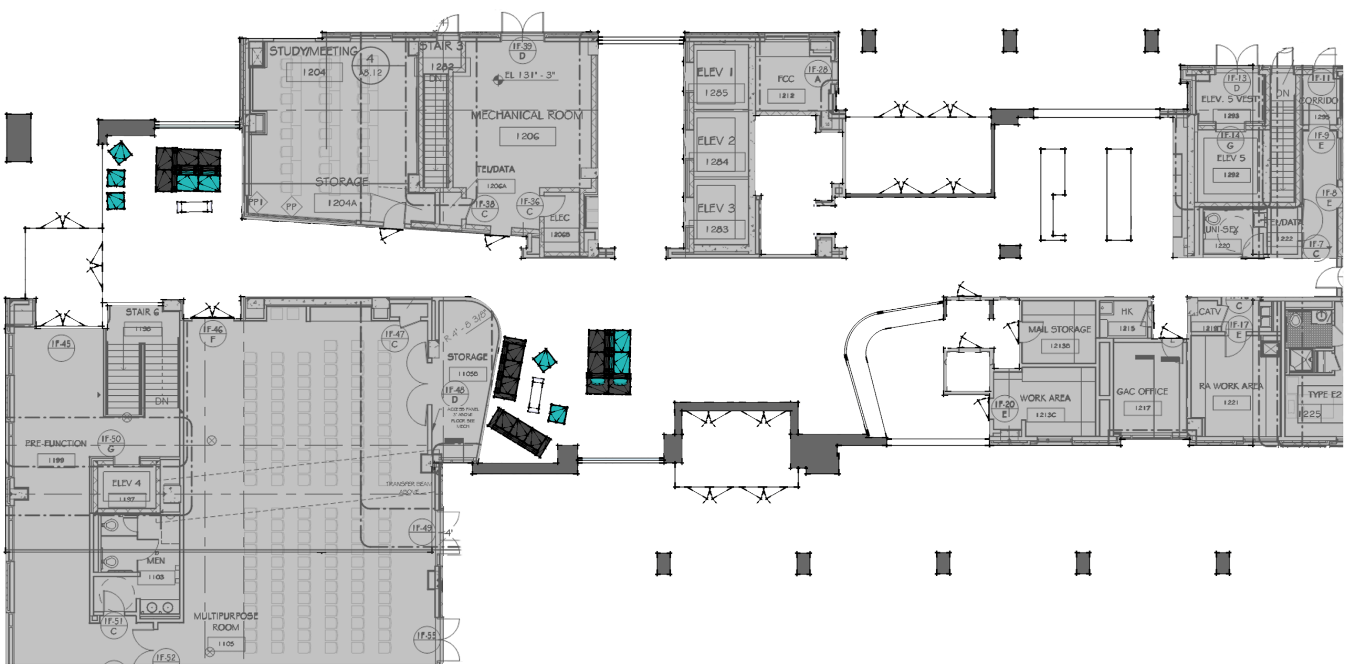
This design features sustainability in two different ways. One is that it uses less energy to provide a lighting design that better meets IES recommendations. The second green aspect of this design is that it accomplishes its goals without using any upward-facing fixtures; thus helping to maintain dark skies over The University of Maryland's campus.

Lobby

As the main entrance, there is tremendous opportunity for the lighting in this space to set the mood of the building. And due to the atypical shape of the lobby, there is a need for the lighting to help occupants navigate to their intended destination. The lobby contains access points to all the building's main functions, ranging from public to private. By applying different lighting techniques to these areas, visual differentiation will invite occupants to discover the space around them.



Spatial Environment



The lobby provides access to all of the main functions of the building. Three vestibules provide access from the exterior, where the south vestibule accesses the entry plaza. The lobby serves as the main circulation to the academic spaces on the west side of the first floor, dormitory spaces on the upper floors, and other services throughout the building. Located within the lobby is a front desk, elevator lobby for building residents, seating areas, and mailboxes.

Design Approach

In the lobby, discovery is applied in the sense of wayfinding. By juxtaposing varying lighting techniques, attention is called to the difference between public and private spaces. In a large space such as this lobby, it is important to create division. The following are some of the goals for the lighting design in this space.

AUGMENT WAYFINDING: With so many different spaces served by this irregularly shaped lobby, it is important to help visually differentiate these areas. This will aid in visitors' discovery of the building.

HIGHLIGHT ARCHITECTURE: With so many other strictly functional spaces in the building, this is one of the few places to celebrate the architecture and inject a sense of playfulness into the design. Additionally, this will help create a good impression for visitors of the building.

JUXTAPOSE PUBLIC & PRIVATE: Discovery, as discussed, is applied in the sense of wayfinding. Contrasting lighting techniques are used in different areas to reinforce the difference between public and private.

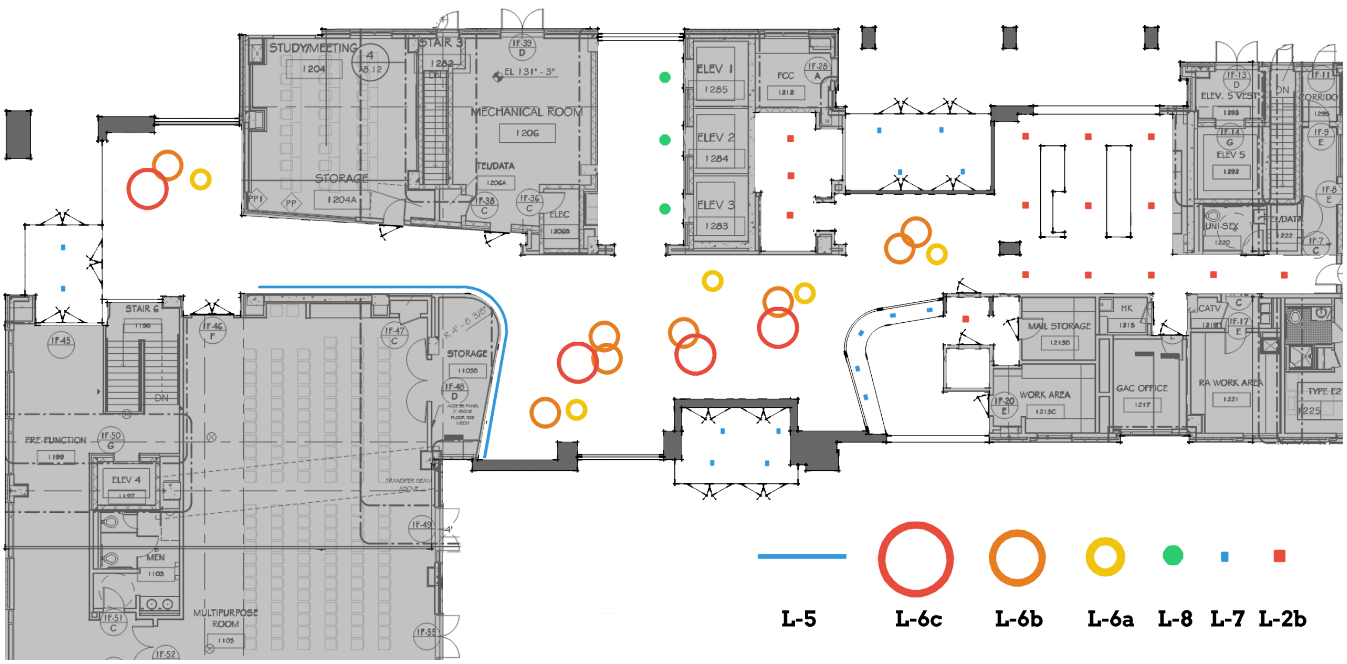
WELCOMING ENTRANCE: The most effective way to accomplish this is to ensure bright, uniform light levels throughout the space. Accomplishing the other three criteria will also provide a more welcoming entrance for the building.

Lighting Layout

lobby seating area

from right: elevator lobby, front desk, lobby south entrance

west lobby entrance



lobby lighting plan

Lighting Equipment*

L-6: by Eureka	**L-5:** by LED Linear	**L-7:** by iGuzzini	**L-8:** by Eureka	**L-2b:** by Lightolier
				
Input: 40/64/87 watts	**Input:** 1.4 watts/ft	**Input:** 4.2 watts	**Input:** 40 watts	**Input:** 19.8 watts
Output: 3880/6200/8530 lumens	**Output:** 124 lumens/ft	**Output:** 300 lumens	**Output:** 1800 lumens	**Output:** 1000 lumens
Lamp: LED	**Lamp:** LED	**Lamp:** LED	**Lamp:** 2 - 18W CFL	**Lamp:** LED

L-6: three different sizes of these large, circular pendants are used for general illumination
L-5: LED tape in the wall slot provides indirect, grazing light
L-7: this small LED is used in the vestibules and at the front desk
L-8: pendants located in the elevator lobby
L-2b: downlights with higher output, located around residential mailboxes and back hallway

*see Appendix B: Lighting for complete schedule of equipment and LLF calculations

Calculations and Metrics

Numerical criteria for this space are based on IES recommendations and ASHRAE 90.1. Lighting levels are compared below, in units of lux, for criteria values, calculations of the existing lighting design, and calculations of the lighting redesign. The general illumination and reception desk criteria are based on values given for educational facilities' transition spaces, where each of these is considered to be a lobby and information desk, respectively. The values for the vestibules are from common applications, building entries of high activity at night. The elevator lobby values are based on the recommendations from common applications, elevator cab thresholds. And the reading/work area criteria is from common applications, transition spaces, reading/work areas.

According to ASHRAE 90.1 a lobby of this type should target a lighting power density of 0.90 watts/ft^2.

LIGHTING LEVELS

	General Illumination			Reception Desk			Vestibules		
	Criteria	Existing	Thesis	Criteria	Existing	Thesis	Criteria	Existing	Thesis
E (horizontal)	100	251	251	150	293	205	50	142	79
E (vertical)	30	121	177				30	98	41
Avg:Min	4:1	6:1	2.2:1	4:1	1.7:1	1.6:1	2:1	3.3:1	1.9:1

	Elevator Lobby			Reading/Work Area		
	Criteria	Existing	Thesis	Criteria	Existing	Thesis
E (horizontal)	50	173	60	150	237	244
E (vertical)				50	72	105
Avg:Min	2:1	2.2:1	3:1			

POWER USE

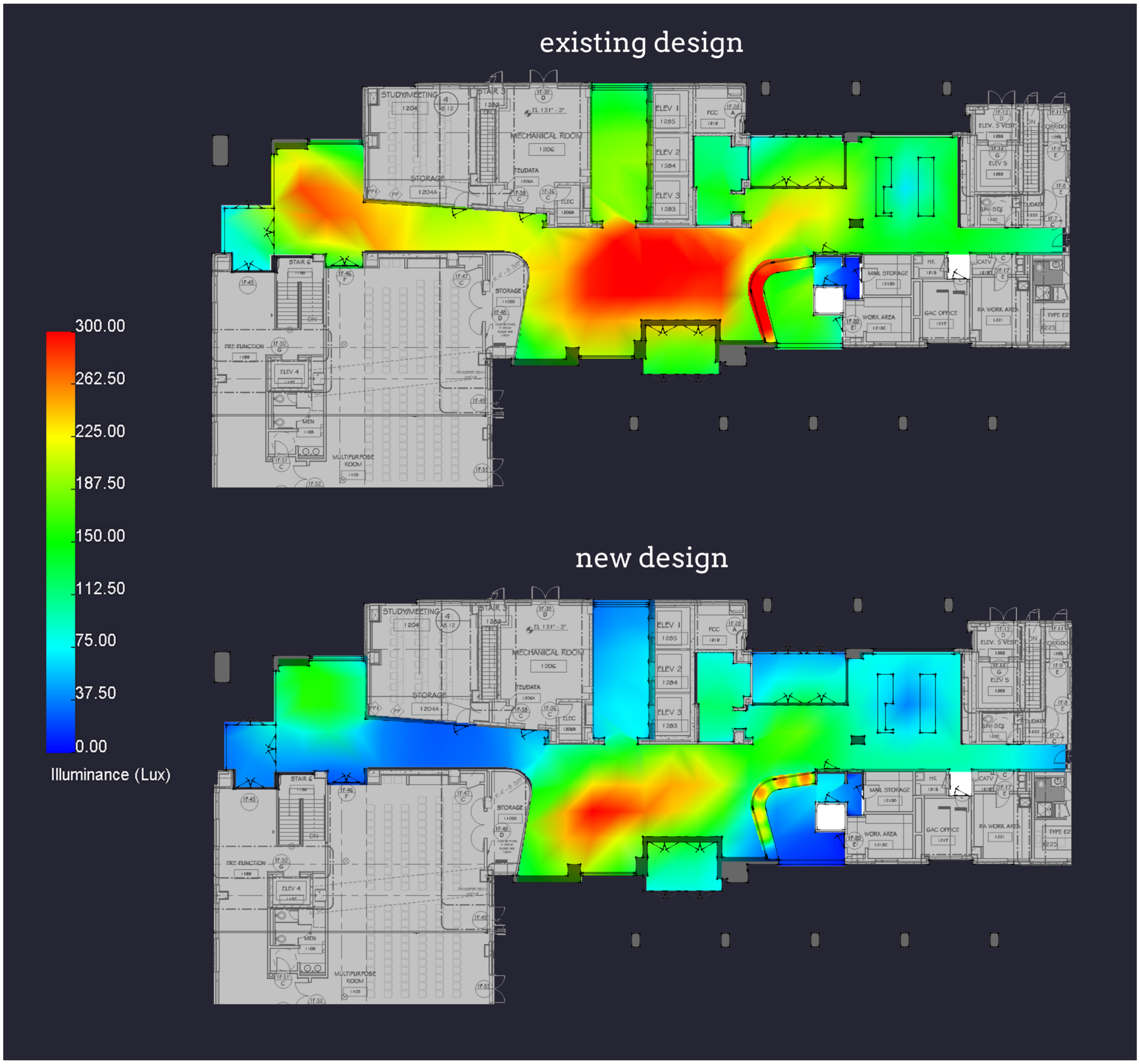
Existing LPD	Area (SF)	Total Watts	LPD	Target LPD	% Difference
0.70	5,152	1,427	0.28	0.90	69.22%

Criteria Evaluation

With so many different spaces served by the lobby, the most important criteria is reinforcing wayfinding. Prince Frederick Hall features many strictly functional spaces throughout it, such as classrooms and dormitory rooms. This makes the lobby the perfect moment to take time to celebrate the architecture of the building. Juxtaposition is key to create the visual diversity necessary for wayfinding and for artistic expression. In this case, it is the juxtaposition of public and private spaces. The final criteria for the lobby is to provide a welcoming entrance for the building.

QUANTITATIVE

This lighting design provides adequate light levels in all spaces, as per IES recommendations, where the primary occupants are less than 25 years old. Light levels are slightly higher than recommended at the most important areas of the space: the main entrance, the front desk, and the seating areas. This design also uses less power than the existing design and the ASHRAE allowance for a space of this type.



QUALITATIVE

Light levels are optimized to reflect the gradient of public to private spaces. The brightest areas are also the most important public areas: the main entrance, and the front desk. Circular pendants throughout the space provide visual interest at the ceiling plane, and the direct/indirect light from these pendant fixtures means that both the ceiling and the floor is illuminated. This creates a bright space with a welcoming feeling.

In more private areas, different lighting techniques are used to create juxtaposition to public areas. For example, in the elevator lobby direct pendants are used to create a more closed, private atmosphere. In this space the ceiling is darker than in the main lobby, and the overall light levels are lower.

SUSTAINABILITY

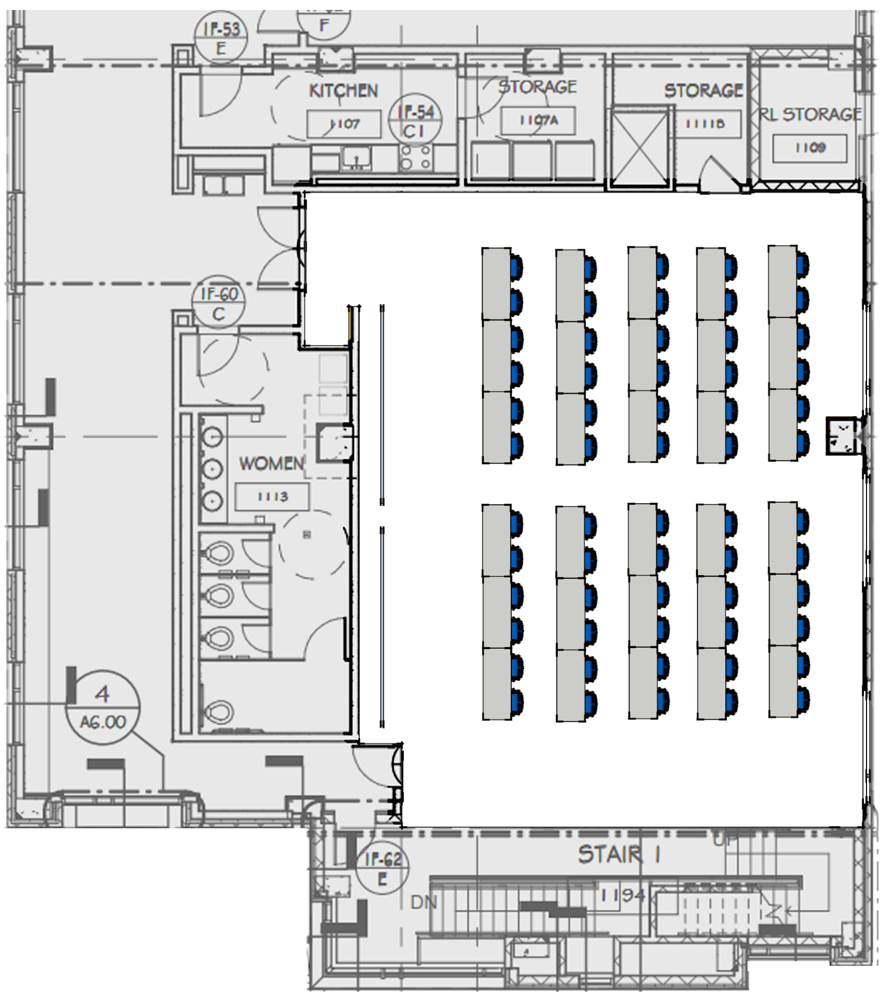
By adhering to the IES recommendations for light levels in each area of this space, a great reduction in energy use was achieved. It is important to remember that, since there are many daylight openings throughout the space, during the day most of these luminaires will not be needed. Therefore the criteria focused on night time illuminance values for all spaces adjacent to large windows. This allowed for the use of lower output fixtures, and ultimately a low LPD.

Luminaire selection was also important to reducing the LPD. In the existing design, the lobby is lit almost entirely with compact fluorescent downlights. These types of luminaires are inefficient at getting light onto the plane below them. By selecting more efficient fixtures, the LPD is easily decreased without sacrificing light levels.

Seminar Room

The design for this space utilizes several different types of lighting to provide flexibility. The main goal of the lighting for this classroom is to provide an effective learning environment. In this case, by providing a space free from distraction, discovery is made accessible to students through their education.

Spatial Environment



This is one of several academic spaces located throughout the first and ground floor of the building. This room is on the first floor, and is capable of seating around 60 students. Desks in this room face away from three, east-facing windows that offer a view of the entry plaza and the south facade of the building. The room features whiteboards on the front three walls and two motorized projection screens.

Design Approach

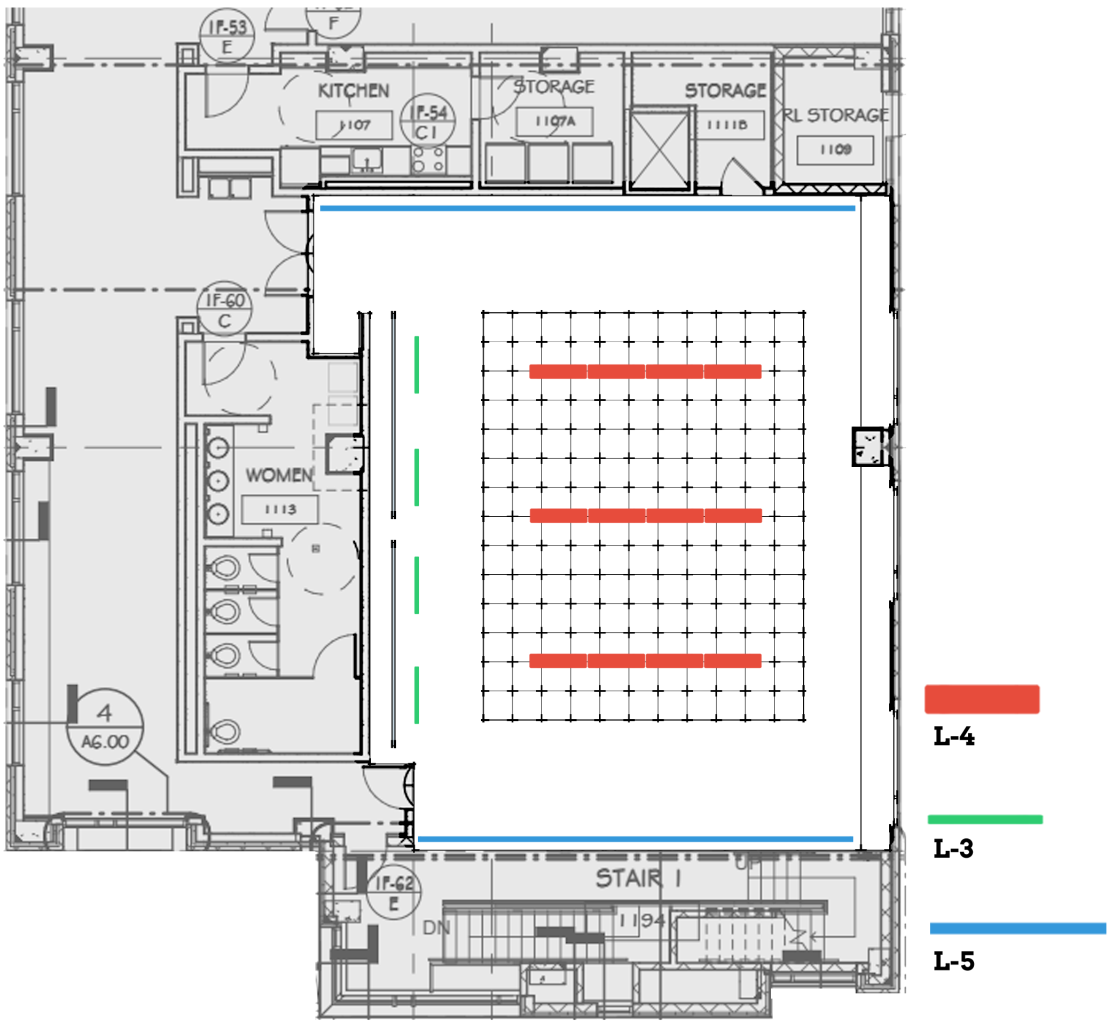
The seminar room emphasizes educational discovery, and therefore, requires a clean yet layered approach. This is evaluated in two ways:

> **FUNCTIONAL ENVIRONMENT:** To ensure a productive learning environment, and enhance discovery, this space is functionally driven. This lighting design, therefore, focuses on achieving IES Handbook recommendations for illumination and uniformity. As a university building it is assumed that the primary user is under 25 years old. Additionally, the perceived brightness of the space is increased by lighting the peripheral walls.
>
> **FLEXIBLE CONTROLLABILITY:** Since this is a multi-use classroom, providing flexibility in the controls of the room is also important. This design incorporates several layers of lighting, to accommodate multiple scenes. Calculations have been conducted to determine lighting levels for different schemes.

Lighting Layout

from back of seminar room

from front of seminar room



seminar room lighting plan

Lighting Equipment*

L-4: by Focal Point	**L-3:** by Arch Lighting Works	**L-5:** by LED Linear
		
Input: 98 watts	**Input:** 32 watts	**Input:** 1.4 watts/ft
Output: 3373 lumens	**Output:** 2610 lumens	**Output:** 124 lumens/ft
Lamp: LED	**Lamp:** 1 - 28W T5	**Lamp:** LED

L-4: general illumination is provided by direct/indirect pendants
L-3: semi-recessed fixtures at the front of the room illuminate the whiteboard
L-5: LED tape is recessed into wall slots for peripheral lighting

*see Appendix B: Lighting for complete schedule of equipment and LLF calculations

Calculations and Metrics

Criteria for the seminar room comes from IES recommended light levels and ASHRAE 90.1 for LPD. The three situations listed in the table below are based on the values for general classrooms in educational facilities.

LIGHTING LEVELS

	General Illumination, non-AV			General Illumination, AV			Whiteboard		
	Criteria	Existing	Thesis	Criteria	Existing	Thesis	Criteria	Existing	Thesis
E (horizontal)	200	503	344	25	145	24			
E (vertical)	75	353	304	15	57	14	300	258	295
Avg:Min				2:1	4.34:1	3:1	3:1	1.44:1	2.11:1

POWER USE

Existing LPD	Area (SF)	Total Watts	LPD	Target LPD	% Difference
0.74	1,750	1,350	0.77	1.24	37.78%

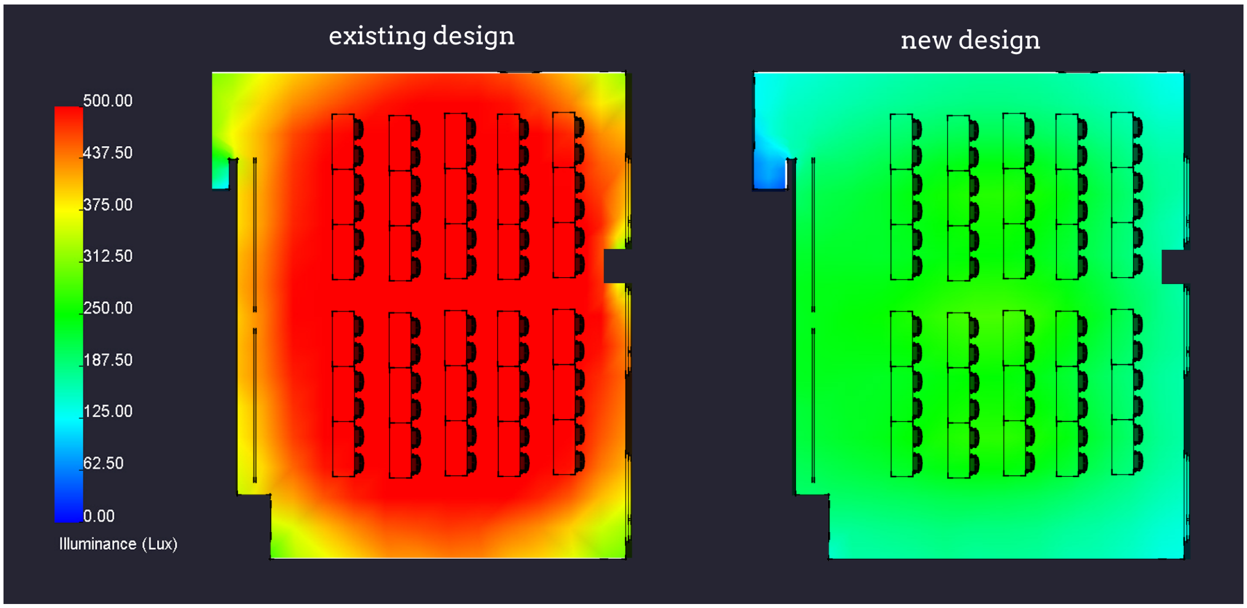
Criteria Evaluation

First and foremost, this space needs to be functional. Criteria are therefore based on recommendations given by the IES Handbook[3]. In this case, illuminance values have been selected for spaces where the primary user is under 25 years old. In order to increase the feeling of brightness in the space, some type of peripheral lighting is applied to the walls.

Lastly, since this is a multi-use classroom, flexibility must be provided in the lighting scheme and controls of the room.

QUANTITATIVE

The following graphic shows a comparison of light levels for the existing design and the new design.



According to the criteria established for this space, the horizontal illuminance at the work plane only needs to average 200 lux. Both lighting designs provide higher illuminance values than this recommendation. The new lighting design's average illuminance is still 70% higher than the recommendation, but it more closely meets this criteria.

QUALITATIVE

One of the major qualitative criteria set for this space was peripheral lighting. This was accomplished with the use of wall slots to evenly graze the sides of the room. By lighting the walls, the room is given an extra feeling of brightness. This effect is added to by the direct/indirect pendants used in the main part of the room. Finally, the lighting on the whiteboard is important for directing attention to this educational tool. The final result of this lighting scheme is one that promotes a productive learning environment.

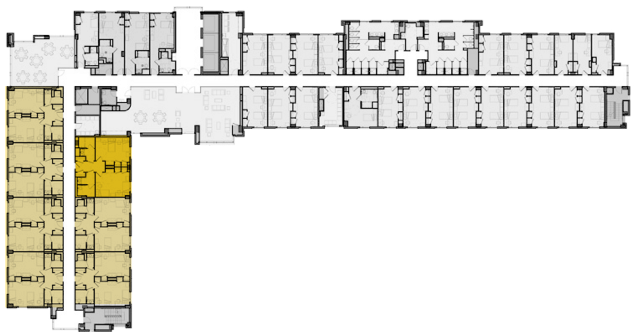
These several layers of light also helped to accomplish the goal of providing flexibility in the lighting scheme. This allows for several different schemes. The whiteboard light can be used alone to direct attention when there is adequate daylight at the desks. The peripheral lighting can be used alone, for AV presentations. Or if more light is needed during an AV presentation, the general illumination pendants have independent up/down components.

SUSTAINABILITY

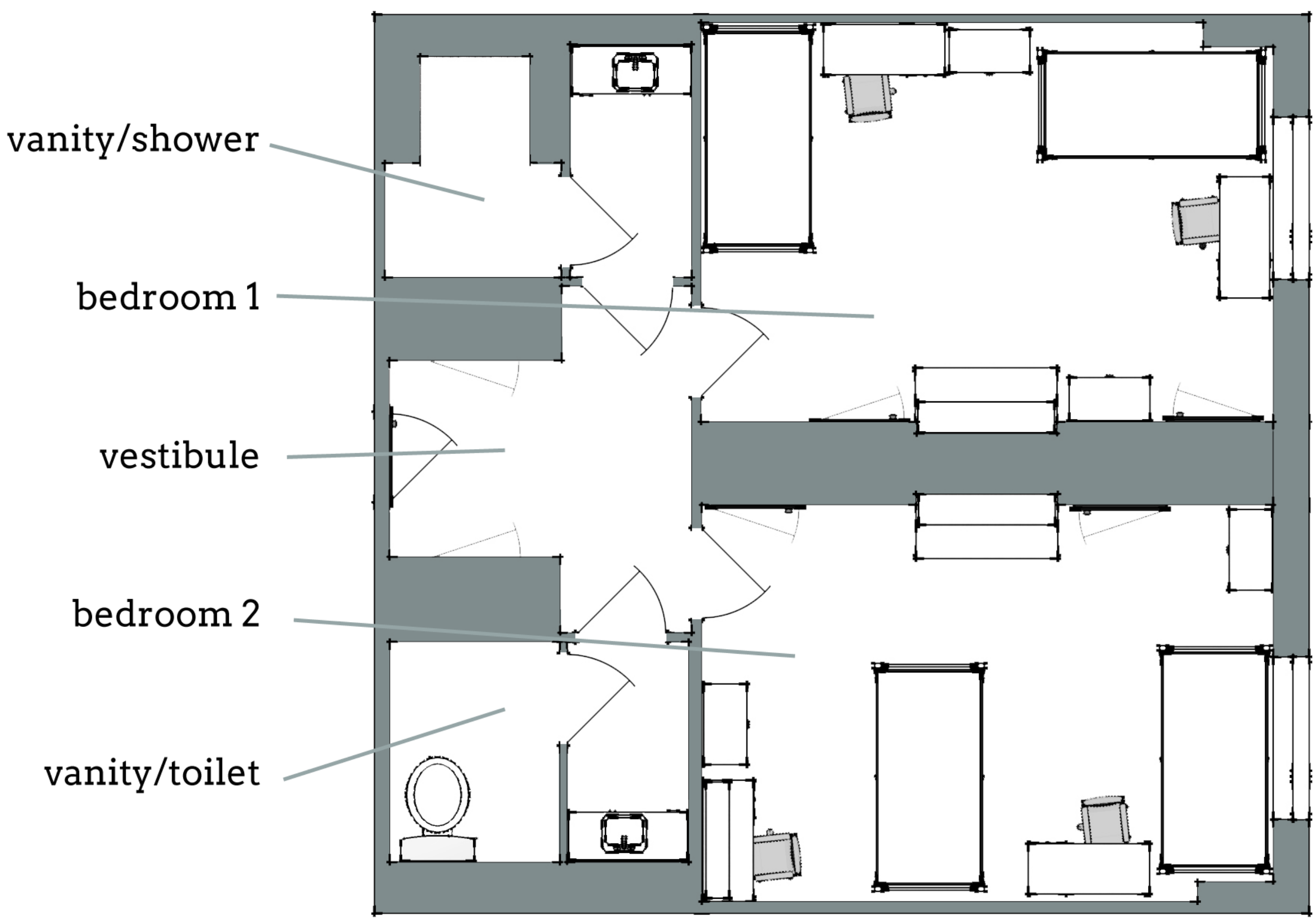
This scheme allows for different lighting combinations, so only the necessary lights need to be turned on. This space's large daylight openings will help to augment illuminance levels during the day. Most importantly, this lighting design is 37% below the ASHRAE 90.1 LPD allowance.

Dormitory Suite

The concept is applied to this space in the sense of social discovery; this isn't, after all, a totally private space. A shared dorm room, isn't going to express itself the same way that a bedroom or hotel room would. In the life of busy college students, a dorm room is more like to a social office space. It needs to have sturdy, functional work light. A bright ceiling will help reduce the heaviness of the concrete surfaces. A focal point can create a more casual atmosphere for social life. Ideally, all of these elements are applied in layers to reduce the institutional feel of this otherwise utilitarian space.



Spatial Environment



This is a typical suite, located throughout the 2nd - 7th floors. It is one of several different typical dorm rooms, but represents the living quarters for a little more than one-third of the total students living in the building. Each suite has two bedrooms to accommodate a total of four students per suite. Residents enter into a vestibule area that serves both bedrooms, two bath areas, and two storage closets. One bath area contains a vanity and shower, the other has a vanity and toilet. The finishes in this room are all hard surfaces. The flooring is a vinyl tile. The walls are painted concrete block, and the bedrooms' ceiling is the exposed concrete slab. These surface types pose additional challenges to the lighting design.

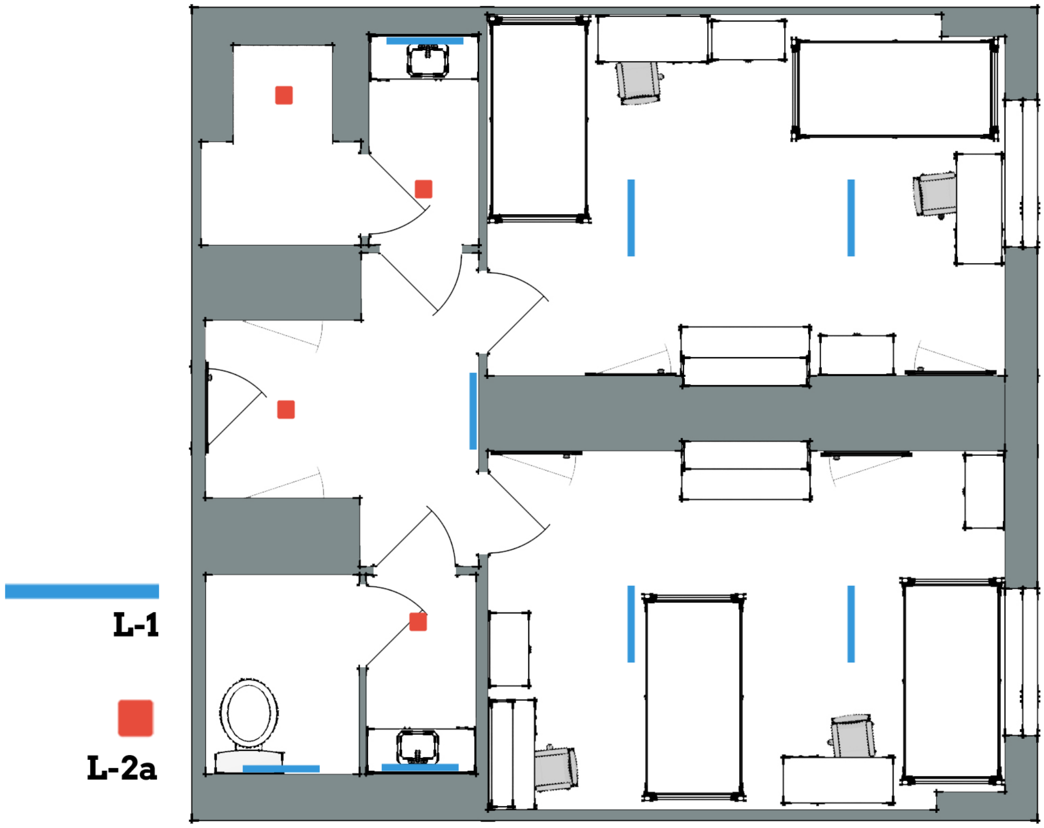
Design Approach

The most private of the four spaces, this dormitory suite, uses the concept of discovery in the sense of social discovery.

> **FLEXIBILITY:** Due to the high concentration of people living in this space, comfort can be increased for the occupants by adding controllability. This means not simply using a 2x2 troffer, like every other dorm room, but instead using layers of light that can be adjusted according to preferences.
>
> **POWER REDUCTION:** There are 42 duplications of this suite throughout the building. By reducing the lighting power density by even 10%, this small savings per space will have a large effect when multiplied throughout the building.

Lighting Layout

dormitory suite bedroom from entrance



dormitory suite lighting plan

Lighting Equipment*

L-1: by Architectural Lighting Works	**L-2a:** by Lightolier
	
Input: 15.8 watts	**Input:** 8.7 watts
Output: 1222 lumens	**Output:** 500 lumens
Lamp: LED	**Lamp:** LED

L-1: this fixture is used in varied applications around the dormitory suite for general lighting
L-2a: accent and direct lighting is provided by a recessed LED downlight

*see Appendix B: Lighting for complete schedule of equipment and LLF calculations

Calculations and Metrics

Lighting level criteria were developed from IES recommendations for educational facilities. Where this dormitory suite consists of desk areas, and general spaces. The criteria for the bath and vanity areas are based on values given in the common applications chapter for toilets/locker rooms.

The target lighting power density given by ASHRAE 90.1 is 0.38 watts/ft^2. However, this design was created with the intent of reaching 10% below that, which is 0.34 w/ft^2.

LIGHTING LEVELS

	General Illumination			Desk Areas			Bath Areas		
	Criteria	Existing	Thesis	Criteria	Existing	Thesis	Criteria	Existing	Thesis
E (horizontal)	25	626	290	250	590	268	50	1066	550
E (vertical)									
Avg:Min	3:1	1.2:1	1.3:1				2:1	1.4:1	1.3:1

	Vanities			Foyer		
	Criteria	Existing	Thesis	Criteria	Existing	Thesis
E (horizontal)	150	960	627	50	732	423
E (vertical)	200	1022	628			
Avg:Min	2:1	1.1:1	1.1:1	3:1	1.2:1	1.3:1

POWER USE

Existing LPD	Area (SF)	Total Watts	LPD	Target LPD	% Difference
0.45	777	161	0.21	0.38	45.40%

Criteria Evaluation

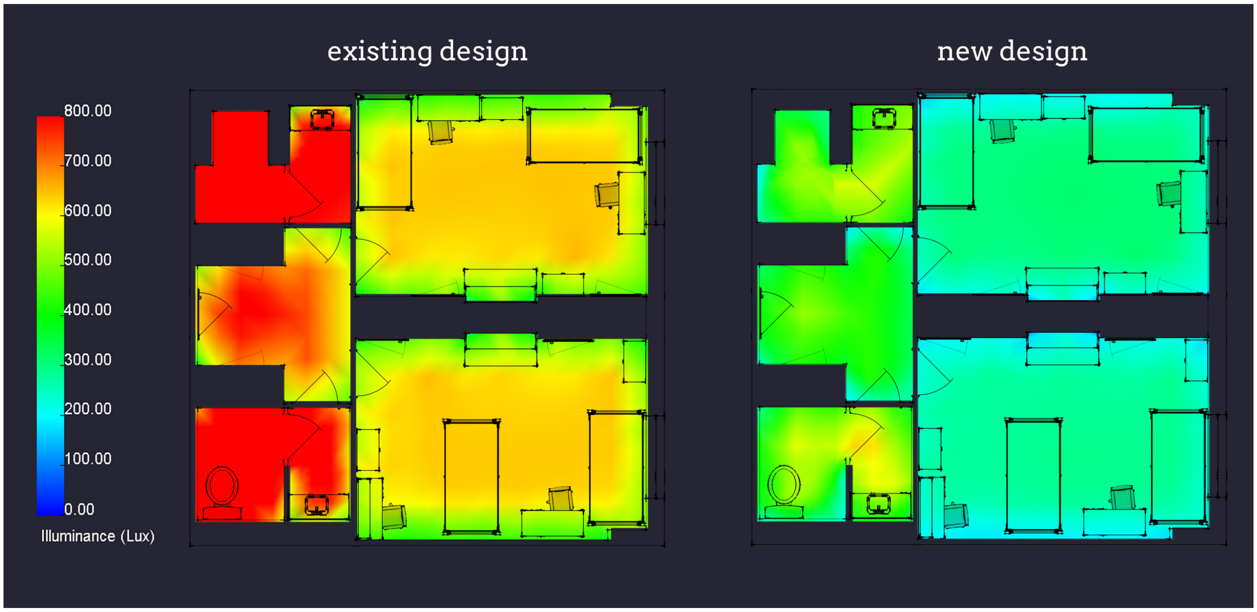
Comfort is the most important factor for a living space. And due to the high concentration of people living in this space, extra comfort can be provided in the form of controllability. This means not simply using a 2x2 troffer, the standard for many dormitory rooms across the country, but instead using layers of light. On a more practical side, by staying 10% under the ASHRAE requirements for a space of this type, this design has the potential to create savinging throughout the building. Since there is 42 duplications of this suite in the building, even small savings per space will have a large effect.

QUANTITATIVE

The new design for the lighting in this space is focused on achieving power savings for the building. By first evaluating the needs of the space, as per IES recommendations, this has been done without sacrificing the comfort of adequate illuminance levels. IES recommendations revealed that the existing lighting was over-illuminating this space by a large margin. By reducing the size/output of fixtures throughout the space, savings are provided in form of reduced LPD. Originally, this was planned as 10% below ASHRAE 90.1 standard, but the final design achieved an LPD 45% below ASHRAE.

As shown in the diagram below, the new lighting scheme provides less light than the existing design. However the lighting is still uniform throughout the space.

Assuming that students are likely to use anywhere in the room as a desk/work area, then the main room needs to be illuminated to an average of 250 lux. This means that areas shown in cyan are adequately illuminated, based on this criteria.



QUALITATIVE

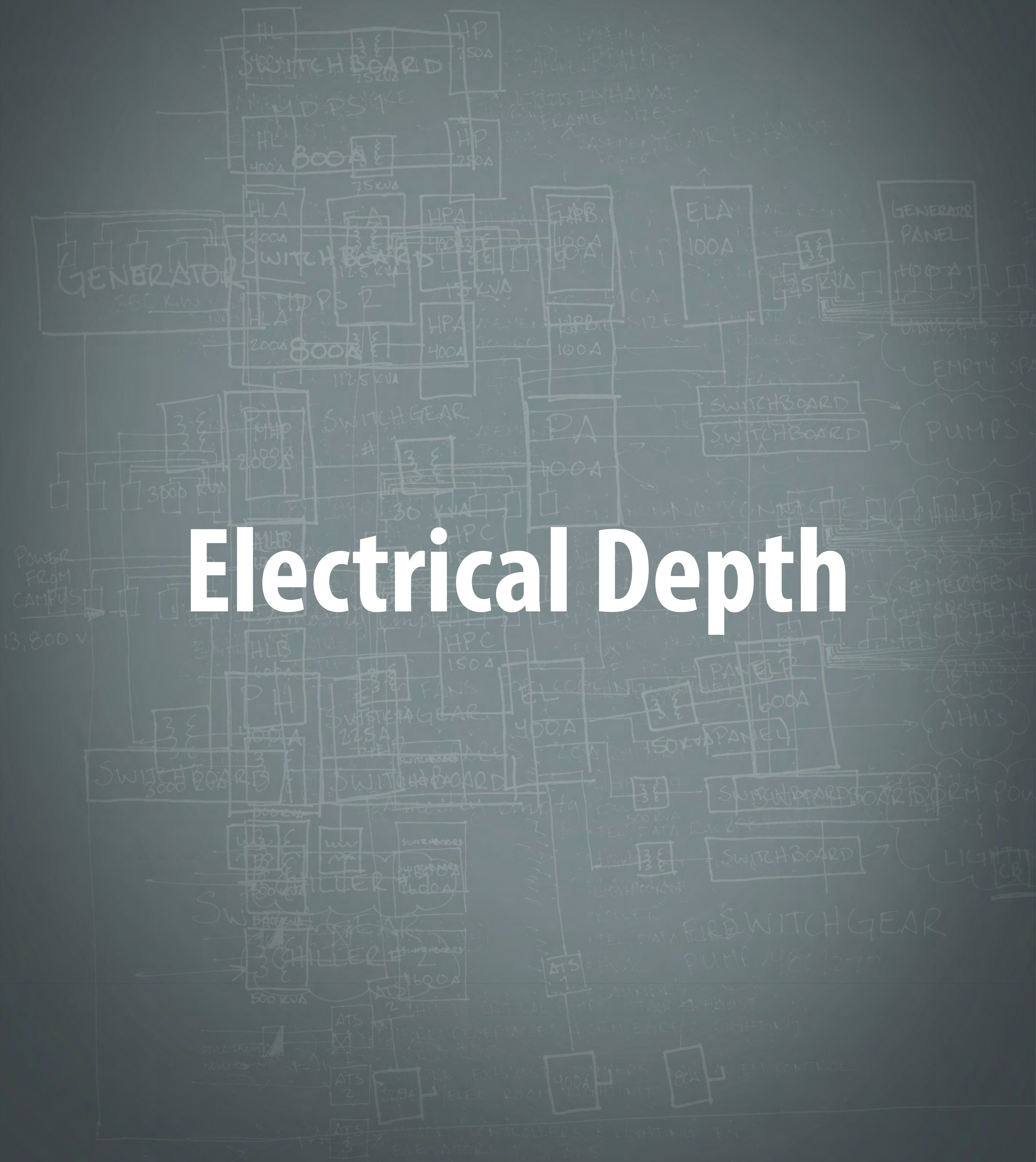
The goal of qualitative criteria in this space were to reduce the institutional feel of the rooms. The key to this was applying layers of light, like a hotel room or restaurant. For several reasons, this final design has changed routes and has not achieved this goal. One reason was due to the professionals' comments to the Tech 3 presentation at Lutron that it is unreasonable to use more than the bare minimum fixtures in a public university's dormitory. Another comment was that student are accustomed to providing their own desk lamps, and that a university would not want to install and maintain atmospheric lighting.

For this design, the fixtures selected for the rooms are different from the existing design in that they have 3-sided lenses. This will allow for a certain amount of light to illuminate the ceiling around them, lightening the otherwise dark and heavy concrete ceiling. The successes of this final design come in the form of adequate and uniform lighting.

SUSTAINABILITY

For this space, sustainability was an important factor. On aspect of this is longevity. By using all LED fixtures, this will save the university the maintenance associated with linear fluorescent fixtures. The LED modules are less likely to need frequent replacing, and are sturdy enough to handle the wear and tear of operating in a dorm setting. The lighting for this space has also been reduced to provide illuminance levels closer to IES recommended values, and more importantly, the result is a more efficient LPD that can be multiplied throughout the many iterations of this dormitory suite.

Electrical Depth

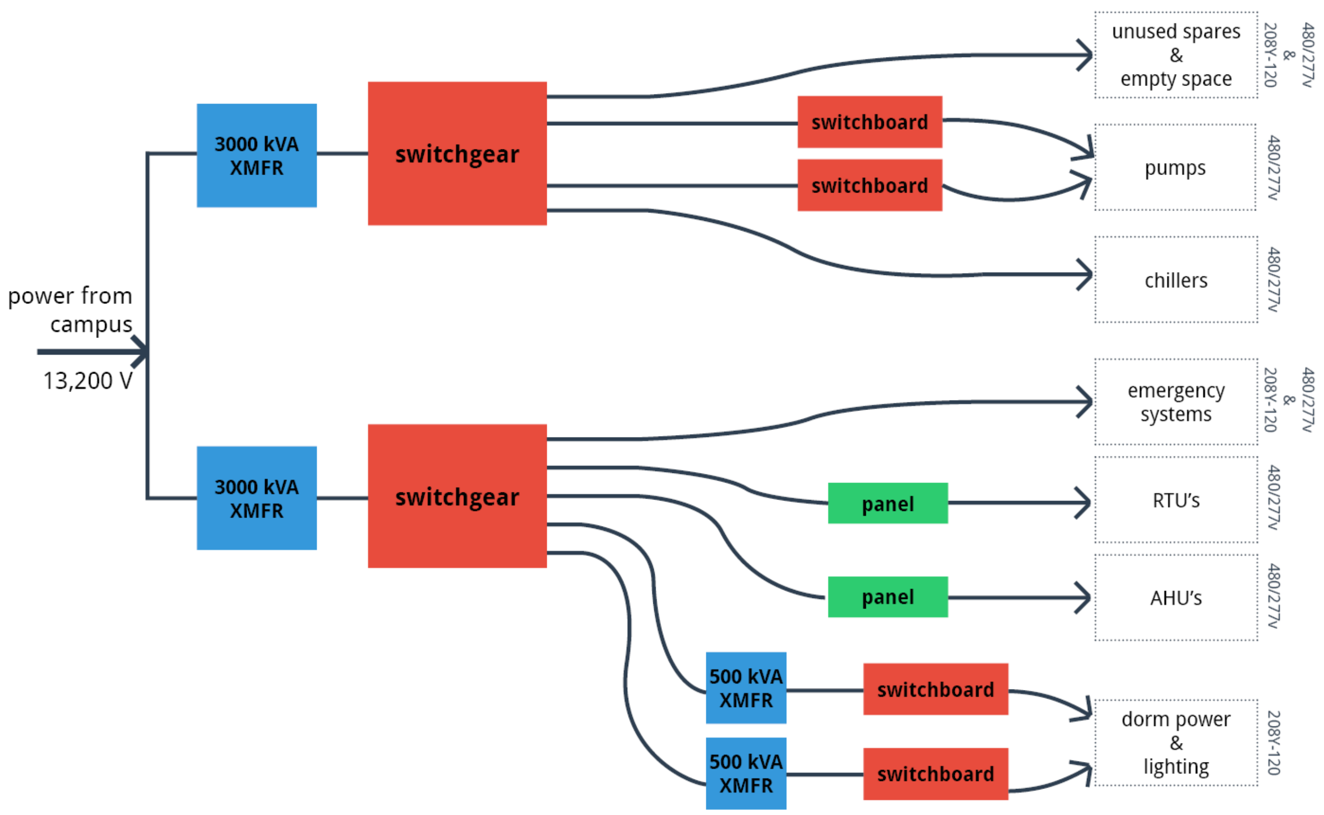


Electrical Introduction

Medium voltage is provided to the building from the university's grid. Two 3000 kVA transformers, outside the building, provide 480/277V to Switchgear#1 and Switchgear#2 in the main electrical room, located in the basement. Power is transformed to 208Y-120V for receptacles and interior lighting. Switchgear#1 is primarily for equipment, and Switchgear#2 is primarily for lighting and power in occupied spaces. Distribution to the residential floors and mechanical pumps occurs through four switchboards.

Distribution throughout the building is at 208Y-120V. For service to the upper floors, two 500 kVA transformers each feed a 1600A switchboard. These deliver power through two main risers. All conductors in the building are copper.

A 350kW natural gas generator is mounted on the roof. This provides power to required emergency loads, but a few loads are on the generator that are not required, such as the telecom/data racks.



The above figure shows the building's complete electrical systems as a condensed diagram. This is for conceptual purposes only. Several smaller transformers and many branch panels are not shown here. The complete single line diagram for the building can be found in Appendix C: Electrical.

Lighting Branch Circuit Redesign

As part of the previous depth study, the lighting systems in four areas of the building have been redesigned (see lighting depth). As a result, power usage has changed for each of these four areas: the entry plaza, the lobby, seminar room, and a typical dormitory suite. To determine the implications this has on the electrical system, the lighting loads from each design have been quantified and compared. This allowed for a list of electrical system recommendations to accompany the lighting system changes.

Existing System

All of the affected lighting circuits are listed below. Each of these circuits are listed by space. The fixture types and quantities in the table are only those that were eliminated through the course of the lighting redesign. The existing load is listed, on a per circuit basis, for the VA of lighting that has been redesigned.

Existing Lighting Circuits							
Entry Plaza Lighting							
Fixture Type	**Load (VA)**	**Fixtures per Circuit**					
		HL-3	**EL-1**				
EX-1	138	4					
EX-3	45		3				
EX-4	25	10					
EX-5	24.5	9					
	Existing Load	**1022.5**	**135**				
Lobby Lighting							
Fixture Type	**Load (VA)**	**Fixtures per Circuit**					
		MP1A-1	**MP1A-3**	**MP1A-4**	**MP1A-8**	**EMP1-3**	**EMP1-5**
F-8	42		12		25	7	
F-9	32	10	9	1	17	7	
F-7E	225					3	
F-7F	64				2	2	1
	Existing Load	**320**	**792**	**32**	**1722**	**1321**	**64**
Seminar Room Lighting							
Fixture Type	**Load (VA)**	**Fixtures per Circuit**					
		MP1A-7					
F-10	32	21					
F-B1	32	15					
	Existing Load	**1152**					
Dormitory Suite Lighting							
Fixture Type	**Load (VA)**	**Fixtures per Circuit**					
		MP*A-#					
F-1	52	4					
F-2	32	2					
F-3	18	1					
F-4	24	2					
FA	32	1					
	Existing Load	**370**					

Redesigned System

The luminaire types used in the new lighting system are listed next. With the exception of the UMD standard outdoor pole light, all the luminaires in new system are different from the existing system. The goal of this step was to determine the total load, per space, that would be added in place of the existing system's lighting load.

Redesigned Lighting Circuits			
Fixture Type	**Load (VA)**	**Quantity**	**Total Load (VA)**
Lobby Loads			
L-5	1.4	30	42
L-2b	19.8	15	297
L-6a	40	5	200
L-6b	64	8	512
L-6c	87	4	348
L-7	4.2	15	63
L-8	37	3	111
Total Lobby Load			**1573**
Seminar Room Loads			
L-3	30	4	120
L-4	98	12	1176
L-5	1.4	33	46.2
Total Seminar Room Load			**1342.2**
Dormitory Suite Loads			
L-1	15.8	8	126.4
L-2a	8.7	4	34.8
Total Dorm Suite Load			**161.2**
Entry Plaza Loads			
LE-1	138	4	552
LE-2	1.4	268	375.2
LE-3	8.6	7	60.2
Total Entry Plaza Load			**987.4**

Next, these loads were applied in place of the loads from the existing lighting system. In the case of the seminar room and the dormitory suite, there was only one lighting circuit for these spaces, so the new load was simply replaced on that circuit. For the entry plaza, the same load as the existing lighting system was applied to the emergency circuit, and the remaining new load was put on the other exterior lighting circuit that was originally used by the existing lighting system. The final space, the lobby, was the most challenging to assign to existing circuits. The table below gives a summary of how different fixtures were placed onto those circuits.

Redesign of Lobby Lighting Circuits							
Fixture Type	Load (VA)	Fixtures per Circuit					
		MP1A-1	MP1A-3	MP1A-4	MP1A-8	EMP1-3	EMP1-5
L-5	1.4					30	
L-2b	19.8	10				5	
L-6a	40				5		
L-6b	64				4	4	
L-6c	87				4		
L-7	4.2				10	4	1
L-8	37				3		
	Redesigned Load (VA)	198	0	0	957	413.8	4.2

Lobby fixtures were placed on circuits based which part of the lobby they are located in, where circuits are used in comparable locations as in the existing lighting layout. Due to the reduced load in the new lighting system, some existing circuits are not needed.

Summary

Finally, the loading on all affected circuits was summarized in the following table. This gives a comparison of the load applied by the existing lighting and the redesigned lighting system.

Lighting Circuits Comparison			
Circuit Name	Total Circuit Load (VA)		Difference
	Existing	Redesigned	
HL-3	1935	1764.9	-170.1 VA
EL-1	670	670	same
MP1A-1	482	360	-122 VA
MP1A-3	1024	1000	-24 VA
MP1A-4	800	0	combined with MP1A-3
MP1A-8	1806	1041	-765 VA
EMP1-3	1739	831.8	-907.2 VA
EMP1-5	777	717.2	-59.8 VA
MP1A-7	1152	1342.2	+190.2 VA
MP*A-#	370	322.4	reduce from 7 to 4 circuits per floor

In every space, except the seminar room, the lighting load was significantly reduced by using the redesigned lighting systems. For several circuits this allows for some electrical equipment savings to occur alongside the new lighting system.

ENTRY PLAZA

For this space, the redesigned lighting uses slightly less power than the existing design. This means a reduction in the amount of power needed to provide lighting to the space, but there is no effect on the layout of the electrical system.

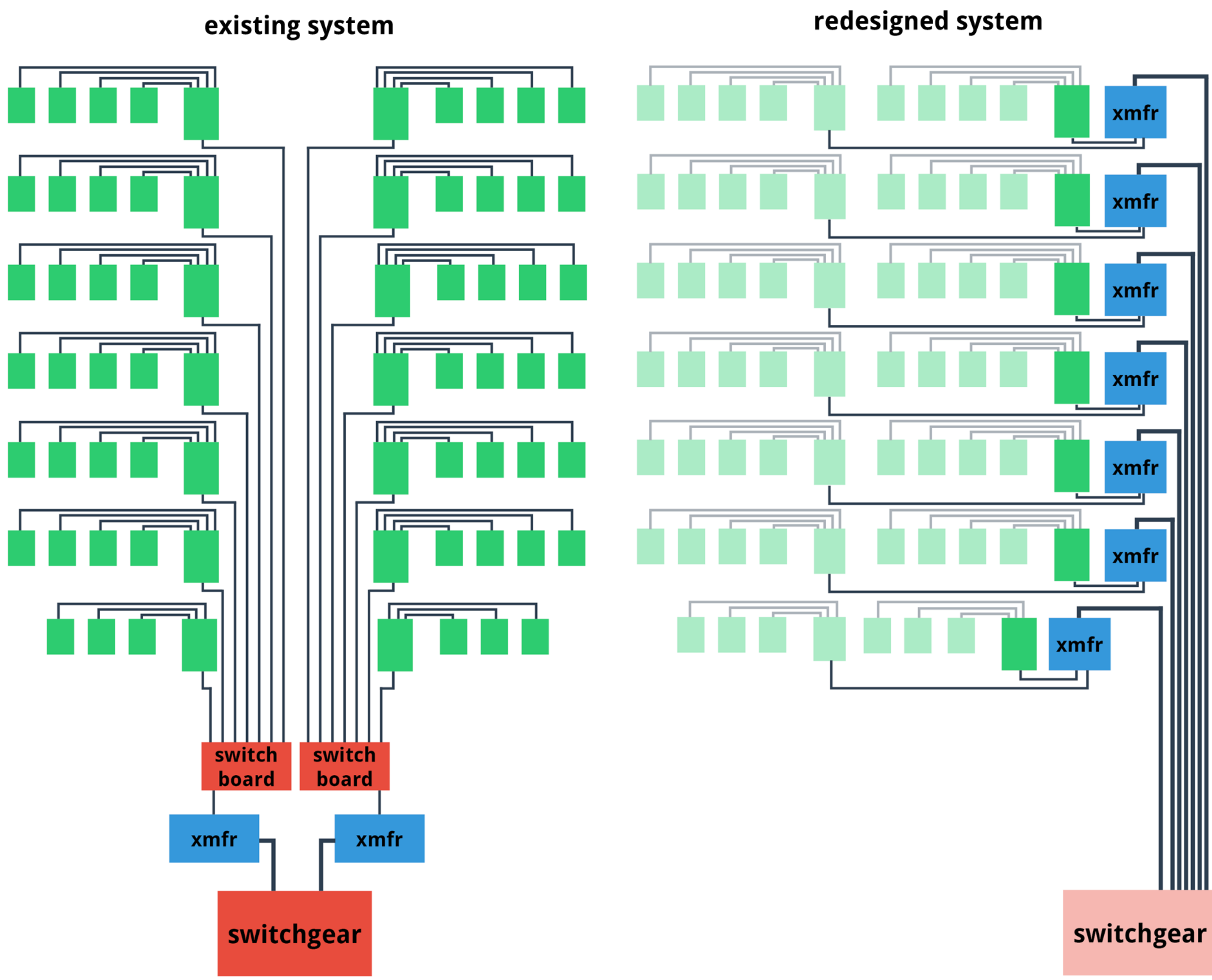
LOBBY
In the lobby, the reduction of loading was such that two circuits (MP1A-3 and MP1A-4) can be combined and one of those can become a spare circuit. Other circuits in this space will see a decrease in power consumption, but they do not require any changes.

SEMINAR ROOM
The new lighting system in this space uses slightly more power than the existing design. No changes are needed to the electrical system.

DORMITORY SUITES
In the dormitory suites, the lighting load of the new system is about half that of the existing system. Like in the lobby, this means two circuits can be combined. With seven dormitory suites per floor, and one circuit per room, the new lighting system allows for the new electrical system to use four circuits per floor in the same area.

Dormitory Riser Redesign

This next study is intended to determine the benefits of distributing power in a different way to the upper dormitory floors of the building. In the existing design, two 500kVA transformers distribute 208Y-120 through two risers to the upper floors. In this redesign, one riser distributes 480/277 to the upper floors, where it is transformed at each floor to 208Y-120. The following diagram shows a simplified schematic of the two systems for comparison.



Scope

For this study, certain boundaries had to be set to ensure a consistent comparison between the two systems. The area under investigation includes the circuits that provide lighting and power to floors one through seven in the building. They are fed, in the existing system, from two draw-out breakers in a switchgear in the basement level. This study follows those circuits from switchgear to branch panels. To see these circuits in their full context, see Appendix C: Electrical, where the building's complete riser diagram is included with these circuits highlighted.

Also in regards to scope, the basis of this study is focused on the electrical systems. Since this is intended first and foremost as an electrical study, disciplines outside of electrical engineering are noted for possible interaction with this system, but are not investigated.

Metrics

For this redesign, changes occur in three major areas: wire sizes, equipment, and installation. The latter, installation costs, are based largely on the cost of labor for this project. This falls largely out of the scope of the study, which is intended to compare two electrical systems, so while it is acknowledged as having a unique effect on each of the two systems, it is not included here. The first two types of changes: wire sizes and equipment are used to quantify the differences between the existing system and the redesigned system.

EQUIPMENT

Pricing for equipment has been estimated using RSMeans Electrical Cost Data[2]. Only material costs are compared in this study. Due to the uncertain nature of equipment and labor prices, this is acknowledged as not the actual prices that would be paid. The RSMeans material costs are used strictly to create a fair comparison between the existing and redesigned system.

WIRE SIZES

The following material costs were applied to create a comparison between the two systems. Like with equipment costs, RSMeans[2] data was used for a fair comparison:

Type	Material Cost	
	$ per C.L.F.	$ per L.F.
500 kcmil	1175	11.750
400 kcmil	990	9.900
350 kcmil	860	8.600
300 kcmil	705	7.050
250 kcmil	590	5.900
4/0	505	5.050
3/0	395	3.950
2/0	315	3.150
1/0	251	2.510
1	202	2.020
2	160	1.600
3	126	1.260
4	101	1.010
6	64	0.640
8	37.5	0.375
10	23	0.230
12	14.45	0.145
14	9.4	0.094

RSMeans Electrical Cost Data (26 05 19.90 Wire)

These prices were pro-rated from 100 LF to LF values and applied based on the LF of wired needed in each feeder. Wire sizes for the existing system were taken directly from the existing electrical riser diagram. And wire sizes for the new system were determined using the allowable ampacities listed in NEC 2011[7]: Table 310.12(B)(16) and grounding conductors in Table 250.122.

Systems Comparison

The differences between the two systems have been divided into two categories: equipment and wire. The chart below details the estimated cost differences between equipment needed for each system. In this case, using distributed transformers was more expensive than using the two large transformers, but this allowed for the elimination of the two large switchboards. Instead of distributing through switchboards, distribution is now handled by the switchgear. A draw-out breaker for each floor, with the redesigned system, is almost the same cost as the two large draw-out breakers, used in the existing system. According to RSMeans materials cost data, the equipment for the redesigned system will cost about $37,000 less than the existing system.

Existing System				Redesigned System				Estimated Price Difference
Type	Name	Size	Material Cost	Type	Name	Size	Material Cost	
SWITCHGEAR								
Draw-out breaker	MDPMP	800A	5300	Draw-out breaker	N1	250A	2825	$275
Draw-out breaker	MDPNP	800A	5300	Draw-out breakers	N2 - N7	150A (ea)	7500	
SWITCHBOARDS								
Switchboard	MDPMP	1600A	3550					$40,150
Feeder Circuit Breakers			16525					
Switchboard	MDPNP	1600A	3550					
Feeder Circuit Breakers			16525					
TRANSFORMERS								
Transformer	T-5	500kVA	10500	Transformer	T-N1	225kVA	5000	-$950
Transformer	T-6	500kVA	10500	Transformer	T-N2	112.5kVA	2825	
				Transformer	T-N3	112.5kVA	2825	
				Transformer	T-N4	112.5kVA	2825	
				Transformer	T-N5	112.5kVA	2825	
				Transformer	T-N6	112.5kVA	2825	
				Transformer	T-N7	112.5kVA	2825	
PANELS								
Main Circuit Breaker	in NP1	400A	5125	Main Circuit Breaker	in NP1	500A	7025	-$1,900
				Estimated Equipment Cost Savings				**$37,575**

Aside from equipment cost savings, one of the other advantages is savings created by using smaller wire sizes. The same portion of each system was evaluated using the wire pricing schedule given earlier in this report. As comparison of both systems is given on the next two pages. The total estimated savings created by the smaller wire sizes in the redesigned system is approximately $34,000.

Existing System Wire Sizes

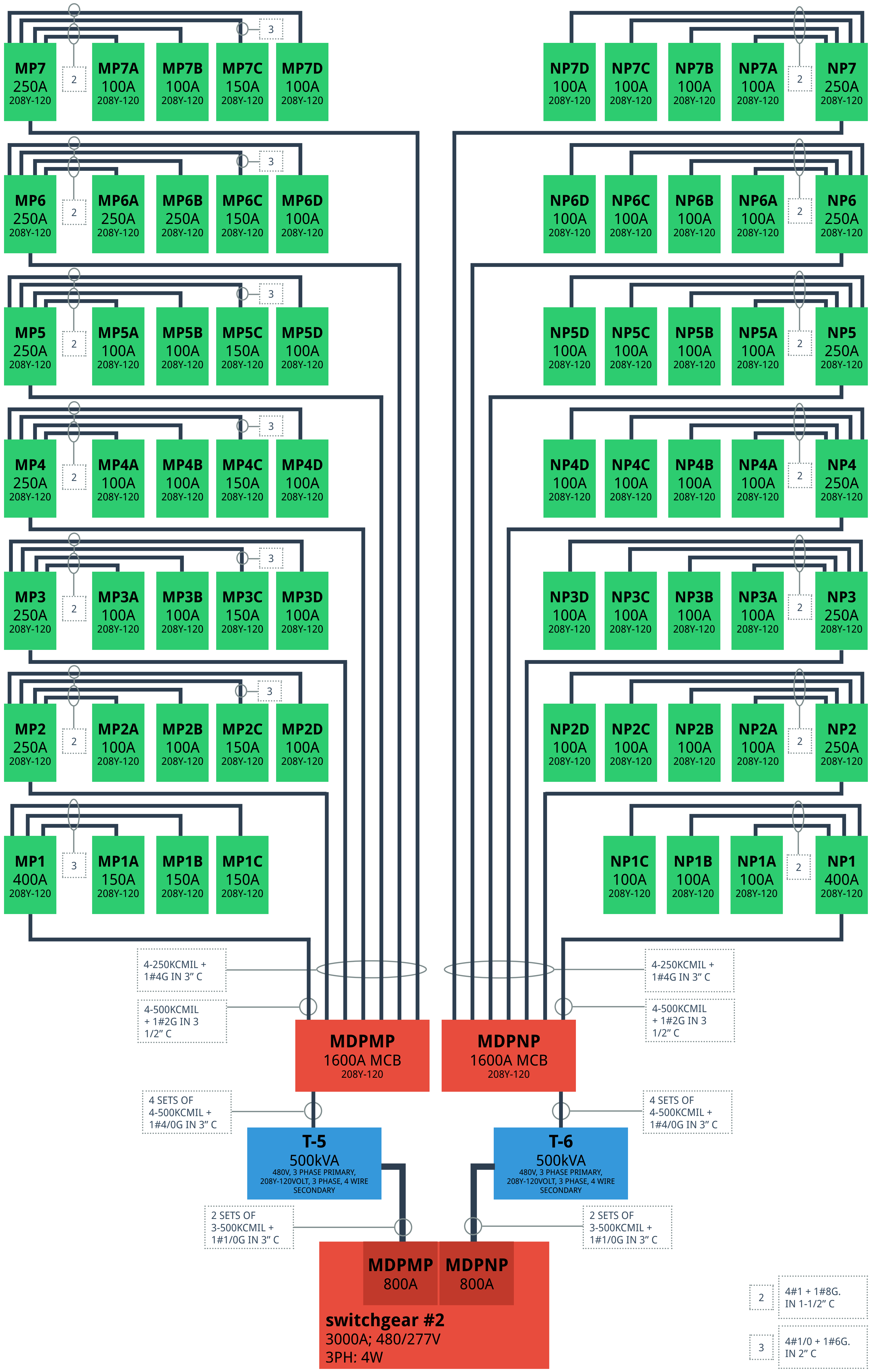
Equipment			Incoming Feed								
Type	Name	Location	From	Protection (A)	Wire Properties					Apx. Length	Total Price
					Listed Feed	Quantity	Type	Ground	Price per ft		
Switchgear	Switchgear #2	M0226									
Transformer	T-5	M0226	Switchgear #2		2 SETS OF 3-500KCMIL + 1#1/0G IN 3" C	6	500 kcmil	1/0	73.010	35	$2,555.35
Transformer	T-6	M0226	Switchgear #2		2 SETS OF 3-500KCMIL + 1#1/0G IN 3" C	6	500 kcmil	1/0	73.010	54	$3,942.54
Switchboard	MDPMP	M0226	T-5	1600	4 SETS OF 4-500KCMIL + 1#4/0G IN 3" C	16	500 kcmil	4/0	193.050	10	$1,930.50
Switchboard	MDPNP	M0226	T-6	1600	4 SETS OF 4-500KCMIL + 1#4/0G IN 3" C	16	500 kcmil	4/0	193.050	10	$1,930.50
Panelboard	MP1	E1206B	MDPMP	400	4-500KCMIL + 1#2G IN 3 1/2" C	4	500 kcmil	2	48.600	296	$14,385.60
Panelboard	MP2	E2101	" "	250	4-250KCMIL + 1#4G IN 3" C	4	250 kcmil	4	24.610	260	$6,398.60
Panelboard	MP3	E3101	" "	250	" "	4	250 kcmil	4	24.610	271	$6,669.31
Panelboard	MP4	E4101	" "	250	" "	4	250 kcmil	4	24.610	282	$6,940.02
Panelboard	MP5	E5101	" "	250	" "	4	250 kcmil	4	24.610	293	$7,210.73
Panelboard	MP6	E6101	" "	250	" "	4	250 kcmil	4	24.610	303	$7,456.83
Panelboard	MP7	E7101	" "	250	" "	4	250 kcmil	4	24.610	314	$7,727.54
Panelboard	NP1	E1229	MDPNP	400	4-500KCMIL + 1#2G IN 3 1/2" C	4	500 kcmil	2	48.600	88	$4,276.80
Panelboard	NP2	E2228	" "	250	4-250KCMIL + 1#4G IN 3" C	4	250 kcmil	4	24.610	52	$1,279.72
Panelboard	NP3	E3228	" "	250	" "	4	250 kcmil	4	24.610	63	$1,550.43
Panelboard	NP4	E4228	" "	250	" "	4	250 kcmil	4	24.610	74	$1,821.14
Panelboard	NP5	E5228	" "	250	" "	4	250 kcmil	4	24.610	85	$2,091.85
Panelboard	NP6	E6228	" "	250	" "	4	250 kcmil	4	24.610	95	$2,337.95
Panelboard	NP7	E7228	" "	250	" "	4	250 kcmil	4	24.610	106	$2,608.66
										Total Wire Cost	**$83,114.07**

Redesigned System Wire Sizes

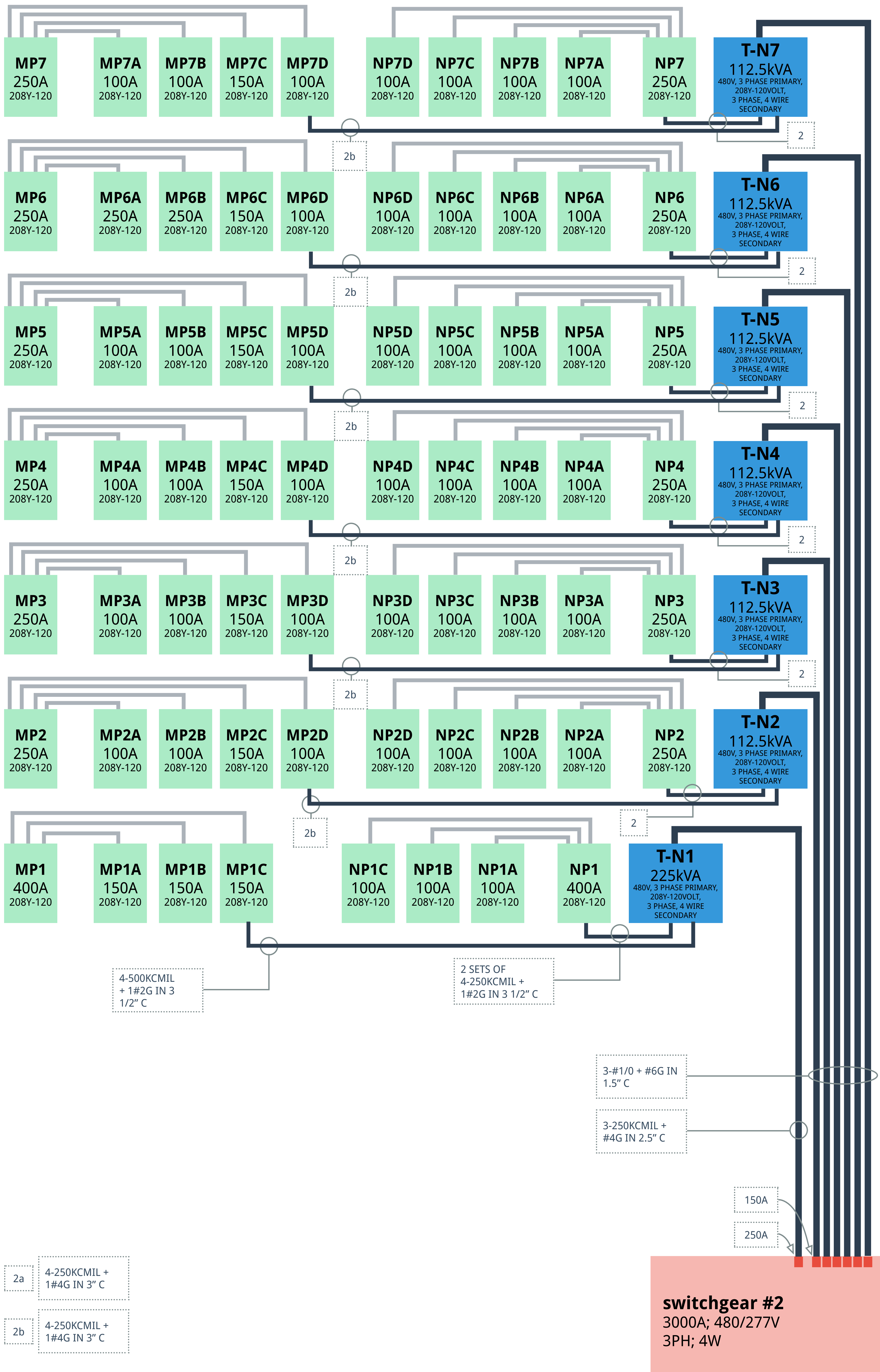
Equipment			Incoming Feed								
Type	Name	Location	From	Protection (A)	Wire Properties					Apx. Length	Total Price
					Listed Feed	Quantity	Type	Ground	Price per ft		
Switchgear	Switchgear #2	M0226									
Transformer	T-N1	E1229	Switchgear #2	350	3-250KCMIL + #4G IN 2.5" C	3	250 kcmil	4	18.710	88	$1,646.48
Transformer	T-N2	E2228	Switchgear #2	175	3-#1/0 + #6G IN 1.5" C	3	1/0	6	8.170	52	$424.84
Transformer	T-N3	E3228	Switchgear #2	175	" "	3	1/0	6	8.170	63	$514.71
Transformer	T-N4	E4228	Switchgear #2	175	" "	3	1/0	6	8.170	74	$604.58
Transformer	T-N5	E5228	Switchgear #2	175	" "	3	1/0	6	8.170	85	$694.45
Transformer	T-N6	E6228	Switchgear #2	175	" "	3	1/0	6	8.170	95	$776.15
Transformer	T-N7	E7228	Switchgear #2	175	" "	3	1/0	6	8.170	106	$866.02
Panelboard	MP1	E1206B	T-N1	400	4-500KCMIL + 1#2G IN 3 1/2" C	4	500 kcmil	2	48.600	210	$10,206.00
Panelboard	MP2	E2101	T-N2	250	4-250KCMIL + 1#4G IN 3" C	4	250 kcmil	4	24.610	210	$5,168.10
Panelboard	MP3	E3101	T-N3	250	" "	4	250 kcmil	4	24.610	210	$5,168.10
Panelboard	MP4	E4101	T-N4	250	" "	4	250 kcmil	4	24.610	210	$5,168.10
Panelboard	MP5	E5101	T-N5	250	" "	4	250 kcmil	4	24.610	210	$5,168.10
Panelboard	MP6	E6101	T-N6	250	" "	4	250 kcmil	4	24.610	210	$5,168.10
Panelboard	MP7	E7101	T-N7	250	" "	4	250 kcmil	4	24.610	210	$5,168.10
Panelboard	NP1	E1229	T-N1	400	4-500KCMIL + 1#2G IN 3 1/2" C	4	500 kcmil	2	48.600	10	$486.00
Panelboard	NP2	E2228	T-N2	250	4-250KCMIL + 1#4G IN 3" C	4	250 kcmil	4	24.610	10	$246.10
Panelboard	NP3	E3228	T-N3	250	" "	4	250 kcmil	4	24.610	10	$246.10
Panelboard	NP4	E4228	T-N4	250	" "	4	250 kcmil	4	24.610	10	$246.10
Panelboard	NP5	E5228	T-N5	250	" "	4	250 kcmil	4	24.610	10	$246.10
Panelboard	NP6	E6228	T-N6	250	" "	4	250 kcmil	4	24.610	10	$246.10
Panelboard	NP7	E7228	T-N7	250	" "	4	250 kcmil	4	24.610	10	$246.10
										Total Wire Cost	**$48,704.43**

Existing System

The next two pages contain a complete summary of the components of both the existing system and the redesigned system.



Thesis System



Summary

The redesign of the dormitory electrical riser proved to be successful. The estimated savings created by the different equipment and wire sizes is approximately **$71,000**.

DISADVANTAGES

Like with any system, there are a few disadvantages to this redesigned system:

- less space on occupied floors
    - the existing system had the transformers in the basement where space wasn't as important
    - the largest of the new transformers is height - 75.00; width - 44.20; length - 36.23, and the smallest is height - 48.56; width - 28.22; length - 23.42
    - see Appendix C: Electrical for electrical room plans
- extra loading on the structural system
    - each transformer can be expected to weigh between 930 - 1440 pounds each

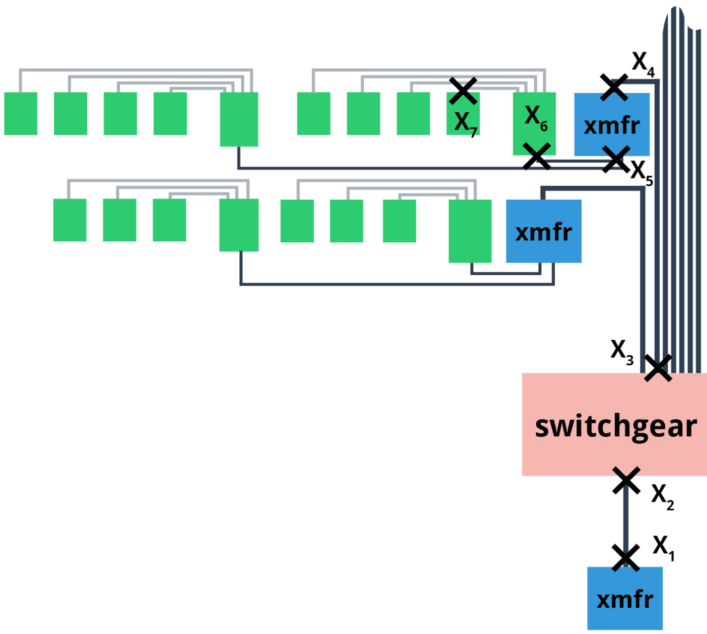
ADVANTAGES

However, the advantages to the redesigned system far outweigh the disadvantages:

- smaller transformers are needed at each floor
    - the two transformers in the existing design that are used to feed power to the dormitory floors are way larger than they need to be
- smaller wire sizes can be used
    - due to higher voltage distribution
    - savings created by using less copper
    - savings of **$34,000**
- less voltage drop to the top of the building
    - due to higher voltage distribution
    - this increases the overall efficiency of the system
- several pieces of equipment that can be eliminated/resized, including:
    - (2) 1600MCB switchboards
    - (2) 800A draw-out breakers
    - (2) 500kVA transformers
    - savings of **$37,000**

Short Circuit Analysis

The last part of this electrical study is a short circuit current calculation. This 7-level analysis was used to determine the maximum short circuit current available at 7 critical points between the main transformer and branch panel NP2A. This particular branch circuit was selected because it is typical of branch circuits feeding panels NP2A - NP7A, where these calculations were completed for the the typical branch circuit with the shortest wire lengths, to ensure AIC ratings would be adequate for all other typical branch circuits. All other branch circuits (for NP2A - NP7A) will have an equal or lower short circuit current, and can be sized to match panel NP2A.



These calculations were conducted using the Cooper-Bussman method for finding short circuit currents. Each level occurs at the locations shown to the left.

X1: Transformer (T-2) Secondary	
I sc sys RMS (A)	1.00E+30
Primary Voltage (V)	13200
Secondary Voltage (V)	480
Impedance	5.75%
Transformer Size (kVA)	3000
	100,000.00
f	4.38E+26
M	0.0000
I sc sys RMS	**62,757.30**

X2: at Switchgear	
I sc (A) from X1	62,757.30
Wire Length	105
Number of Wires per	8
C Value	22185
Voltage (V)	480
f	0.1340
M	0.8819
I sc sys RMS (A)	55,342.95
% motors	0%
I motor contribution (A)	0
I total sym sc RMS (A)	**55,342.95**

X3: Switchgear	
Main Transformer Size	3000
Voltage at Switchgear (V)	480
Full Load Current (FLA)	3,608.55
I sc (A) from X2	55,342.95
% motors	25%
I motor contribution (A)	3,608.55
I total sym sc RMS (A)	58,951.50
Wire Length	92
Number of Wires per Phase	8
C Value	26706
f	0.0860
M	0.9208
I sc sys RMS (A)	50,960.74
I motor contribution (A)	3,608.55
I total sym sc RMS (A)	**54,569.28**

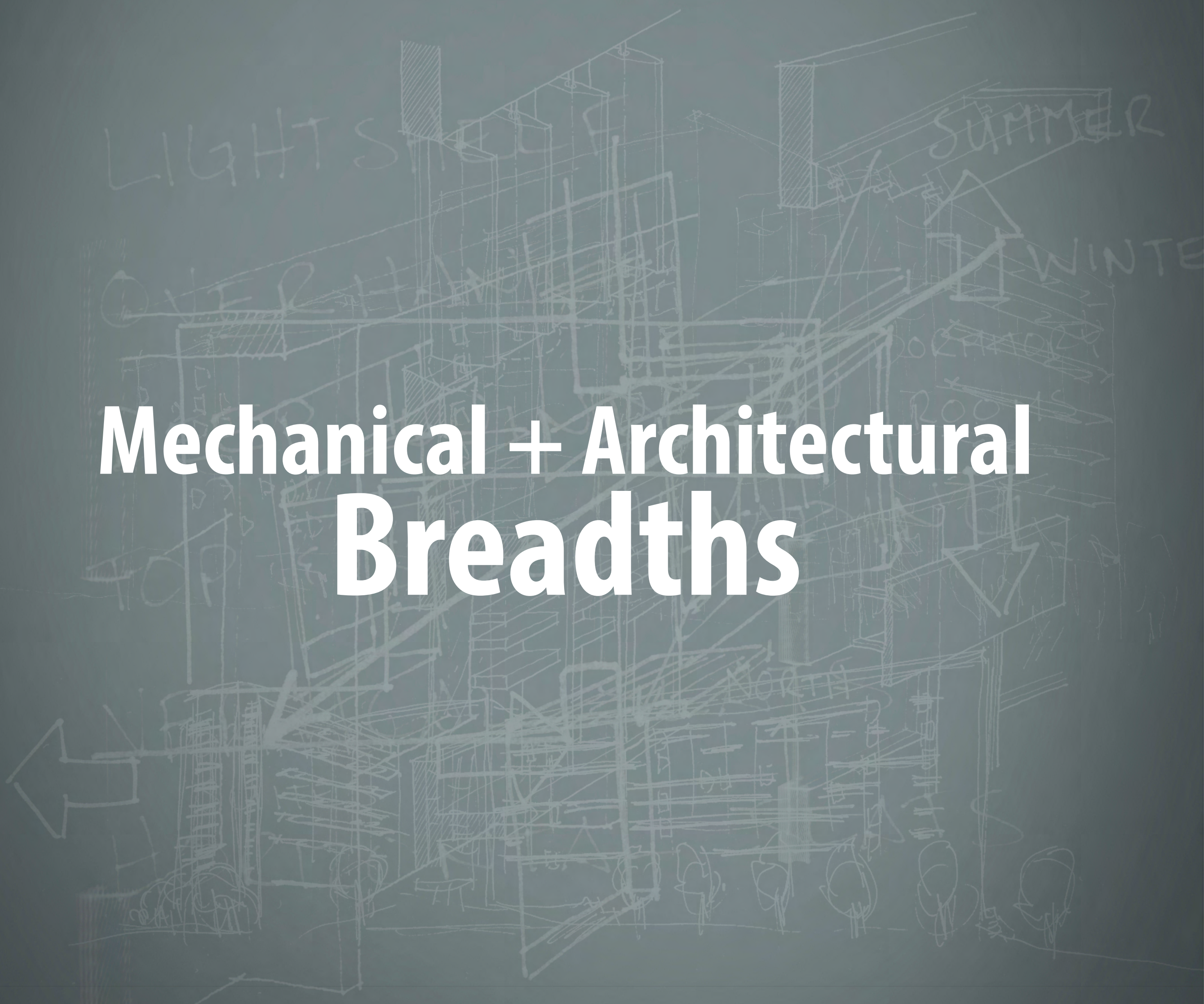
X4: at Transformer (T-N2) Primary	
I sc (A) from X3	54,569.28
Wire Length	52
Number of Wires per	1
C Value	7493
Voltage (V)	480
f	1.3665
M	0.4226
I sc sys RMS (A)	23,059.29
% motors	0%
I motor contribution (A)	0
I total sym sc RMS (A)	**23,059.29**

X5: Transformer (T-N2) Secondary	
I sc sys RMS (A) from X4	23,059.29
Primary Voltage (V)	480
Secondary Voltage (V)	208
Impedance	2.30%
Transformer Size (kVA)	112.5
	100,000.00
f	3.9193
M	0.2033
I sc sys RMS	**10,817.30**

X6: Panel NP2	
I sc sys RMS (A) from X5	10,817.30
Wire Length	8
Number of Wires per	1
C Value	16483
Voltage (V)	208
f	0.0437
M	0.9581
I sc sys RMS (A)	10,364.20
% motors	0%
I motor contribution (A)	0
I total sym sc RMS (A)	**10,364.20**

X7: Panel NP2A	
I sc sys RMS (A) from X6	10,364.20
Wire Length	8
Number of Wires per Phase	1
C Value	7293
Voltage (V)	208
f	0.0947
M	0.9135
I sc sys RMS (A)	9,467.90
% motors	0%
I motor contribution (A)	0
I total sym sc RMS (A)	**9,467.90**

Mechanical + Architectural
Breadths



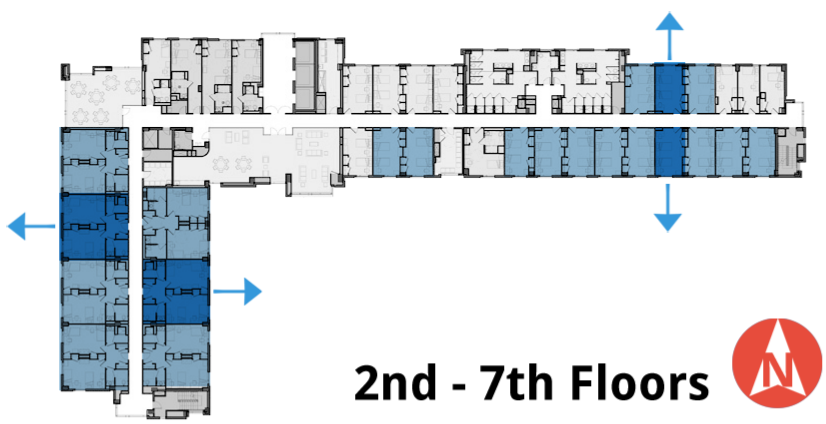
Breadths Introduction

> **"Shading windows from solar heat gain is a key design strategy for passive cooling and to reduce cooling loads on active HVAC systems."**
> -Mechanical and Electrical Equipment for Buildings[5], page 164

The existing design for Prince Frederick Hall features numerous daylight openings. While this is great for achieving high illuminance values, these unshaded openings also apply a heating load within the building. With proper shading, optimized for each facade, this solar heating load can be minimized in the hot, summer months and maximized in the cold, winter months. This study is comprised of two parts: mechanical and architectural. These studies are linked by the desire to increase solar utility. This means that passive architectural features are used to provide mechanical systems savings.

Scope

In order to create the largest impact on the total building load, dormitory spaces have been selected as the target for this study. Floors 2 - 7 consist mainly of dormitory rooms, so by selecting typical spaces, the savings calculated for one room can be multiplied throughout all other iterations of that room. The room selection process involved a quick study of the orientation of Prince Frederick Hall and its different typical dormitory rooms. This building is interesting for solar study because it is oriented along the four cardinal directions. To study different shading techniques for different orientations, rooms facing each direction have been selected. At each of these directions, the most common typical space was selected for study. The resulting scope for the mechanical breadth is that solar shading is optimized for the following spaces:

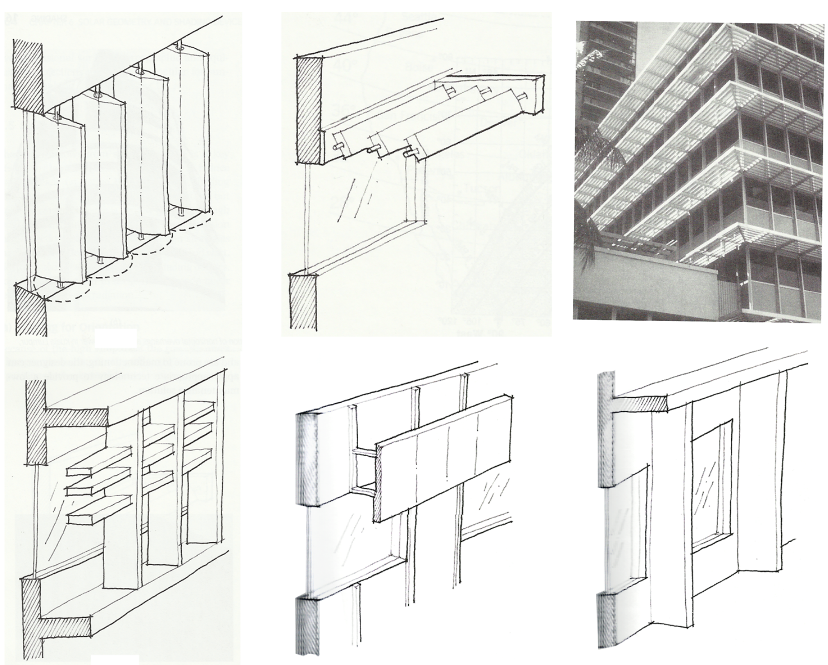


By adjusting the facade to optimize daylight within these spaces, the look of the building will also change. To protect its architectural form, this second breadth will be used to study the changes made during the mechanical study. Daylighting control systems are integrated within the building's architecture, where the scope for this study includes all exterior surfaces of the building. This scope includes the entire facade, not just what was optimized for solar loads, to ensure a consistent architectural expression. This is communicated with a series of renderings to illustrate difference between existing conditions and final design.

Solar Shading Options

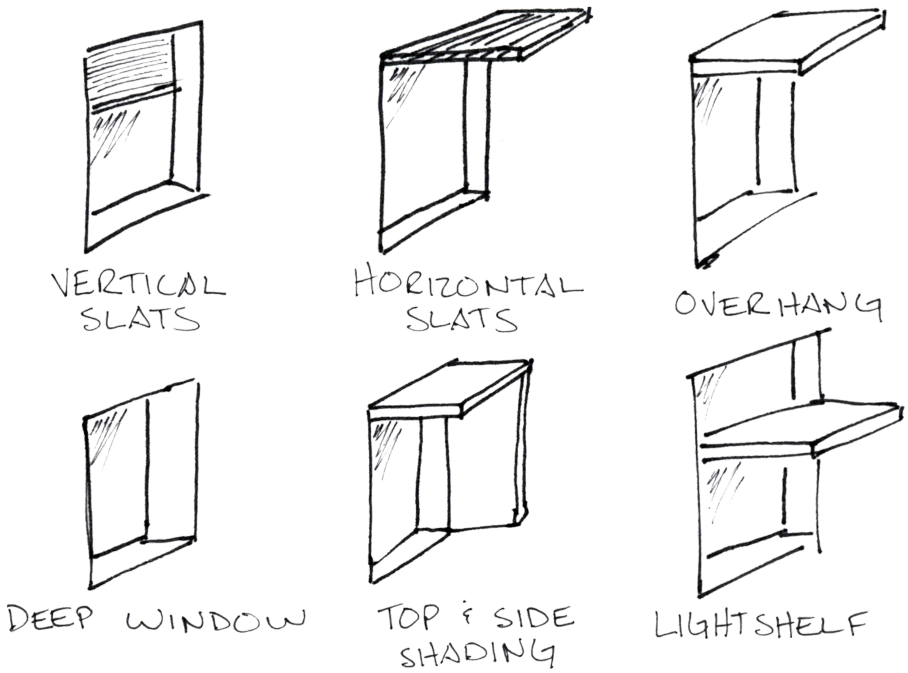
The pivotal point of these two breadth studies (mechanical and architectural) is the performance and aesthetics of the passive solar shading. In terms of performance, this is the only variable between the existing design and the redesigned building facade. The glazing type and daylight openings are purposefully left as a constant factor for both situations. The shading devices themselves then are the sole elements responsible for energy savings. Using architecture to provide heating and cooling benefits is not a new idea, as is discussed in the second breadth of this report, so precedent architectural examples were gathered to indicate realistic design techniques. With that in mind, the following are some examples of passive shading elements.

solar shading examples from the life of a PSU student (Photos by: Sarah Miller)



solar shading examples from *Mechanical and Electrical Equipment for Buildings* [5]

Of the previous examples, the following were determined to be viable options for use on Prince Frederick Hall:

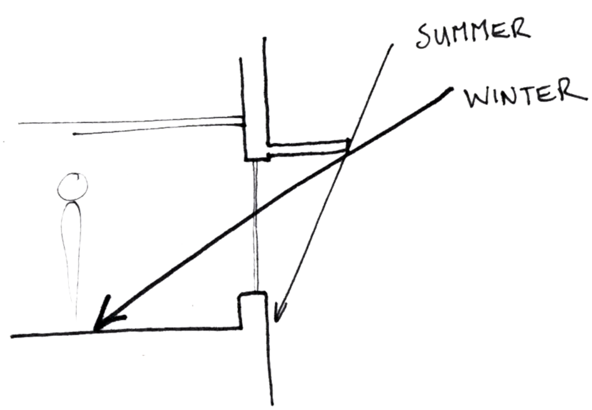


Solar Data

To determine which shading techniques would be the most successful, solar data for the location had to be obtained.

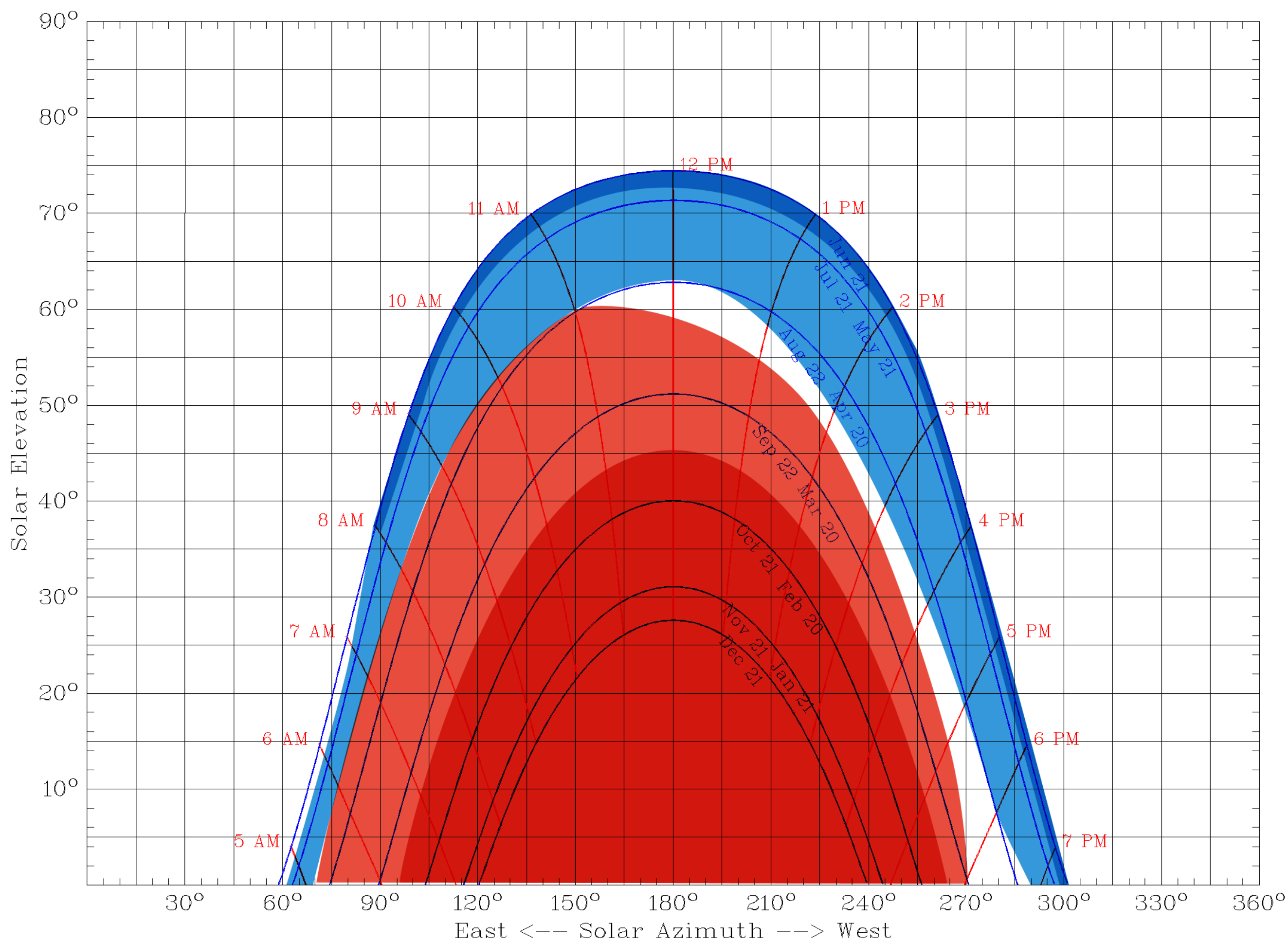
Location: College Park, Maryland
Latitude: 38.9967° N
Longitude: 76.9275° W
TMY Weather Station: 724060, Baltimore Blt-Washngtn Int'l, Class I

The chart on the following page shows the solar altitude and azimuth throughout the year for this specific location. The concept of solar shading is to block the sun when you want to cool a space and allow the sun to enter when you want to heat a space, thus taking full advantage of solar heat gain. In its most simplified form, we see something like this:



Goal

Solar shading added to Prince Frederick Hall must be optimized according to the location. This means, taking into account both the solar angles and the heating and cooling cycles throughout the year. On this solar path diagram, specifically for the latitude of Prince Frederick Hall, the blue and red shading indicate cooling and heating seasons, respectively:



solar path diagram from: University Oregon Solar Radiation Monitoring Laboratory

The goal of the solar shading, then, is to reduce solar penetration between June - August, while still allowing maximum sunlight to enter spaces between October - March.

Mechanical Breadth

This study focuses primarily on cooling loads. The very nature of adding shading to the windows means that only a decrease in solar heat gain can be achieved. Furthermore, it is important to focus on cooling loads because cooling systems are sized to handle daytime solar gain. Where "heating load calculations are generally done for a single hour and are assumed to occur during the nighttime."[9] Nighttime is when there is no solar irradiation to aid in heating the space. This means that optimizing winter solar penetration into the space will not have a direct effect on the size of heating equipment needed because, regardless of daytime optimization, the heating system will still be sized to meet nighttime heating requirements. However, optimizing solar penetration does mean blocking light during the summer, while still allowing daylight in during the winter. This does not affect the size of the heating system, but it does affect the energy used for heating during the day.

Calculation Method

To compare the heat gain with and without shading, the methods described by Spitler's *Load Calculation Applications Manual*[9] are used. These steps are outlined fully in section 7.5, Computation of Fenestration Heat Gains, and shown in greater detail in Appendix D: Breadths. A summary is given here:

- Compute relevant solar angles (altitude, azimuth, angle of incidence)
- Use to solar angles to find the unshaded area of windows
- Calculate direct beam solar heat gain
- Calculate diffuse solar heat gain

Equations to Find Total Solar Heat Gain

First, find direct **beam** solar heat gain:

$$q_{SHG,D} = E_D A_{sunlit} \mathrm{SHGC}(\theta)$$

E_D calculate (see below)
A_{sunlit} is the unshaded area of the window
$\mathrm{SHGC}(\theta)$ is the manufacturer's SHGC with an angle correction factor applied

where the method to find E_D is:

$$E_D = E_{DN} \cdot \cos(\theta)$$

$$E_{DN} = \frac{A}{\exp(B/\sin(\beta))} \times CN$$

A and B are both coefficients
CN is the clearness number, a regional coefficient
β is the solar altitude

Next, find **diffuse** solar heat gain:

$$q_{SHG,d} = (E_d + E_r)A \cdot \mathrm{SHGC}_{diffuse}$$

E_d calculate (see below)
E_r calculate (see below)
A is the total area of the window
$\mathrm{SHGC}_{diffuse}$ is the manufacturer's SHGC with a diffuse correction factor applied

where E_d (for a vertical surface) is:

$$E_{dV} = Y \cdot E_{DN} \cdot C$$

$$Y = 0.45 \qquad for \cos(\theta) \geq -0.20$$

E_{DN} is known from above
C is a listed coefficient

E_r is the ground-reflected diffuse irradiation:

$$E_r = E_{DN}(C + \sin\beta)\rho_g \frac{1 - \cos\Sigma}{2}$$

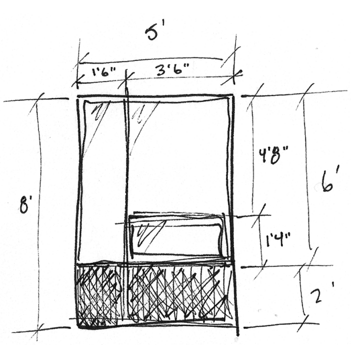
E_{DN} is known from above
C is a listed coefficient
β is the solar altitude
ρ_g is the albedo (ground reflectance)
Σ is the surface tilt angle (90° for vertical surfaces)

Last, combine diffuse and direct solar heat gain to find **total** solar heat gain:

$$q_{SHG} = q_{SHG,D} + q_{SHG,d}$$

This method of calculation relies on finding the area of the window that is left unshaded. Where the greater the unshaded area is, the greater the solar heat gain will be. Methods exist to calculate this unshaded area at different solar angles, but using Trimble SketchUp, this area was easily estimated.

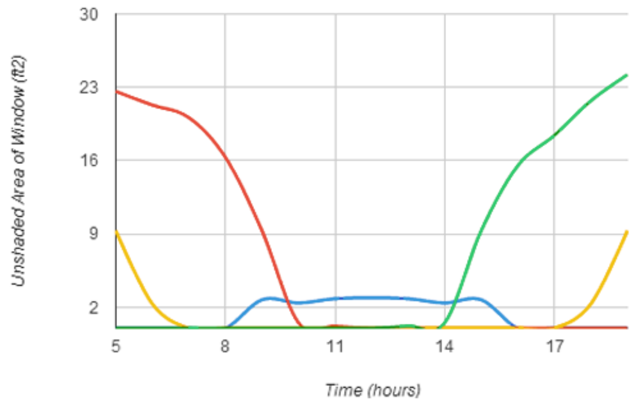
Optimized Shading



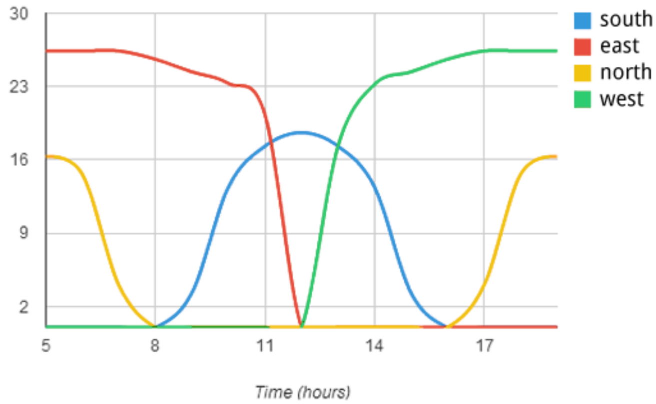
SketchUp was used to iterate the different solar shading options seen earlier in this report. For the four rooms selected for study, all used the same window type, diagramed on the left. Keeping in mind that the unshaded area of the window was the key to controlling solar heat gain, SketchUp's solar angles feature helped to reveal what shading techniques would perform best for each orientation. A summary of the performance of the final shading is shown on the next page. The exact geometry of the shading is discussed afterwards.

Summer: June 21

With Shading

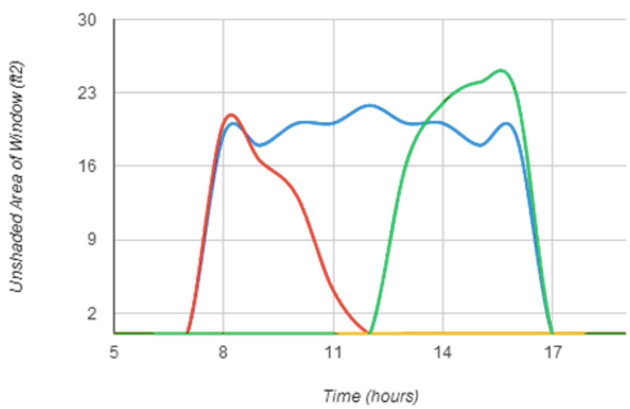


Without Shading

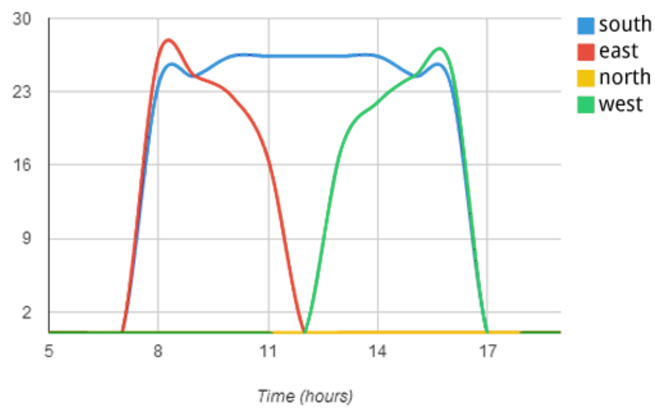


Winter: December 21

With Shading

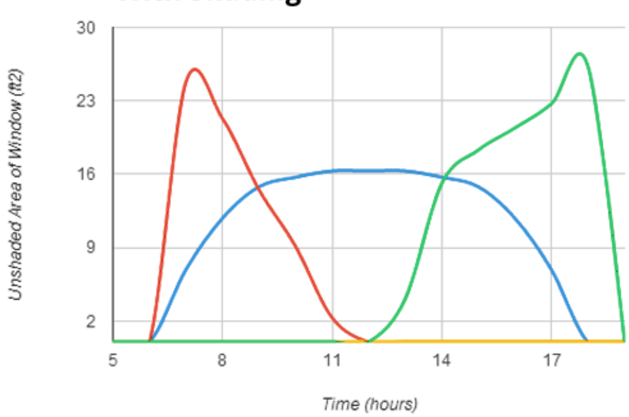


Without Shading

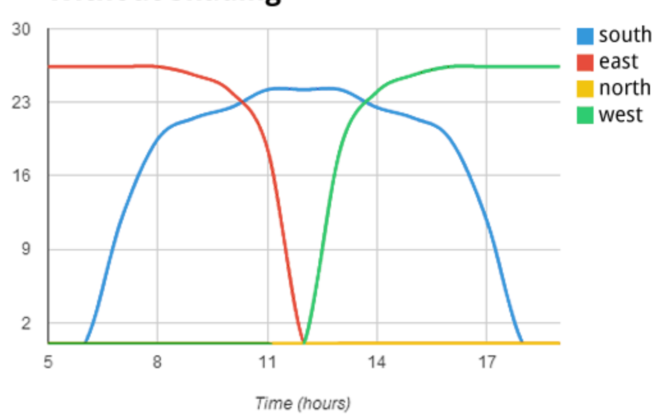


Equinoxes: September & March 21

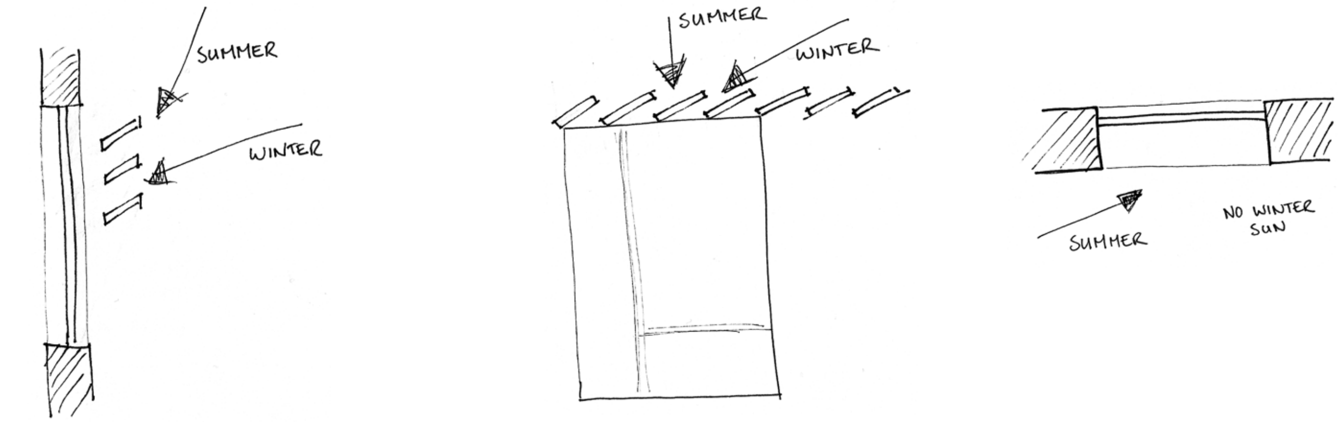
With Shading



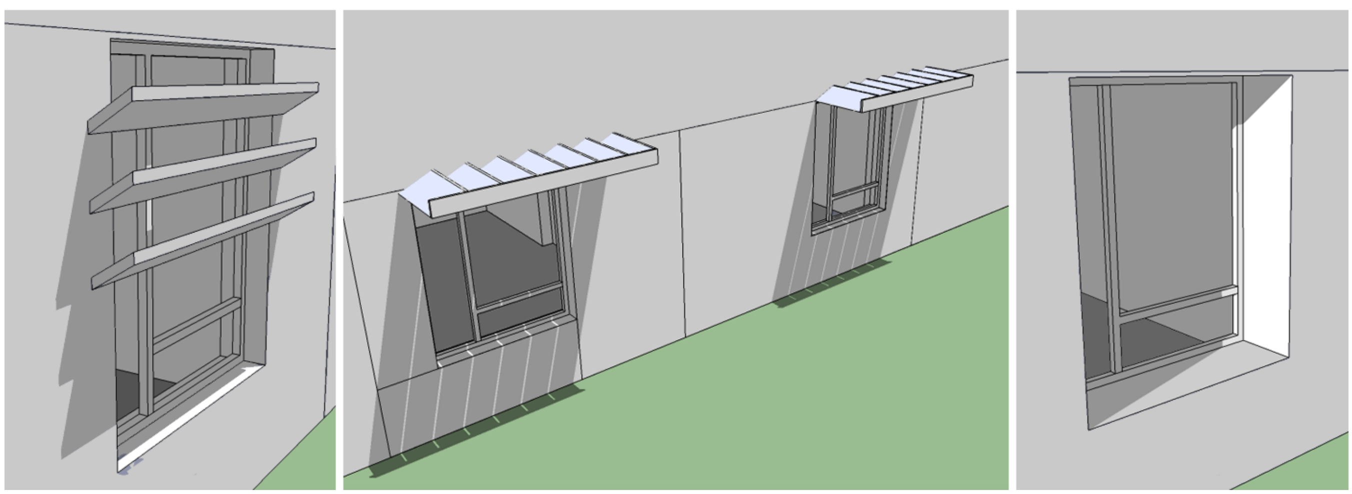
Without Shading



Below are the different shading techniques that were used to achieve the shaded areas graphed on the previous page. For South, East, and West orientations, angled slats were used to allow most winter angle sunlight to pass through and block the majority of summer angle sunlight. For North-oriented windows, winter sunlight doesn't reach these windows, so setting them a few inches deeper into the facade blocks very early morning and very late evening summer sunlight.



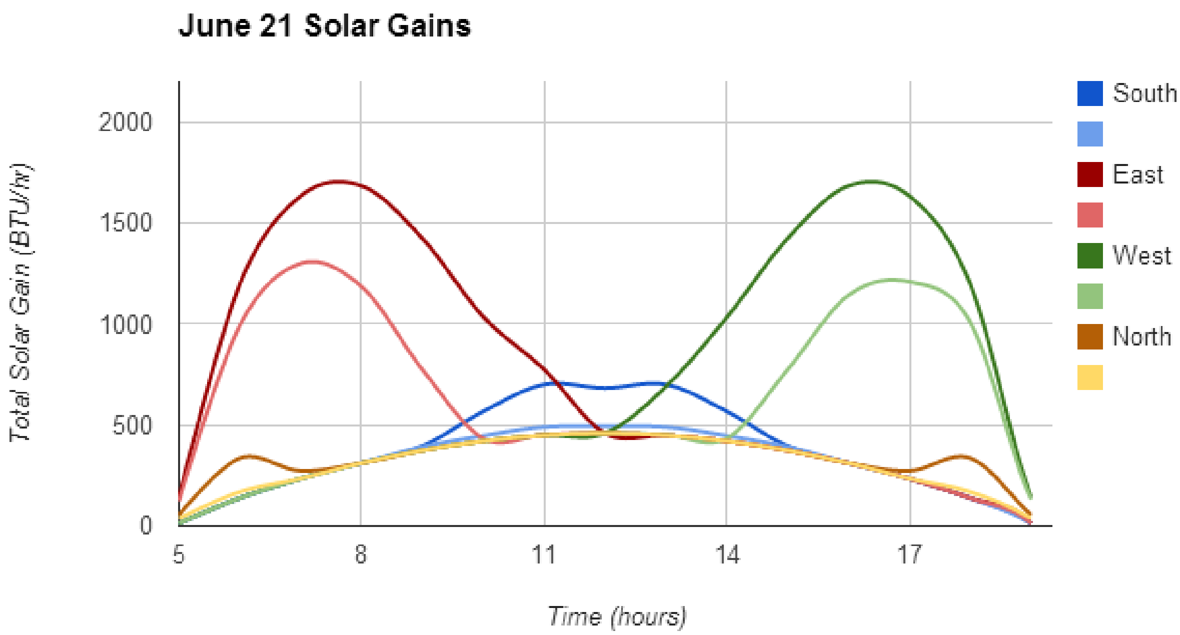
South | **East & West** | **North**

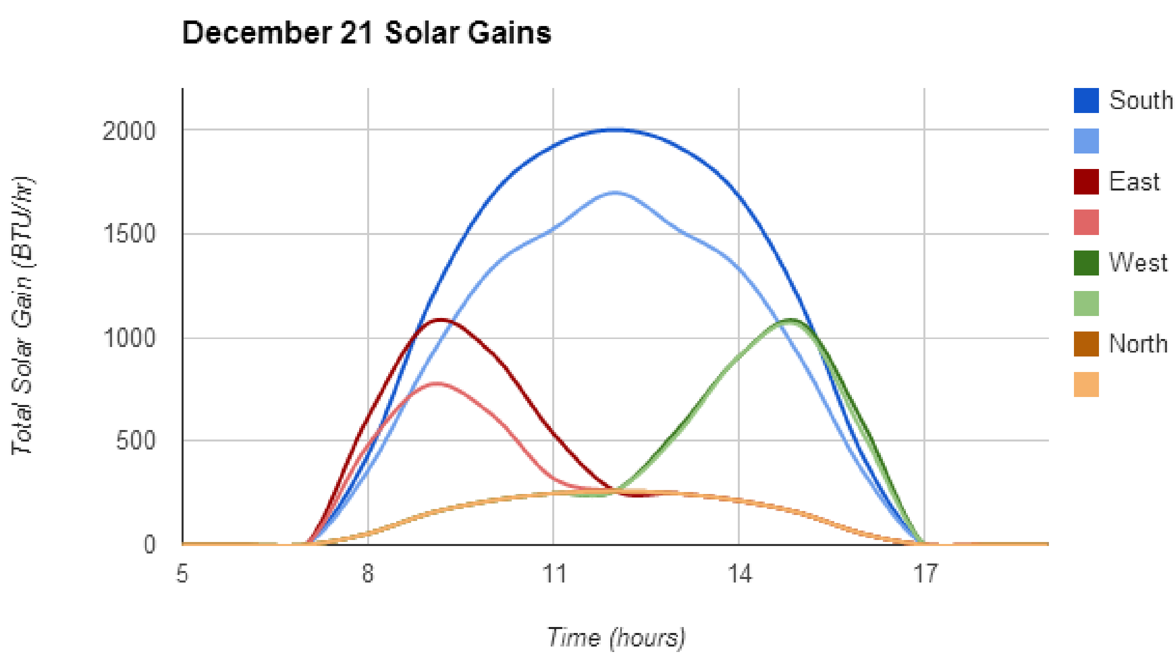


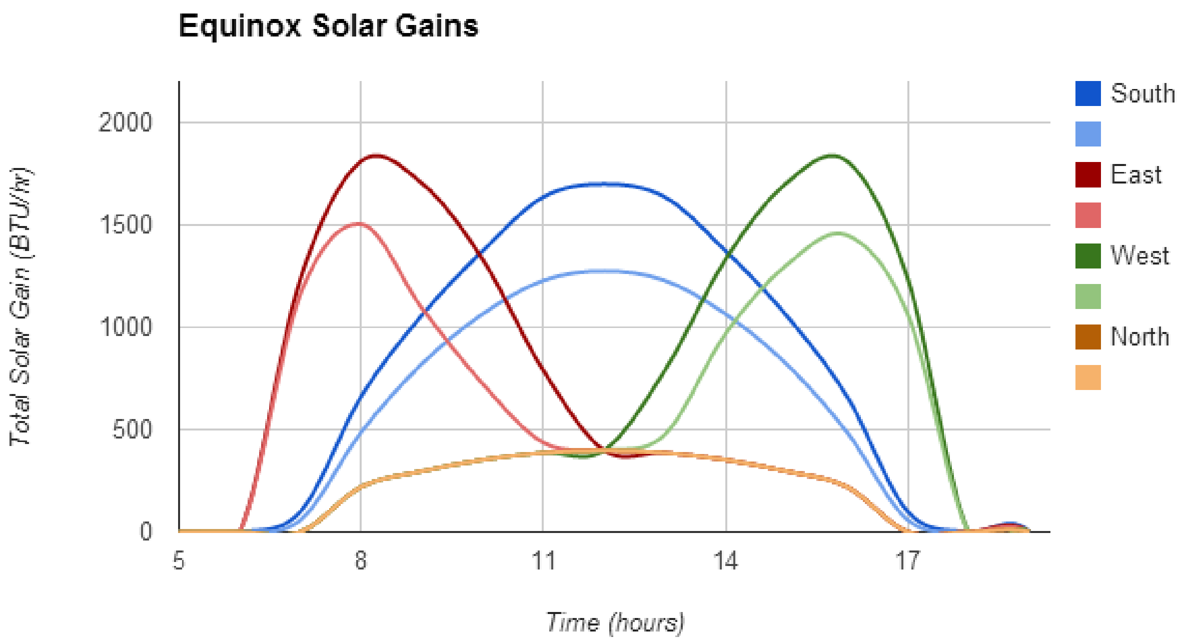
Results

Using the calculation method described above and the area of unshaded window for different days and orientations, the shading techniques applied to Prince Frederick Hall have be quantified in terms of q_{SHG} (BTU/h), the total solar heat gain through a daylight opening.

The following graphs show the different solar gains seen per window at each orientation, on four key days: the summer solstice, the winter solstice, and the equinoxes. The difference is graphed for solar heat gain with and without shading on windows, where the gains without shading are shown in dark colors and the solar gains with shading are shown in light colors.


June 21 Solar Gains
Total Solar Gain (BTU/hr)
2000
1500
1000
500
0
5
8
11
14
17
Time (hours)
South
East
West
North


December 21 Solar Gains
Total Solar Gain (BTU/hr)
2000
1500
1000
500
0
5
8
11
14
17
Time (hours)
South
East
West
North



The four days selected for study are the two solstices (when the sun is at its lowest and highest) and the equinoxes (which both have the same sun angles). During the summer, the goal was to reduce the shaded area as much as possible, but during the winter, the goal was to leave as much area unshaded as possible. However, due to the nature of shading, a reduction of thermal gain still does occur in the winter. To determine if the proposed shading is an effective addition to the building, the beneficially reduced summer solar gain has been compared to the detrimentally reduced winter solar gain. In this case it is assumed that it is beneficial to reduce the solar gain during cooling season: June 21 and September 21. And it is detrimental to reduce the solar gain during the heating season: December 21 and March 21.

Reduction in Solar Heat Gain				
BTU/window/day				
	South	**East**	**West**	**North**
June 21	-858.88	-2,630.91	-2,652.41	-444.66
December 21	-2,494.79	-947.23	-91.49	0.00
September 21	-2,765.25	-1,953.55	-1,613.39	0.00
March 21	-2,765.25	-1,953.55	-1,613.39	0.00

The above values are the calculated difference between the BTUs of solar thermal gain without shading and the BTUs of solar thermal gain with shading. These were first calculated per window at each orientation. Since there is not an equal number of windows per facade, these values were then multiplied based on the number of windows per facade. The total energy savings represents the net solar thermal BTUs saved during the summer less the solar thermal BTUs blocked in the winter.

Energy Savings				
	South	East	West	North
Number of Windows	66	36	48	18
Cooling Season Net BTUs	-239192	-165040	-204758	-8004
Heating Season Net BTUs	-347163	-104428	-81834	0
Net BTUs	-107970	60612	122924	8004
Total			83570	BTUs

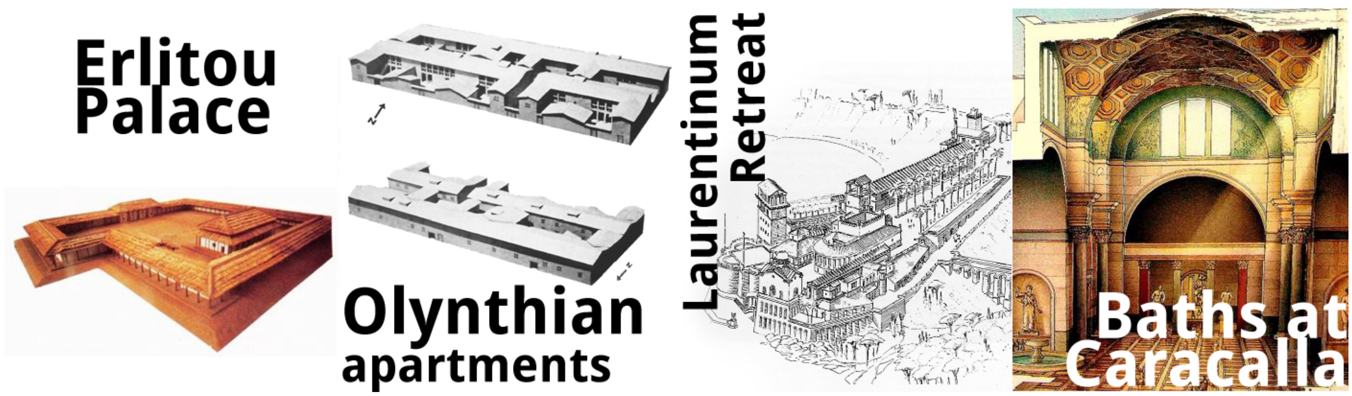
By adding the proposed shading to Prince Frederick Hall, the HVAC system will be required to produce approximately **83,500 less BTUs** of energy per year.

Architectural Breadth

> **"The house in which the owner can find a pleasant retreat in all seasons… is at once the most useful and the most beautiful."**
>
> -Socrates

Historical Passive Solar Architecture

With the growing popularity of photovoltaics and large-scale solar concentrating systems, it might be easy to think of solar technology as symbolic of our modern society. However, humans have been looking to the sun's energy since the dawn of civilization. As early as the 12th century BCE[8] the Chinese began orienting their buildings to maximize solar utility. Historically, there is evidence of many other cultures that used solar design in their architecture.



The Chinese were only the first "to perfect the art of designing homes and whole cities so that all people could warm their houses with the sun's heat in winter and, during summer, keep the sun out of their houses so they could stay cool and comfortable."[8] The Erlitou Palace was one of their first solar buildings that we have archaeological evidence of today, but the Chinese refined solar architecture over the centuries, establishing cities that were oriented to the sun, making solar accessible to all social classes.

To the Greek's, the solar design of buildings was important as well. Around 432 BCE, a group of Greeks from Athens pioneered a new city. Olynthus was a city designed around solar angles, where streets were spaced so every house could receive sunlight without shadowing those around it.[8] Olynthus proved to the Greeks how effective solar heating was. The growing wealth of Greece began to constrict available fuel sources. And as wood became more and more expensive, the government implemented legislation to protect citizens from ever increasing prices. Incidentally, this "coincided with the popularization of solar architecture there, no doubt also a response to the scarcity of wood."[8] This isn't the last time we will see a nation with rising fuel prices turn to the sun for energy.

In Roman times, Vitruvius addresses solar design in his *The Ten Books of Architecture*. Later Palladius takes up his mantle and recommends sun-heating techniques to his rich clients. Like in Greece, solar design only saw widespread popularity after the rising cost of wood drove the population to seek new innovations to heat their homes.

Modern Architecture

In the Greeks and Romans we see two separate cultures driven to solar power when other energy sources became constrained. So if less available fuel drives a culture to maximize utilization of solar design, is it possible that an abundance of fuel could drive a culture to neglect solar design? In *Solar Energy Conversion Systems* [1], Jeffrey Brownson writes that an "examination of economics and social behavior leads one to hypothesize that the perception of solar energy as diffuse is as much a result of the available geofuels in the USA as it is the perceived necessity of those fuels and the non-substitutability of geofuels for the modern public." The lack of passive solar design in the last 50 years of architecture is, in part, reflective of the public's perception of solar energy as insufficient.

Shown above are buildings characterizing International Style architecture. Skyscrapers all throughout the 20th century exhibit characteristics of this style. And while this style certainly has its merits and many aesthetic and practical reasons for such popularity, it shows a lack of interest in solar utilization. In *Let It Shine : The 6,000-year Story of Solar Energy*[8], John Perlin writes that, "a growing affluence that allowed people to indulge their appetite for new electric appliances, combined with the postwar baby boom, helped increase electricity generation by over 500 percent between 1945 and 1968…U.S. fuel consumption as a whole more than doubled between 1945 and 1970." It seems no mere coincidence that this perception of energy abundance coincides with the popularity of characteristics of the International Style.

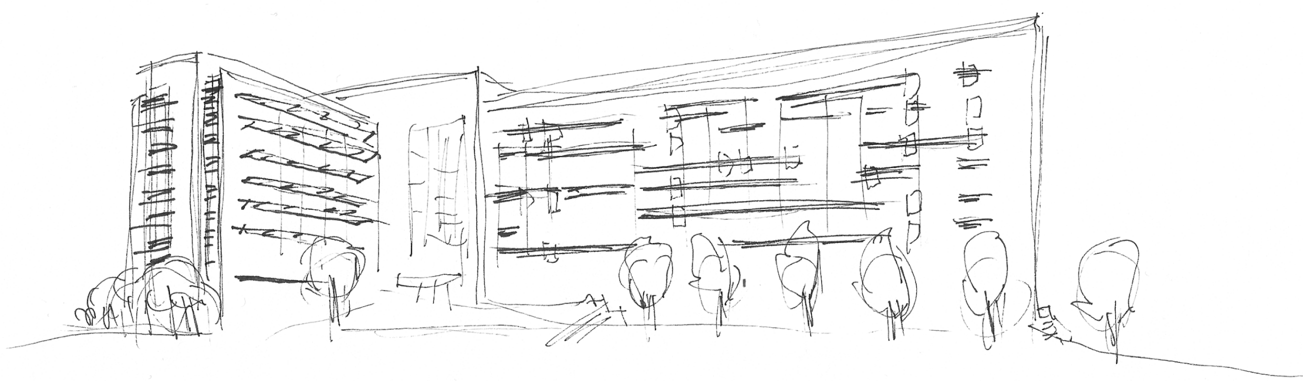
The dawn of nuclear energy turned people further away from solar energy. Until, in the 1970's, when other energy forms hit a crisis. It wasn't until then that reformist groups began to embrace solar energy as having "sufficient potential for changing the institutional structures of the country so that some of the powers find it threatening."[8] This idea has since grown into a potential way for us to combat global warming and increase self-sufficiency. And not unlike the Greeks and Romans, we see a new awareness of solar power as a viable energy source for the 21st century.

Passive Solar at Prince Frederick Hall

> **"The aesthetic goal in any composition is to achieve synergy, where all the elements are so well composed that the whole exceeds the sum of its parts, giving the composition a transcendent quality… passive solar architecture using the theme of comfort, health and sustainability is becoming the architecture of the twenty-first century."**
>
> -Passive Solar Architecture Pocket Reference[6], page 79

The most important goal of the architectural changes applied to Prince Frederick Hall was to create a more comfortable and more energy efficient space. Therefore, the form of the solar shading devices was determined solely by their functionality. In the previous mechanical breadth section, shading devices are defined for use on this building. In this architectural breadth these functionally defined shades are added to the existing building, where other changes have also been made to the facade for a unified composition.

Conceptual Design



Existing Facade

Passive Solar Facade

Summary

Prince Frederick Hall is to be a new beacon of sustainability for The University of Maryland, currently targeting LEED Gold. But this is also a building used by students, for: learning, working, socializing, and living, and maximizing the comfort of the building means increasing student satisfaction and productivity. It was important that all four studies, lighting, electrical, mechanical, and architectural, embraced both of these goals.

In the lighting depth study, illuminance criteria were adhered to for maximum comfort and reduction of lighting power density. By avoiding over-illuminating the four spaces selected for the study, LPD was reduced by 51%. For the electrical depth, decentralizing transformers proved to be a cost effective change, and distributing a higher voltage also means less voltage drop in the building's main risers, thus increasing the efficiency of this system. The two breadth studies, mechanical and architectural, were linked by the desire to add solar shading to the facade of the building. The mechanical system benefits from a reduction of solar heat gain during peak cooling hours, and the passive solar shading visibly communicates the sustainable aspirations of this project.

Humans have instinctually been able to orient themselves appropriately to the sun for millennia. The ancient Chinese, Greeks, Romans, and Native Americans all applied passive solar design to their architecture. But with the onset of the industrial revolution and the rise of skyscrapers, the sun somehow lost its importance to us. We've spent a century now, using the power of machines to fight against the sun's irradiance and ignoring its light. Recently sustainable design has seen a surge in popularity, and it seems new to us. But in truth, we're only just coming back to what so many ancient cultures already knew: the sun is our most powerful resource.

Sustainable design is going to drive a new era of architecture. And it won't be the same this time around. Our requirements are different than they were hundreds of years ago, and today we have new materials. We continue to develop new tools to calculate, design, and improve our buildings. Now we can quantify and communicate across the globe what is most efficient, always with the goal devising new innovations. But it's not going to happen fast. Sustainable design has to come one building at a time. It happens first with the desire to improve the efficiency of a single system within a building, to study the movements of the sun, and discoveries of past cultures. But one study at a time, we can improve our buildings, our comfort, and our environment.