UNIVERSITY OF PENNSYLVANIA NEURAL AND BEHAVIORAL SCIENCES BUILDING

415 University Ave, Philadelphia, PA 19104

Reinhardt Swart | Lighting + Electrical
Advisor | Shawn Good + Leslie Beahm

Final Thesis Report
04.09.14

UPENN NEURAL + BEHAVIORAL SCIENCES BUILDING

philadelphia, pa

reinhardt swart

l/e option

building statistics

occupant | University of Pennsylvania
function | Education and assembly
size | 77,100 GSF
stories | Five stories and a basement below grade
construction dates | January 2014 – March 2016
estimated building cost | $49,300,000
delivery | Guaranteed Maximum Price (GMP)
owner | University of Pennsylvania
architecture & engineering | SmithGroupJJR, Inc.
construction manager | P. Anges
landscape architecture | Christopher Allen
civil engineering | Pennoni Associates, Inc.
a/v, telecomm, acoustics | Shen Milsom & Wilke, LLC

Interior view looking South through scrim

Looking South-East at copper clad block facade

http://www.engr.psu.edu/ae/thesis/portfolios/2014/rxs5160/index.html

architecture

The NBS Building creates a cohesive street front and inviting place for students and faculty. The modern building is a unifier and connector for other nearby buildings through organic and connective forms. The cantilevered east end is a white metal and glass office block; the west end is a copper clad lab block.

Green building strategies include a green roof, scrim sunshade along the south façade, and a on-site bio-retention basin. Low VOC content, local, and recycled materials are specified.

structural

A composite beam system is used throughout the building. The typical floor construction is 3.25" thick reinforced lightweight concrete on 3" metal deck supported by steel wide-flange beams. A 3' reinforced normal weight concrete mat serves as foundation. Moment frames in the North-South direction and braced frames in the East-West direction resist lateral forces.

lighting + electrical

Primarily LED and linear fluorescent fixtures create a minimal and complementary lighting design. Occupancy sensors are placed in classrooms and offices; corridor lighting responds to time-schedules and photosensors for additional energy savings.

Building power is supplied at medium voltage by the campus power system. In the penthouse, a 15kV switchgear distributes power to 1500 kVA transformers. 480Y/277V, 3PH, 4W, 3200A double-ended substations service building and step-down transformers. A 500kW diesel generator provides emergency power for life safety, required, and optional standby loads.

mechanical

Four air handling units are located in penthouse. AHU-1 and 2 supply 32,000 CFM each. Spaces are fitted with volume control boxes. Heating is supplied by campus steam system; cooling is supplied by campus chilled water. AHU-3 (12,000 CFM) is a DOAS with heat recovery wheels serving laboratory spaces. Fin-tube perimeter heating is typical along the building façade.

EXECUTIVE SUMMARY

The following report is a detailed account of all work and analysis performed during the AE 897G senior thesis. This thesis provides a redesigned lighting and electrical solution for four spaces, one electrical depth, one architecture breadth, one mechanical breadth, and one MAE daylighting depth. It is the not the intent of this senior thesis to suggest that there are any problems with the existing design. This senior capstone project provides a unique opportunity to learn new methods of design and propose alternate design solutions, free of budget restrictions.

A redesigned lighting solution and electrical system addresses four spaces in the NBS Building: the scrim façade, lower lobby/lounge, main classroom, and underground lecture hall. Please reference the appropriate sections of this report for a detailed explanation of the lighting and electrical systems. Conceptually, the lighting solution hopes to convey connection and interaction through biomimicry of a deciduous tree.

Moreover, the electrical depth introduces a simple payback analysis for changing low-voltage distribution transformers from NEMA-TP1 Standard dry-type to NEMA Premium dry-type. In the same manner, an analysis concerned with replacing dry-type unit substation transformers with vegetable-based fluid transformers is presented. In summary, upgrading distribution transformers to Premium efficiency does not provide reasonable payback while using vegetable-based fluid transformers in the unit substation offers immediate payback: *savings of $17,171 in initial cost and $2,765 savings per year in owner operating costs.*

The architecture breadth consists of creating an open-office floor plan in a typical graduate student office area, adding Kalwall + Lumira Aerogel to the exterior façade to increase daylighting (MAE depth) and energy performance (mechanical breadth). *Rhino* is used as a common platform to model geometry while *DIVA* and *VIPER* through *Grasshopper* is utilized to parametrically design an optimized Kalwall system.

Informed by parametric design, a subjective design decision yields a solution that improves daylighting deep into the floor plan while slightly improving the energy efficiency of the space. *Simply stated, the proposed design offers $237.53 per year in energy savings at an increased initial cost of $10,975. Despite a 46 year payback, the proposed architecture does provide a more comfortable, inviting, and visually pleasing space.*

TABLE OF CONTENTS

Executive Summary 1

Table of Contents 2

Building Overview 5

Lighting Design Depth 21

Spaces 24

Concept 24

Scrim + Site 26

- Description 27
- Overall Design Goals 31
- Design Criteria/Considerations 33
- Design Development 35
- Fixture + Equipment Selection 42
- Controls Strategy 44
- Calculation Summary 44
- Evaluation 46

Lobby/Lounge 48

- Description 49
- Overall Design Goals 54
- Design Criteria/Considerations 56
- Design Development 59
- Fixture + Equipment Selection 62
- Controls Strategy 64
- Calculation Summary 64
- Evaluation 67

Classroom 68

Description 69
Overall Design Goals 72
Design Criteria/Considerations 73
Design Development 76
Fixture + Equipment Selection 79
Controls Strategy 81
Calculation Summary 81
Evaluation 85
Lecture Hall 86
Description 87
Overall Design Goals 91
Design Criteria/Considerations 95
Design Development 98
Fixture + Equipment Selection 105
Controls Strategy 107
Calculation Summary 107
Evaluation 113
Electrical Depth + Breadths 115
Introduction 117
Electrical Information 119
Short Circuit Analysis 127
Depth Topic | Transformer Analysis 128
Depth + Breadths Integration 138
Introduction 139
Breadth Topic | Architecture 141
Introduction 142
Existing Architecture 148

Proposed Architecture 151
Conclusion 155
MAE Depth Topic | Daylighting 156
Introduction 157
Existing Conditions 165
Original Design 171
Proposed Design 184
Conclusion 202
Breadth Topic | Mechanical + Energy Analysis 207
Introduction 208
Existing Conditions 208
Original Design 211
Proposed Design 216
Conclusion 220
Depth + Breadth Conclusion 222
Summary 223
Conclusion 226
Summary 227
References 229
Acknowledgments 232
Appendix A | Fixture Cutsheets 233
Appendix B | Coraflon ADS Product Information 290
Appendix C | Fixture Schedule 297
Appendix D | Electrical Plans 299
Appendix E | Comcheck Report 304
Appendix F | Mechanical System Cost Analysis 312
Appendix G | Eaton Consulting Application Guide 314

BUILDING OVERVIEW

THE **BUILDING**

The project is a higher education lab building with instructional labs, faculty offices, student spaces, and an auditorium. As an expansion of existing laboratory space, the new building will provide for the collaboration, exchange, and integration of knowledge that characterizes the study of Biology and Psychology at UPenn.

Name | University of Pennsylvania Neural and Behavioral Sciences Building
Location | 415 University Ave, Philadelphia, PA 19104
Occupant Name | University of Pennsylvania faculty, staff and students
Occupant Type | Business (B), Assembly (A-3), and Storage (S-1)
Size | 77,100 SF total
Number of Stories | Five stories and a basement below grade
Construction Dates | January 2014 – March 2016
Estimated Building Cost | $49,300,000
Project Delivery Method | Guaranteed Maximum Price (GMP)

THE **PROJECT TEAM**

Architecture & Engineering | SmithGroupJJR, Inc.

Project Manager: Mark Potter
Architect: Sven Shockey
Structural Engineer: ZY Liu + Liliana Blackson
Mechanical Engineer: Dan Mather + Liz Kaminsky
Electrical Engineer: Joe Trusk + Andrew Verilone
Lighting Designer: Matt Alleman + Leland Curtis
Interior Designer: Lori James
Sustainability: Chris Heine

Owner | University of Pennsylvania
Construction Manager | P. Anges
Landscape Architecture | Christopher Allen
Civil Engineering | Pennoni Associates, Inc.
Audio, Visual, Telecomm, Acoustics | Shen Milsom & Wilke, LLC
Signage | InkSpot DESIGN Inc.

ARCHITECTURE

Fig. 1: Northeast rendering, courtesy of SmithGroupJJR

Fig. 2: West façade rendering, courtesy of SmithGroupJJR

The new Neural and Behavioral Sciences (NBS) building creates a cohesive street front and inviting place for students and faculty. The NBS building, roughly 77,000 SF in size, will contain research and instructional laboratories, a 174-seat lecture hall, and office space. The building will adjoin the existing Leidy laboratories to the north at the lower through third floor levels. Likewise, the building will be connected to the existing Lynch Laboratories Building to the south via an underground tunnel at the lower level.

The placement and design of the building allows the structure to become a unifier and connector for other nearby buildings which are all part of the Neural and Behavioral Sciences neighborhood. This idea is conceptually apparent in the organic and connective architectural design. The massing of the NBS building is simple yet effective—the east end is a white metal and glass faculty office block, which cantilevers into the garden to help minimize excavation impact on roots and simultaneously provide a protected entry porch below. The west end is a copper clad lab block.

Architecturally, the prepatinated copper enclosing the west lab block references the greens of biology, thus adding variety to the mix of buildings in the neighborhood which are all built in red and brown brick. The white metal and glass contrasts with the green copper and trees to improve readability of the massing.

Fig. 3: Lobby entrance rendering, courtesy of SmithGroupJJR

Fig. 4: East office block rendering, courtesy of SmithGroupJJR

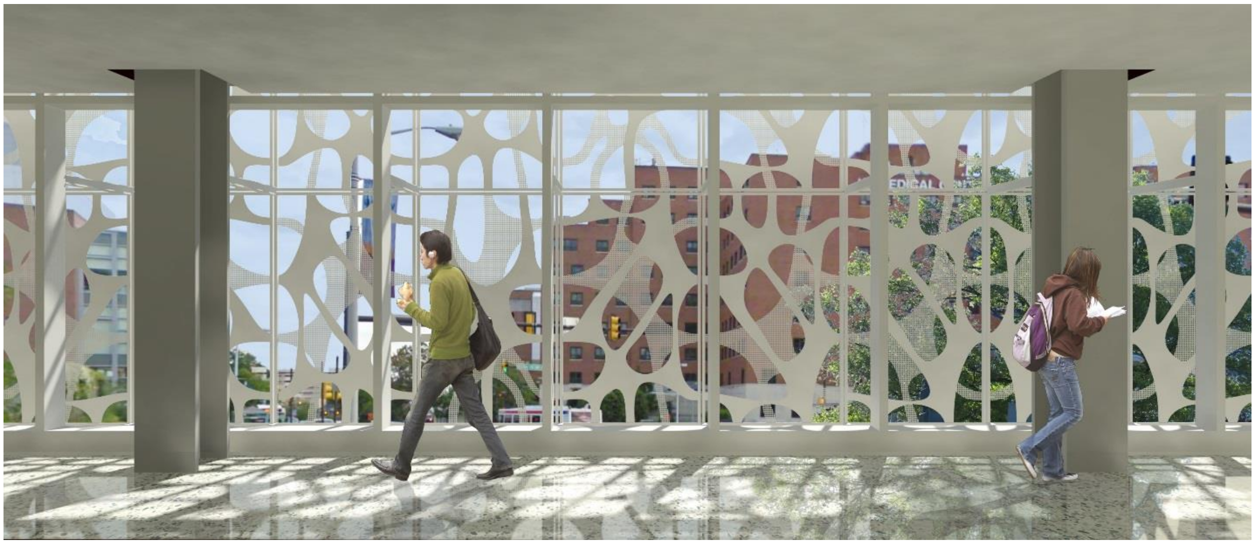


Fig. 5: South Corridor rendering, courtesy of SmithGroupJJR

The south side of the copper block is cut open to expose the main circulation corridors; this south facing glass is protected with a prominent and unique sunscreen that conceptually connects the adjacent garden with the behavioral disciplines who study inside the building through form and function.

MAJOR **NATIONAL CODES**

The applicable codes used when designing this building include the IBC 2009, IEC 2009, IECC 2009, IFC 2006, IMC 2009, and Philadelphia Plumbing Code 2007, as well as more specific compliances with NFPA 70 2008, ADA 2010, NFPA 72 2007, and ASME 2000.

ZONING **REQUIREMENTS**

Construction Type IB

A-3 Assembly - Lecture hall
B Business - Education for students above 12th grade, laboratories
S-1 Moderate-hazard storage

The NBS building will be fully sprinkled and will include non-separated mixed uses so that the allowable height and area are based on the most restrictive allowance, in this case, S-1.

As this is a lab building, the NBS building will include spaces with hazardous material use; the building will thus have one control area for each occupied floor level in accordance with IBC-414.2. At the intersection of the NBS building and the existing Leidy Building, there will be a three-hour fire barrier. The tunnel connecting the lower level of the new NBS building to the existing Lynch Laboratories to the south will be fully sprinkled, of noncombustible construction, and separated from the interior of NBS and Lynch by two-hour fire barrier walls.

Allowable building height | 11 stories (per IBC Section 503)
*Note: No allowable area modification to be used.

HISTORICAL **REQUIREMENTS**

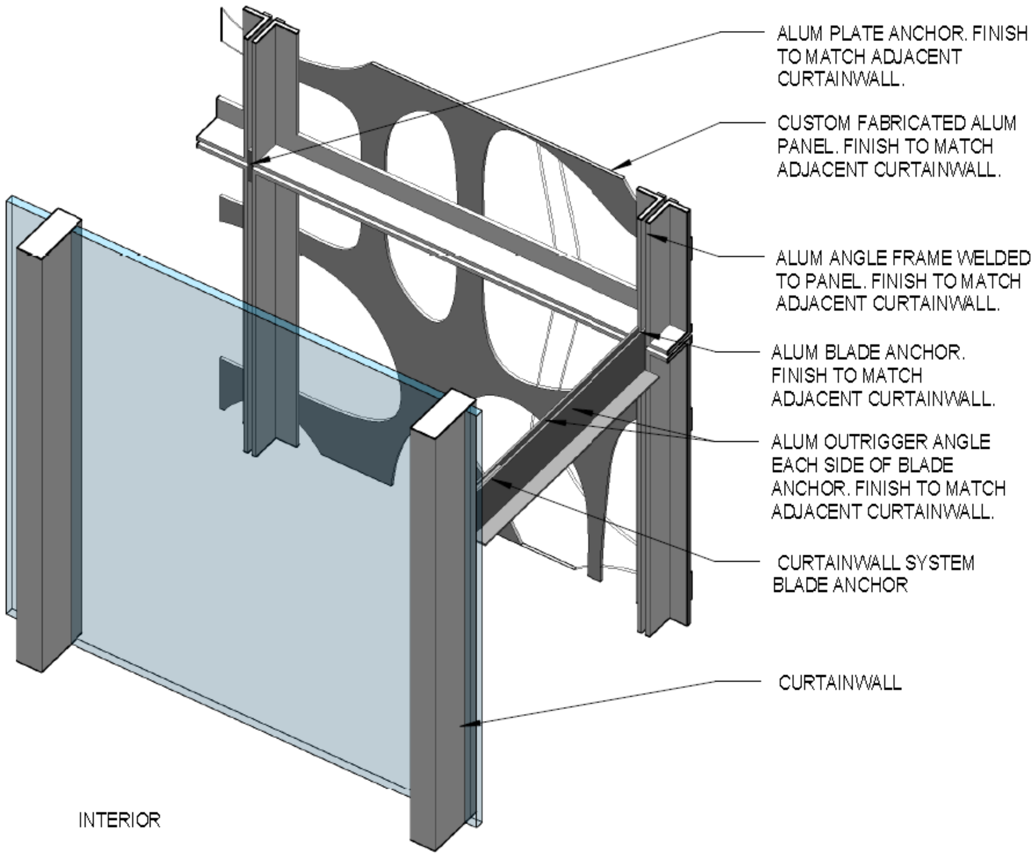
There are no historical requirements as this is a new building but the existing adjacent building—to which the NBS Building will connect—is historic and requires the historic elements are preserved and protected.

BUILDING **ENCLOSURE**

Generally, the building enclosure is a system of curtain walls and composite metal panels consisting of various elements of clear and low-E glazing, shading devices, and a unique scrim on the southern side of the building; typically, behind a metal panel is aluminum rainscreen drainback subframing, mineral wood insulation, airspace, a vapor barrier on the outside of the substrate inboard of the air space, 5/8″ glassmat sheathing, 6″ cold-form framing, and 5/8″ gypsum board. The insulation will be extruded poly-styrene bonded to the sheathing by the vapor retarder.

Fig. 6: Southern scrim rendering, courtesy of SmithGroupJJR

A | The vertical scrim is a single sheet of painted aluminum panel with areas of solid metal, perforated metal with a 40% openness factor (3/8″ diameter holes), and voids to create the appearance of multiple layers. The panel units are 3/8″ thick. The curtain wall is a butt glazed system with painted aluminum mullions and 1″ insulated clear and spandrel glass, adding frit where the scrim does not screen the glazing along the second floor.



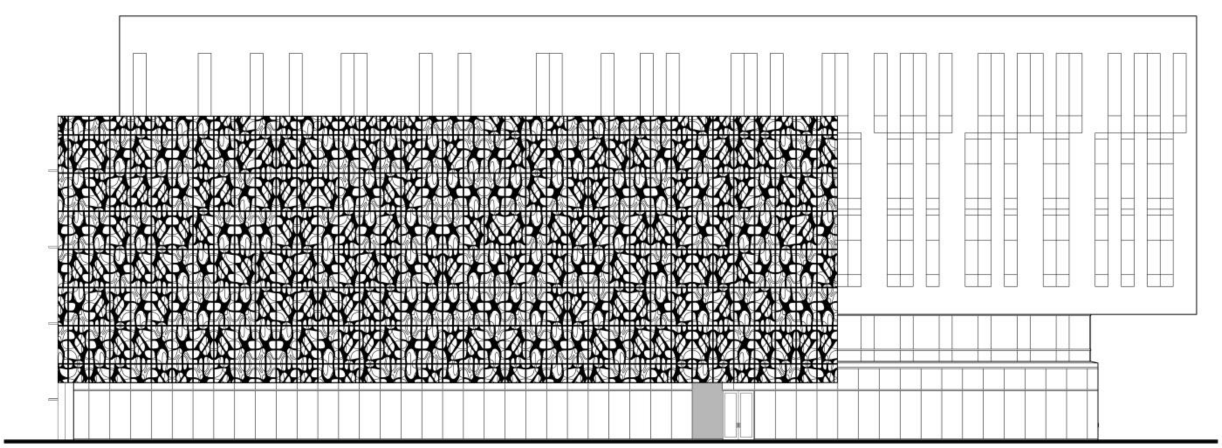


Fig. 7: South Elevation, Courtesy of SmithGroupJJR

Fig. 8: Rendering, Courtesy of SmithGroupJJR

B | The lab block on the west consists of prepatinated copper clad composite metal panels with the typical curtain wall construction. The west block has perforated composite panel horizontal sunscreens, which match the vertical sunscreen on the south, for protection from late afternoon sun. The curtain wall incorporates 1" low-e insulated glazing units.

C | Coil-coated aluminum face metal panels enclose the penthouse with a three-coat fluoropolymer finish and similar back-up system.

D | Light colored metal panels (white aluminum, not shown in image above) on the east block are largely shaded by surrounding buildings resulting in no shading devices. The curtain wall consists of 1" low-e, reflective low-e, and normal insulated glazing units (east block not seen in image above). The lower level curtain walls consist of clear and spandrel 1" low-e glazing set in a grey painted aluminum metal panel system with backing as described above.

ROOFING

Flat roof areas consist of a single-ply fully adhered 60 mils thermoset membrane (EPDM) on a cover board over 6" minimum polyisocyanurate board insulation and taper fastened to the roof deck with a vapor retarder. Where applicable, sections of the roof have green roof components—a 4" minimum growth medium, filter fabric, protection board/drainage mat, root barrier, and plantings. The green roof areas require a thermoplastic sheet (spec 07 13 54).

SUSTAINABILITY **FEATURES**

The NBS building is designed and will strive for LEED Silver through integrated green strategies and design. The major elements of design visible from the outside are the green roof, the scrim along the south façade that acts as a sunshade, and the on-site bio-retention basin. The green roof will work with the bio-retention basin—directly south of the building—to capture and treat up to 90% of the annual rainfall on site and relieve some of the burden on the municipal storm sewer.

The scrim is a design element that will also shade the south façade from direct sunlight while filtering the light in to the space. The form of the skin and orientation of the building aims to optimize the amount of natural daylight delivered to the space while mitigating the solar heat gain in the warmer months. Generally, natural daylighting is a key strategy in this project, evident through the programming of spaces and ideal shape of the building.

Less visible, the HVAC system is sized to work in tandem with operable windows to optimize thermal comfort through natural ventilation. The building will be powered by 100% green power through Renewable Energy Certificates (RECs) purchased by the university.

Finally, the materials specified for the project will meet the LEED requirements for low-VOC content as well as local materials and recycled content.

PRIMARY **ENGINEERING SYSTEMS**

CONSTRUCTION

P. Anges is the construction manager responsible for the construction of the NBS Building to begin in January 2014 and finish around March 2016. The project is bid as guaranteed maximum price (GMP) for an estimated $49,300,000. The project delivery method is design-bid-build.

Construction trailers are currently planned to be placed to the East of the existing Leidy building. A construction entrance to the lower level of the NBS Building is planned to the South of the NBS Building along University Avenue. More construction and loading entrances are planned towards the West of the Leidy and NBS Building. The biggest anticipated construction issue is the limited construction space on UPenn's campus and the safe demolition of the existing Kaplan Wing and multi-story brick building (where the new NBS Building will stand).

ELECTRICAL

As designed, the existing electrical system utilizes a building voltage of 480/277V and provides high redundancy. Power is supplied at medium voltage (13.2 kV) through UPenn's campus distribution. A 15kV (18,000 AIC) main switchgear located in the penthouse receives this power at the building service entrance. The switchgear has a normally open 1200A tie for extra redundancy. Each side of the switchgear has a 1200A draw-out circuit breaker.

Power is then delivered to a double-ended substation. A 1500AA/2000FA kVA dry-type transformer steps the primary 13.2 kV voltage down to 480Y/277V, 3PH, 4W secondary power to service the substation. Buses for Substations 1A and 1B are sized as 480/277V, 3200A, 65,000 AIC units. For added redundancy, a 2500A tie is located between Substations 1A and 1B. The substations have various-sized fixed molded-case breakers that service equipment and lighting.

Substation 1A services the fire pump, a mechanical distribution panel, legally required loads, and optional standby loads. Substation 1B services the fire pump, life safety loads, and bus duct. Several lighting and mechanical loads are powered through emergency panels. The central copper 600A, 35,000 AIC bus duct passes vertically through the NBS Building and provides power for lighting loads through remotely operated circuit breaker panelboards. On every floor, a step-down transformer connected to the bus supplies power to panelboards for receptacles and small equipment loads.

A 500kW diesel generator located on the roof of the NBS building provides emergency power for a 480Y/277V 800A switchboard, the central load bank, and 25 HP fire pump (ATS-FP2). This switchboard distributes power to various distribution panels and panelboards. Emergency power is supplied to ATS-LS (life safety), ATS-LR (legally required), and ATS-OS (optional standby).

The NBS Building utilizes a combination of panelboards with main lugs only or main circuit breakers. Thermal-magnetic circuit molded-case breakers have an inverse time-current element for low-level overloads and an instantaneous magnetic trip element for short circuits. All panelboards have copper buses and are to be rated with NEMA 1 enclosures unless otherwise noted.

LIGHTING

The overall lighting scheme for the NBS Building is minimal, effective, and complementary of the architecture. Linear fixtures are integrated well into the architecture and interiors. Lighting, thus, visually reinforces modernity and a stylish aesthetic; the solution emphasizes the concept of organic growth and neural connections.

The building is lit primarily by LED and linear fluorescent fixtures. Several direct/indirect fluorescent fixtures illuminate classrooms and laboratories while the lecture hall is lit almost entirely by direct LED fixtures. Public spaces utilize LED downlights and other integrated fixtures; LED and fluorescent fixtures are used in cove, wall-washing, and grazing applications. Exterior lighting is realized by a University of Pennsylvania standard direct Type V LED pole-mounted fixture. All lighting is on a 277V system. A large portion of the lighting is specified as emergency lighting at the discretion of the owner.

Lighting is controlled using a variety of control system protocols. Offices and classrooms have wall switches, scene controls, and occupancy sensors for manual-on/automatic-off operation. Many spaces implement simple 0-10V dimming while others—such as the lecture hall—require ELV dimming; Creston Master Controls are used in large spaces for easy scene control and use with A/V equipment. Photocells (dual zone daylight sensors) are installed in public spaces to maximize energy savings when daylight is available. Corridor, façade, and decorative lighting are on time-control schemes that turn off at sunset and on at sunrise.

MECHANICAL

Four air handling units (in penthouse) service the NBS Building. Conditioned air is delivered to the interior using two air handling units: AHU-1 and AHU-2 each supply 32,000 CFM and are fitted with heating and cooling coils. Air through these units is delivered to offices and public corridors fitted with volume control boxes (VCBs). AHU-1 is specified with a 78.2% efficient energy recovery wheel. AHU-3 (12,000 CFM) is a dedicated outdoor air system (DOAS) with a heat recovery wheel to service laboratory spaces. AHU-4 is a CHW/HHW modular system that services the mechanical equipment room. Fin-tube perimeter heating is typical along building façade.

Building heat is supplied by UPenn's campus steam system through a steam pressure reducing station; the corresponding heat pumps are used in a 30% glycol pre-heat piping system with AHU-1/2/3. Cooling is supplied by UPenn's campus chilled water serving AHU-1/2/3/4 and one fan cooling unit per floor. The mechanical system is controlled with a Building Automation System (BAS).

STRUCTURAL

A composite beam system—structural steel with composite decking—is used throughout the building (ground to penthouse floors). The typical floor construction is 3.25" thick 3000 psi reinforced lightweight concrete on 3" deep galvanized metal deck (gage 20) supported by steel wide-flange beams. Steel grid spacing is approximately 15' x 20' across the floors. Beams as large as W30 x 116 are used to support the lecture hall ceiling which supports exterior paving above. Steel beams range between W12 x 14 and W21 x 131 for the ground floor and floors above. The penthouse roof (green roof) slopes ¼" per foot and is supported by steel beams are large as W21 x 144.

As a result of the lower level being well below the water table, a 3' 4000 psi reinforced normal weight concrete mat with #8 gage rebar spaced at 6" serves as the foundation. Moment frames in the North-South direction and braced frames in the East-West direction resist lateral forces.

ADDITIONAL **ENGINEERING SYSTEMS**

FIRE PROTECTION

This project is built as type 1B construction. Primary structural framing, interior bearing walls, and exterior bearing walls are built for two hour fire-ratings. Floor construction and secondary members are also rated for two hours while the roof and its secondary members are rated for one hour. The maximum travel distance for common paths of egress is 100'. Dead ends have a maximum travel distance of 50'.

The NBS building is fully sprinkled. Smoke detectors are in all transition spaces, electrical rooms, and telecom rooms. Every room has at least one strobe; main corridors implement strobes with speakers. Heat detectors are located in the lower mechanical room and penthouse. A remote fire alarm annunciator plate is located in the ground floor lobby.

Wet stand-pipes in the stairwell supply water to the sprinklers. One 25 HP (500 gpm) fire pump on the lower level supplies pressured water through 6" sprinkler lines near the bottom of the building. Towards to the upper floors, the pipe reduces to 4" in diameter. An integral part of the fire pump's control system, a jockey pump maintains pressure in the fire protection piping system.

TRANSPORTATION

Vertical circulation is realized with two central elevators and two stairwells. One stairwell is centrally located near the elevators. The second stairwell is located to the west end of the building along the southern façade. Both stairwells extend from the lower floor up to the penthouse. There is an intermediate stairwell along the southern façade that connects the ground and lower levels. Both elevators extend vertically from the lower floor up the fourth floor. Only one elevator can access the penthouse.

Access to the northern Leidy Building is accomplished by a connection tunnel on the ground, second, and third floors. An underground tunnel connects the NBS Building to the southern Lynch Building.

TELECOMMUNICATIONS

Stacked telecom rooms are located to the north of each floor plan. Seventy-eight square feet on each floor is dedicated to these rooms. Telecom racks are connected to the existing Lynch and Leidy Buildings—telecommunication lines enter the building on the lower level; lines then travel through risers up the floors. From these telecom rooms, data is distributed throughout the building.

Phone and data is available in every room. Wall phone outlets are dispersed throughout the building, located on walls and floors. Several Wireless Access Points (WAP) are located in the lecture hall, several larger classrooms, and labs.

SECURITY/ACCESS CONTROL

The NBS Building introduces access control using card swipe technology and keypads to restrict entry into the building. Major doors have monitoring hardware, request for exit sensors, and audible horns to monitor the flow of traffic in and out of the building. Several closed-circuit television (CCTV) cameras with swiveling capabilities strategically monitor building entrances and public corridors on the ground floor. There is a security guard located in the southern lobby of the ground floor.

AUDIO/VISUAL

A/V equipment includes projector screens in educational spaces, televisions located in classrooms and main lobby (three 46″ LED TV's in lobby), and speakers throughout the building. The lecture hall includes fourteen ceiling speakers, two wall-mounted loud speakers, a projector, and HD video camera in the back. Team study rooms are outfitted with wall-mounted web video cameras and ceiling-mounted microphones.

CATV cable runs throughout the building for use with several media displays.

LIGHTING DESIGN DEPTH

LIGHTING **DEPTH**

In this section, the lighting solutions of four spaces are described in detail. Design criteria will be presented and compared against the lighting design in each space. The lighting narrative is driven by a central concept which will be apparent in the choice of fixtures, layout, visual scene, and renderings.

ASHRAE/IESNA 90.1-2010 STANDARDS

An outline of potential ASHRAE/IESNA 90.1 Standards is presented. Not all of the following standards will apply to each respective space.

9.4.1 Lighting Control

Any automatic control device required in sections 9.4.1.1, 9.4.1.2, and 9.4.1.4 shall either be manual on or shall be controlled to automatically turn the lighting on to not more than 50% power.

9.4.1.1 Automatic Lighting Shutoff

Interior lighting in buildings shall be controlled with an automatic control device to shut off building lighting in all spaces. This automatic control device shall function on either

1. a scheduled basis using a time-of-day operated control device that turns lighting off at specific programmed times—an independent program schedule shall be provided for areas of no more than 25,000 ft^2 but not more than one floor—or
2. an occupant sensor that shall turn lighting off within 30 minutes of an occupant leaving a space, or
3. a signal from another control or alarm system that indicates the area is unoccupied

9.4.1.2 Space Control

Each space enclosed by ceiling height partitions shall have at least one control device to independently control the general lighting within the space. Each manual device shall be readily accessible and located so the occupants can see the controlled lighting. All controlled lighting shall meet the following requirement:

1. an occupant sensor or a timer switch shall be installed that automatically turns lighting off within 30 minutes of all occupants leaving a space in classrooms and lecture hall.
2. each control device shall be activated either manually by an occupant or automatically by sensing an occupant. Each control device shall control a

maximum of 2500 ft^2 area for a space 10,000 ft^2 or less and a maximum of 10,000 ft^2 area for a space greater than 10,000 ft^2. The occupant shall be able to override any time-of-day scheduled shutoff control for no more than two hours.

9.4.1.4 Automatic Daylighting Controls for Primary Sidelighted Areas
When the combined primary sidelighted area in an enclosed space equals or exceeds 250 ft^2, the lamps for general lighting in the primary sidelighted area shall be separately controlled by at least one multilevel photocontrol (including continuous dimming devices) having the following characteristics:

1. the light sensor for the photocontrol shall be remote from where calibration adjustments are made;
2. the calibration adjustments shall be readily accessible, and
3. the multilevel photocontrol shall reduce electric lighting in response to available daylight with at least one control step that is between 50% and 70% of design lighting power and another control step that is no greater than 35% (including off) of design power.

SPACES

A new lighting solution will be implemented in four spaces within the Neural and Behavioral Science Building in order to further effectively express the architecture and function of each space:

- South façade
- Lobby/lounge
- Large classroom
- Lecture hall

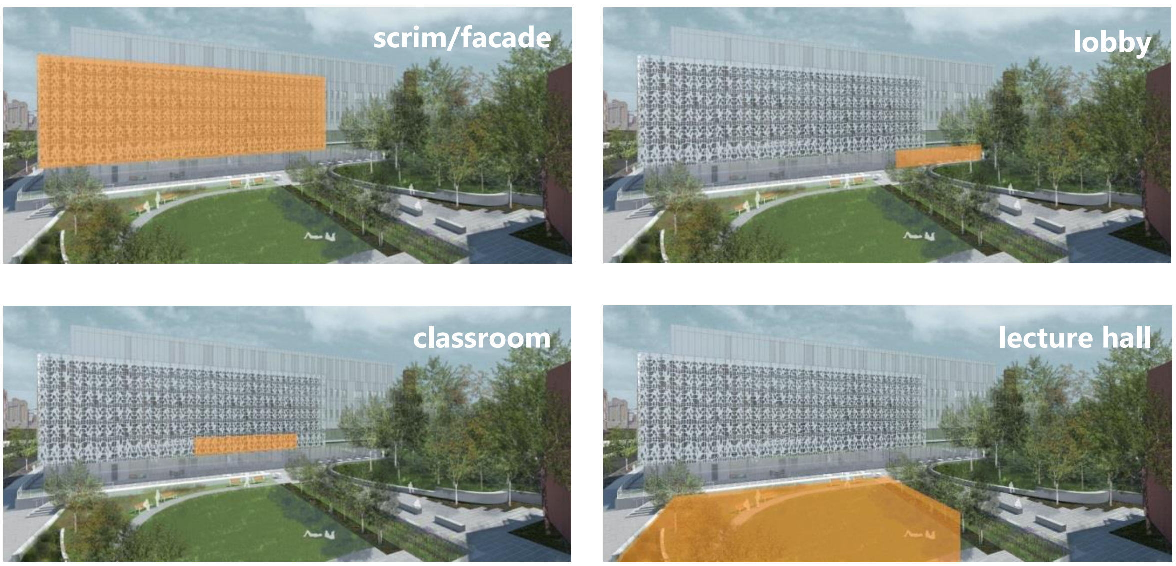


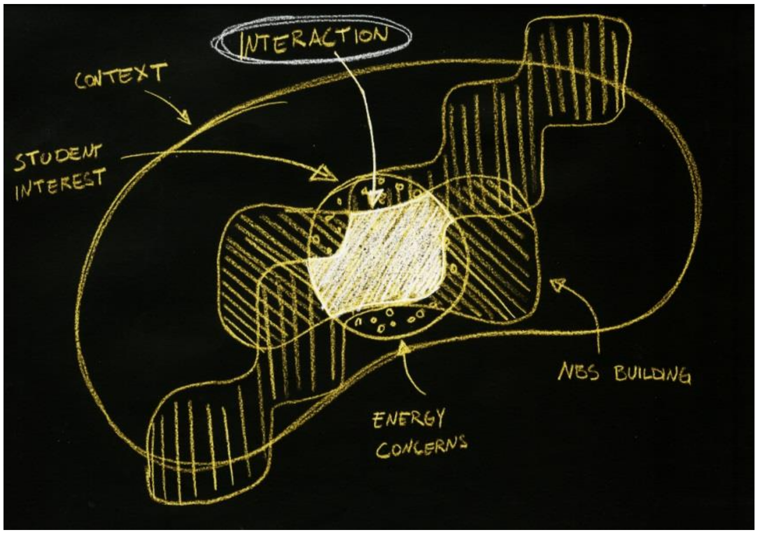
Fig. 9: South renderings, courtesy of SmithGroupJJR

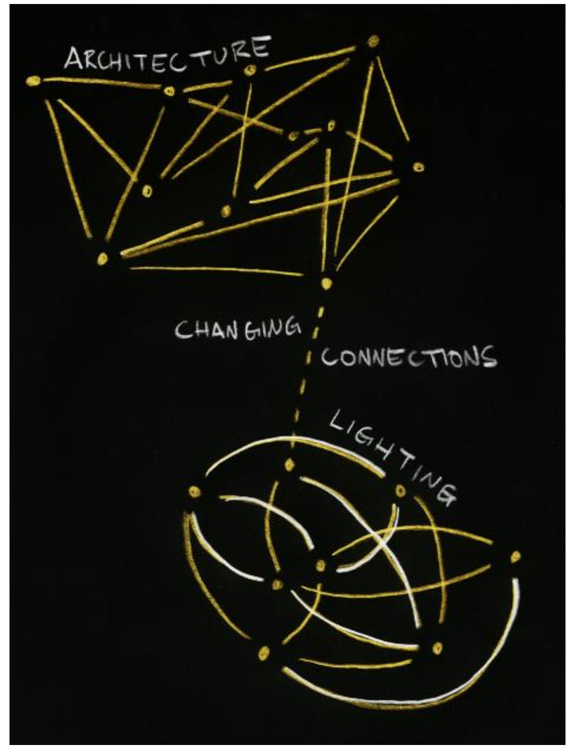
CONCEPT

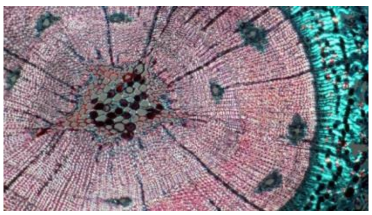
Building upon the architect's original concept of connections, analytical models, and organic notions, the lighting design seeks to create a cohesive and spherical analytical model that connects the architecture, students, and nature. To establish this **connection and interaction**—essentially allowing students to connect to, relate to, and recognize the NBS Building—biomimicry of a deciduous tree drives the lighting solution.

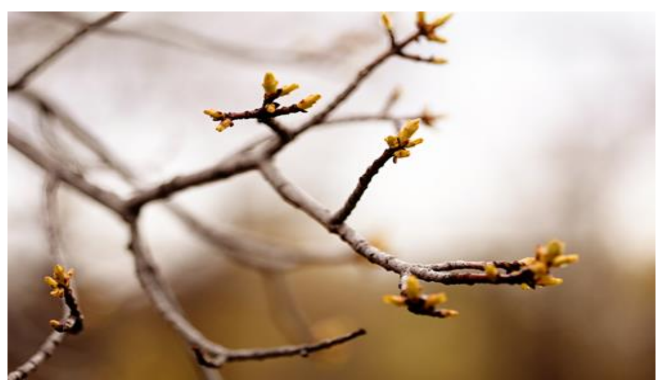
Biomimicry of a deciduous tree inspires the lighting design to conceptually connect the architecture and students of the program. The processes, functions, and aesthetics of a tree guide the lighting design; cohesive and initially unrecognized connections are developed.

The deciduous **tree becomes the muse** through which light visually speaks.


INTERACTION
CONTEXT
STUDENT INTEREST
NBS BUILDING
ENERGY CONCERNS


ARCHITECTURE
CHANGING
CONNECTIONS
LIGHTING





1 | SCRIM + SITE

This section is dedicated to the explanation of the final lighting solution for the southern scrim and site. The following includes pertinent information that describes the visual impression of the space, relation to the overall concept, design goals and criteria as compared to the final design, fixtures used, a control narrative, quantitative calculation summaries, and applicable renderings. Below is an outline of the information included in this section:

Description
- Dimensions
- Site Plan
- Finishes + Glazing
- Planting
- Tasks

Overall Design Goals

Design Criteria/Considerations
- Qualitative Criteria
- Desired Psychological Impression
- Quantitative Criteria
- LEED-NC v4 Draft
- Energy Allowances
- Design Goals Prioritized

Design Development
- Summary
- Mock-up

Fixture + Equipment Selection

Controls Strategy

Calculation Summary

Evaluation
- Summary
- ASHRAE/IESNA 90.1

DESCRIPTION

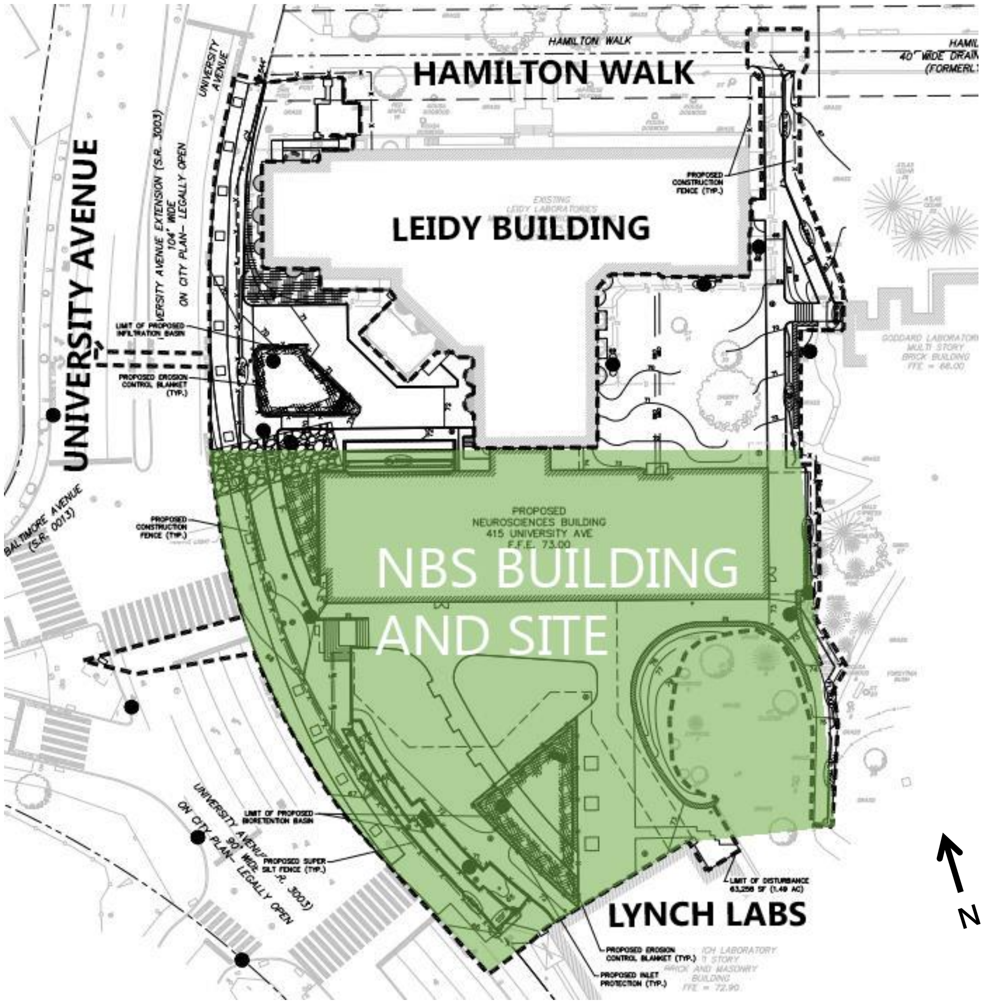
The scrim on the southern wall is a recognizable architectural feature that strongly impacts the architectural concept. Visually, the organic aluminum sunscreen appears to be growing; in reaction to the sun, interesting shadows are created inside the southern corridor during the day. The sunscreen is constructed of two layers of aluminum, one perforated and one solid. The aluminum is coated with a white fluoropolymer paint. High architecture suggests high lighting: the driving force for the proposed lighting design.

Fig. 10: Rendering of south sunscreen, courtesy of SmithGroupJJR

DIMENSIONS

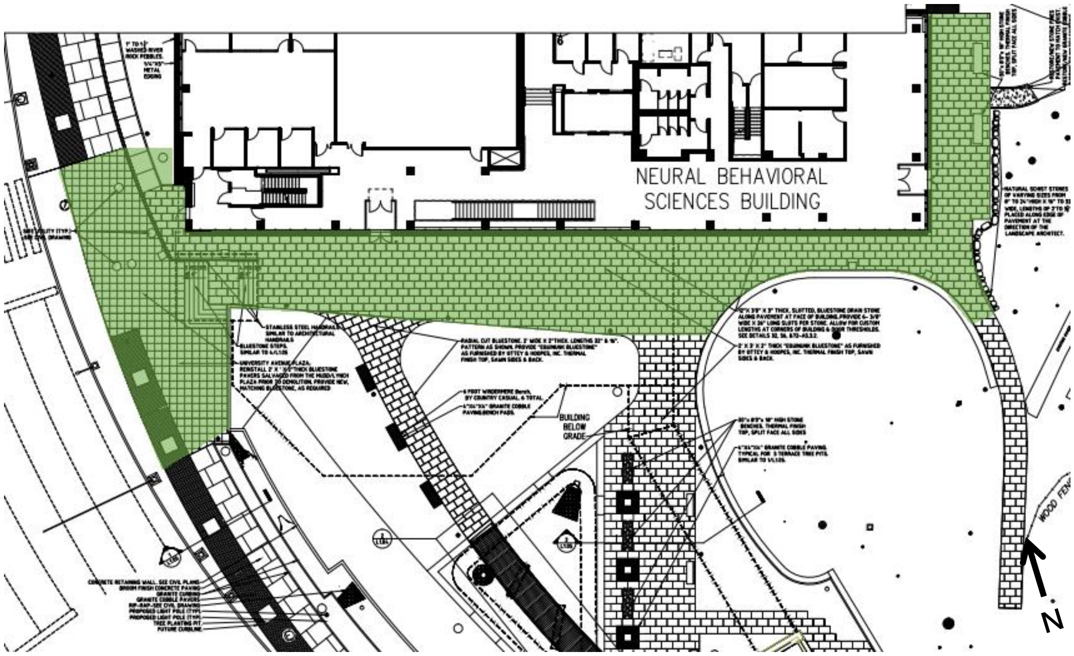
Building grounds area – 39000 ft^2
Overall façade area – 17125 ft^2
Approximate scrim width – 140 ft
Approximate scrim height – 48 ft

SITE PLAN



Reference: Sheet CS0501

ENLARGED SITE PLAN



Reference: Sheet L1.03

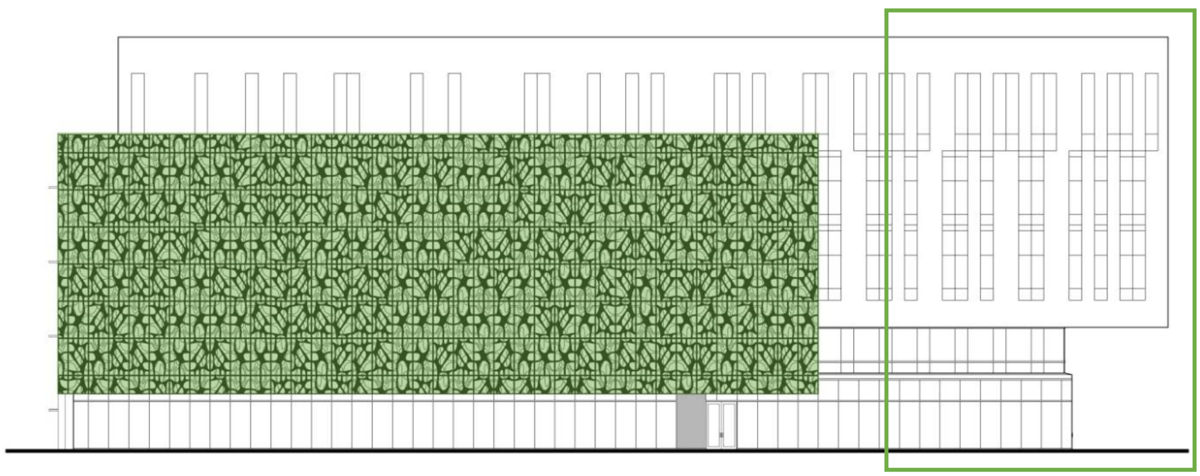
VIEW LOOKING WEST FROM GARDEN

Fig. 11: Rendering of main entrance, courtesy of SmithGroupJJR

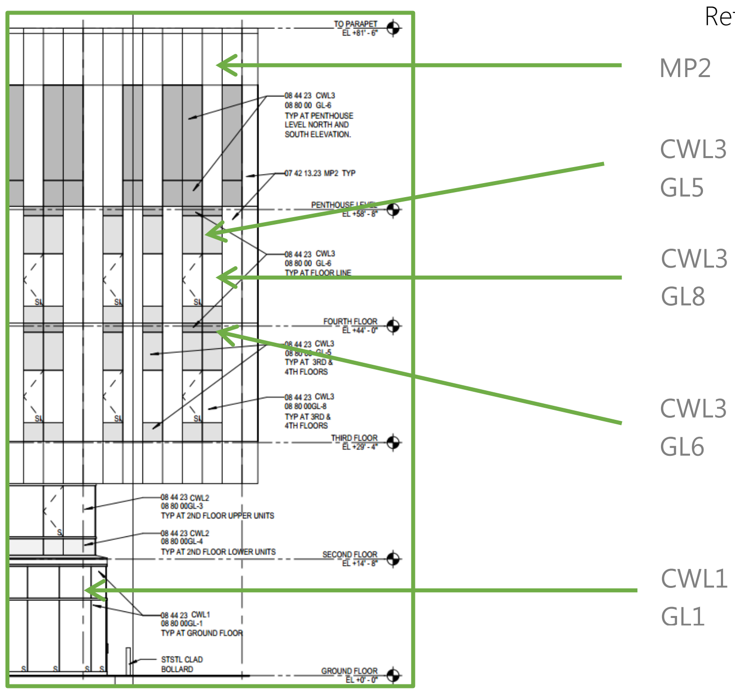
FINISHES + GLAZING

The vertical scrim is a single panel of painted aluminum with areas of solid metal, perforated metal with a 40% openness factor (3/8" diameter holes), and voids to create the appearance of multiple layers. The panel units are 3/8" thick. Aluminum panels are painted with a two-coated fluoropolymer satin finish. The curtain wall is a butt glazed system with painted aluminum mullions and 1" insulated clear and spandrel glass, adding frit where the scrim does not screen the glazing along the second floor. Metal panels on the southern face of the building are white and gray. Natural low-e 1" clear insulated glazing units span the ground floor corridor and lobby.

SOUTH ELEVATION



Reference: Sheet A4.1.1



Façade and Site Materials				
Surface	Material	Description	Style/Color	Reflectance (ρ)
Scrim	SS-2	Solid and perforated aluminum panel with satin coated finish	Gray	0.45
Exterior Walls	CWL1, CWL2, CWL3, MP2	Various types of curtain walls, white metal panels, gray metal panels	Gray, white	0.40*
Site	Pavers	12" x 3" pavers	Bluestone	0.20
Exterior Ceiling	AWC-1,2,3,4	Acoustical wood ceiling with varying grid of hole diameters	White oak wood	0.70

*Reflectance averaged for materials; actual materials will exhibit varying values

PLANTING

Immediate to the building, the site is fairly open. There are various trees to the east of the NBS building: horsechestnut, Lydia Morris holly, common crapemyrtle, and Maidenhair trees. Grass is to be planted in between the paver walkways.

TASKS

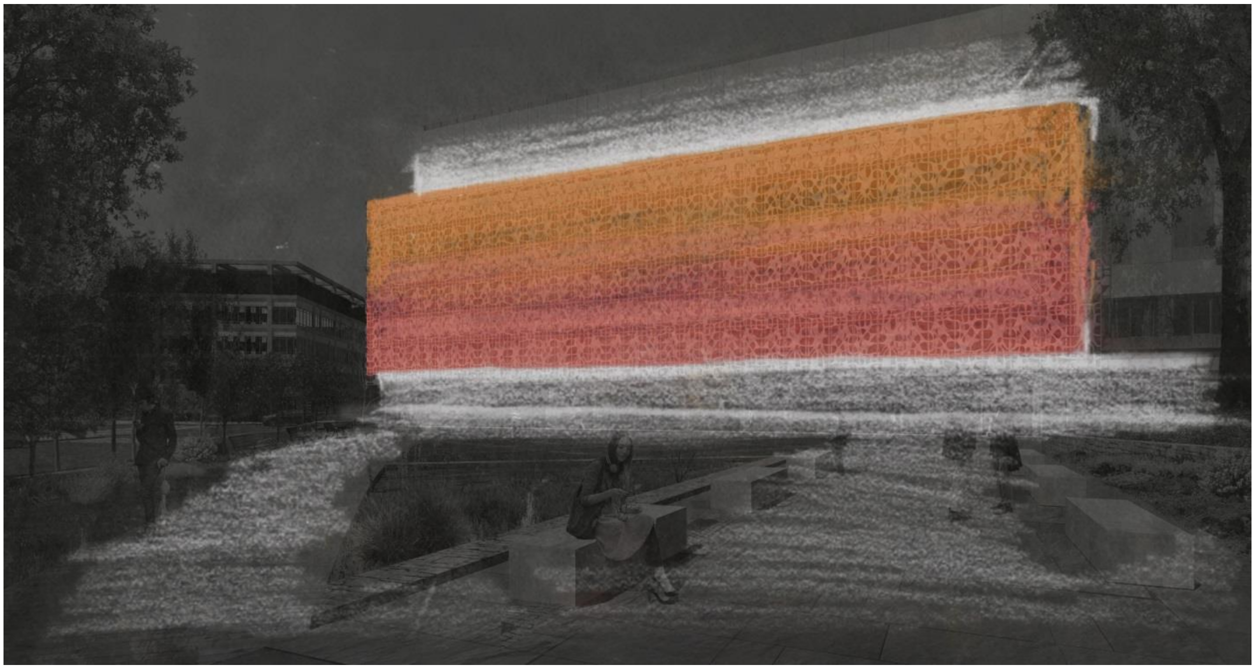
Night time pedestrian way-finding and safety are of great importance. The exterior lighting should ensure a safe and comfortable environment. Visual tasks address human activity and movement. Orientating an occupant to the entry spaces and building should also be a lighting goal. Importantly, creating a sense of place and art through light is not inherently a task but a crucial consideration in the proposed lighting scheme.

OVERALL DESIGN GOALS

Trees produce energy and receive nutrients through photosynthesis. As days shorten and the temperature drops, less chlorophyll (essential to photosynthesis) is created giving rise to the festive red, orange, and yellow pigments of leaves. In the same manner, at night, the new lighting solution will allow the scrim to become *a festive expression of the absence of daylight.*

Fig. 12: www.starwall.info

Fig. 13: www.starwall.info



Colorful + dynamic: the design will use a pastel color palette that slowly changes between colors to impose a dynamic and festive impression. One goal is to draw out the curves, form, and shadows of the scrim: a direct juxtaposition to the day-time character (which washes the scrim in light) yet responsive to the architecture. Non-uniform lighting and theatrical elements around the site will encourage exploration and visual sensations.

Form: the form of the scrim will be reinforced by adding fixtures but allowing the scrim to be separated from the building and visually placed in silhouette.

Glare: the new solution facilitates a detailed study of glare control; fixture selection and placement, cut-off angles, and visual assessment are of high importance.

Dark Sky: besides energy concerns, limiting up-light or obtrusive lighting will be considered. Specifying the right fixtures, locations, and aiming angles will address the concern.

DESIGN CRITERIA/CONSIDERATIONS

QUALITATIVE CRITERIA

Very Important

- **Light Distribution on Task Plane**
  - Providing for safe pedestrian travel is important to ensure security.

- **Lighting Controls**
  - Exterior lighting should be controlled so that the fixtures are only on when needed, i.e. at sunset. This will increase energy savings.

Important

- **Accent**
  - Highlighting the exterior architectural elements can add drama and visual appeal. The lighting should be responsive to the architecture and applied appropriately.

- **Appearance of Space and Lighting Fixtures**
  - Site fixtures will be compliant with UPenn campus standards.

DESIRED PYSHCOLOGICAL IMPRESSION

As outlined by John Flynn and discussed by Gary Steffy, the goal of the redesigned lighting solution for the façade and site is to warrant a festive psychological response in the community. This could be realized by applying color, appropriate distributions, and/or dynamic effects to the façade and lighting.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance – Important

- IES Classification | Common Applications

  - Building Entries, paths to curbs, medium activity, LZ2
    - Category C: 4 lux (0.4 fc), at ground plane
    - Avg/Min: 3:1

Horizontal illuminance ensures that pedestrians can see where they are going. There is potential for more activity at night time if there are night classes, sporting events nearby, or other events held in the building.

Recommended Vertical Illuminance – Very Important

- IES Classification | Exterior (Moderate Ambient Lighting) + Common Applications

  - Facade, high reflectance, medium activity, LZ2
    - Category M: 50 lux (5.0 fc)
  - Building Entries, paths to curbs, medium activity, LZ2

- Category C: 1 lux (0.1 fc), at ground plane
- Avg/Min: 3:1

Facial recognition is critical for safety and security. Dark shadows should be avoided. Proper illuminance and brightness contrast on the façade will ensure that the lighting solution is effective and recognizable. Lighting of the vertical scrim is the primary goal of the exterior lighting solution.

LEED-NC v4 Draft

EAp2: Minimum Energy Performance

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.01-2010.

ENERGY ALLOWANCES

According to ASHRAE Standard 90.1 version 2010 (most recent version upon completion of thesis) for building exteriors, Zone 3 type construction has the following allowances:

Energy Allowance (ASHRAE 90.1 – 2010)			
Space	Area (SF)	W/SF	Allowed Wattage
Building Grounds	39000	0.16	6240 W
Facade	17150	0.15	2568 W

DESIGN CRITERIA PRIORITIZED

1. Meet ASHRAE Energy Code requirements
2. Create safe environment with proper vertical illumination
3. Accent southern scrim to add drama to exterior
4. Limit uplight to minimize light pollution
5. Meet LEED requirements for lighting controls and minimum energy requirements

DESIGN DEVELOPMENT

SUMMARY

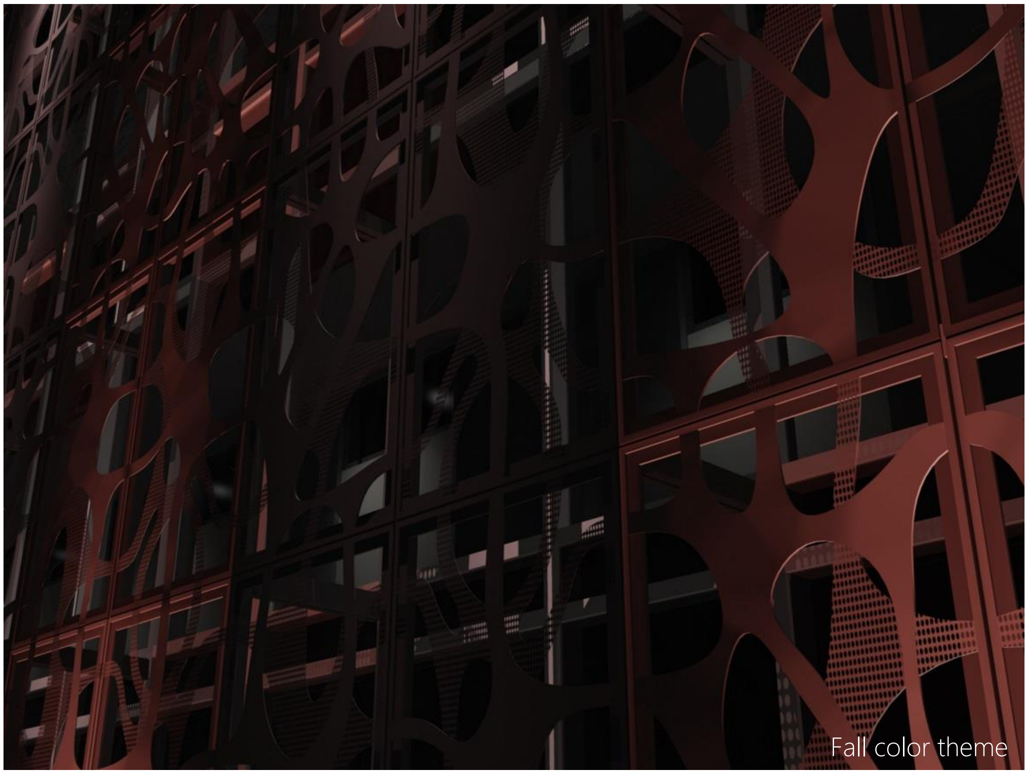
To add drama to the nighttime character of the NBS building, the new lighting design highlights the southern scrim in a festive manner: narrow distribution RGB LED floodlights illuminate the scrim non-uniformly from both below and above the surface. The fixtures will slowly and subtly cycle between a predetermined set of colors: spring colors, fall colors, and a neutral setting. A quote from an interviewer talking with James Turrell captures the idea perfectly: "The actual view of the architecture, its volume, its surface depends on the change from one color to another."

As described above, the scrim is organic in form with several curves and repeated mirrored forms. A solid layer of aluminum with perforated sections provides depth and texture to the vertical plane. The surface is satin white painted aluminum to mitigate uncomfortable reflections and inversely, "carry" light across the plane (see Mock-up section below).

Spring color theme

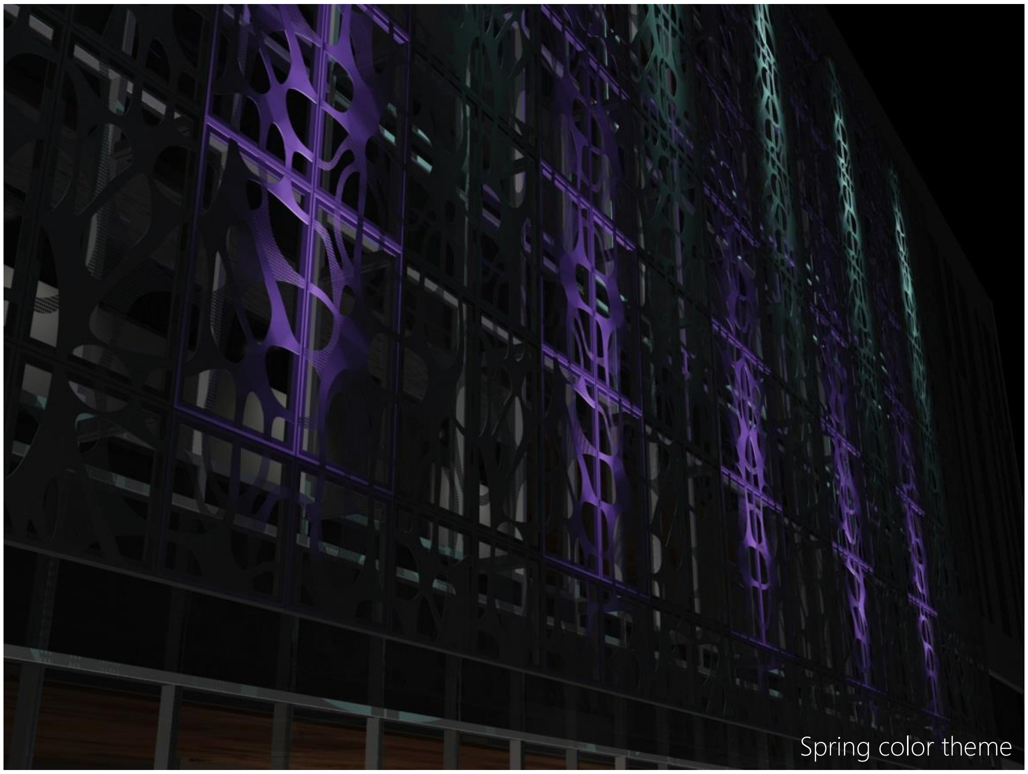

Fall color theme

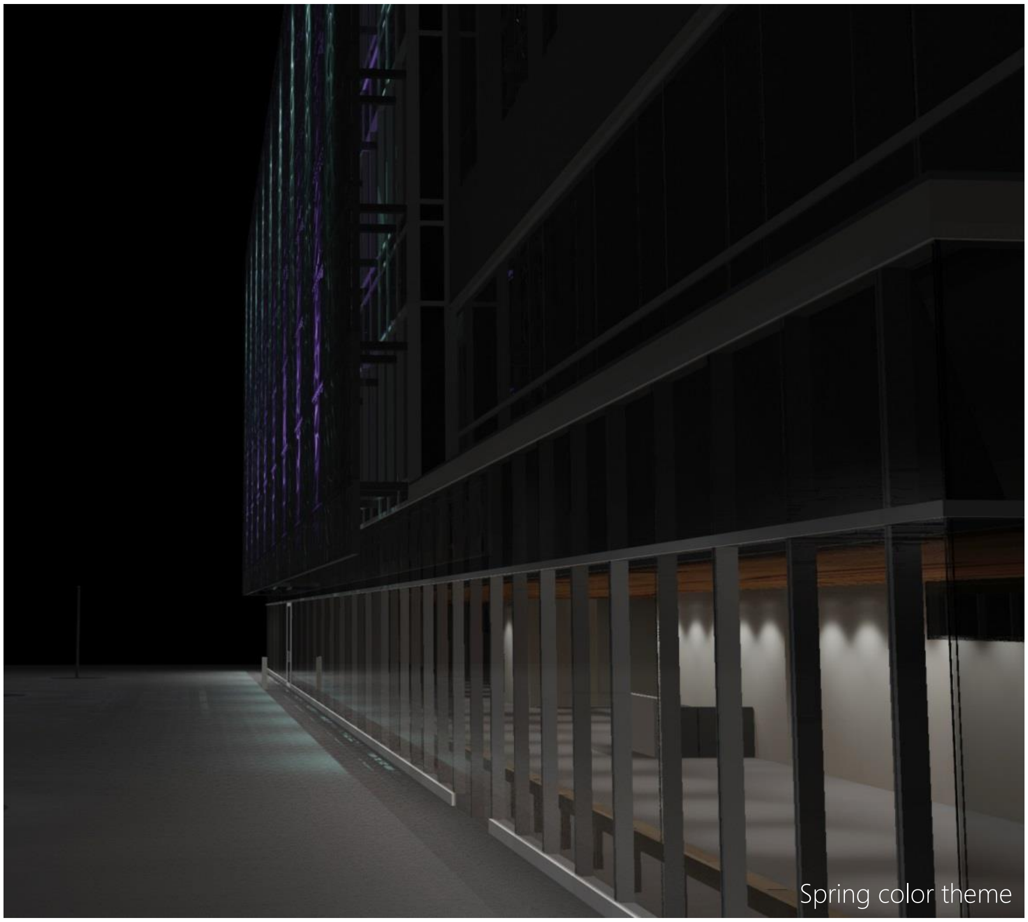

Spring color theme



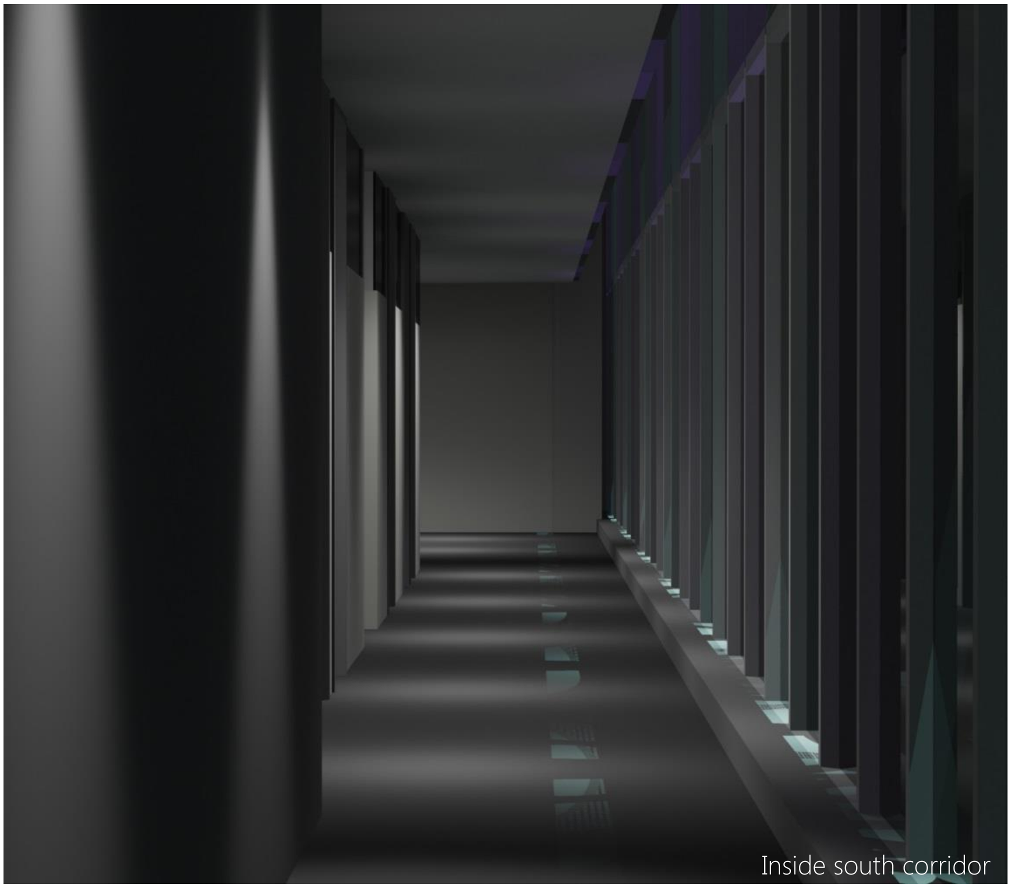
Point sources are specified to achieve a higher candela centerbeam value towards the middle of the scrim. Custom two foot mounting brackets are connected to the existing scrim façade to suspended the fixtures into the exterior space. Aiming is performed as to light the screen effectively while limiting uplight.

Dark skies are not a limiting factor in the proposed lighting solution. The original lighting design for interior corridors along the southern façade specifies linear uplights. These uplights light the ceiling but also spill light out into the exterior space. This component of lighting alone violates recommendations as stated in MLO and LEED. Since the original design alone cannot meet dark skies recommendations—set forth by LEED—some artistic liberty justifies a solid lighting expression, one that does add to the overall uplighting within the site. However, fixtures are chosen and aimed to limit uplight. Controls will ensure that fixtures are on only at appropriate times, hereby respecting the community and increased concerns for light pollution.


Spring color theme


Spring color theme

Shadows are not apparent within the interior southern corridor. This aspect of the original design was sacrificed due to energy concerns and glare control. The current design meets energy codes while limiting a direct view of the fixtures.


Inside south corridor

MOCK-UP

The sunscreen is constructed of two variations of aluminum, one perforated and one solid. The aluminum is coated with white fluoropolymer paint; it is noted, based on research, that a white satin paint will be applied to the panels (see Appendix B, Coraflon ADS Product). The materiality of the sunscreen presents several challenges when designing the lighting of the space: diffuse and specular reflection as well as luminance characteristics are considered and guides the overall visual solution.

In order to verify the characteristics of a painted aluminum, a mock-up is performed with a piece of aluminum bought at Home Depot. Two coats of Behr exterior satin enamel paint is applied to the aluminum. A linear LED with exposed diodes is used to illuminate the panel and study the character of the light.

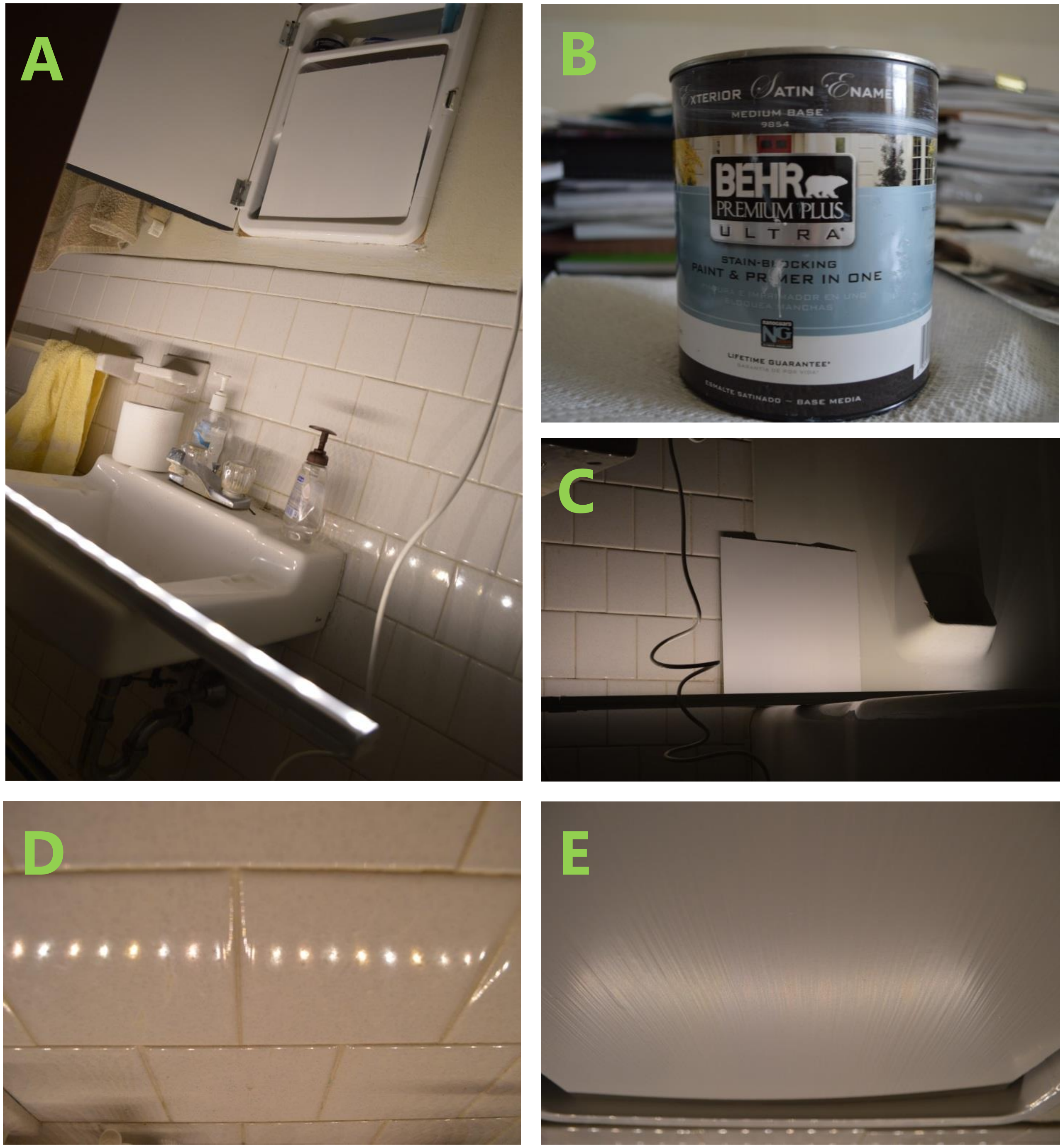


Image A shows the full mock-up set-up; the linear LED is two feet from the painted panel which sits three feet above the fixture. Image B describes the paint used to coat the aluminum. Image C shows an extreme version of grazing the panel, illustrating the ability of the paint to “carry” light. Images D and E are taken from the set up as described in image A. As seen in image D, a glossy finish lends to diode reflections and little light being distributed along the surface (not finish of scrim). On the other hand, a satin finish panel diffuses the LED diodes and distributes the light better across the surface. Hereby, most reflections are diffuse (Lambertian) while only some are specular—this is the proposed finish of the scrim.

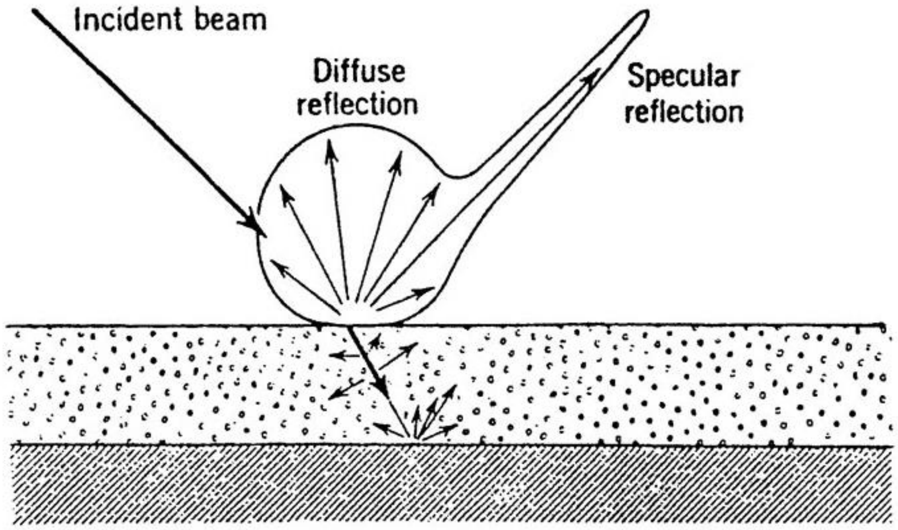
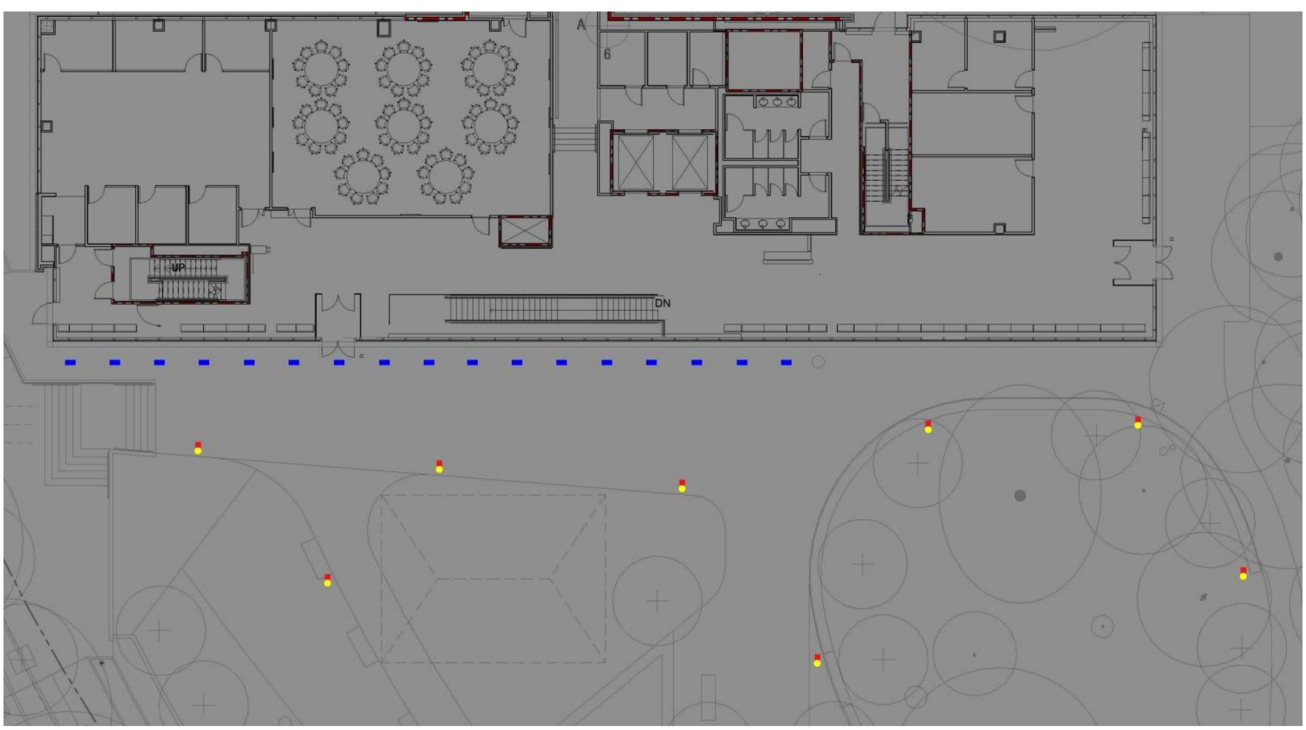
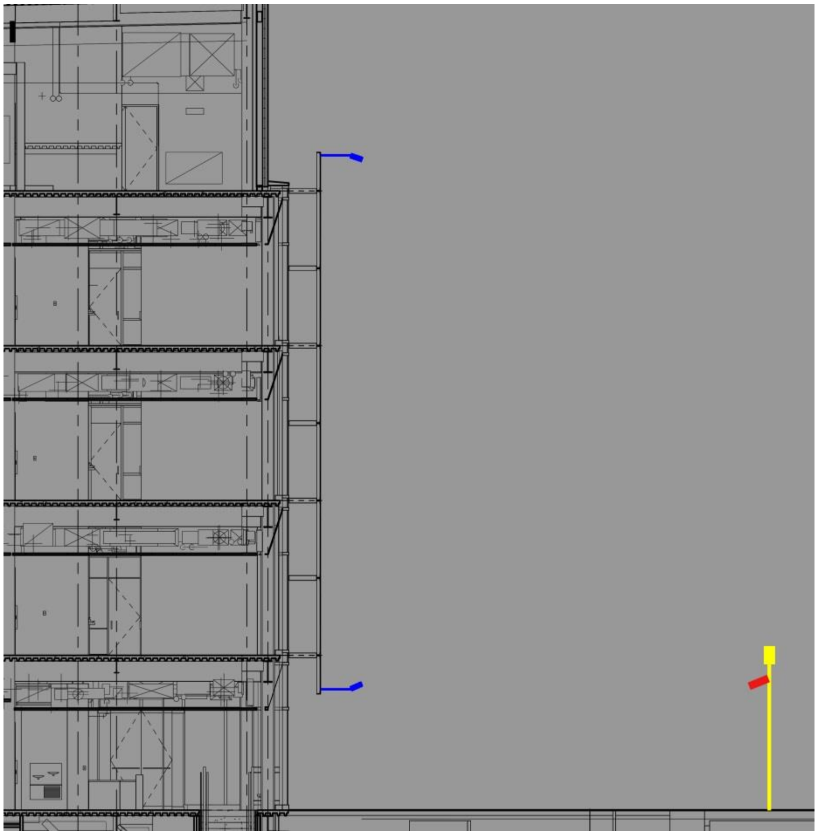


Fig. 14: Specular reflection, www.cermaicartsdaily.com

FIXTURE + EQUIPMENT SELECTION

Below are lighting plans that describe the exterior lighting design. For a detailed lighting schedule refer to Appendix C. Please see cutsheets (Appendix A) for detailed information on specified fixtures.





Fixture Schedule				
Type	Symbol	Fixture Image	Description	Manufacturer
L9			Exterior pole mounted theatrical fixture with WFL (wide flood) lens and leaf gobo, RGBA LED, DMX compatible, IP65-rated	Wash Lighting
L10			Half-unit long-throw exterior LED floodlight with 8° optic, 3796 lumen output, RGB channels, mounted with rotatable fixture bracket and 2' arm extension, DMX/Ethernet control system, die-cast aluminum, powder-coated finish, IP66-rated.	ColorKinetics
S1			Type V rectangular distribution pole fixture, LED retrofit kit, UL1310 Class 2 and UL48 compliant.	Beacon

The total volt-amps of each fixture type is calculated below. These values are used to revise the existing panelboards (see Electrical Depth section of this report). Likewise, appropriate light loss factors are applied (this procedure will be repeated for all four lighting spaces).

Site lighting is a University standard and is not applied in this calculation. The existing canopy lighting is sufficient and warrants little change in relation to the overall lighting concept. Adding more light (in way of direct lighting) to the entrance canopy area would be detrimental to the overall lighting character. Allowing light to pour out from the lobby floats the building and scrim above the horizontal plane. Safe but minimal site lighting keeps visual focus on the scrim and provides for easy way-finding.

Fixture Calculations							
Type	Lamp	Quantity	W/fixtures	Total Wattage (W)	PF	VA/fixture	Total VA
L9	LED	10	100	1000	1	100	1000
L10	LED	17	145	2465	1	145	2465
S1	LED	11	55	605	1	55	605

Light Loss Factors						
Type	Lamp Lumens		Light Loss Factors			
	Initial	Mean	LLD	LDD	BF	Total
L9	--	--	0.70	0.90	--	0.63
L10	--	--	0.70	0.90	--	0.63
S1	--	--	0.70	0.90	--	0.63

CONTROLS STRATEGY

Scrim lighting is to be controlled using a time clock; hereby, scrim lighting as well as site lighting will be switched on at sunset. Site lighting will remain on to ensure pedestrian safety while scrim lighting will shut-off at 2 a.m.

To reinforce lighting effect on scrim, at 10 p.m., corridor lighting will consist of only emergency lighting where needed. All rendered views have this condition.

LED floodlights illuminating the scrim are controlled using a DMX control protocol; this will allow for a flexible choice of colors. Several pre-programmed color settings will be used. Predominantly, the default settings include the fall setting (orange and red), spring setting (purple and green) and neutral (white).

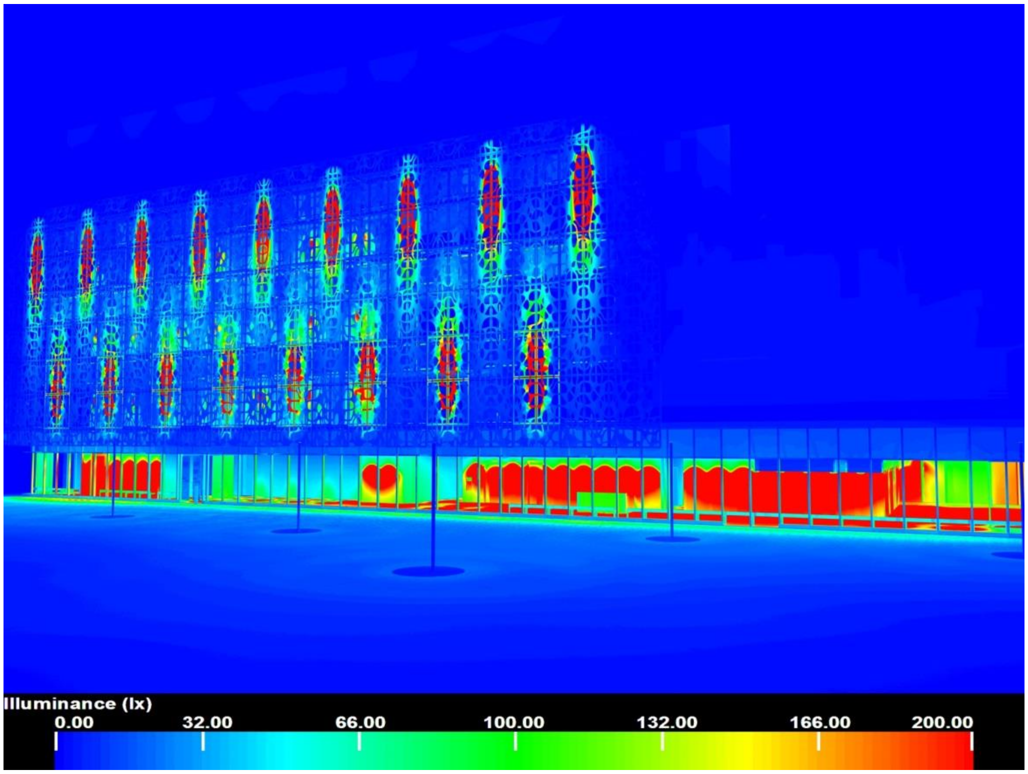
CALCULATION SUMMARY

This section of the report focuses on a quantitative comparison of the recommended light levels versus the design light levels. Pseudo color renderings are provided to further increase the understanding of the space and the visual response to light.

Exterior Illuminance Criteria: Recommended vs. Designed					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Set	Quantity	Recommended	Achieved	Recommended	Achieved
Scrim	Average	--	--	50	--
	Avg/Min	--	--	--	--
	Max	--	--	--	250
	Min	--	--	--	0
Site	Average	4	4	1	1
	Avg/Min	3:1	3:1	6:1	6:1

Right near the fixtures, light levels reach 250 lux. Light levels near the center of the scrim falls to 0 lux from both above and below. This lighting is intentional as a non-uniform gradient of lighting emphasizes the organic form of the scrim. A rhythmic pattern of light is established across the vertical plane.

Site lighting is mandated by the University of Pennsylvania. The University requires a certain LED retrofit fixture be used for general site lighting; hereby, an accepted fixture is specified and assumed sufficient concerning light levels. Poles are installed for safety, and horizontal and vertical illuminance levels. The focus of this lighting space is on the southern scrim and its lighting impact on the overall building.



EVALUATION

SUMMARY

A festive psychological impression is achieved in the exterior space using non-uniform point sources of colored and dynamic light. The scrim becomes active when the sun sets, recalling the initial concept of fall leaves changing color with less available sunlight. Higher illuminance levels near the fixtures (approximately 250 lux) create flashes of rhythmic light along the parallel lines of the scrim structure.

By aiming both the top and bottom fixtures towards the center of the scrim, light is caught along the edges of the solid layer of aluminum and within the perforations of the second layer of aluminum. The illuminance drops to nearly 0 lux in the center of the scrim. This gradient of light allows for overlapping colors to coexist and draw ones focus from the exterior boundaries towards the center line.

As seen in the interior rendering, light from the fixtures barely penetrate into the corridor space. Although this was the intent of the initial design, less shadows on the interior space inherently means less direct glare. A direct view of the fixture is difficult to reproduce as the viewer would have to be right against the curtain wall glazing.

Viewed from below, a slight specular reflection of the upper band of fixtures will be noticed by an occupant. However, this is brief when walking, present at only a few specific angles, and limited by the use of satin paint. Finally, to achieve the desired visual effect, interior lighting consists of only emergency lights during the hours of façade lighting: this will minimize the silhouette effect on the scrim, further enhancing the depth and shadowing on the sunscreen forms.

ASHRAE/IESNA 90.1

Although only a portion of the southern façade—the scrim—is lit, it has been assumed that the entire southern façade contributes towards the square footage count for energy compliance. This allowed for higher wattage fixtures as a high lumen output was required to create an obvious visual impression on the large organic form. The southern scrim uses 2465 watts of untradeable energy. This meets ASHRAE/IES Standard 90.1.

To meet energy codes, pole mounted flood lights had to be removed from the design; the loss of an additional layer of light is unfortunate; however, glare was no longer a pertinent issue along the southern corridors.

Energy Consumption (ASHRAE/IESNA 90.1 – 2010) - Facade		
Category	Allowable	Calculated
Area (SF)	-	17150
Input Wattage	2573	2465
Power Density (W/SF)	0.15	0.14

Energy Consumption (ASHRAE/IESNA 90.1 – 2010) – Building Grounds		
Category	Allowable	Calculated
Area (SF)	-	39000
Input Wattage	6240	1430

Refer to Appendix E for a detailed COMCHECK report of the proposed scrim lighting solution.

2 | LOBBY/LOUNGE

Described below is the final lighting solution for the ground floor lobby and lounge. Like the lighting for the scrim, the following includes important information that describes the visual impression of the space, relation to the overall concept, design goals and criteria as compared to the final design, fixtures used, control narrative, quantitative calculation summaries, and applicable renderings. Below is an outline of the information included in this section:

Description
- Dimensions
- Floor Plan
- Finishes
- Furniture/Equipment
- Tasks

Overall Design Goals

Design Criteria/Considerations
- Qualitative Criteria
- Desired Psychological Impression
- Quantitative Criteria
- LEED-NC v4 Draft
- Energy Allowances
- Design Goals Prioritized

Design Development
- Summary

Fixture + Equipment Selection

Controls Strategy

Calculation Summary

Evaluation
- Summary
- ASHRAE/IESNA 90.1

DESCRIPTION

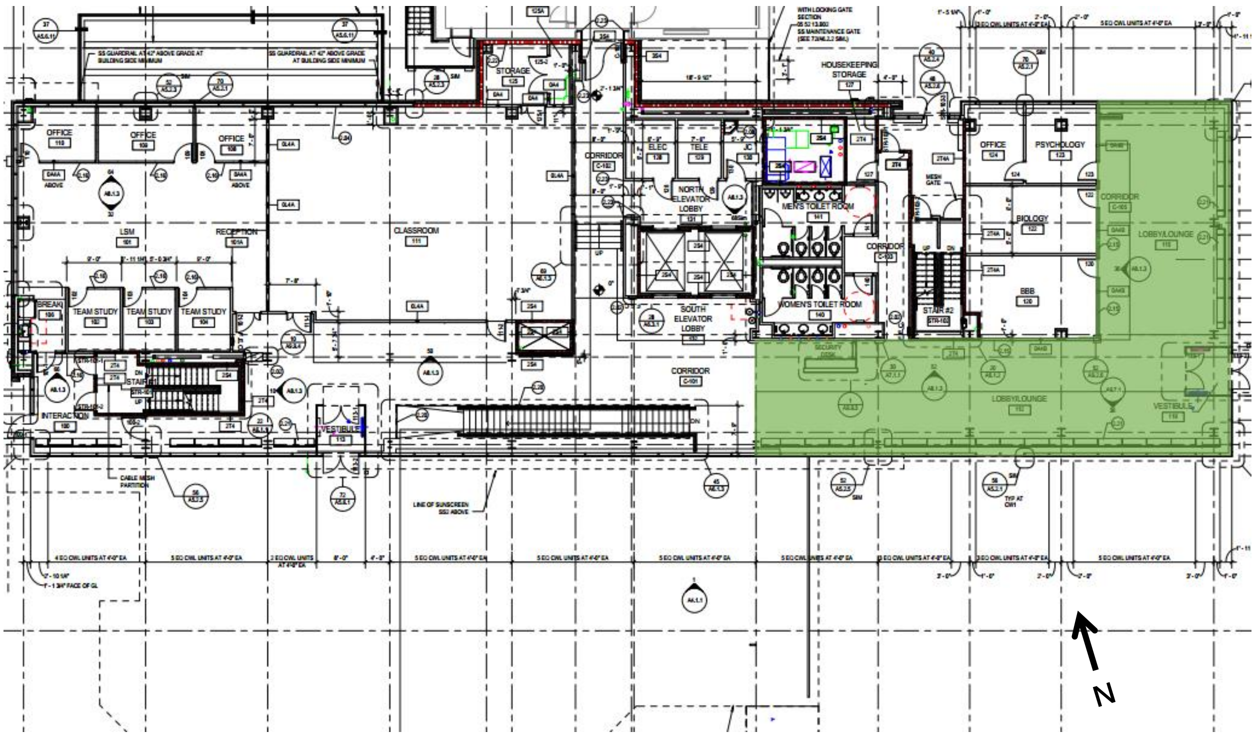
Fig. 15: Lobby looking east, courtesy of SmithGroupJJR

The main L-shaped lobby and lounge is a welcoming space that is abundantly lit by daylight. The ceiling is kinetic in form and promises to provide opportunities for a unique lighting solution. It consists of a custom ceiling panel system with different sized perforations. The lower lobby houses public seating as well a guard desk that faces south into the garden. Exterior vertical glazing spans from the floor to ceiling allowing for incredible views.

DIMENSIONS

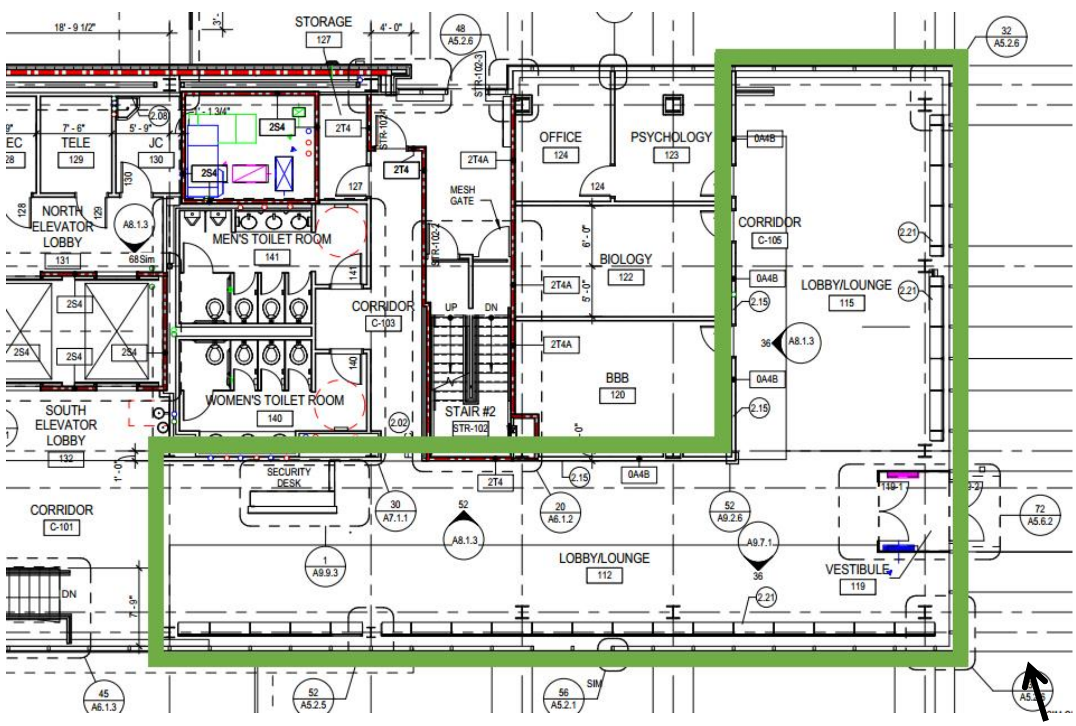
Area – 2407 ft^2.
Approximate width – 80 ft (L-shaped)
Approximate length – 60 ft (L-shaped)
Approximate ceiling height – 9’6”

FLOOR PLAN



Reference: Sheet A2.1

ENLARGED FLOOR PLAN



Reference: Sheet A2.1

NORTH-SOUTH SECTION

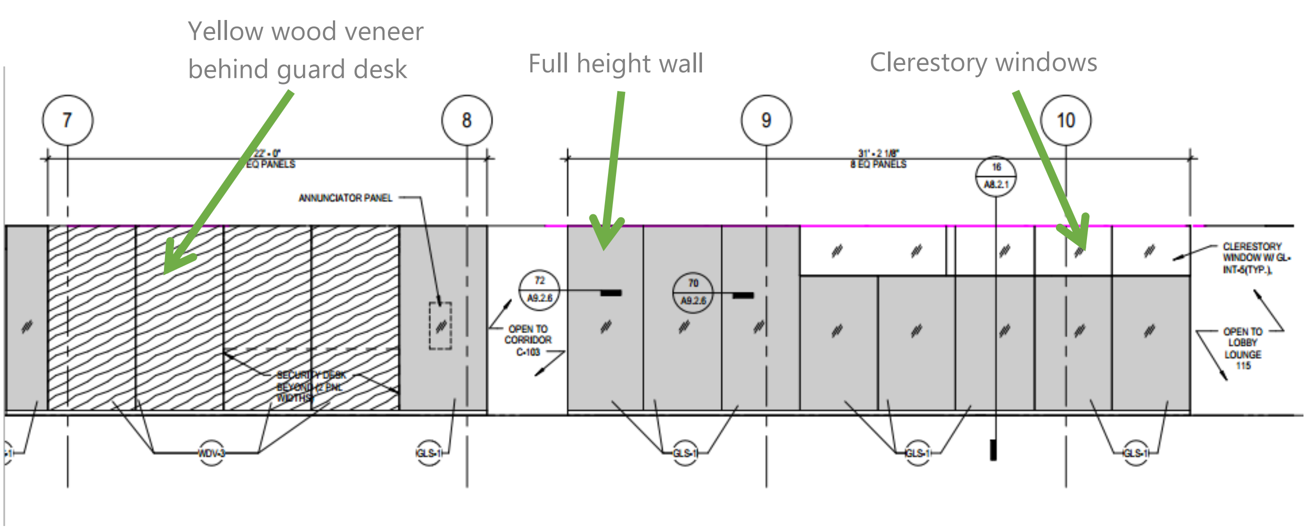
Reference: Sheet A4.2.1

FINISHES

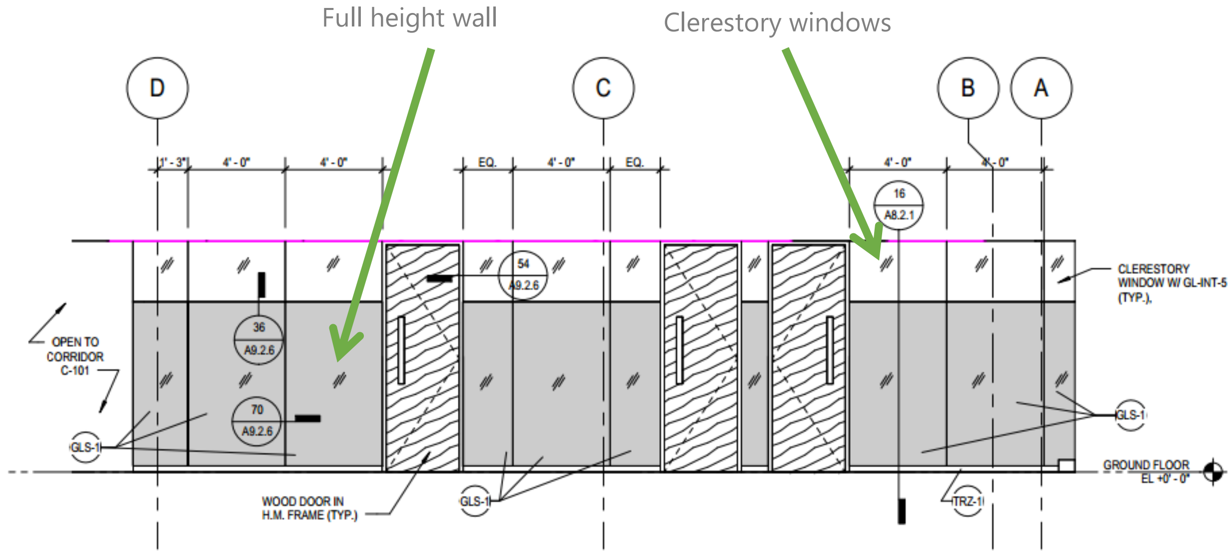
The ceiling consists of acoustic wood panels (2′ x 4′) with a grid of holes ranging from 1/2″ to 2 1/2″ in diameter. The interior walls are constructed of full height writable and magnetic glass (opaque glass backer). Like the furniture, the material reinforces collaboration in public spaces. Some interior walls of the lobby have laminated 65% clear clerestory windows for burrowing natural daylight.

A lighter terrazzo flooring material aids in daylight distribution deeper into the space. Behind the guard desk, there is a textured feature yellow wood wall.

INTERIOR ELEVATION (NORTH)



INTERIOR ELEVATION (WEST)



Lobby/Lounge Materials				
Surface	Material	Description	Style/Color	Reflectance (ρ)
Ceiling	AWC-1,2,3,4	Acoustical wood ceiling with varying grid of hole diameters	White oak wood	0.70
Walls	GLS/PNT-1/WDV3 and GL-INT-5	Ultra white, writable, magnetic glass, paint, clerestory windows, wood veneer feature wall	Glass, sea pearl white paint, yellow wood veneer	0.50*
Floor	TRZ-1	Terrazzo flooring	Pearl	0.30

*Reflectance averaged for materials; actual materials will exhibit varying values

GLAZING

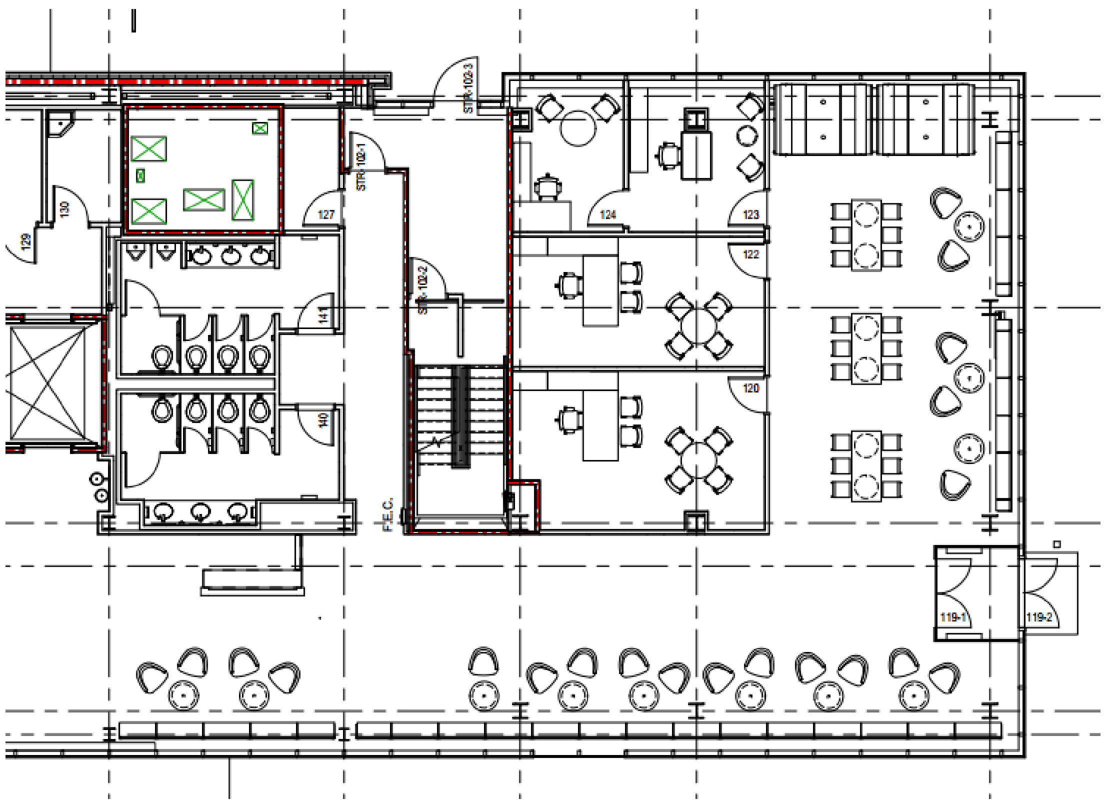
Interior glass elements are described above. Exterior glazing on the ground floor is a 1" natural low-e insulated unit. This is typical on the south and east side. On the east side, at the main entrance vestibule, there is 1" natural low-e IGU with an imbedded custom digital image. The exterior glazing has a visibility of roughly 65%.

FURNITURE/EQUIPMENT

Public spaces are furnished as to promote community and public interaction between the users of the NSB Building. The seating is mobile and modern. As seen above, several loose chairs and coffee tables fill the space. Along the southern glazing, a wooden bench runs the length of the lobby. Additionally, larger tables with surrounding chairs are located in the eastern block of the space.

There is a special guard desk next to the elevator at the western end of the lobby. The lobby and lounge area have three 46" LED displays mounted on various interior walls (not seen in above furniture plan).

FURNITURE PLAN



Reference: Sheet AI2.1

TASKS

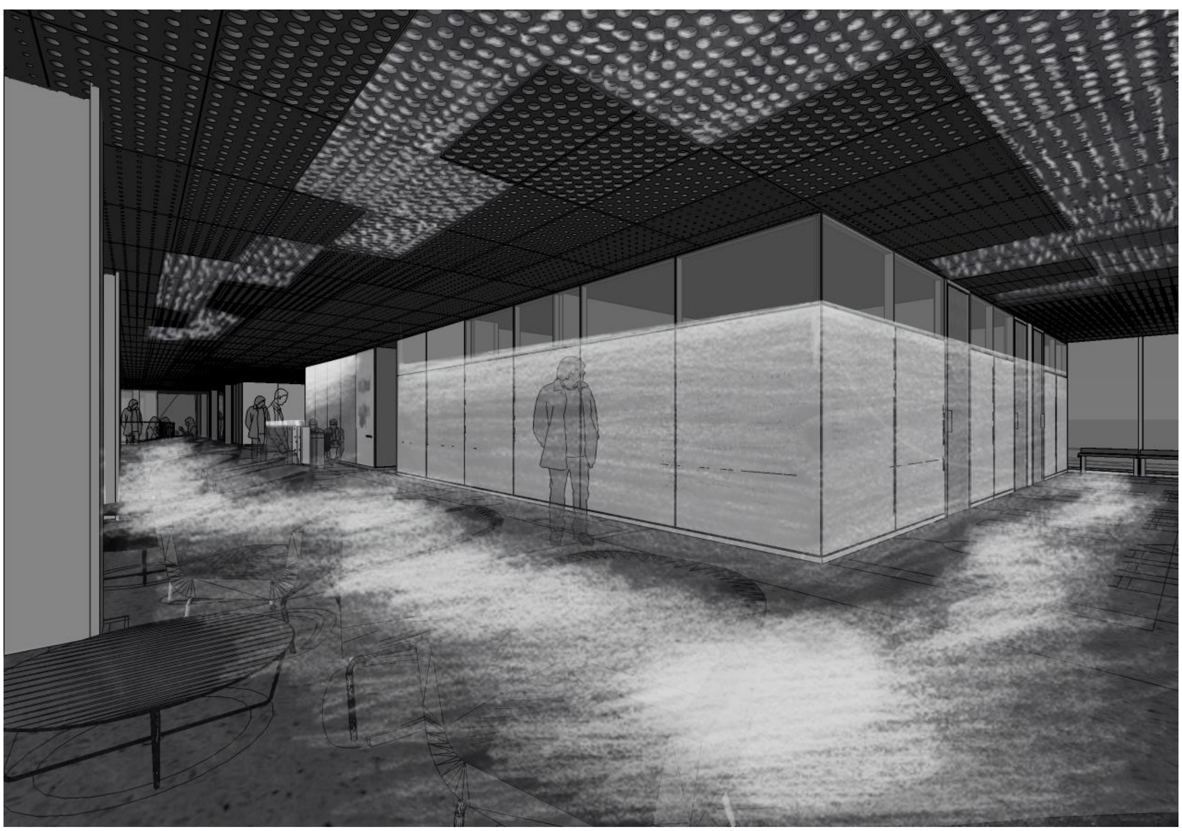
Foremost, the lobby and lounge serve as an entrance space. Here, the ground floor lobby and lounge function as a public transition area; since users will be orientating themselves to the NBS building, way-finding is an important activity. There may be some reading given the furniture plan. The guard desk introduces different tasks including reading, writing, and computer work. Lobby lighting will clearly denote the main entrance to the NBS building.

OVERALL DESIGN GOALS

As a result of uneven pressures in a tree, nutrients are exchanged between the crown and roots of the tree (known as transitional pull). In a similar manner, the lighting responds to the form of the perforated ceiling, increasing brightness at areas of high congestion and interest on horizontal and vertical planes; *organic movement and direction is implied as a result of uneven pressures.*

Fig. 16: www.starwall.info

Fig. 17: www.borealgardening.com



Movement: non-uniform transitional lighting and subtle pools of light encourage direction through the space. Areas of high importance are relatively brighter facilitating visual clarity and relaxation.

Architecture: the proposed lighting solution aims to complement the high architectural element of the space: a custom perforated ceiling panel system.

Connection: it is the goal of the lighting solution to connect the exterior site and scrim by allowing light to spill out from within the lobby space; highlighting vertical surfaces will define spatial boundaries and establish the lobby as an entrance.

Daylighting: lighting controls and daylight integration will present an energy efficient design; photosensors and time schedules are potential solutions.

DESIGN CRITERIA/CONSIDERATIONS

QUALITATIVE CRITERIA

Very Important

- **Light Distribution on Task Plane**
  - During the day, recommended light levels (referencing the tenth edition IES handbook) will be met. At night, it is important that the electric lighting produces the recommended light levels for safety and architectural value.

- **Daylighting Integration and Controls**
  - The lobby and lounge receive ample daylight throughout the year; the lighting should effectively respond to daylight to maximum energy savings and improve the daylight quality in the space

- **Appearance of Space and Lighting Fixtures**
  - The entrance is the most public area in the building. The perforated ceiling introduces a dynamic element in the space. For these reasons, the lighting solution should reinforce the architectural details and render the materials appropriately. This will ensure a visually appealing entrance.

- **Occupant Orientation**
  - Way-finding is important so that occupants are comfortable in the space and can easily orient themselves to the building.

Important

- **Accenting**
  - Architectural elements should be accented for aesthetic appeal.

- **Color Appearance and Color Contrast**
  - Aesthetically, the lighting should render colors of materials and users well so that space is naturally comfortable.

DESIRED PYSHCOLOGICAL IMPRESSION

As outlined by John Flynn and discussed by Gary Steffy, the goal of the redesigned lighting in the lobby and lounge is to ultimately encourage a public and relaxed impression on occupants.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance – Important

- IES Classification | Common Applications
  - Transition spaces, lounges, social/waiting areas
    - Category J: 40 lux (4.0 fc), at ground
    - Avg/Min: 2:1
  - Transition spaces, lobbies, reading/work areas
    - Category N: 150 lux (15.0 fc)
    - Avg/Min: 2:1
  - Transition spaces, reception/waiting areas, reception desk
    - Category N: 400 lux (40.0 fc)
    - Avg/Min: 2:1

Given the space type and function, uniformity is not critically important. Visually, a non-uniform lighting scheme will facilitate a hospitality-like environment; this could be beneficial since it is a lobby and lounge area meant to draw outside occupants in and likewise, impress the users upon entry. Recommended horizontal light levels are derived for effective way-finding and isolated desk work.

Recommended Vertical Illuminance - Important

- IES Classification | Common Applications
  - Reading and Writing, white board, reading (reference)
    - Category J: 150 lux (15 fc)

- Transition spaces, reception lobbies, desk top
  - Category N: 150 lux (15.0 fc)

It is important to model faces well for security purposes. In this regard, appropriate light distribution and fixture spacing should be utilized. One goal for the lighting should be to highlight the feature wall to create a visual edge and focal point. Visual comfort is imperative; lighting should be placed to create a subtle edge along the space, creating an organic and fluid space.

LEED-NC v4 Draft

EAp2: Minimum Energy Performance

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.01-2010.

EAc2: Optimize Energy Performance

- Reduce energy consumption of entire building by 6-42% to respectively receive 1-16 points.

EQc6: Interior Lighting

- For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences with at least three lighting levels or scenes (on, off, midlevel).
  - For multi-zone spaces, include multi-zone control system readily available to occupant
- For entire project, use light sources with a CRI of 80 or higher
- For all regularly occupied spaces, use light fixtures with a luminance of less than 2,500 cd/m^2 between 45° and 90° from nadir.

EQc8: Quality Views

- Achieve a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area, no obstructed by frits, fibers, patterned glazing, or added tints.
  - 75% of all regularly occupied spaces must also have multiple lines of sight to vision glazing in different directions at least 90 apart.
  - Views must include a flora, fauna, or sky and objects at least 25 feet from the exterior of the glazing.

ENERGY ALLOWANCES

According to ASHRAE Standard 90.1 version 2010 (most recent version upon completion of thesis) space-by-space method, a lobby has an allowed wattage of 0.90 W/SF.

Energy Allowance (ASHRAE 90.1 – 2010)			
Space	Area (SF)	W/SF	Allowed Wattage
Lobby	2407	0.90	2166 W

DESIGN CRITERIA PRIORITIZED

1. Meet ASHRAE Energy Code requirements
2. Implement daylighting strategies and controls to optimize energy efficiency
3. Create a visually appealing space for users inside the lobby and viewers outside the building
4. Meet IES recommendations for light levels in transition space/lobby
5. Provide for way-finding and occupant orientation through lighting in conjunction with materials and interior planning
6. Meet LEED requirements for lighting controls and minimum energy requirements

DESIGN DEVELOPMENT

SUMMARY

Throughout the lobby, warmer light sources around 3500K are used to create a comfortable and familiar space. In the lobby, the appeal of the design is in the interaction of the perforated ceiling and the lighting from beyond. The form of the ceiling is emphasized by backlighting the perforations—a diffusing lens is integral the ceiling panel as to diffuse the light. To achieve this notion of organic movement and flow of pressure, simple linear fluorescent fixtures are suspended above the ceiling and light the cavity behind the panels.

The fixtures are placed as to follow the curve of the larger perforated panels (in plan view); fixtures are to be installed between existing mechanical duct work to not interfere with the equipment but still allow for light to fill the ceiling cavity. Downlights in the original concept were removed because the bright sources seemed to fight the feeling of the space. Instead, a more reflective terrazzo finish floor introduces an interesting reflection of the ceiling perforations above, further emphasizing the concept.

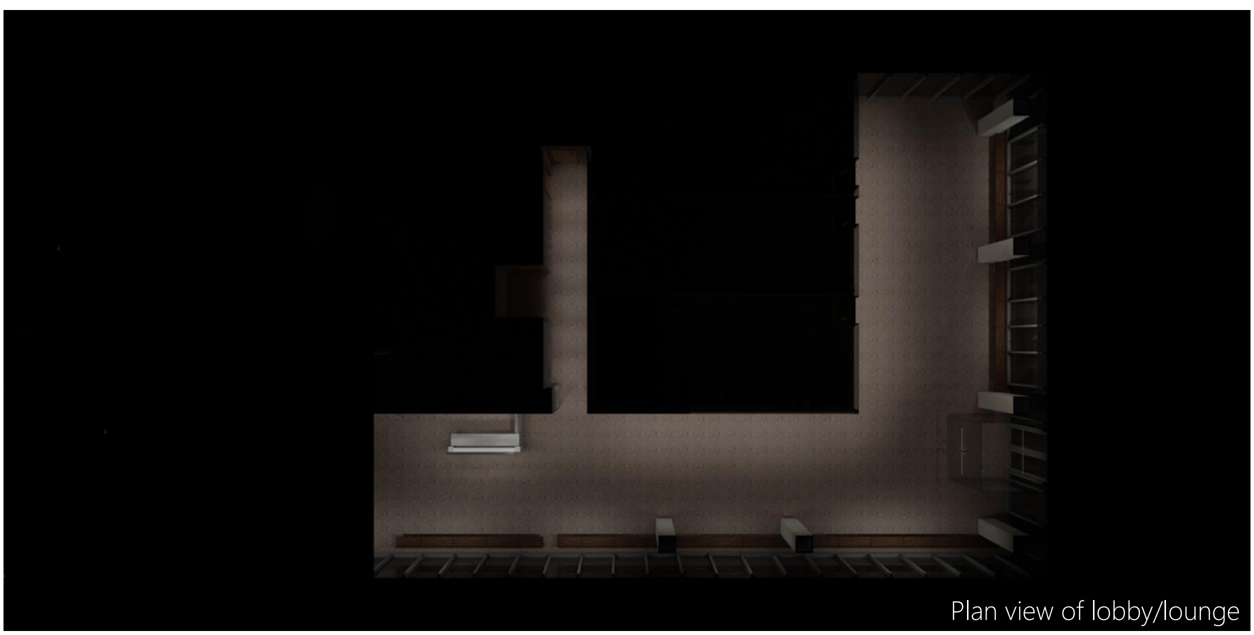
Where the ceiling draws visual interest and leads one through the space, linear recessed perimeters LEDs define the spatial boundary. Installed along the perimeter seating, these very narrow distribution fixtures create pools of light spaced along the periphery. The lighting is thus comfortable and rhythmic. Non-uniformity between light and dark along the seating is organic and facilitates a relaxed sensation at night time.

Looking west to guard desk

The final aspect of general lighting is achieved with circular wall washers across the floor. LED wallwashers illuminate writable ViviChrome Scribe wall panels; higher luminance values here emphasize the vertical planes of the space, again creating a relaxed and pleasant atmosphere. No downlights are needed for supplemental lighting down the corridor. In this way, lighting is applied to periphery, pulling light away from the center—where people walk—and pushing spatial boundaries into place. The space is pleasant, organic, and encourages movement.

Above the guard desk, an eight foot linear pendant provides sufficient task lighting and vertical illuminance. An LED fixture grazes the yellow wood veneer panel behind the guard desk, effectively creating dimension and highlighting a point of interest for occupants upon entering the lobby.

Looking east to main entrance

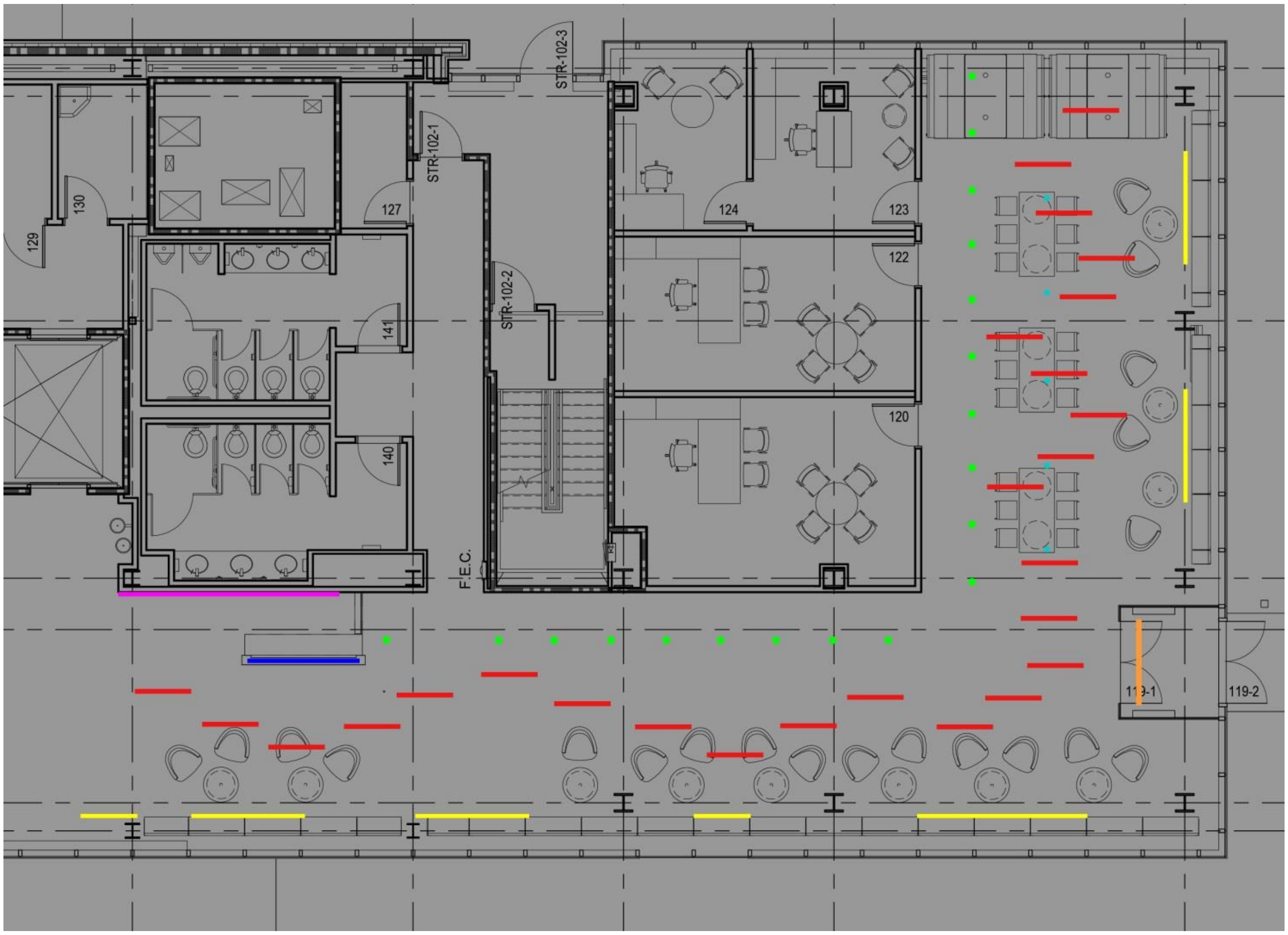


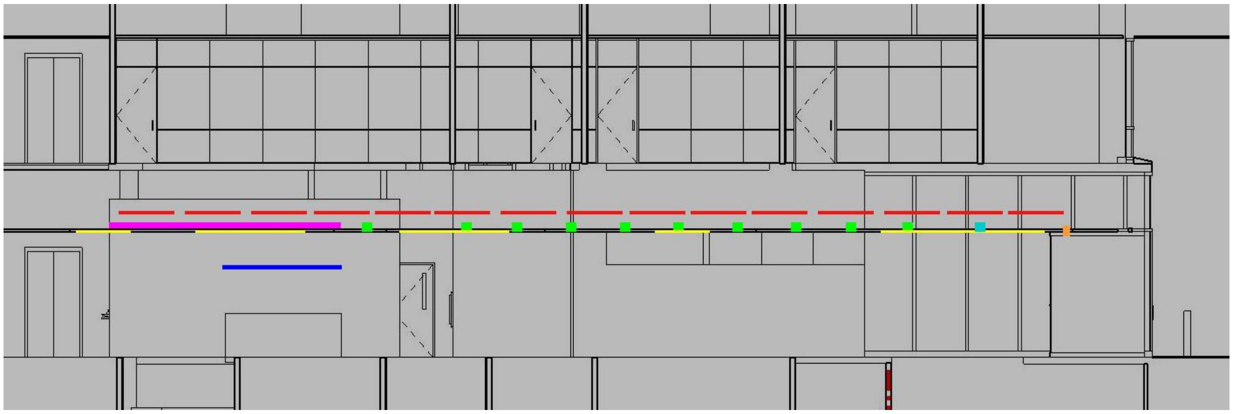
Plan view of lobby/lounge

The eastern wing of the lobby requires supplemental two inch LED downlights to illuminate horizontal desks to the appropriate light levels. Even there, the lighting is somewhat non-uniform as pools of task lighting illuminate the surface. To minimize intrusive fixtures, the two inch downlights are integrated into two inch perforations of the ceiling panels.

FIXTURE + EQUIPMENT SELECTION

As seen below, the lighting solution consists of primarily LED and linear fluorescent fixtures. For a detailed lighting schedule, refer to Appendix C. Cutsheets can be found in Appendix A.





Fixture Schedule				
Type	Symbol	Fixture Image	Description	Manufacturer
F1			Low profile T5 fluorescent fixture	Bartco
L1			Cable suspended direct linear 8' LED fixture, narrow beam distribution	Selux
L2			Self-flanged recessed wall wash, 4" aperture, clear semi-specular reflector, 1800 lumen output with 45° cutoff to source	Gotham
L3			Low wattage LED 3" architectural slot, frosted lens with linear micro prism pattern	Focal Point
L4			Recessed direct linear 4' LED fixture, narrow distribution	Selux
L5			Recessed 6' direct linear LED	Selux
L11			Mini LED downlight with 2.5" aperture, flood distribution, 3500 K	Juno

Fixture Calculations							
Type	Lamp	Quantity	W/fixtures	Total Wattage (W)	PF	VA/fixture	Total VA
F1	28W T5	26	32	832	1	32	832*
L1	LED	1	72	72	1	72	72
L2	LED	18	29	522	1	18	522
L3	LED	4	22.9	91.6	1	22.9	91.6
L4	LED	13	36	468	1	36	468
L5	LED	1	57	57	1	57	57
L11	LED	5	4.8	24	1	4.8	24

Light Loss Factors						
Type	Lamp Lumens		Light Loss Factors			
	Initial	Mean	LLD	LDD	BF	Total
F1	2600	2418	0.93	0.90	1.00	0.84
L1	N/A	N/A	0.70	0.93	N/A	0.65
L2	N/A	N/A	0.70	0.93	N/A	0.65
L3	N/A	N/A	0.70	0.93	N/A	0.65
L4	N/A	N/A	0.70	0.93	N/A	0.65
L5	N/A	N/A	0.70	0.93	N/A	0.65
L11	N/A	N/A	0.70	0.93	N/A	0.65

CONTROLS STRATEGY

Lighting in the lobby is controlled by a time schedule programmed into the electronically operated circuit breaker Panelboard. Moreover, fixtures F1, L4, and L2 are also controlled by daylight photosensors; when there is adequate daylight, these fixtures will turn off (including emergency lighting). All lighting in the public lobby and lounge are keyed and hidden from the general population.

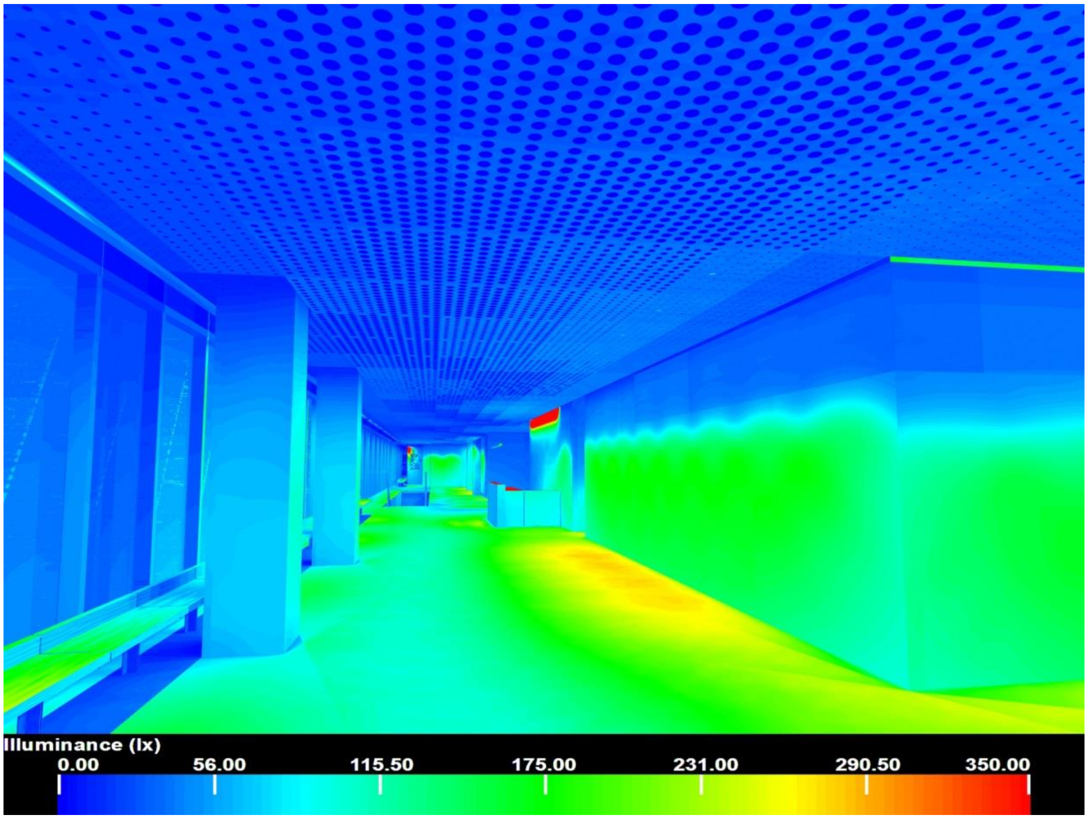
For emergency lighting, see Electrical section of this report. There, a rendering of the space with emergency lighting as well as circuiting is reported.

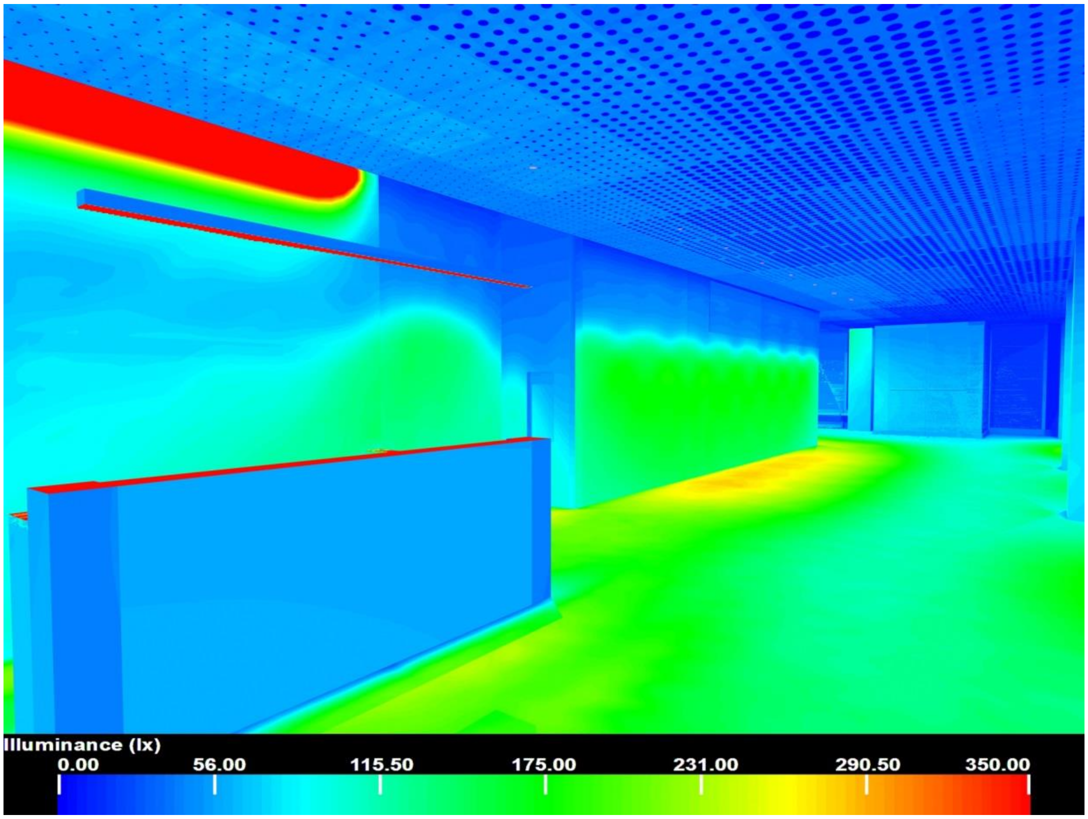
CALCULATION SUMMARY

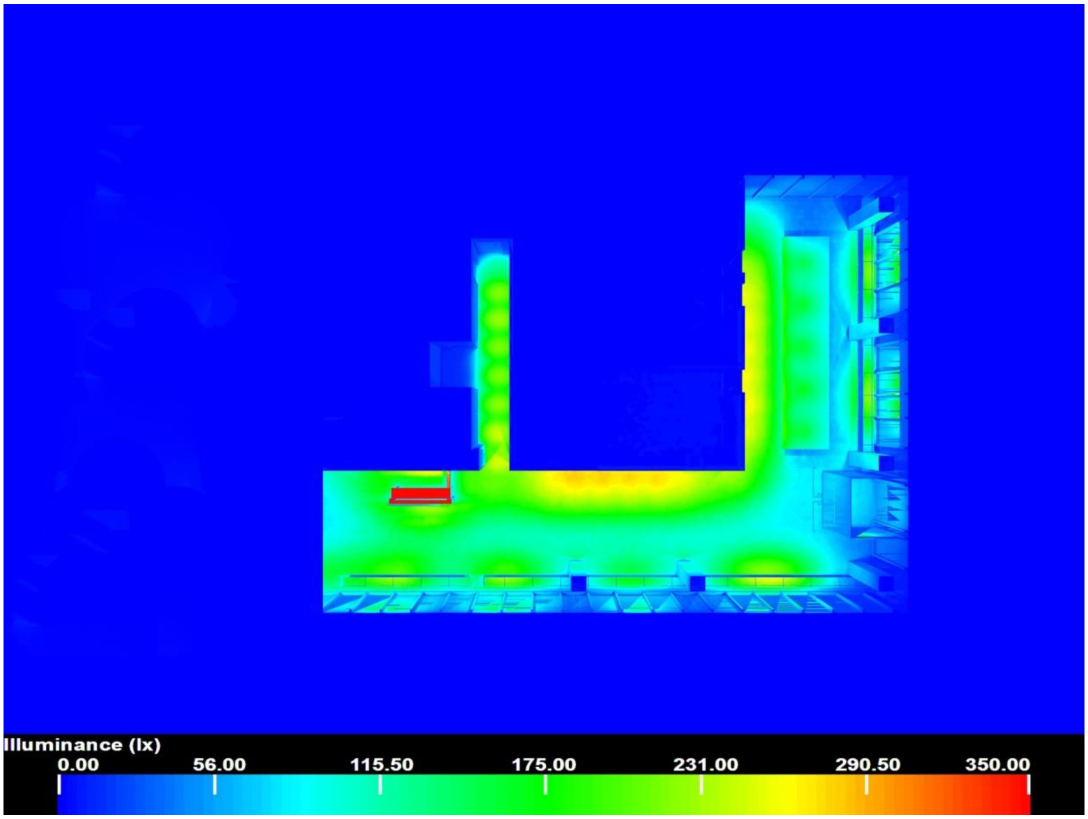
Illuminance level calculations are summarized below. Additional analysis can be visually assessed using pseudo color renderings of the space.

Lobby/Lounge Illuminance Criteria: Recommended vs. Designed						
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)		
Set	Quantity	Recommended	Achieved	Recommended	Achieved
Corridor	Average	40	105	15	20
	Avg/Min	2:1	1.3:1	--	--
Desktop	Average	400	430	150	200
	Avg/Min	2:1	1:1	--	--
Seating	Average	150	150*	50	60
	Avg/Min	2:1	1.5:1	--	--
	Max	--	200	--	--
	Min	--	100	--	--
Writing Wall	Average	--	--	150	148
	Avg/Min	--	--	--	--
	Max	--	--	--	230
	Min	--	--	--	110
Tables	Average	150	130	50	42
	Avg/Min	2:1	1.6:1	--	--

*200 lux in pools of light and 100 lux outside of pools




Illuminance (lx)
0.00
56.00
115.50
175.00
231.00
290.50
350.00


Illuminance (lx)
0.00
56.00
115.50
175.00
231.00
290.50
350.00

EVALUATION

SUMMARY

Complimentary of the lobby architecture, light is used organically to direct motion and encourage pressure change within the space. Lighting vertical surfaces allows the space to be seen easily from the outdoors area, floating the NBS building above the ground and providing an entrance point. The lit surfaces are comfortable and generate enough light in the space to avoid using unnecessary downlights which would otherwise deter from the ceiling plane.

At ground level, the corridor is twice as bright as recommended by the *IES Lighting Handbook*. However, as this is a public institution, safety is an important factor for students, staff, and security. Reflected light from the vertical wall (which needs to be and achieves 150 lux) bounces back into the space. The achieved 105 lux on the ground plane is not excessive as it is still relatively dimmer than the seating and vertical wall.

People often do not like to be in the light; they like to look at lit surfaces. In this regard, the seating is non-uniformly light to create a rhythmic effect. The centers of the pools of light reach 200 lux and falls to 100 lux outside of the distribution. The rhythm, then, is organic and compliments the placement of vertical beams.

All design goals were met: the light levels are appropriate, daylighting integration controls electric lighting, warmer light sources and distributions compliment the architecture and materials of the lobby, and energy codes are met.

ASHRAE/IESNA 90.1

As designed, the lighting solution is 43% better than Standard 90.1 – 2010 requirements. The lighting solution delivers appropriate light levels and visual impressions while only consuming 1235 watts. Fluorescent strips (F1) which fill the ceiling cavity with light are considered decorative lighting consuming only 832 system watts (2407 decorative watts allowable). The minimal energy use is due to the specification of LED fixtures; with improved technology and stricter energy codes, LEDs are becoming a more viable and reliable tool for achieving desired lighting solutions.

Energy Consumption (ASHRAE/IESNA 90.1 – 2010) – Lobby/Lounge		
Category	Allowable	Calculated
Area (SF)	-	2407
Input Wattage	2166	1235
Power Density (W/SF)	0.90	0.51

See Appendix E for a detailed COMCHECK report of the proposed lobby lighting solution.

3 | CLASSROOM

This section is dedicated to the explanation of the final lighting solution for the main classroom. The following includes information that describes the visual impression of the space, relation to the overall concept, design goals and criteria as compared to the final design, fixtures used, control narrative, quantitative calculation summaries, and applicable renderings. Below is an outline of the information included in this section:

Description
- Dimensions
- Floor Plan
- Finishes
- Furniture/Equipment
- Tasks

Overall Design Goals

Design Criteria/Considerations
- Qualitative Criteria
- Desired Psychological Impression
- Quantitative Criteria
- LEED-NC v4 Draft
- Energy Allowances
- Design Goals Prioritized

Design Development
- Summary

Fixture + Equipment Selection

Controls Strategy

Calculation Summary

Evaluation
- Summary
- ASHRAE/IESNA 90.1

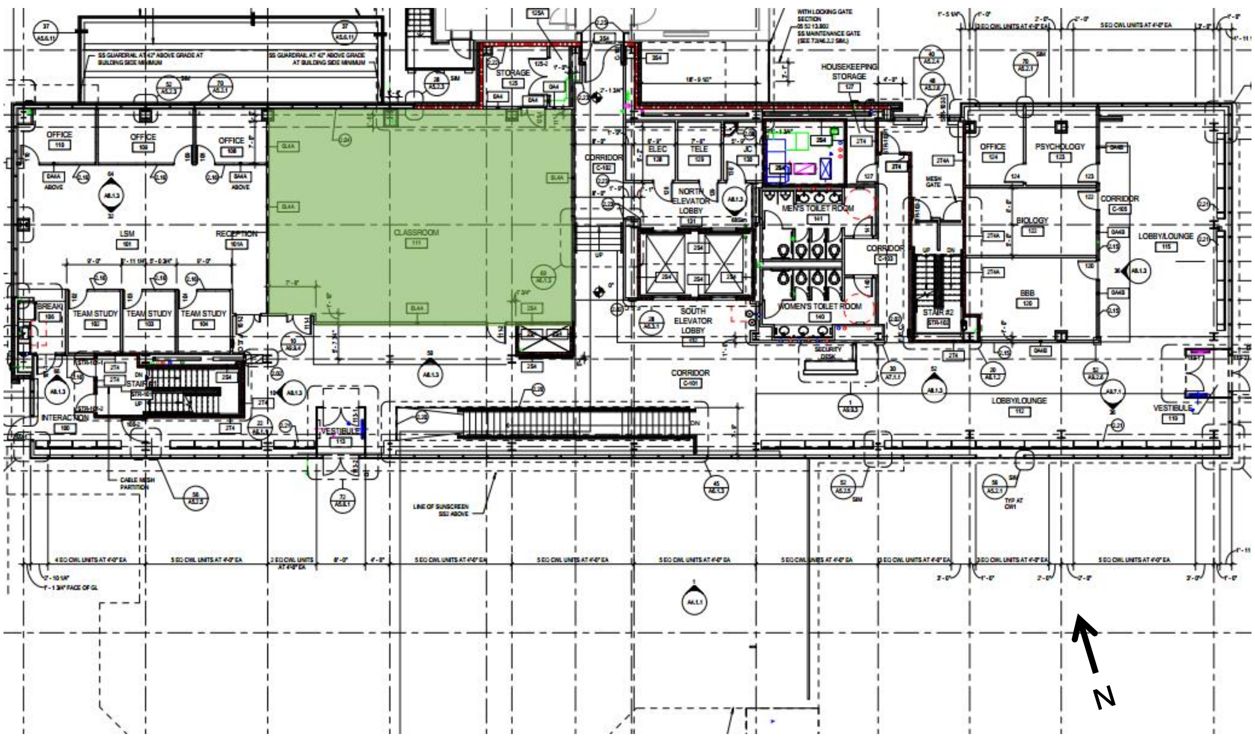
DESCRIPTION

On the ground floor, a large classroom is arranged to inspire collaboration and teamwork. Learning in this classroom is interactive. The interior design is relatively simple and uncluttered. Northern windows allow for potentially good diffuse daylighting. Several televisions and projector screens surround the classroom.

DIMENSIONS

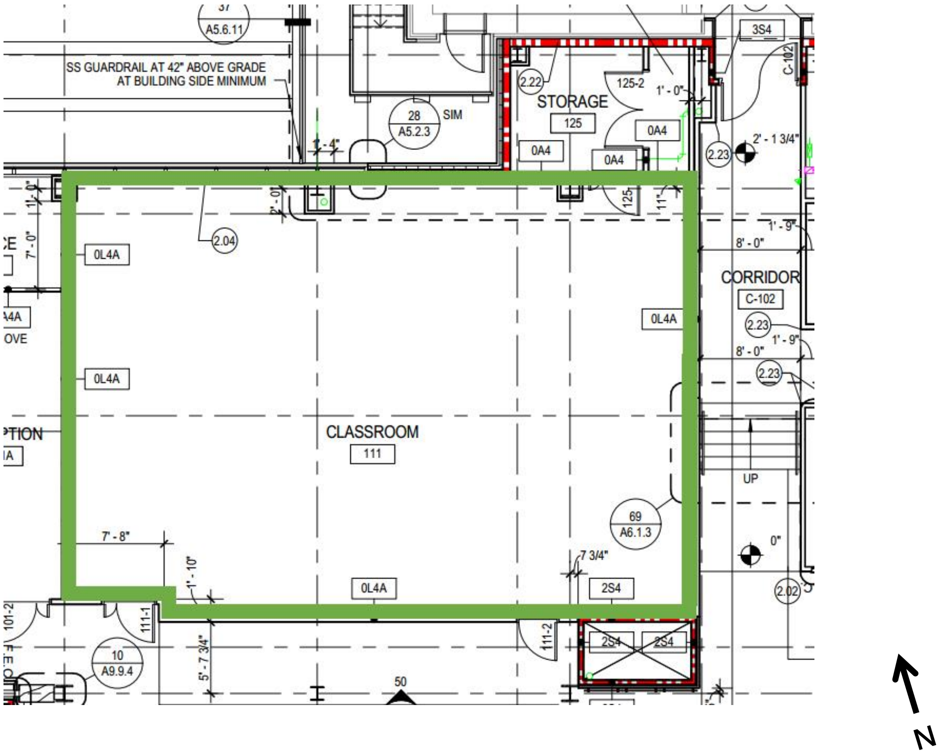
Area – 1700 ft^2.
Approx. width – 50 ft
Approx. length – 34 ft
Approx. ceiling height – 9'6"

FLOOR PLAN



Reference: Sheet A2.1

ENLARGED FLOOR PLAN



Reference: Sheet A2.1

NORTH-SOUTH SECTION

Reference: Sheet A4.2.1

FINISHES

Typical acoustic ceiling tile spans the classroom. Walls are painted a slightly off-white color and are writable. This eliminates the need for a chalkboard/whiteboard. The carpet is a variation of three carpet tile colors that are placed and patterned so that stripes alternate between dark gray and green.

Classroom Materials				
Surface	Material	Description	Style/Color	Reflectance (ρ)
Ceiling	ACT-2	Acoustic ceiling tile	White acoustic tile	0.80
Walls	PNT-1	Painted gypsum walls	Sea Pearl	0.50
Floor	CPTT-3,4,5	Three variations of carpet tile	Stone, Ivy/Stone, Ivy	0.25

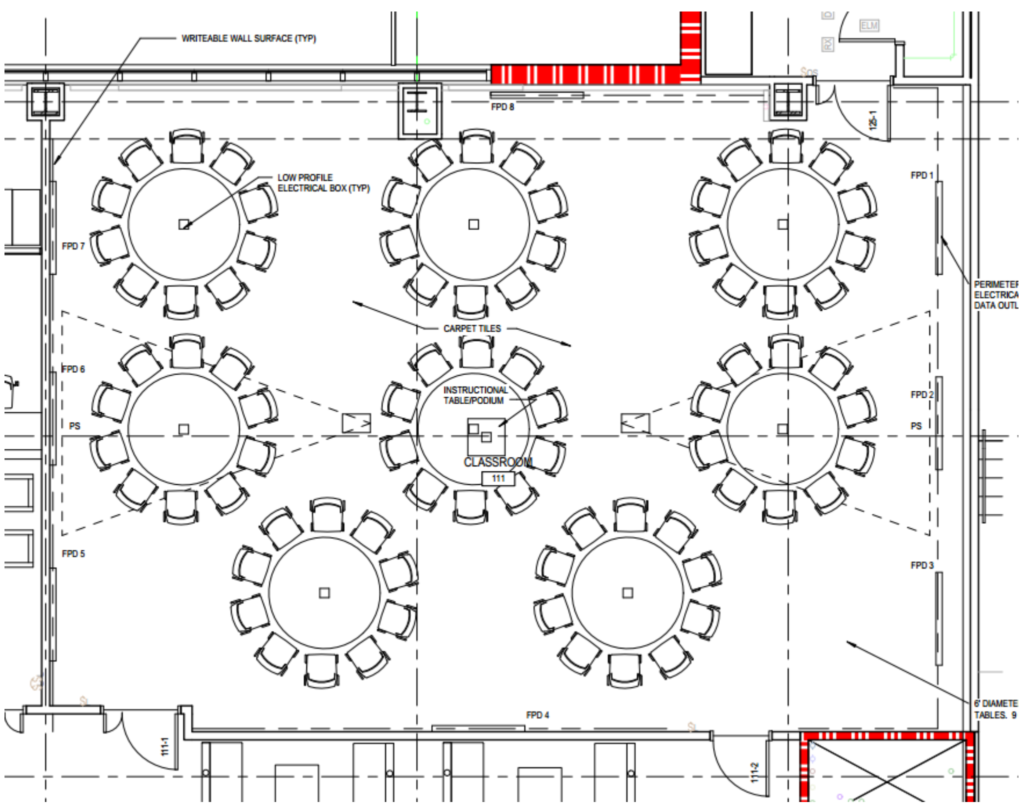
GLAZING

There are only northern facing windows in this classroom. The windows are 1" natural low-e clear insulated glazing units with 62% visibility. The glazing has a 2.14 light to solar gain ratio (LSG).

FURNITURE/EQUIPMENT

Collaborative and interactive spaces serve as inspiration for the furniture selection. Currently, eight large tables with mobile seating fill the majority of space. A lecture podium is to be placed in the center of the room. Eight televisions are mounted on the walls. The east, west, and south walls each have one roll-away projection screen and corresponding projector.

FURNITURE PLAN



Reference: Sheet AQ2.1.1A

TASKS

The classroom is meant to be flexible and used often for A/V presentations (projector and televisions). Reading and writing is an important task that requires comfortable and appropriate lighting. Computer use is probable.

OVERALL DESIGN GOALS

It is visually noted that sunlight behaves in an ominous manner when lighting a tree canopy from above. The sensation of expansion and weightlessness between the interaction of light and asymmetric branches is compelling. *Relating, comfortable uniform functional lighting is achieved through the implementation of a discontinuous and branched placement of fixtures*.

Fig. 18: www.wallpaperup.com

Uniform: light will be uniformly distributed in the space invoking a public sensation. The functional layer of light is achieved through an organic and asymmetric placement of overhead fixtures.

Control: the new design hopes to introduce a highly flexible and controllable space through fixture layout and use of sensors and scene control.

DESIGN CRITERIA/CONSIDERATIONS

QUALITATIVE CRITERIA

Very Important

- **Light Distribution on Task Plane**
  - Being this is a classroom, uniform and appropriate light levels are of high importance.

- **Direct Glare**
  - The collaborative set up of the space introduces multiple viewing directions. This presents a challenge when controlling direct glare which

could be uncomfortable to the users in the space, negatively effecting user productivity and retentiveness.

- **Lighting Controls**
  - Several scenes of lighting are required to ensure proper light levels when performing a variety of tasks. At a minimum, the lighting controls and fixtures should be flexible and responsive enough to allow for a general light setting and an A/V presentation setting.

Important

- **Appearance of Space and Lighting Fixtures**
  - Since people will be utilizing the classroom readily, it is important to consider what the fixtures will look like. The architecture is relatively simple and typical of a classroom. In this way, lighting can either work in harmony with the space or create visual clutter.

- **Daylighting Integration and Controls**
  - The only daylight apertures are located to the north of the classroom. Shading and daylight controls should be considered for user comfort, especially during an A/V presentation when the room generally needs to be darker.

DESIRED PYSHCOLOGICAL IMPRESSION

As outlined by John Flynn and discussed by Gary Steffy, the goal of the redesigned lighting in the classroom is to introduce a public environment.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance – Very Important

- IES Classification | Education
  - Reading and Writing, print media, 12-pt font
    - Category O: 200 lux (20.0 fc), at desk top
    - Avg/Min: 1.5:1
  - Classrooms, general classrooms, learning/teaching, AV
    - Category K: 50 lux (5.0 fc), at desk top
    - Avg/Min: 2:1

Most importantly, horizontal average maintained light levels should be met for reading/writing and AV presentations. Uniformity is also critical in a work space where movement and collaboration will occur. A uniform lighting design will create a comfortable and productive environment.

Recommended Vertical Illuminance - Important

- IES Classification | Education
    - Reading and Writing, white board, reading (reference)
        - Category J: 150 lux (15 fc)
    - Classrooms, general classrooms, learning/teaching, AV
        - Category K: 30 lux (3.0 fc)
        - Avg/Min: 2:1

Reasonably, vertical illuminance is most important during an A/V presentation. Higher luminance ratios ensure that the projector screen or television is easy to see and read. The lighting solution should attempt to diminish the cave-effect; hereby, controlled vertical illumination of the walls is an important criterion.

LEED-NC v4 Draft

EAp2: Minimum Energy Performance

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.01-2010.

EAc2: Optimize Energy Performance

- Reduce energy consumption of entire building by 6-42% to respectively receive 1-16 points.

EQc6: Interior Lighting

- For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences with at least three lighting levels or scenes (on, off, midlevel).
    - For multi-zone spaces, include multi-zone control system readily available to occupant
- For entire project, use light sources with a CRI of 80 or higher
- For all regularly occupied spaces, use light fixtures with a luminance of less than 2,500 cd/m^2 between 45° and 90° from nadir.

ENERGY ALLOWANCES

According to ASHRAE Standard 90.1 version 2010 (most recent version upon completion of thesis) space-by-space method, a classroom has an allowed wattage of 1.24 W/SF.

Energy Allowance (ASHRAE 90.1 – 2010)			
Space	Area (SF)	W/SF	Allowed Wattage
Classroom	1700	1.24	2108 W

DESIGN CRITERIA PRIORITIZED

1. Meet ASHRAE Energy Code requirements
2. Provide sufficient light levels and uniformity for reading/writing/presentations
3. Create visually open and public environment
4. Implement shading and daylight controls for improved visual quality
5. Meet LEED requirements for lighting controls and minimum energy requirements

DESIGN DEVELOPMENT

SUMMARY

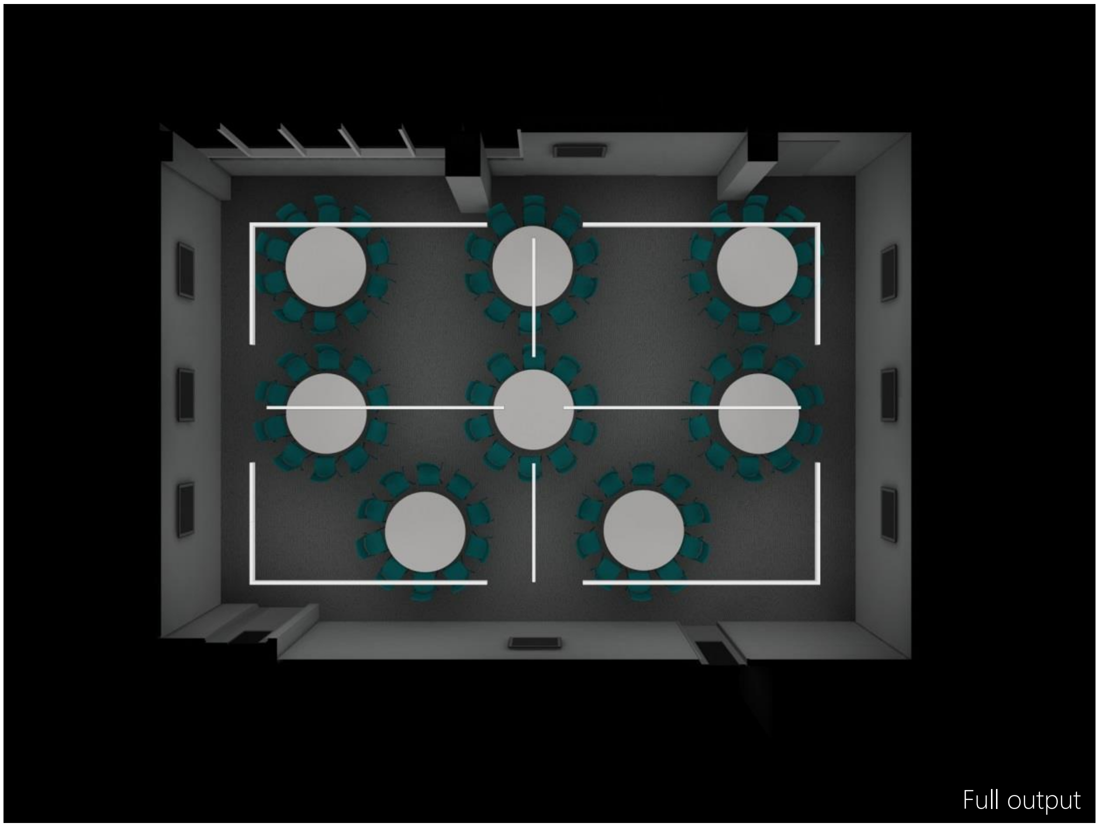
The lighting in the classroom is both aesthetically unique and functional. Like the lobby/lounge and lecture hall, a 3500K fixture is used appropriately in this educational building. Overhead indirect/direct fluorescent pendants are used to illuminate the workplane uniformly, facilitating a public impression in the space. The fixtures are installed in a symmetrical pattern across the "diagonal axis" of the room. Continuous runs of fixtures are broken and layered so that there are perimeter zones and an interior zone.

The cave-like effect is limited by using indirect/direct fixtures. By running fixtures parallel to each respective wall, light effectively falls onto the vertical surfaces. It is important to note that the original interior design calls for acoustic ceiling panels. For the purposes of the proposed lighting solution, the ceiling is gypsum board to provide for a smooth continuous plane.

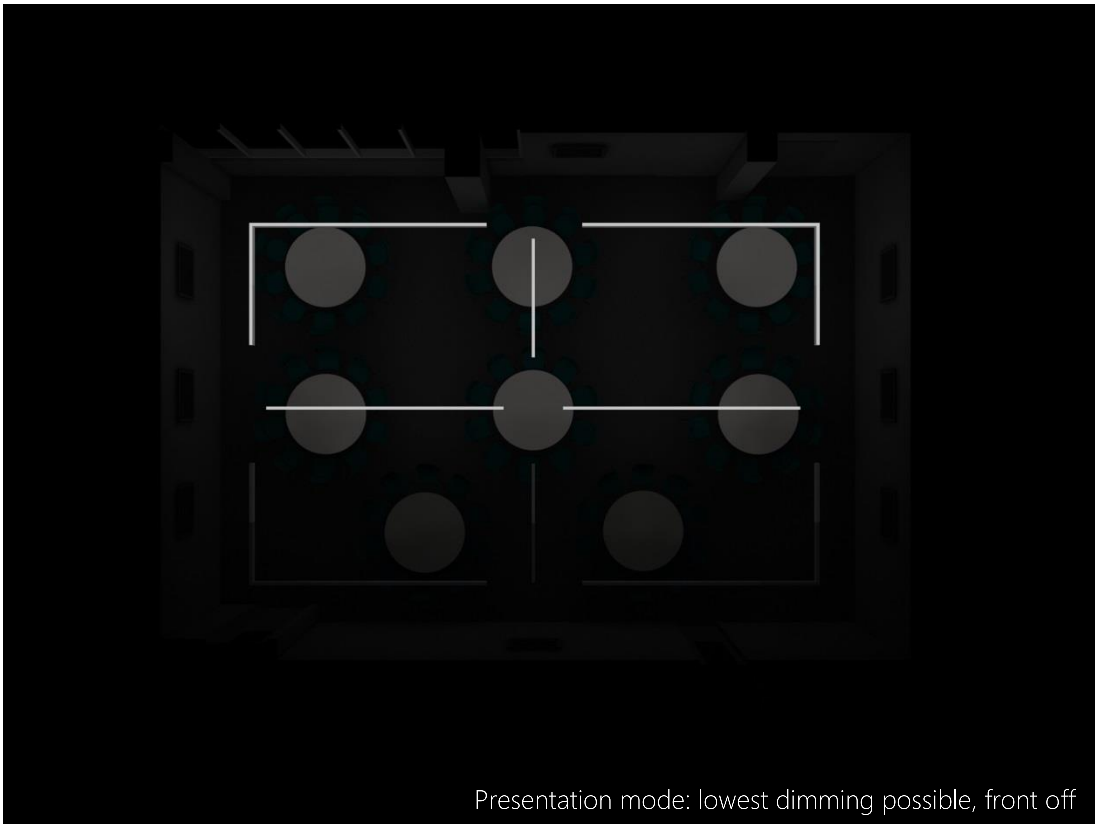
Integral occupancy sensors and photosensors control the electric lighting. The layout of the fixtures allows for ample scene controls, each branch of the layout being on its own dimming zone. This way, the lighting can adapt to several factors including daylight, presentation mode, and classroom size. All fixtures are dimmable to 10% light output for further control.

Full output

Full output

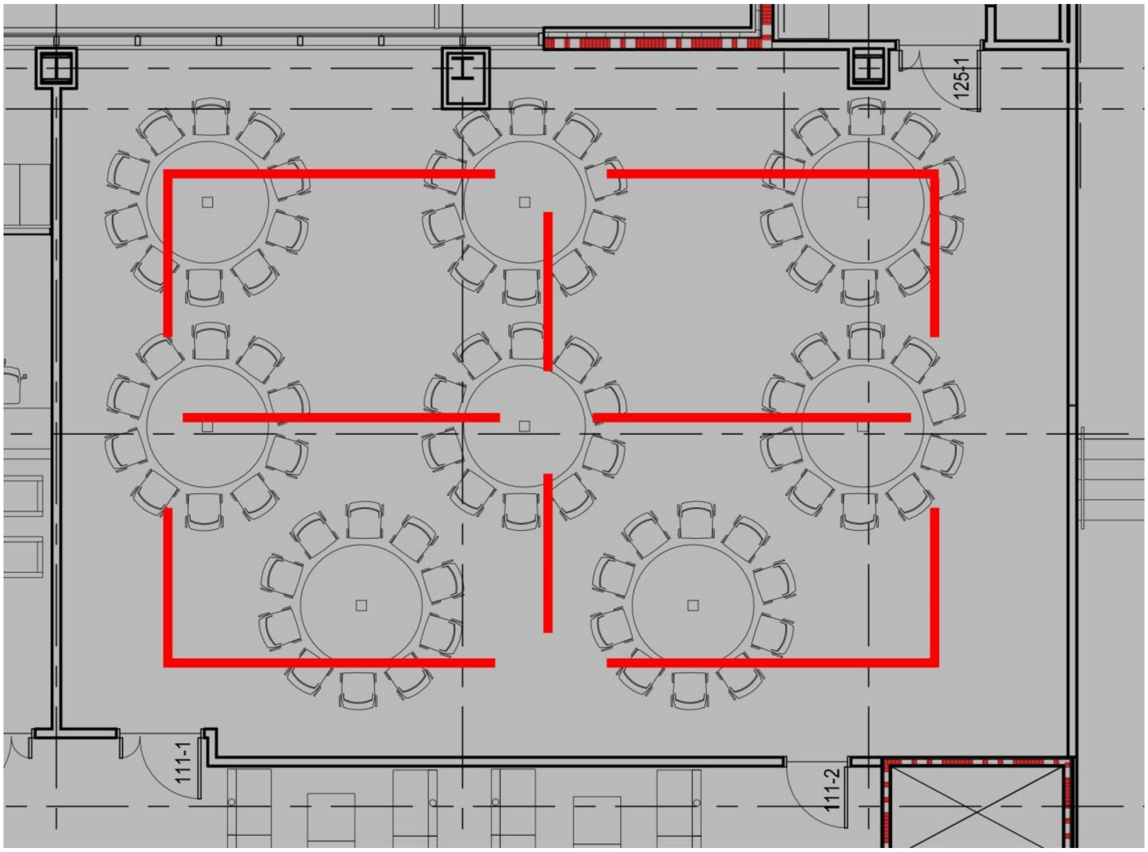

Full output

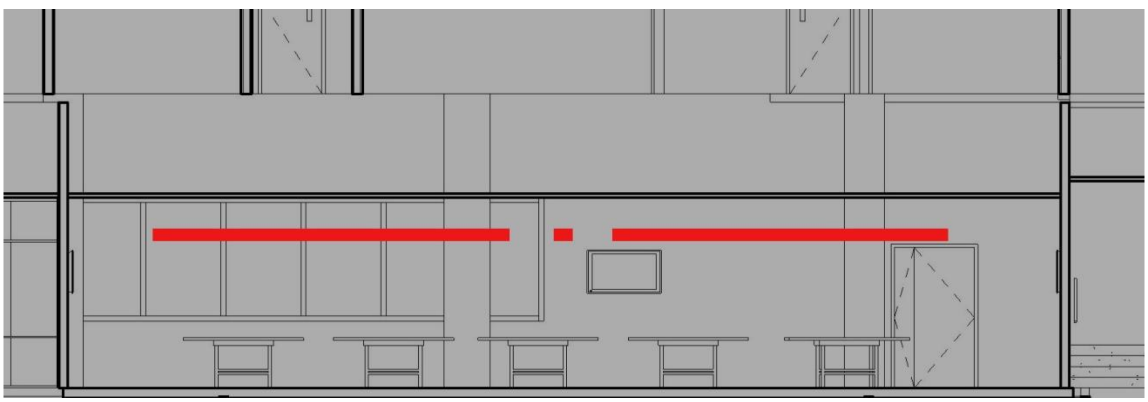

Presentation mode: lowest dimming possible, front off



FIXTURE + EQUIPMENT SELECTION

Here, the lighting solution consists of one type of linear fluorescent fixture with 90° elbow connections. For a detailed lighting schedule, refer to Appendix C. Cutsheets can be referenced in Appendix A.





Fixture Schedule				
Type	Symbol	Fixture Image	Description	Manufacturer
F2	▬		4' suspended pendant in 4.5" by 2.5" cross section housing, frosted acrylic diffuse lens, include dimming option/ballast	Peerless

Fixture Calculations							
Type	Lamp	Quantity	W/fixtures	Total Wattage (W)	PF	VA/fixture	Total VA
F1	28W T5	36	32	1152	1	32	1152

Light Loss Factors						
Type	Lamp Lumens		Light Loss Factors			
	Initial	Mean	LLD	LDD	BF	Total
F1	2600	2418	0.93	0.90	1.00	0.84

CONTROLS STRATEGY

Flexible controls are critical in the classroom given the various tasks and activities that could occur (refer to electrical plans in Appendix D for zone layout). "Zone a" will be controlled by a photosensor near the northern facing window. For a presentation on the southern wall, "zone c" and "zone d" can be dimmed to 10% output or switched off.

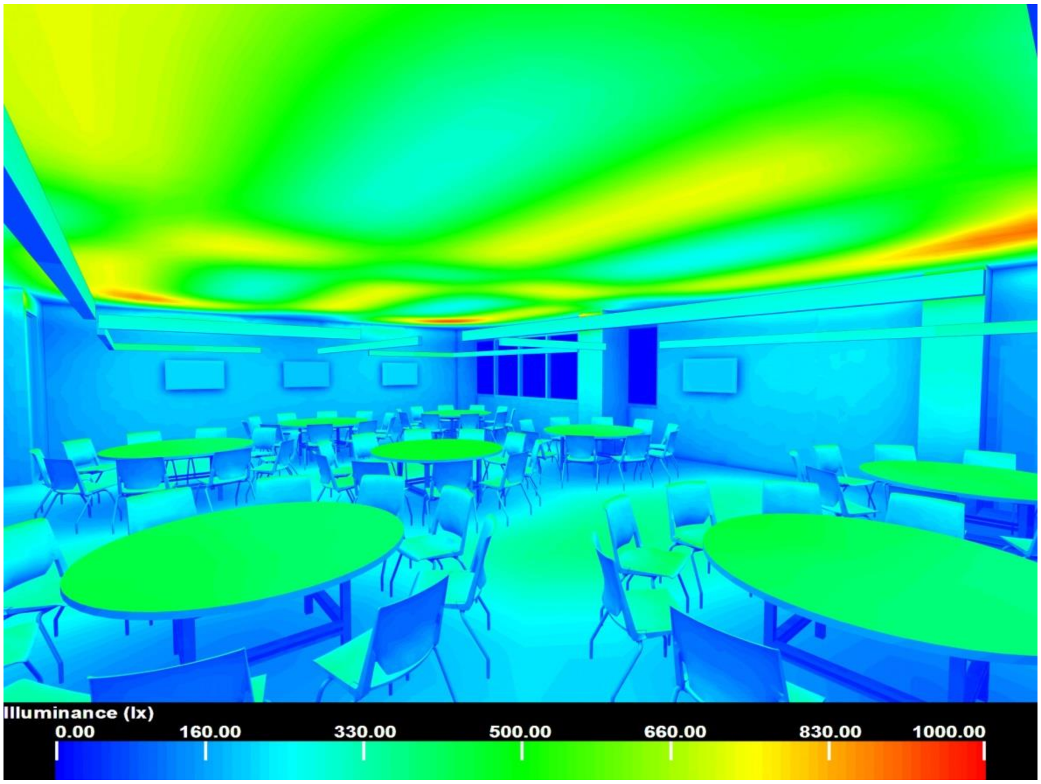
Each zone has its once dimming control on a Creston Master Control iLux interface placed on the south wall. A accompanying wall mounted scene selector control is specified on the west wall to allow control upon entry. Scenes include lighting on, lights off, low, medium, high, and A/V mode. When an occupant enters the space, lighting will turn on to 50% light output. Likewise, lighting controls have an automatic off function. A dimming function is specified on scene control faceplate.

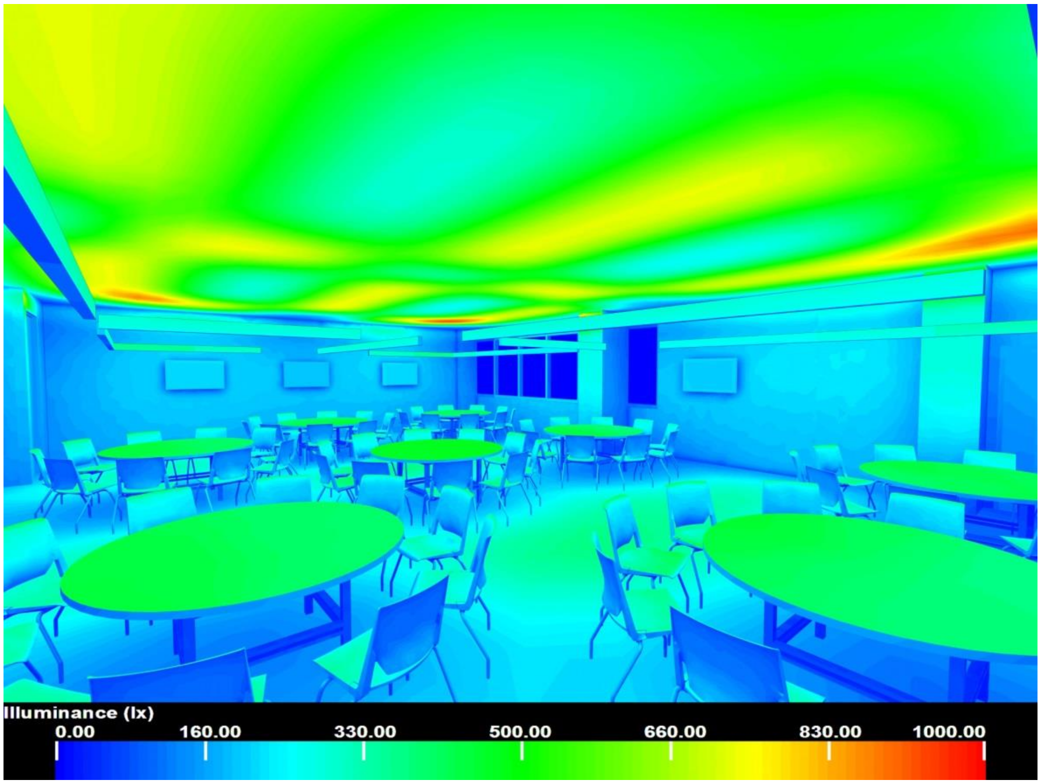
CALCULATION SUMMARY

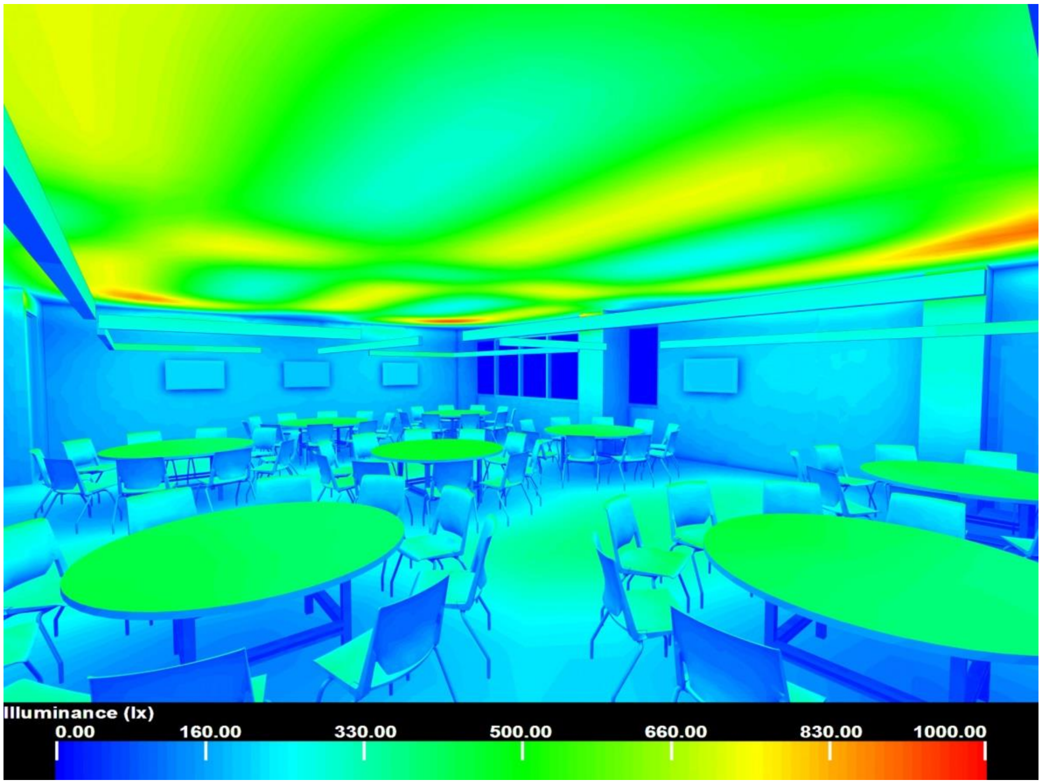
Outlined below is a quantitative analysis of the proposed lighting scheme. The lighting is completely dimmable and controllable so that A/V setting light levels can be easily obtained. Reported below is a simplified version of the scene, with all lights dimmed to 12% light output.

Classroom Illuminance Criteria: Recommended vs. Designed					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Set	Quantity	Recommended	Achieved	Recommended	Achieved
Desk Tops (General)	Average	200	350	50	170
	Avg/Min	1.5:1	1.2:1	--	--
Walls (General)	Average	--	--	200	230
	Avg/Min	--	--	3:1	1.2:1
Desk Tops (AV)	Average	50	50	--	--
	Avg/Min	2:1	2:1	--	--
Walls (AV)	Average	--	--	30	30
	Avg/Min	--	--	2:1	2:1

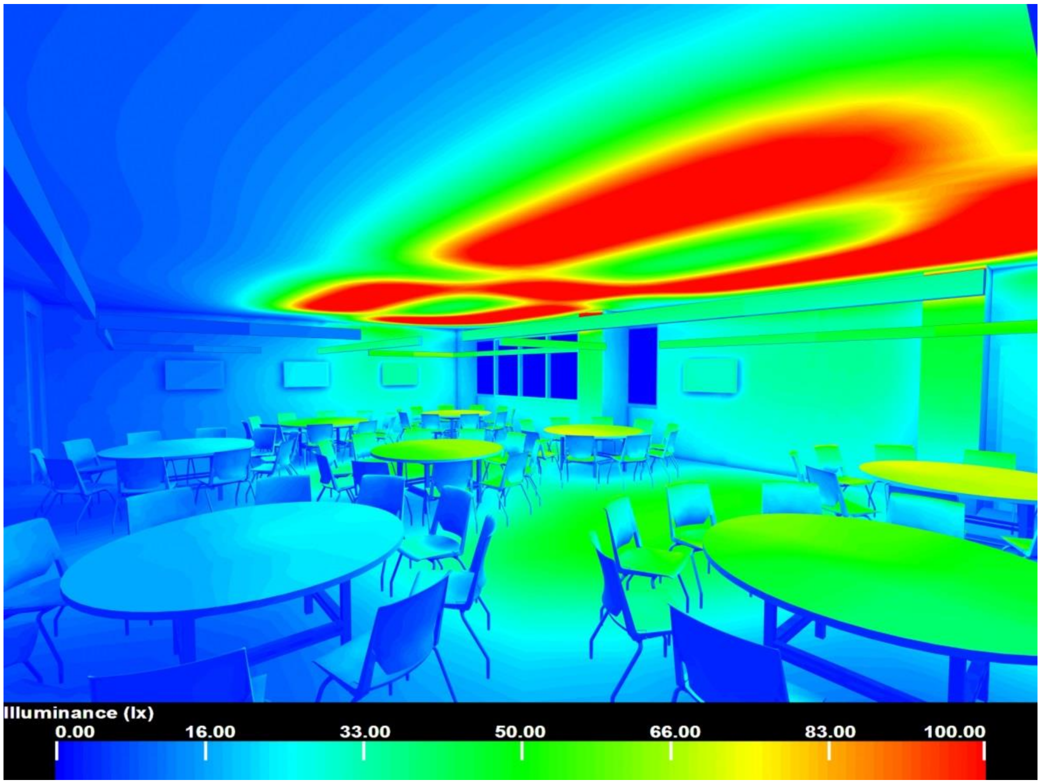
The first pseudo color renderings are at full light output for all fixtures:

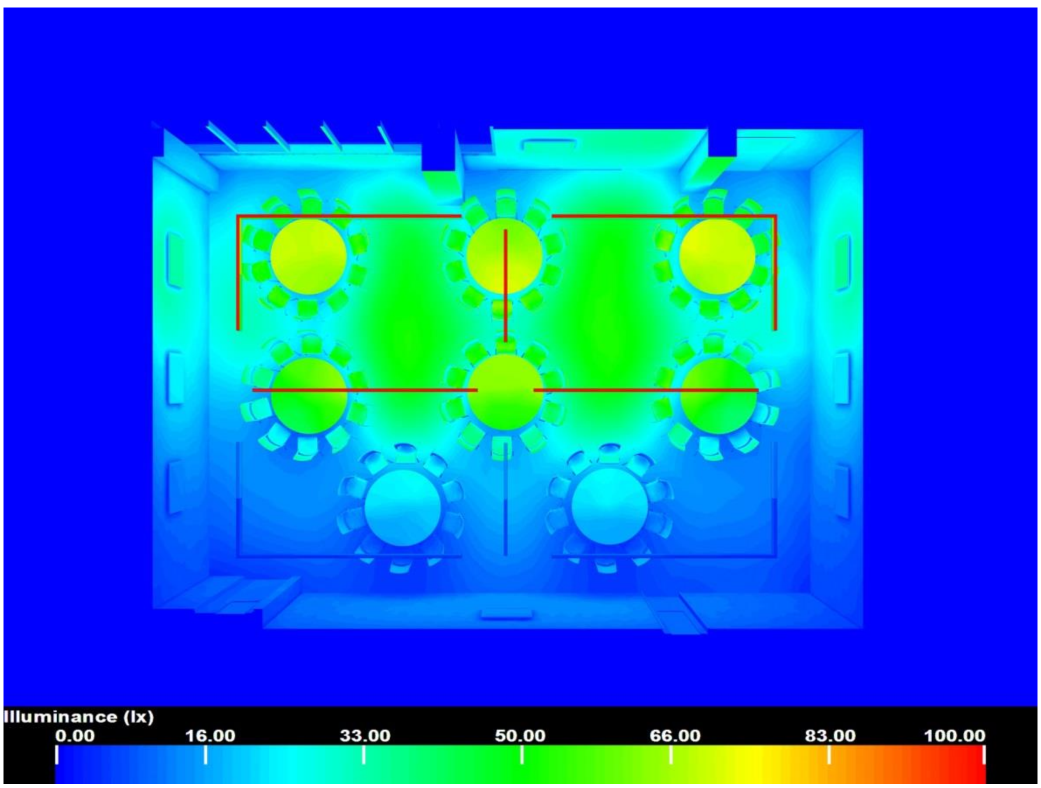






Below are pseudo color renderings of a presentation mode. The front rows of fixtures are off and the back rows dimmed to 12% light output. Here, the light levels are very low near the front of the room, perhaps if the class was watching television. The system is adjustable and the front fixtures can be turned on and dimmed to acquire more light if warranted.


Illuminance (lx)
0.00
16.00
33.00
50.00
66.00
83.00
100.00


Illuminance (lx)
0.00
16.00
33.00
50.00
66.00
83.00
100.00

EVALUATION

SUMMARY

By using a symmetrically unique layout of indirect/direct fixtures, uniform lighting at the task plane is achieved. The design goals are achieved using a simple yet elegant design. A public impression is imposed by providing overhead lighting; the space is responsive to several variables including daylight and various scene demands. The layout of the fixtures provides an even distribution of light along vertical surfaces to help define the spatial boundaries of the space.

The work task plane illuminance is approximately 150 lux more than the IES recommended average horizontal illuminance of 200 lux. Referring to documents citing UPenn standards, the university calls for light levels anywhere between 200 to 500 lux in the classroom. In this sense, 350 horizontal lux on the table tops is acceptable. Furthermore, to not sacrifice uniformity across the workplane, a higher output fixture is used and thus leads to higher illuminance levels.

Through an ominous method of symmetrical lighting, engaging collaboration will be encouraged in the classroom.

ASHRAE/IESNA 90.1

As compared to Standard 90.1 which allows for 2108 watts in this space, the lighting only consumes 1152 watts. The lighting is 45% more efficient than the required standard. Coupled with occupancy sensors, scene control, and daylight integration, the energy needs are effectively meet at no sacrifice to the visual and functional lighting goals.

Energy Consumption (ASHRAE/IESNA 90.1 – 2010) - Classroom		
Category	Allowable	Calculated
Area (SF)	-	1700
Input Wattage	2108	1152
Power Density (W/SF)	1.24	0.68

Refer to Appendix E for a detailed COMCHECK report of the proposed classroom lighting solution.

4 | LECTURE HALL

Lighting for the final space, the underground lecture hall, is presented in the following section. This section includes relevant information that describes the visual impression of the space, relation to the overall concept, design goals and criteria as compared to the final design, fixtures used, control narrative, quantitative calculation summaries, and applicable renderings. Below is an outline of the information included in this section:

Description
- Dimensions
- Site Plan
- Finishes
- Furniture/Equipment
- Tasks

Overall Design Goals

Design Criteria/Considerations
- Qualitative Criteria
- Desired Psychological Impression
- Quantitative Criteria
- LEED-NC v4 Draft
- Energy Allowances
- Design Goals Prioritized

Design Development
- Summary

Fixture + Equipment Selection

Controls Strategy

Calculation Summary

Evaluation
- Summary
- ASHRAE/IESNA 90.1

DESCRIPTION

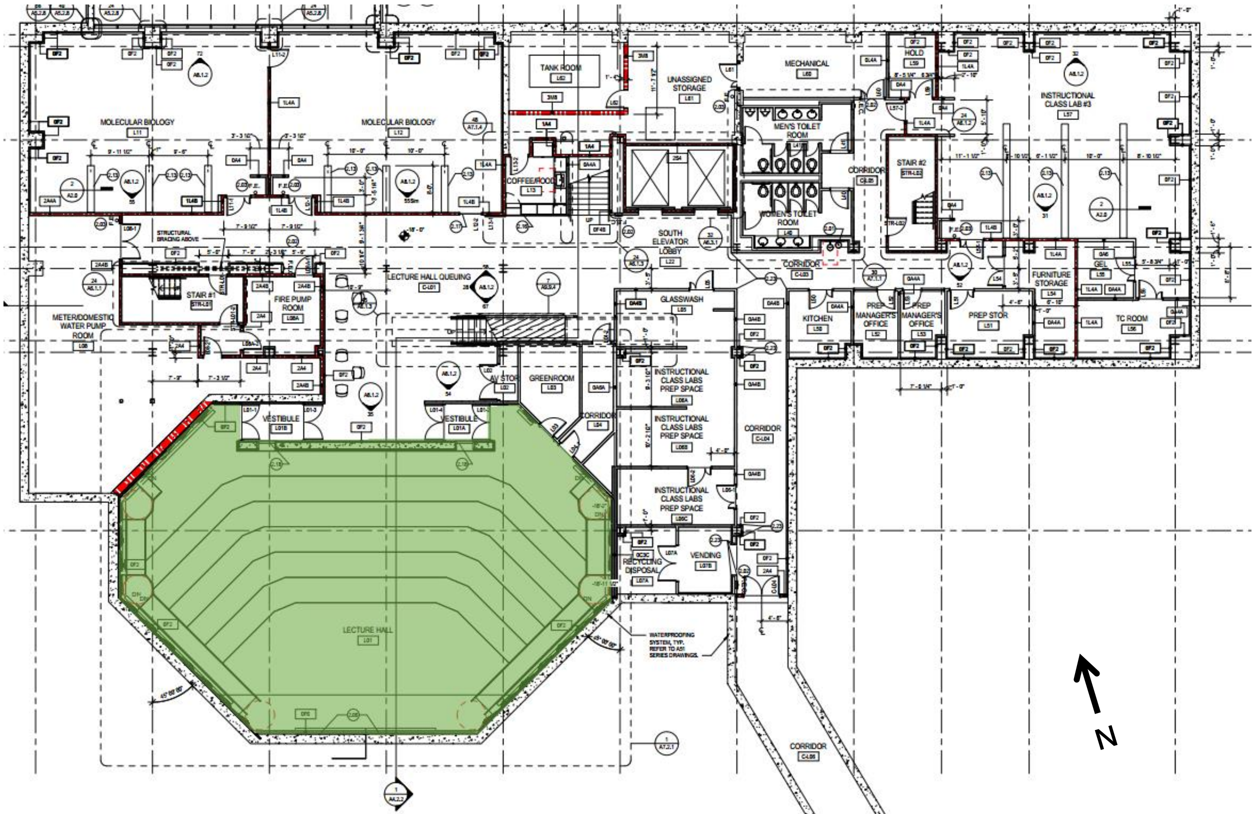
Fig. 19: Lecture Hall, courtesy of SmithGroupJJR

Architecturally, the tiered underground space is organic and includes high architectural elements particularly in the ceiling and walls: custom-made panels that angulate throughout the space. The lecture hall is located on the southern side of the building, directly under the large outdoor garden and entrance. There is appropriately no daylight present in the space as this will be used for presentations.

DIMENSIONS

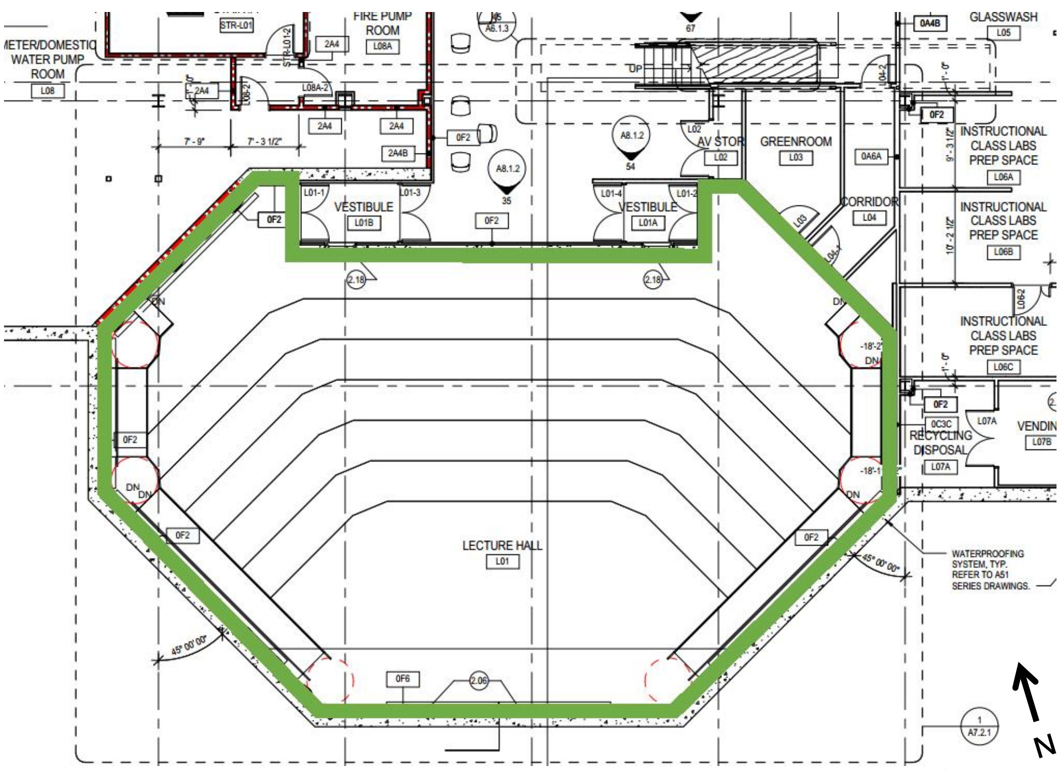
Area – 3200 ft^2.
Approximate width – 90 ft
Approximate length – 55 ft
Approximate ceiling height – 13 ft

FLOOR PLAN



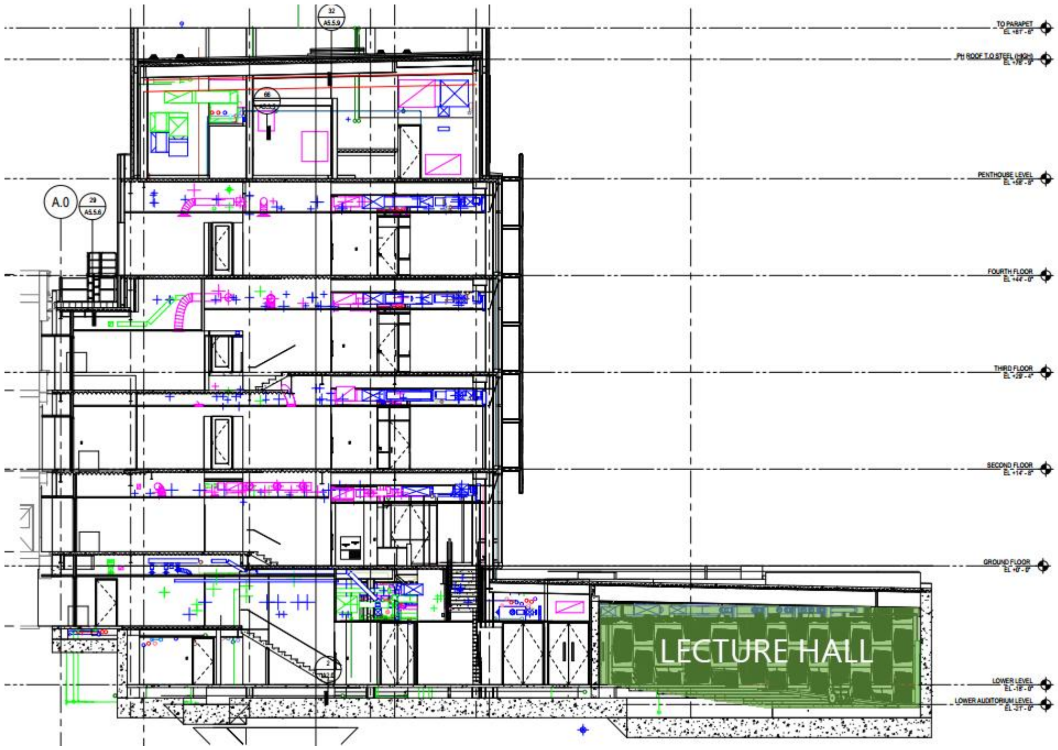
Reference: Sheet A2.0

ENLARGED FLOOR PLAN



Reference: Sheet A2.0

NORTH-SOUTH SECTION



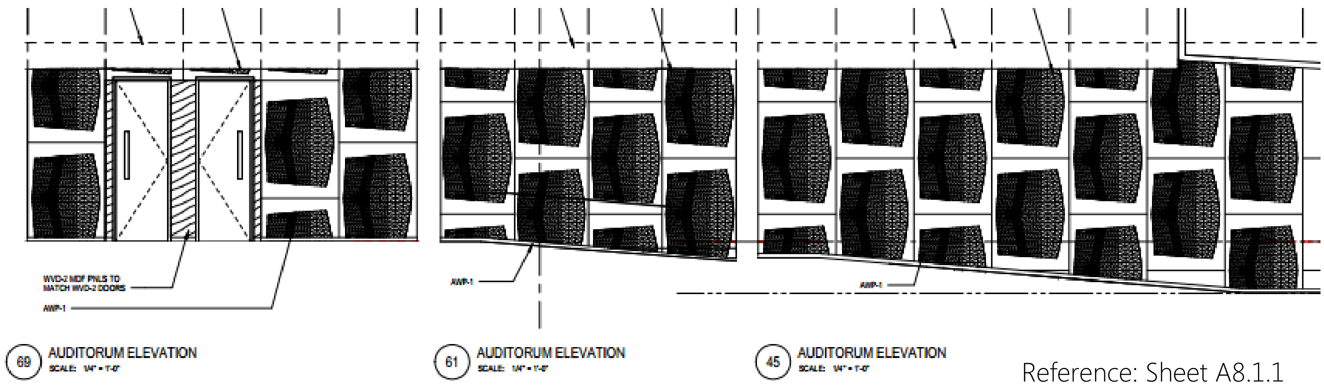
Reference: Sheet A4.2.2

FINISHES

The ceiling and walls are constructed of custom-made acoustic ceiling panels which have unique curved shapes to reinforce the architectural concept of organic and biogenetic. The panels are lightly colored—they have high reflectance values ideal for lighting a public space. The back wall is constructed of yellow wood veneer. The floor is a resilient sheet flooring material, somewhat darker with a lower reflectance value. Overall, the space is relatively reflective which aids in facilitating a public psychological impression.

Lecture Hall Materials				
Surface	Material	Description	Style/Color	Reflectance (ρ)
Ceiling	ACP-1/PNT-8	Arktura custom white fiberglass ceiling panel system with specular finish, paint behind	Light yellow, iron ore SW7069 paint	0.75
Walls	AWP-1/WDV-3	Arktura custom white feiberglass wall panel system with specular finish, back wall yellow wood veneer	Light yellow panel/medium finish wood	0.75/0.50
Floor	RSF-3	Optima Series 1/8” homogeneous vinyl sheet	Cool Beige	0.30

AUDITORIAM INTERIOR ELEVATION

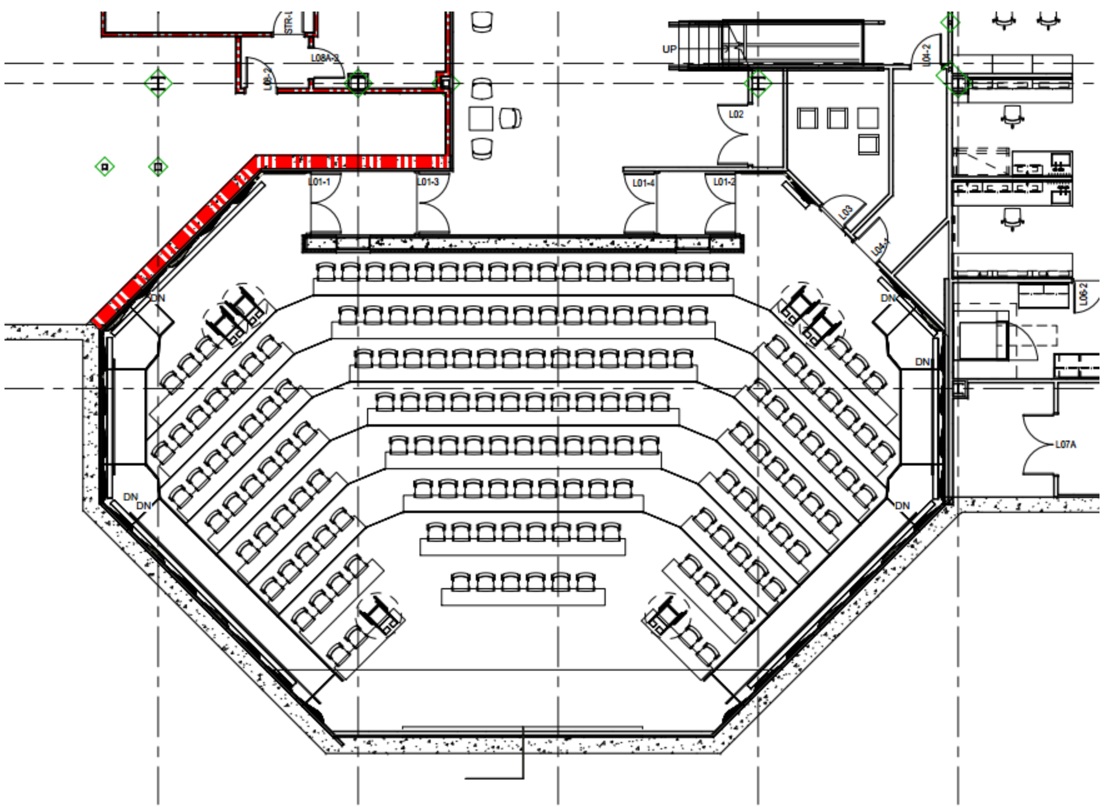


Reference: Sheet A8.1.1

FURNITURE/EQUIPMENT

The lecture hall houses 174 rolling chairs including space for six handicap accessible spots. Medium reflective tables are used for writing; these architecturally mimic a wood finish. There is a single projection screen at the front of the lecture hall with one corresponding ceiling-mounted projector in the center of the room. Sliding chalkboards will be used for presenting material.

FURNITURE PLAN



Reference: Sheet AI2.0

TASKS

Important tasks in this space consist primarily of reading and writing. Laptop and computer use are viable design considerations and will be accounted for in the redesigned lighting solution. Projector presentations require the use of audio/visual equipment and thus, appropriate light settings through the use of lighting controls. The screen must be able to be seen clearly from the back of the room; keeping the surroundings relatively dimmer than the screen will resolve viewing issues.

OVERALL DESIGN GOALS

Nutrients are carried through a tree by way of complex cellular structures particularly larger sieve tubes and smaller companion cells in the sapwood. Vertical movement in the trunk and tree is the essence of the tree's life. *Creative lighting will be used to accentuate the curves of the space, enforcing the presence of the organic ceiling and spatial activity. Lighting speaks to the function as the central learning space and essence of the building.*

To achieve the desired lighting notion, parts of each schematic design will be combined to create an enjoyable space. Notably, peeling back and pushing different modular panels will reveal light, reacting to the form of the ceiling while still providing functional light.

Fig. 20: www.wallsfeed.com

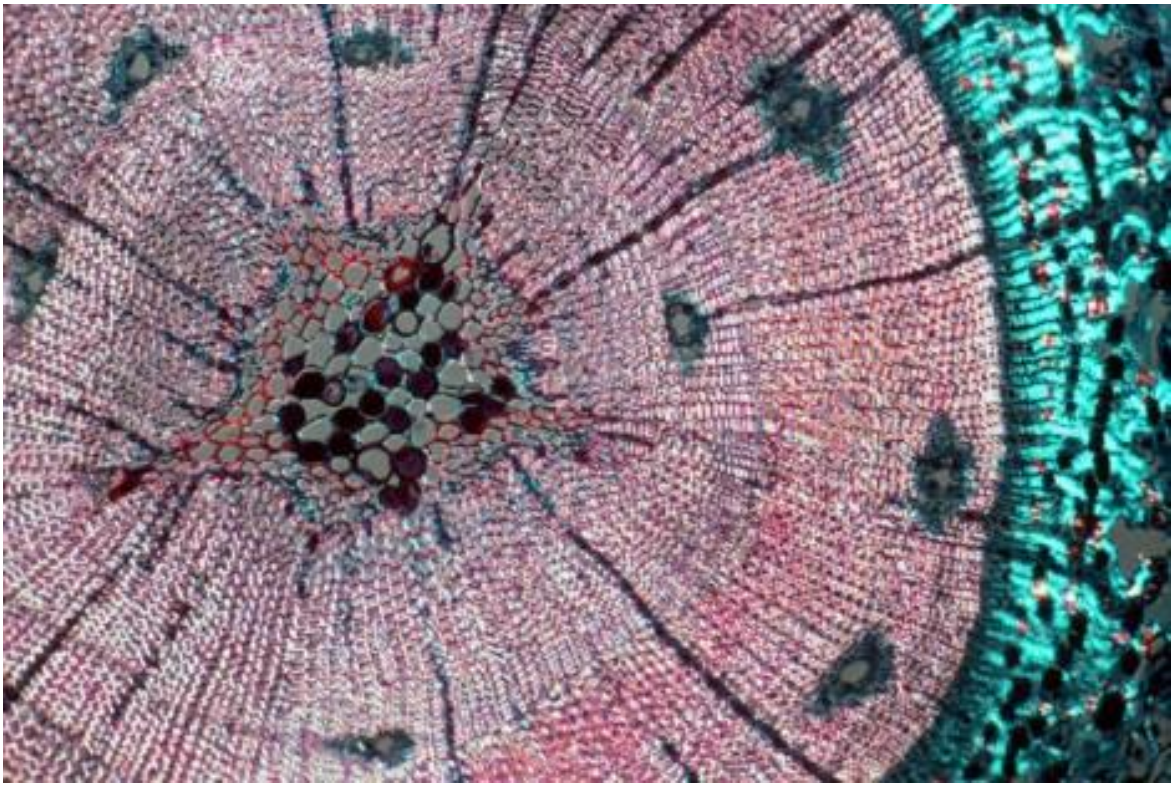
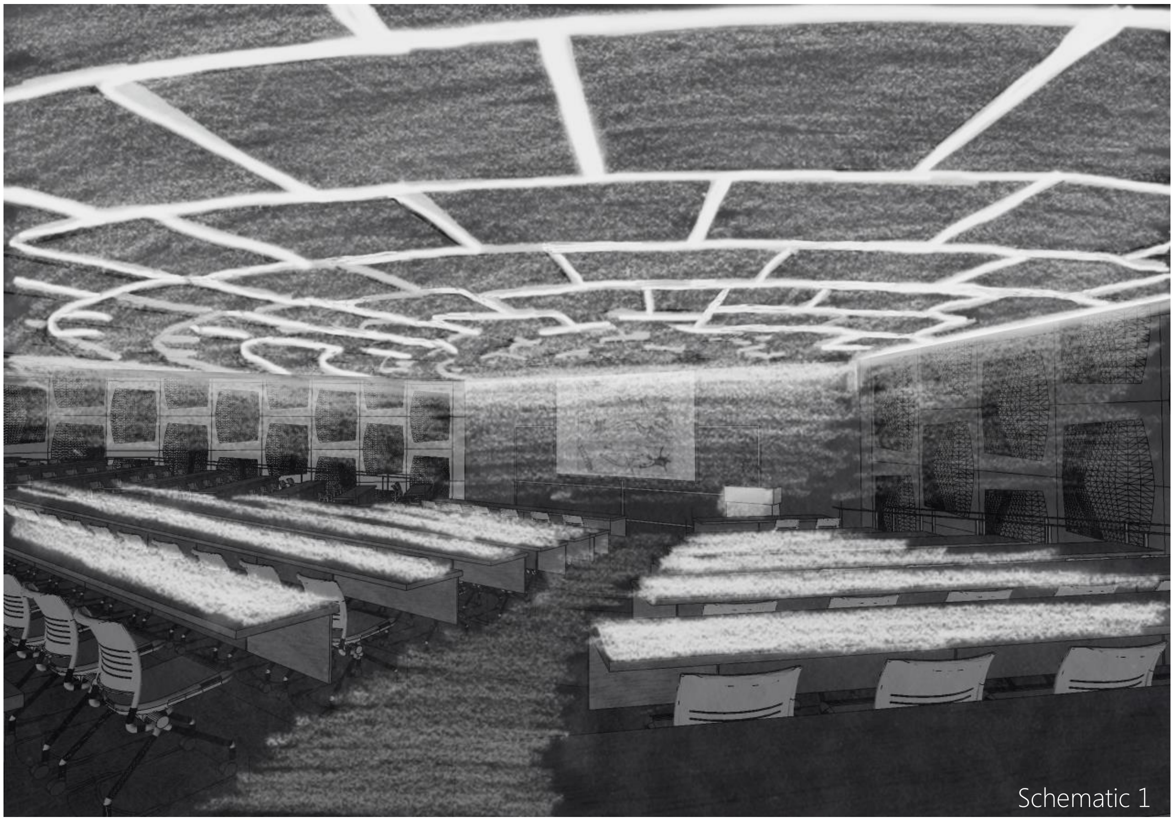


Fig. 21: www.corbisimages.com


Schematic 1


Schematic 2

Verticality: vertical movement can be achieved by revealing vertical slithers of light along the modular walls; space beyond the ceiling is encouraged by perimeter lighting and allowing light to graze select ceiling panels.

Functional: lighting aims to be interesting but will not deter from the functionality of the space. A functional layer of light integrated among the ceiling will address this issue.

Control: lighting controls will allow for flexible scene control and appropriate settings for reading, test taking, and AV presentations.

Distraction: visually, lighting a complex ceiling may suggest distractions to the users. Further studying and sketching will be used to obtain a visual impression of the desired motion as to optimize the effect but limit occupant distraction and glare.

DESIGN CRITERIA/CONSIDERATIONS

QUALITATIVE CRITERIA

Very Important

- **Light Distribution on Task Plane**
  - Meeting the IES Handbook recommendations for illuminance and uniformity will ensure that there are sufficient light levels to comfortably read and write
  - Vertical surfaces (for writing) at the front of the space should be lit to sufficient levels, referencing the IES Handbook, as to help the eye maintain focus and user maintain attention
  - Render lecturer's face well so that occupants can easily identify speaker's emotions and expressions

- **Appearance of Space and Lighting Fixtures**
  - The custom curved ceiling and wall panels are prominent architectural features; the lighting design should respond and complement the space

- **Direct glare**
  - Users of the space should not experience direct glare as this will be irritating and distracting especially since the direction of viewing is in one direction

- **Lighting Controls**
  - It is critical that the space be controlled well so that different lighting modes will respond to the purpose of the space at the time; this is related to relative brightness levels experienced in the space

Important

- **Veiling Reflections**
  - Veiling reflections on specular computer and Ipad screens should be minimized by controlling the overall amount and direction of light with respect to the location and orientation of the task

- **Flicker**
  - Flicker could potentially be distracting to the occupants which would inherently effect their efficiency and retentiveness

- **Group Relamping and Cleaning**
    - A taller ceiling in the hall and quantity of fixtures require careful consideration when specifying product, as to allow for efficient and easy cleaning and relamping post-occupancy

Not applicable

- **Daylighting Integration and Controls**
    - No daylighting apertures present in space

DESIRED PYSHCOLOGICAL IMPRESSION

As outlined by John Flynn and discussed by Gary Steffy, the redesigned lighting in the lecture hall will enable public impressions on the occupants. This will be done by illuminating the peripheral surfaces and introducing uniform and relatively brighter light levels.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance – Very Important

- IES Classification | Education
    - Reading and Writing, Print media, 12-pt font
        - Category O: 200 lux (20.0 fc), at desk height
        - Avg/Min: 2:1
    - Auditoria, Lecture Hall, Audience, A/V and notes
        - Category K: 50 lux (5.0 fc), at desk height
        - Avg/Min: 2:1

Recommended horizontal illuminance levels are driven by two critical tasks. One is a recommendation corresponding to general lighting for reading and writing. The other recommendation relates to a projector screen presentation (A/V equipment) when note-taking is expected.

Recommended Vertical Illuminance – Important

- IES Classification | Education
    - Reading and Writing, Print media, 12-pt font
        - Category O: 50 lux (5.0 fc), at desk height
    - General Classroom, Learning/teaching, Chalkboard
        - 400 lux (40 fc)

- Auditoria, Lecture Hall, Speaker/Panel, no A/V, Faces
  - 200 lux (20 fc)
- Auditoria, Lecture Hall, Audience, A/V and notes
  - Category K: 15 lux (1.5 fc), at desk height
- Auditoria, Lecture Hall, Screen, Feature Presentation
  - 10 lux (1.0 fc)

Correlating to the above horizontal light levels, the vertical recommended values correspond to a general lighting scene where note-taking is expected. In this general lighting setting, recommended light levels are noted for modeling the face of a speaker at the front of the room with no A/V equipment in use. Another lighting scene accounts for projector presentations on the front screen.

LEED-NC v4 Draft

EAp2: Minimum Energy Performance

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.01-2010.

EAc2: Optimize Energy Performance

- Reduce energy consumption of entire building by 6-42% to respectively receive 1-16 points.

EQc6: Interior Lighting

- For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences with at least three lighting levels or scenes (on, off, midlevel).
  - For multi-zone spaces, include multi-zone control system readily available to occupant
- For entire project, use light sources with a CRI of 80 or higher
- For all regularly occupied spaces, use light fixtures with a luminance of less than 2,500 cd/m^2 between 45° and 90° from nadir.

ENERGY ALLOWANCES

According to ASHRAE Standard 90.1 version 2010 (most recent version upon completion of thesis) space-by-space method, a classroom/lecture/training has an allowed wattage of 1.24 W/SF.

Energy Allowance (ASHRAE 90.1 – 2010)			
Space	Area (SF)	W/SF	Allowed Wattage
Lecture Hall	3200	1.24	3968 W

DESIGN CRITERIA PRIORITIZED

1. Meet ASHRAE Energy Code requirements
2. Create a public and visually comfortable space that provides sufficient and uniform lighting for task completion, thus introducing a public impression
3. Control lighting to meet various demands of space
4. Model the speaker's face well and provide adequate task lighting
5. Architecturally complement the space
6. Meet LEED requirements for lighting controls and minimum energy requirements

DESIGN DEVELOPMENT

SUMMARY

Several layers of light create a flexible and visually interesting space. The final lighting solution is a combination of all four schematic sketches seen above. By treating the front of the class as the primary root and the center and perimeter walls as lateral roots, the lighting design emphasizes the undulating form of the ceiling. For cohesiveness, a target CCT of 3500K across the room is established.

Cove lights are placed on top of the custom ceiling panels adjacent to panels pushed up several inches into the ceiling cavity. Hereby, cove lighting allows light to spill out onto several panels and down into to the space. The effect created draws ones focus towards the side walls which then continue the effect down to the ground using recessed reveals within alternating panels. Light seems to come from within the form, stemming from the center of the room. Ceiling panels have been changed from a specular white surface to a matte finish white fiberglass; this will limit veiling reflections. Panels are lit from the side to avoid clashing with downlights, to create an outward flowing notion, and to limit glare.

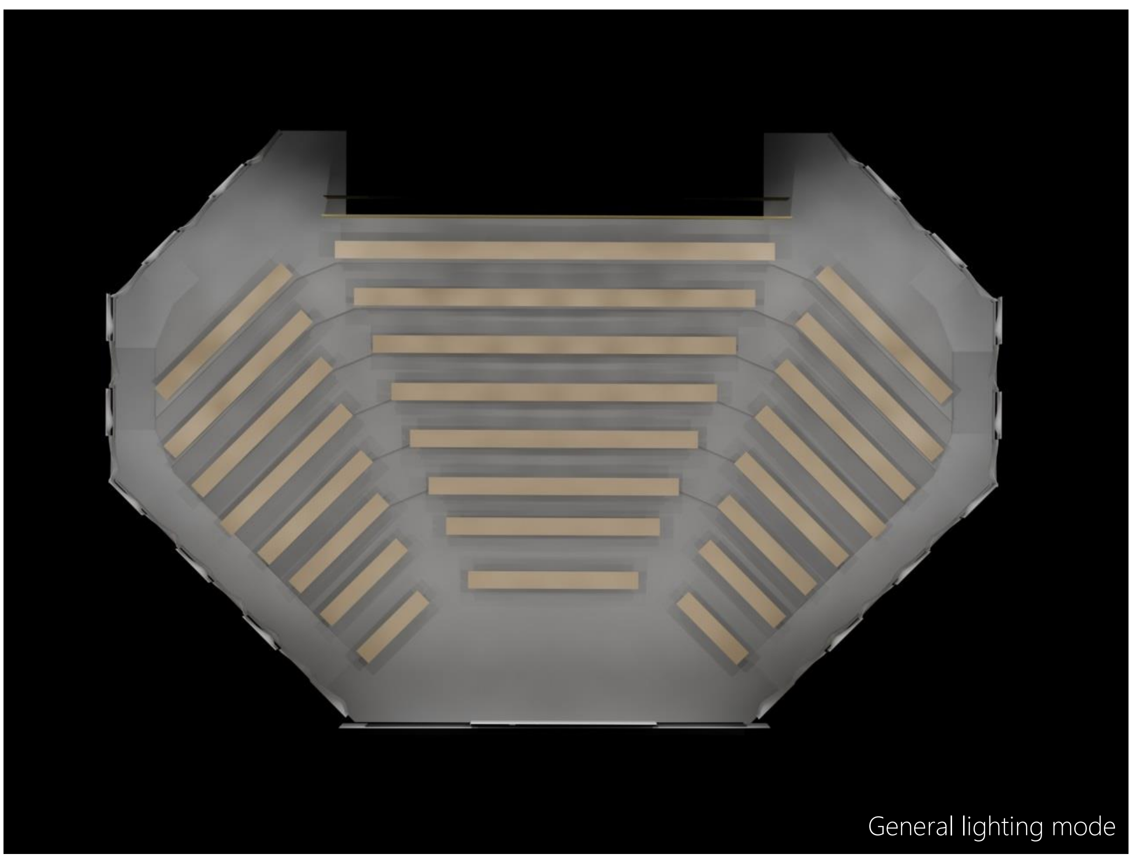
Drawing from another schematic design, downlights installed between the gaps of the custom ceiling panels serve as the companion cells to the somatic cells (cells within a tree that carry vital nutrients). The small downlights provide functional uniform lighting while limiting direct glare and intrusive placement. The space beyond the panels is painted black and visible from below adding another layer of depth to the direct overhead lighting system.

Chalkboard and back-wall wallwashers along with perimeter wall-mounted fixtures from above the horizontal ceiling plane helps define the space. Visual clarity and a pleasant psychological experience are imposed by lighting the vertical surfaces; this light also aids in proper scene control. Three major scenes are displayed below:

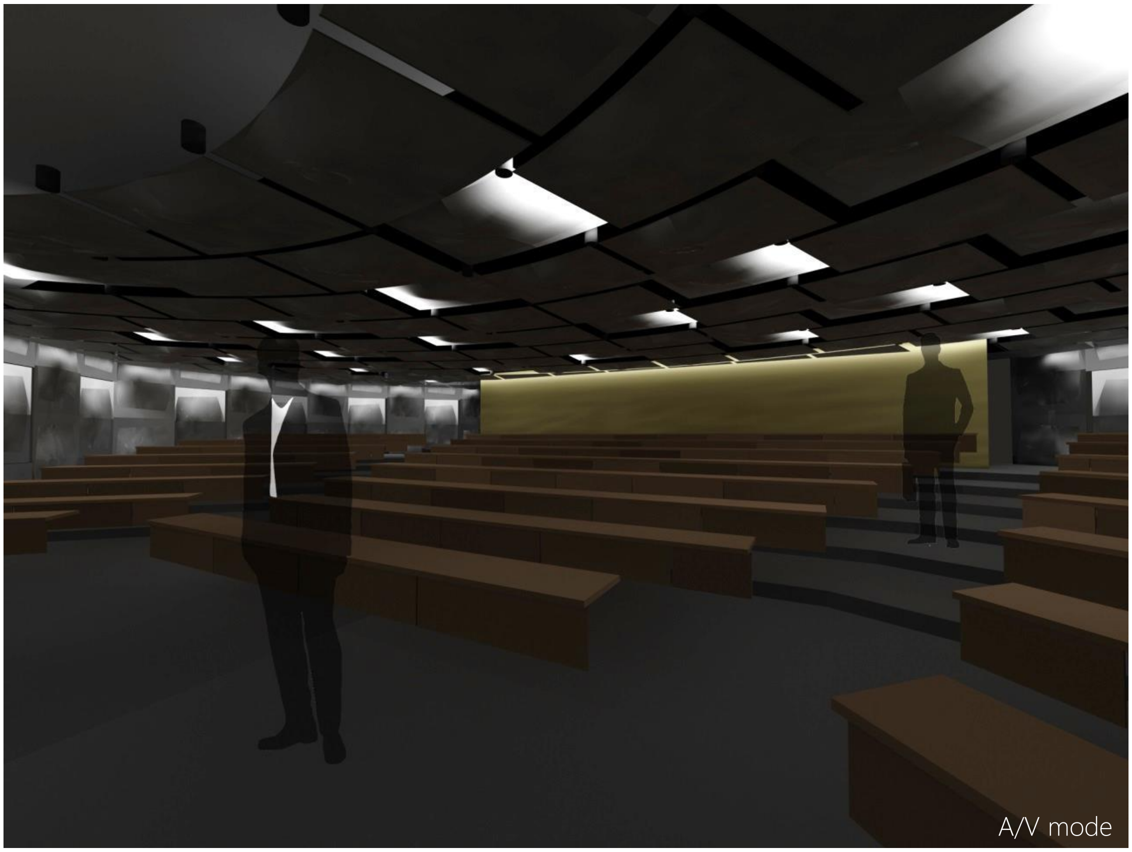

General lighting mode


General lighting mode

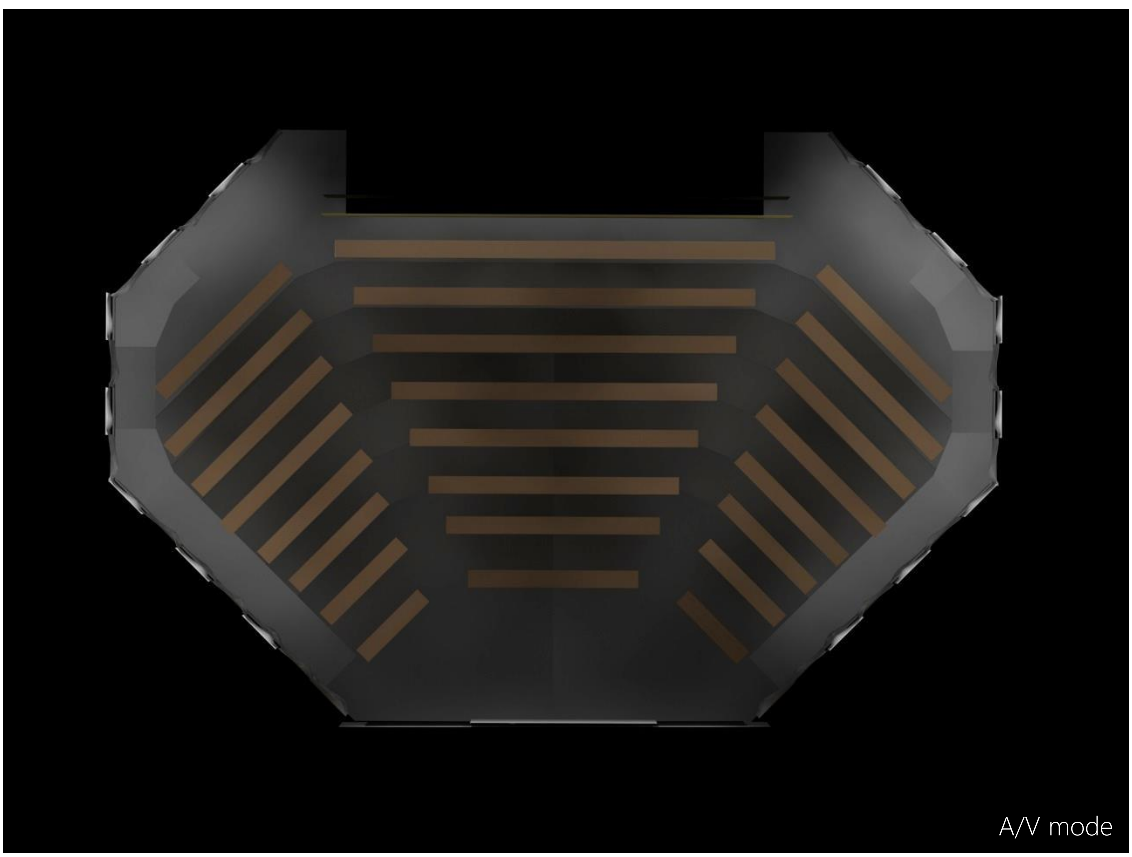

General lighting mode


General lighting mode


A/V mode


A/V mode

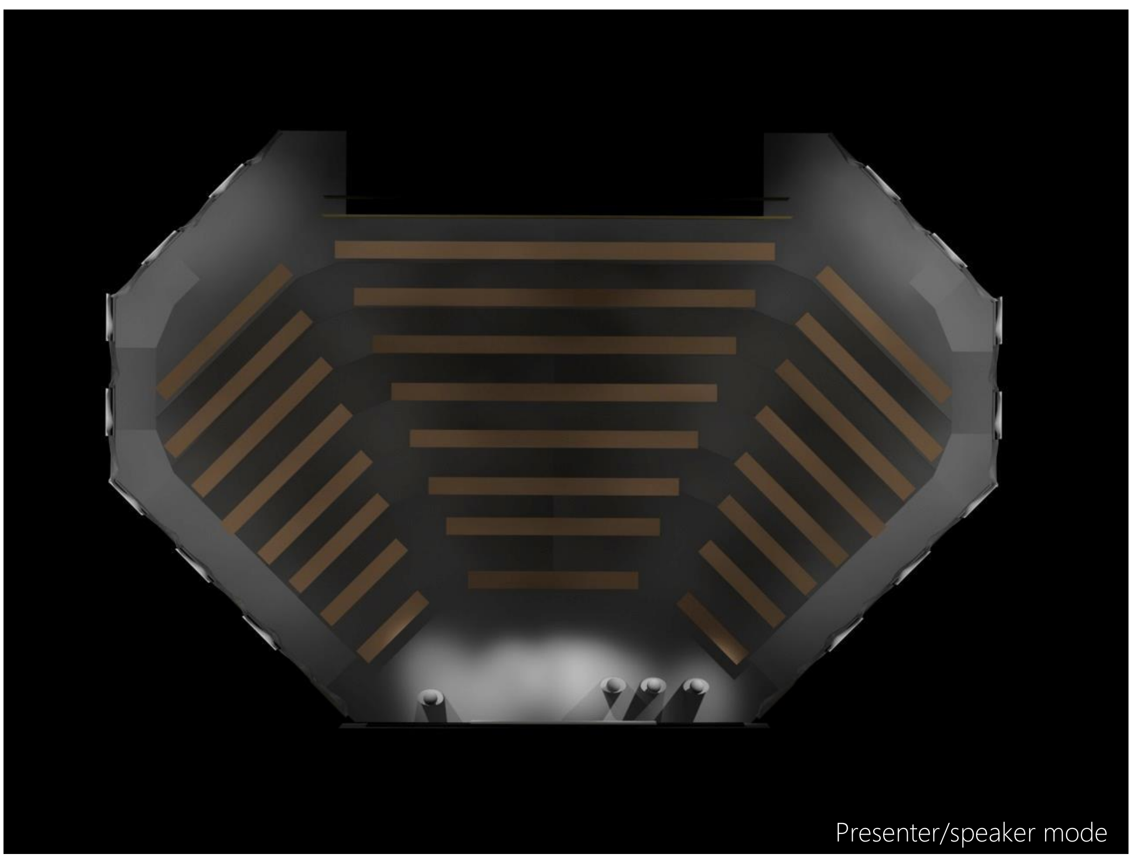

A/V mode


A/V mode

Three major scenes drive the control scheme: general lighting, presentation mode, and speaker mode. When a speaker is present, seven LED track lights placed between the gaps of the ceiling illuminate the faces of the presenter. They are placed to highlight the features of the presenter while control harsh key light.

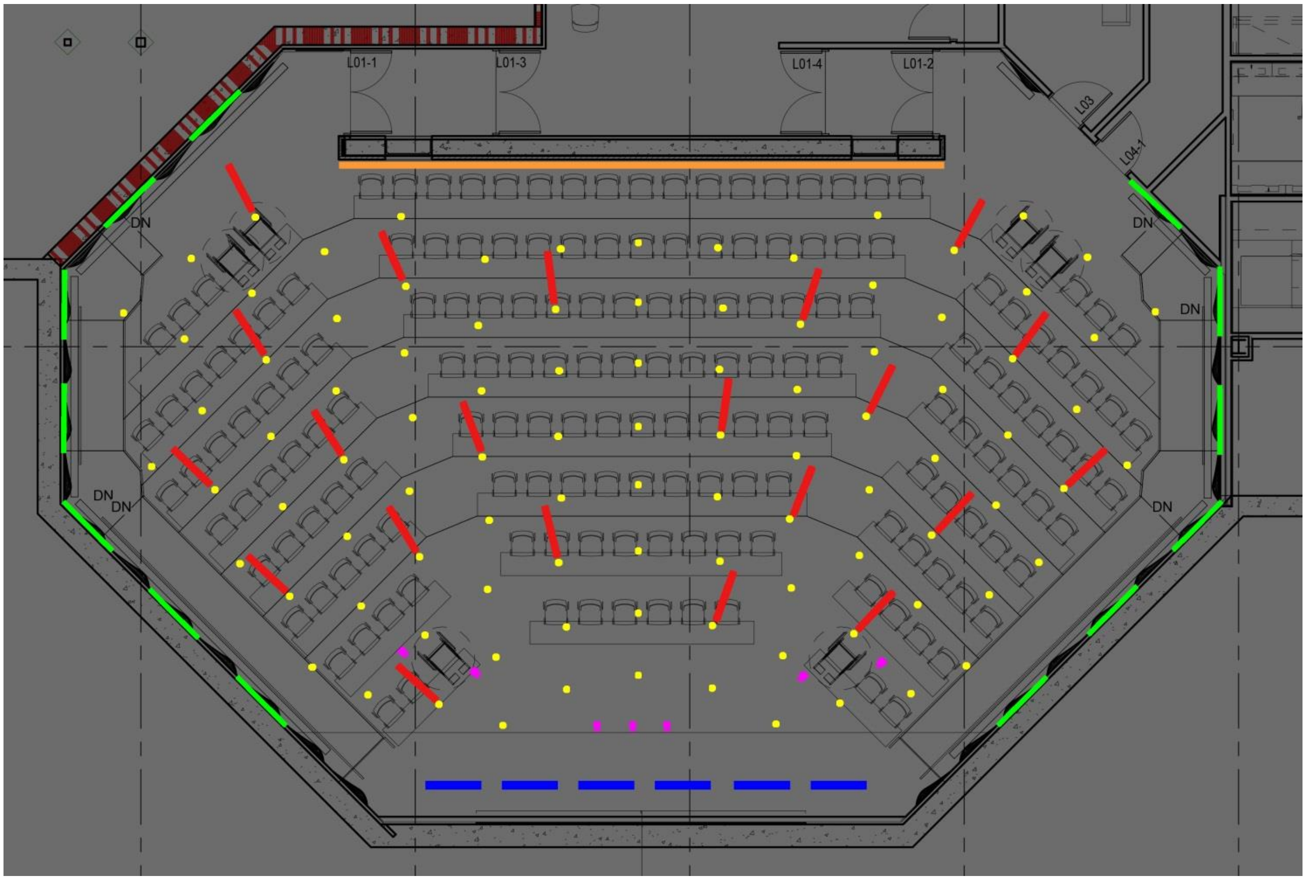

Presenter/speaker mode

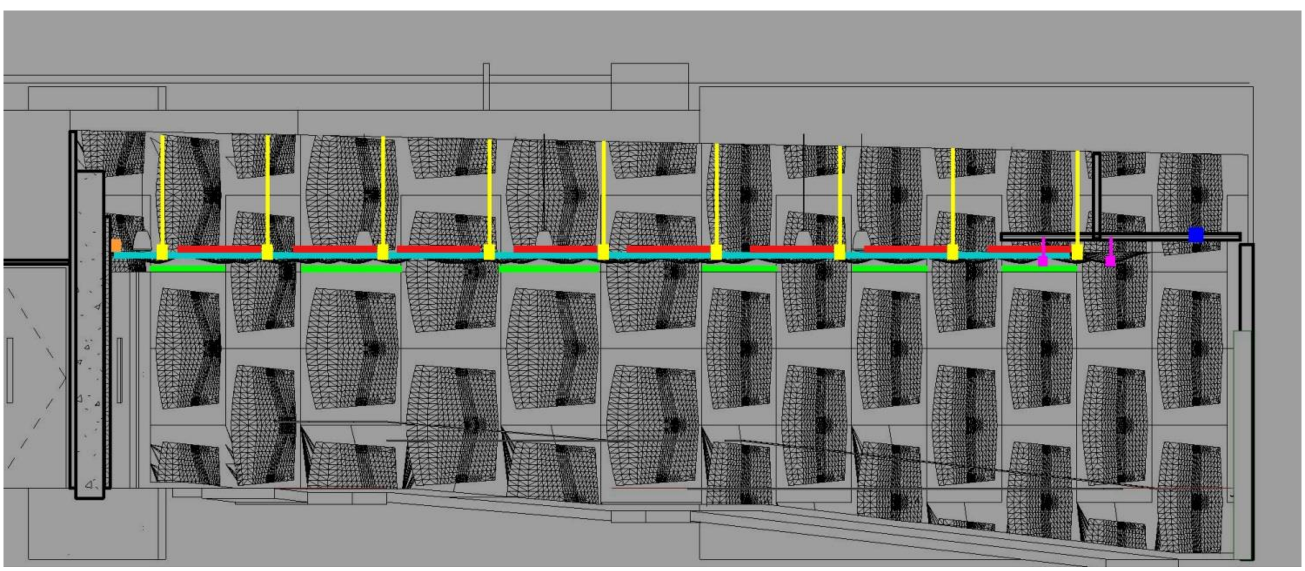

Presenter/speaker mode


Presenter/speaker mode

FIXTURE + EQUIPMENT SELECTION

A combination of various types of LED and fluorescent fixtures are used in the lecture hall to achieve the desired effect. For a detailed lighting schedule, refer to Appendix C. Cutsheets can be referenced in Appendix A.





Fixture Schedule				
Type	Symbol	Fixture Image	Description	Manufacturer
F3			Concealed 4' cove steel fixture with T5 lamping, asymmetric distribution, painted custom black housing, include dimming ballast/option	Litecontrol
F4			4' recessed direct wall wash	Litecontrol
L3			Low wattage LED 3" architectural slot, frosted lens with linear micro prism pattern	Focal Point
L6			Dimmable LED flood spotlight, include black plastic snoot accessory	Erco
L7			5” suspended wide beam architectural cylinder, 4.375 luminous aperture, 0-10V dimming capabilities	Kurt Versen
L8			Direct wall-mounted medium output (MO) fixture, 0-10V dimming, 3500K	Litecontrol
L8A			Same as L8 but high output (HO)	Litecontrol

Fixture Calculations							
Type	Lamp	Quantity	W/fixtures	Total Wattage (W)	PF	VA/fixture	Total VA
F3	54W T5	22	61	1342	1	61	1342*
F4	54W T5	6	61	366	1	61	366
L3	LED	13	22.9	297.7	1	22.9	297.7*
L6	LED	7	12	84	1	12	84
L7	LED	98	14	1372	1	14	1372
L8	LED	11	29	319	1	29	319
L8A	LED	30	39	1170	1	39	1170

Light Loss Factors						
Type	Lamp Lumens		Light Loss Factors			
	Initial	Mean	LLD	LDD	BF	Total
F3	4450	4138	0.93	0.93	1.00	0.86
F4	4450	4138	0.93	0.93	1.00	0.86
L3	N/A	N/A	0.70	0.93	N/A	0.65
L6	N/A	N/A	0.70	0.93	N/A	0.65
L7	N/A	N/A	0.70	0.93	N/A	0.65
L8	N/A	N/A	0.70	0.93	N/A	0.65
L8A	N/A	N/A	0.70	0.93	N/A	0.65

CONTROLS STRATEGY

Lighting in the lobby is adaptable to various lighting scenes. Lighting is controlled by a Master Control Unit such as Crestron iLux. This unit controls the various zones which are all dimmable (see Appendix D for electrical plans). Two wall mounted scene selector controls are mounted at the entrance to the lecture hall. Scene selection here includes lecture, A/V, exam, recording, presenter/speaker, and lights off. A similar larger scene controller is located at the front of the room. The same scene options are present on the gang faceplate with additional controls to dim the lectern spots (L6), front wall-washers (F4), and perimeter grazing (L8A). Refer to the electrical plan for zoning of fixtures.

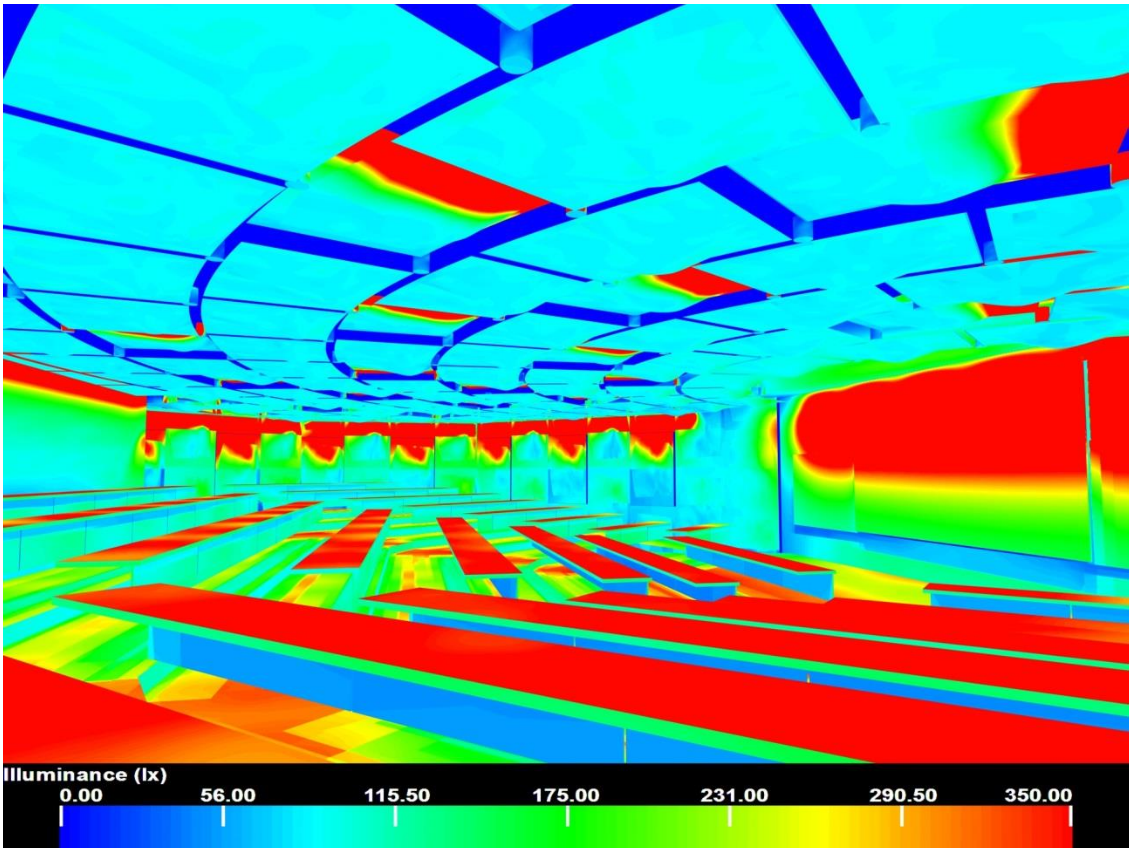
For emergency lighting, see Electrical section of this report. Relevant renderings and emergency circuiting is provided.

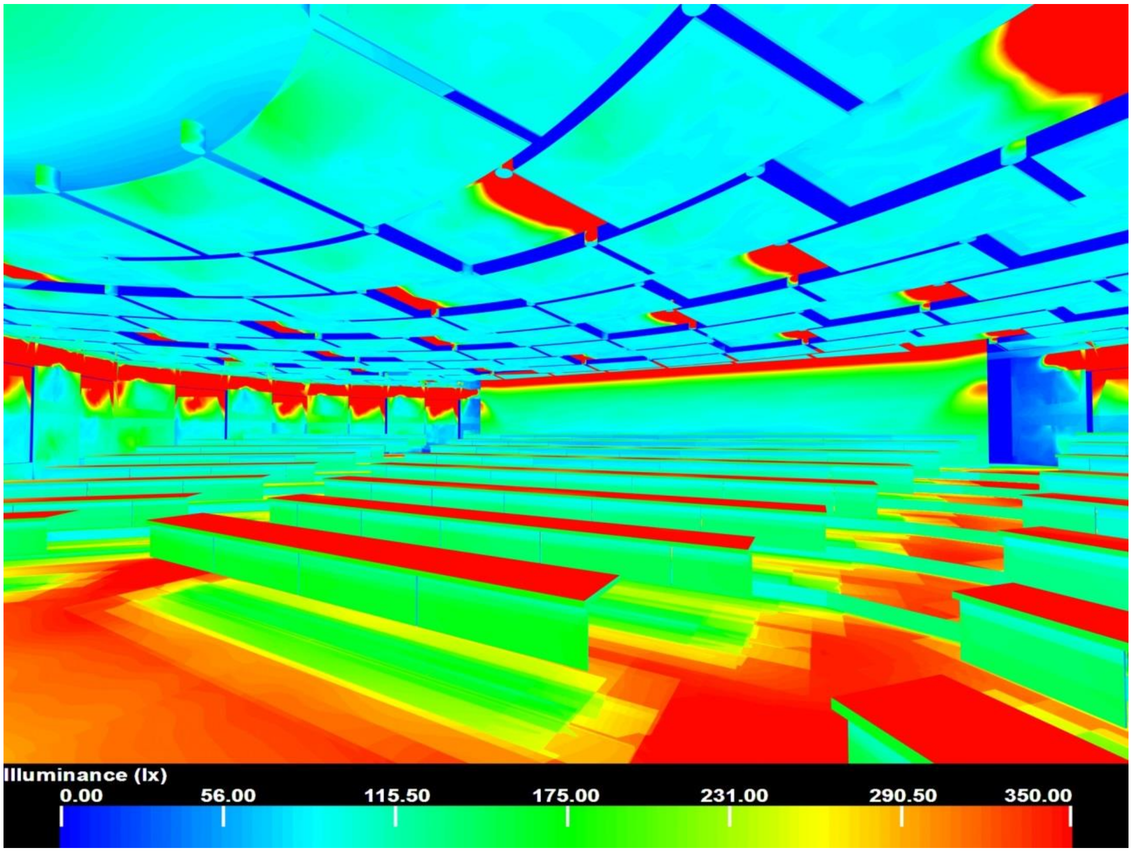
CALCULATION SUMMARY

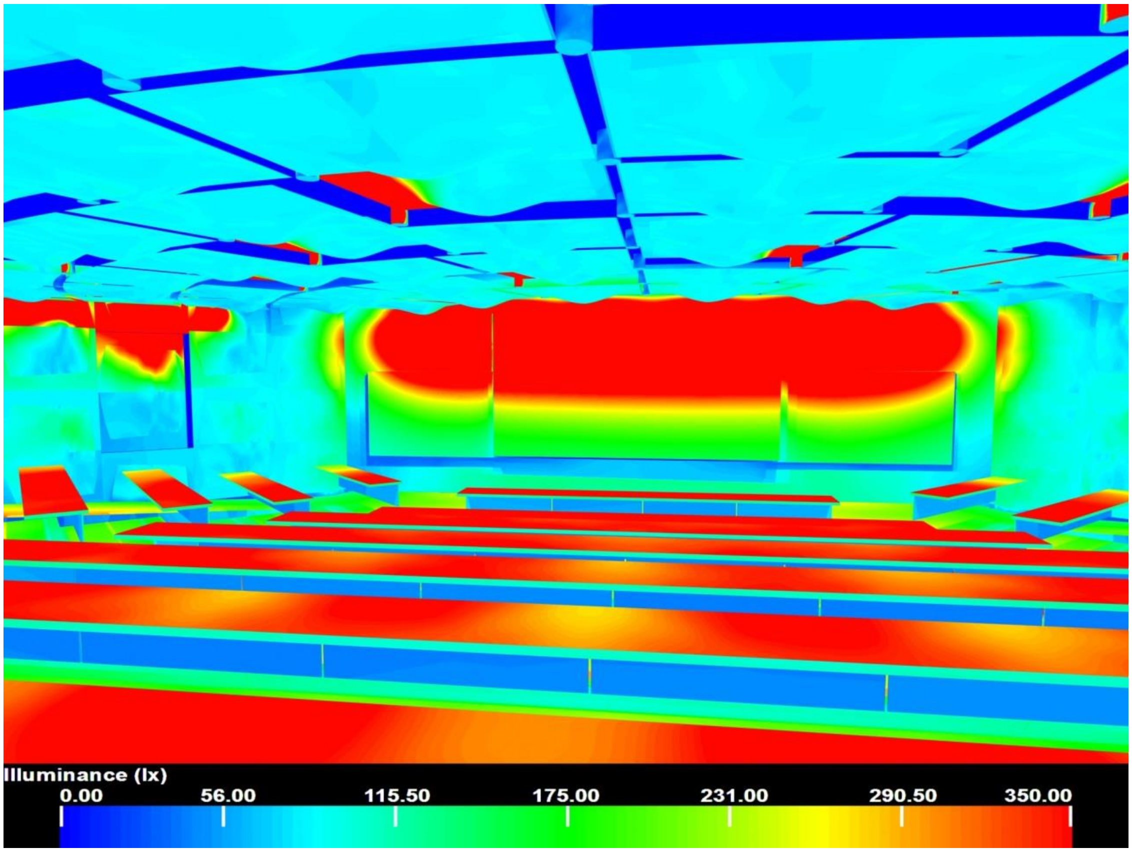
Illuminance levels for several lighting scenes are reported below.

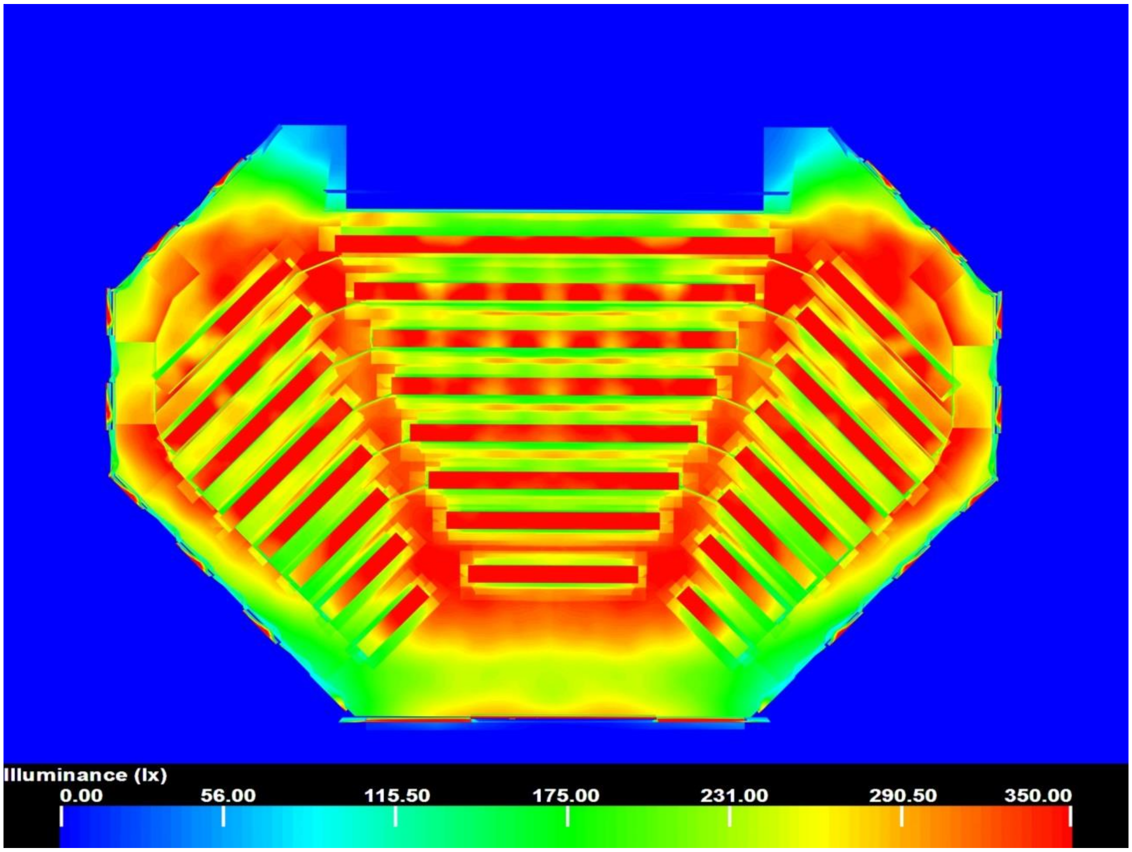
Lecture Hall Illuminance Criteria: Recommended vs. Designed					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Set	Quantity	Recommended	Achieved	Recommended	Achieved
Table (General)	Average	200	330	--	--
	Avg/Min	2:1	1.1:1	--	--
Chalkboard	Average	--	--	400	260
	Avg/Min	--	--	--	--
Table (AV)	Average	50	55	--	--
	Avg/Min	2:1	1.3:1	--	--
Screen	Average	--	--	10	12
	Avg/Min	--	--	--	--
Faces	Average	--	--	200	215
	Avg/Min	--	--	--	--

General Lighting Mode

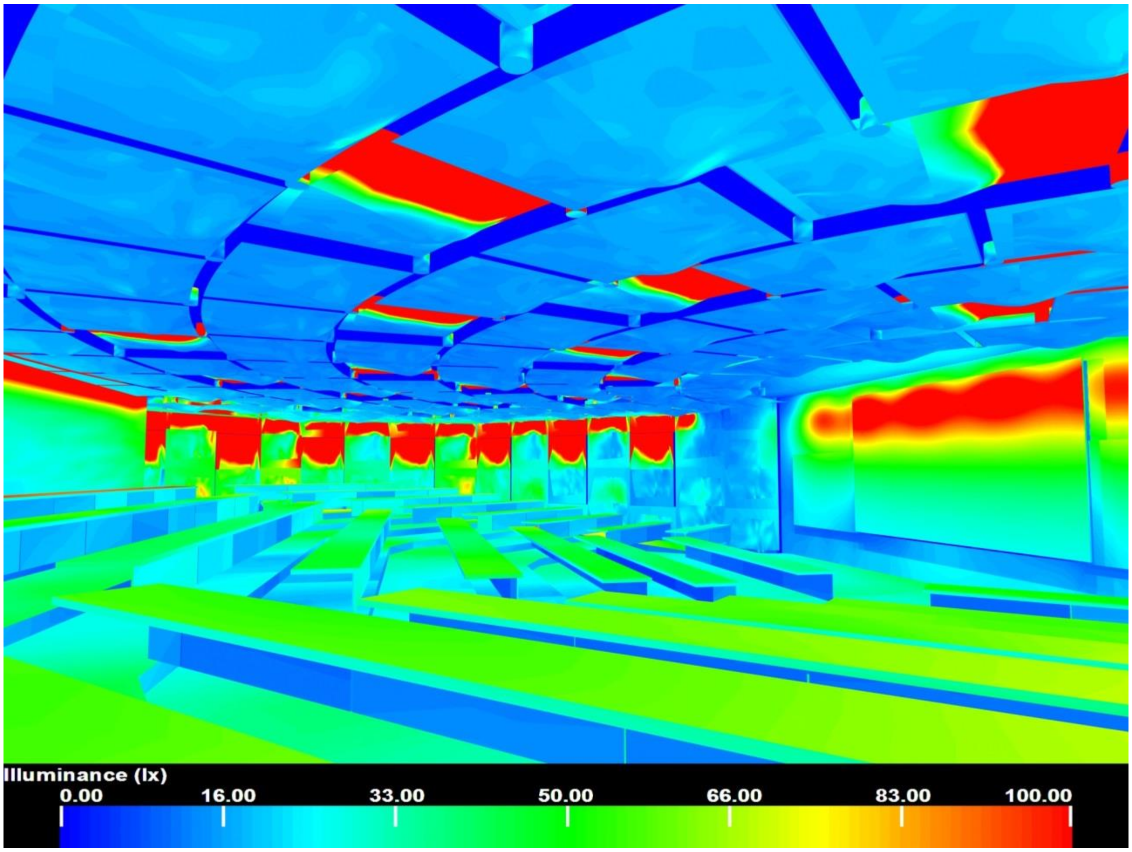


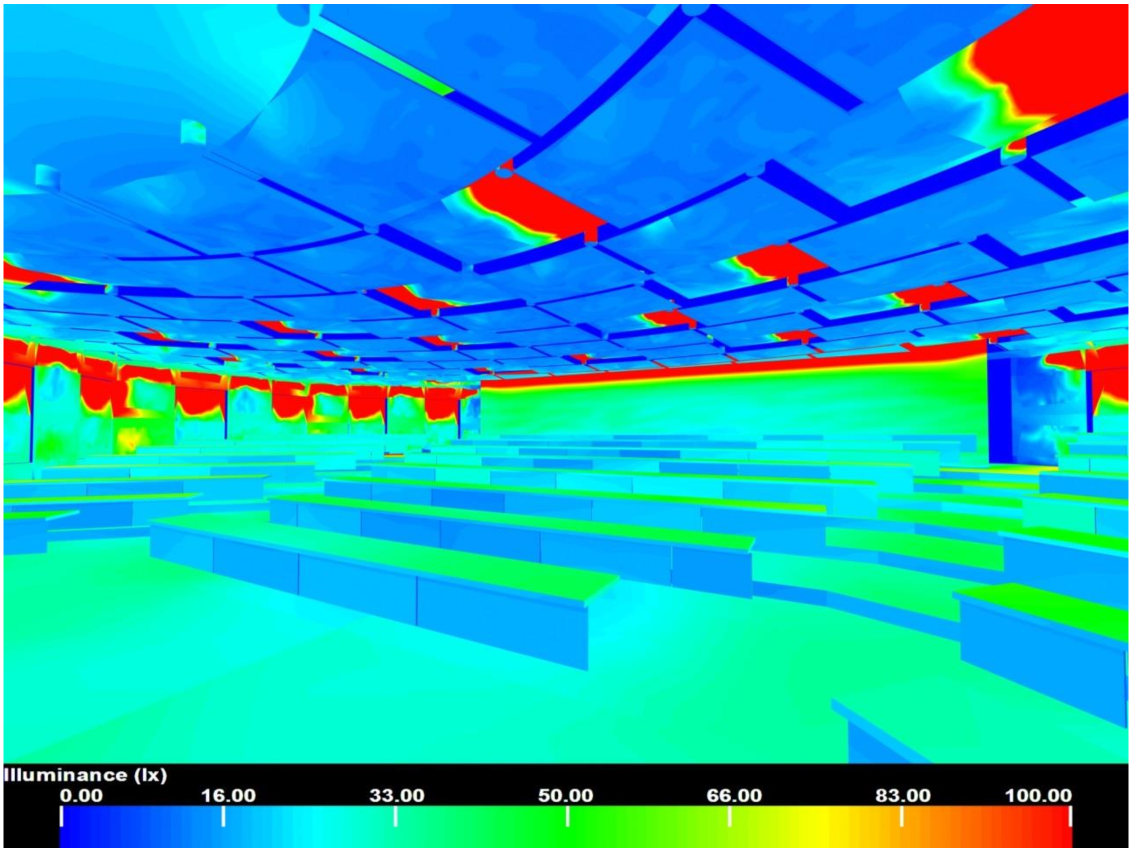


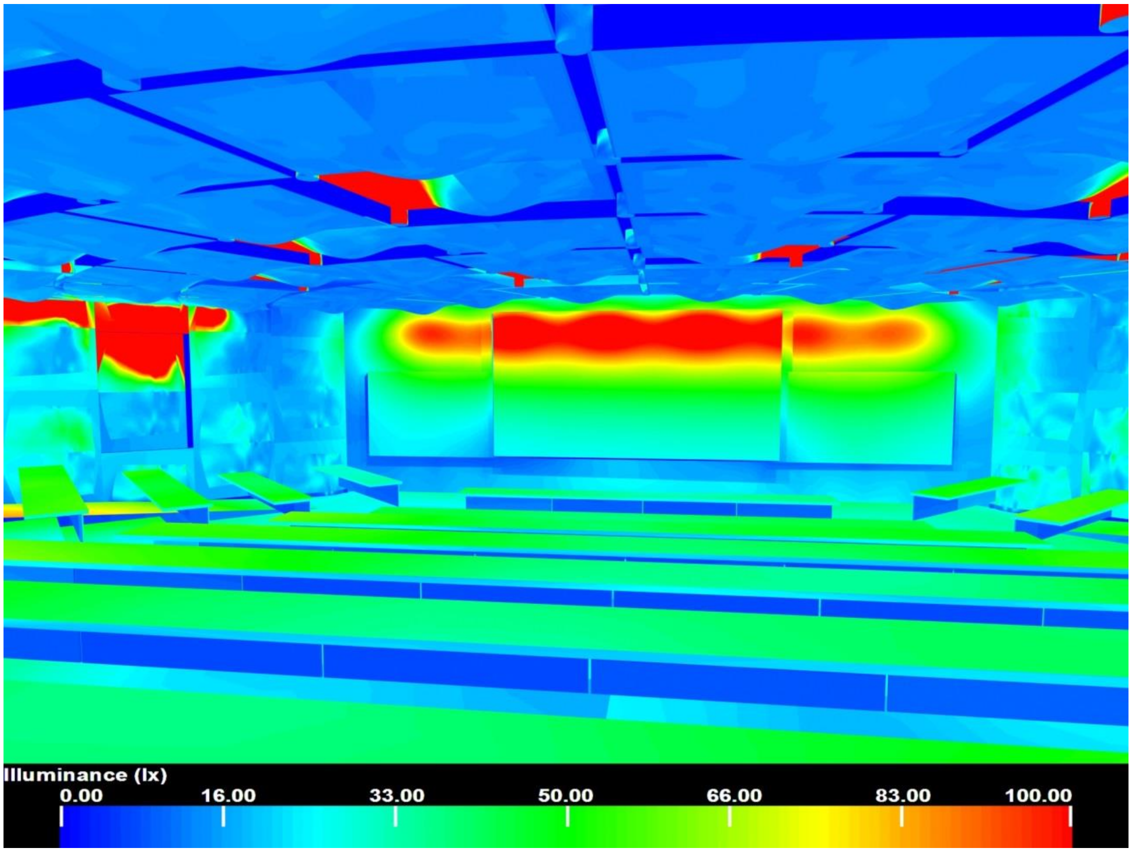

Illuminance (lx)
0.00
56.00
115.50
175.00
231.00
290.50
350.00

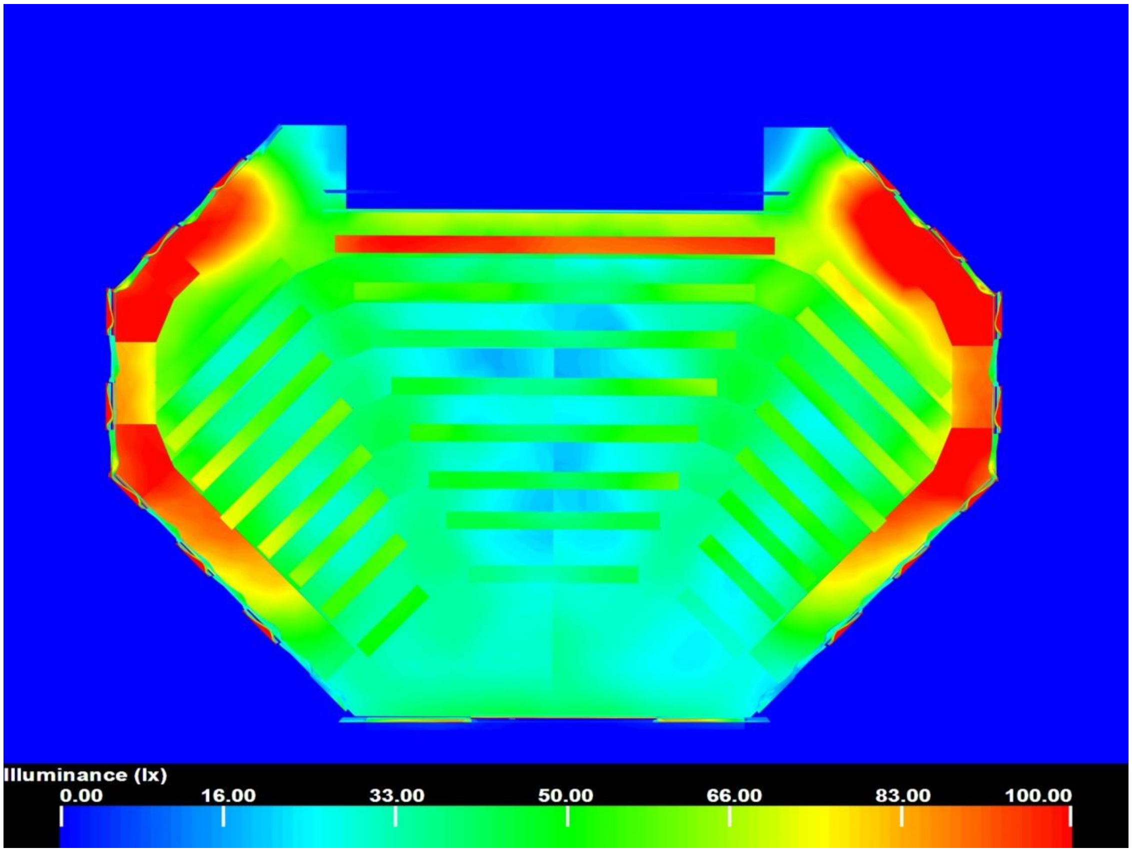

Illuminance (lx)
0.00
56.00
115.50
175.00
231.00
290.50
350.00

A/V Mode

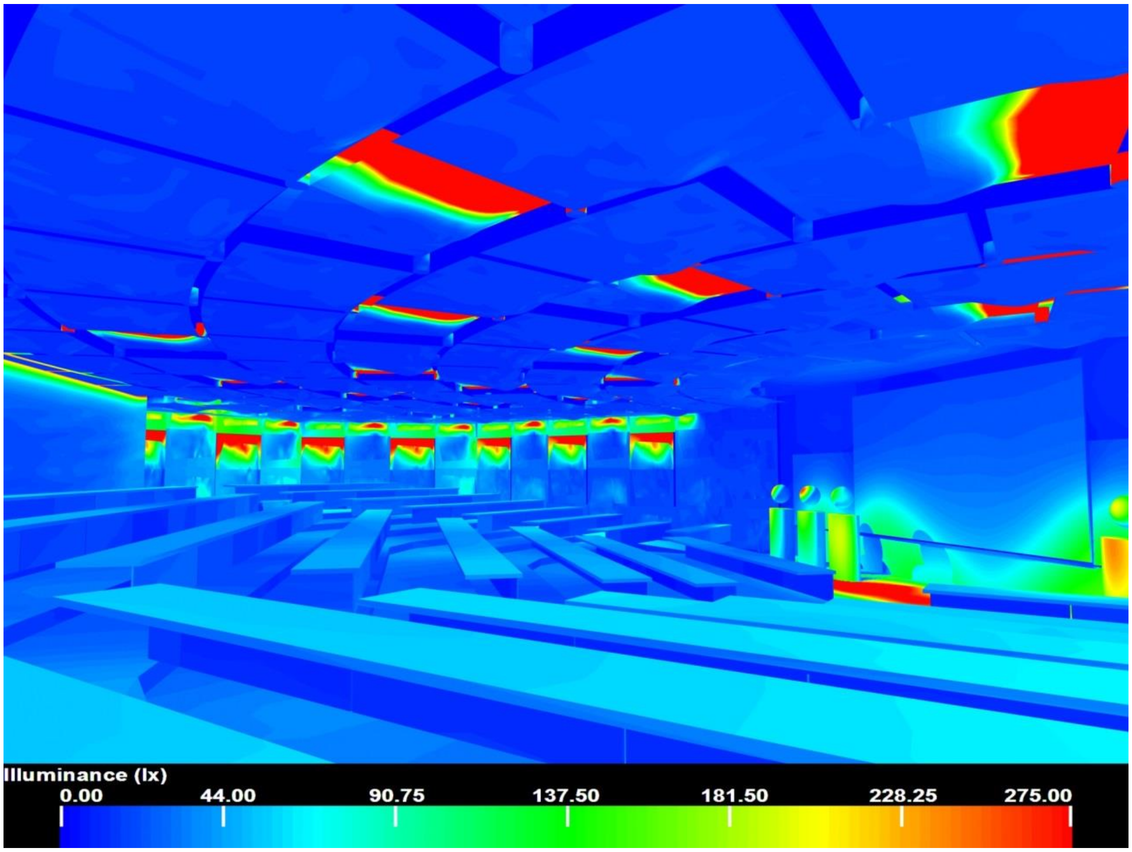

Illuminance (lx)
0.00
16.00
33.00
50.00
66.00
83.00
100.00

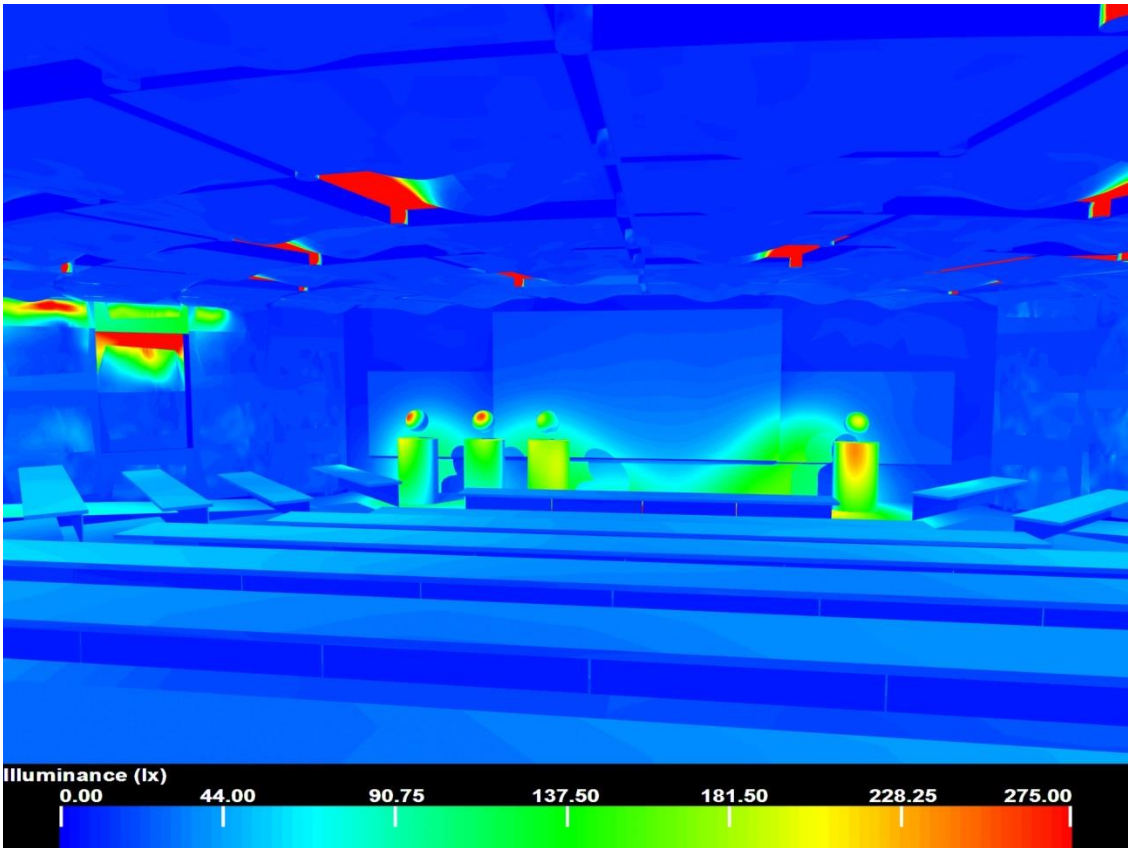

Illuminance (lx)
0.00
16.00
33.00
50.00
66.00
83.00
100.00

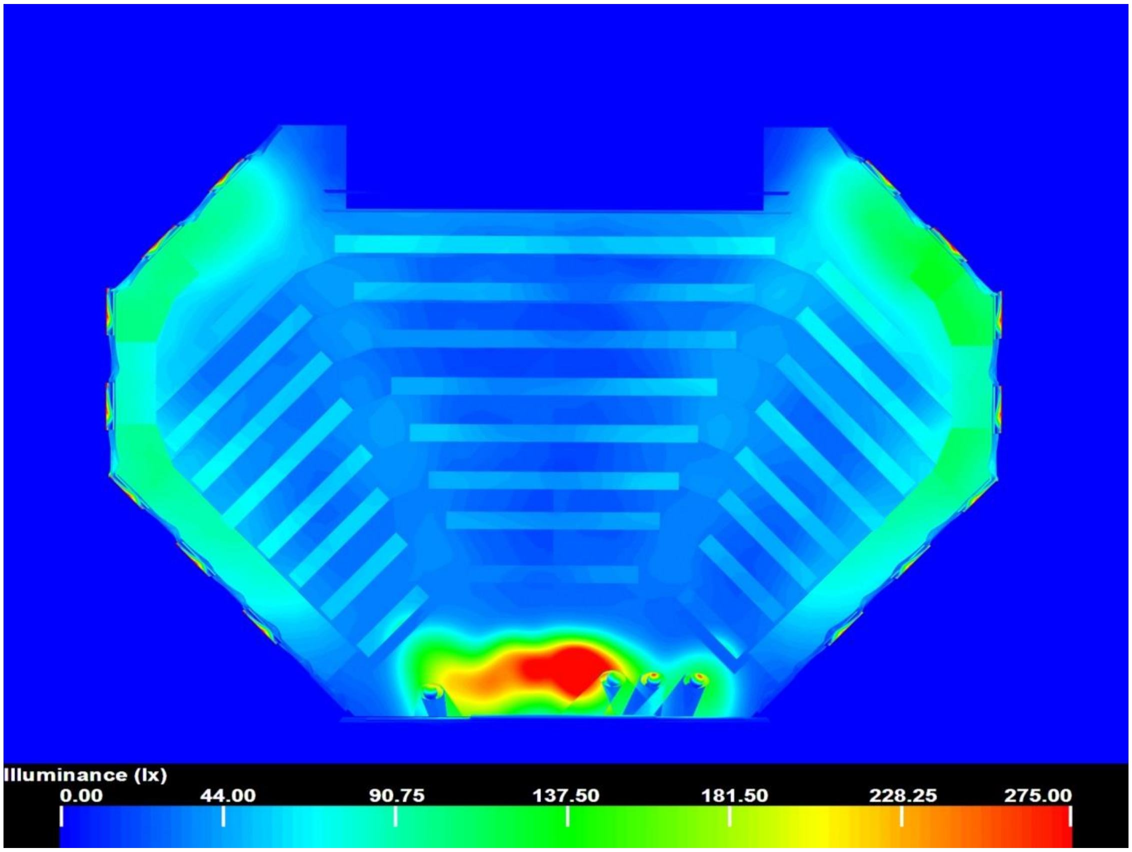

Illuminance (lx)
0.00
16.00
33.00
50.00
66.00
83.00
100.00


Illuminance (lx)
0.00
16.00
33.00
50.00
66.00
83.00
100.00

Presenter/Speaker Mode







EVALUATION

SUMMARY

Overall, by combining different aspects of three schematic designs for this space, the lighting ultimately helps to create a productive, interesting, and flexible lecture hall. Functional task lighting for reading and writing is achieved with 315 lux at the workplane; this is higher than the IES recommended value but warranted for visual uniformity. A lower light level would have meant pools of light across the desks.

Track lighting produces 215 lux on presenters' faces (recommended 200 lux) while limiting harsh shadows. Front wall washers light the chalkboard to 260 lux whereas the recommended average vertical illuminance is 400 lux. Here, the lighting could use improvement, perhaps a localized chalkboard light. For the purposes of the lighting concept, fixtures are mostly hidden and so the proposed design provides functional light but not quite enough. This is a challenging part of the room and warrants further investigation.

Several scene controls make the space responsive to a user's needs. The presentation mode provides a comfortable average 50 lux on the horizontal workplane (desks). This can actually be achieved using either the cove lighting (considered decorative) or the downlights. Downlights have integral dimming capabilities to adjust the light levels as needed. In dimming mode with front lights off, the projection screen is lit to only 12 lux, nearly meeting IES recommendations (10 lux). The periphery remains illuminated for safety and comfort.

Glare control is addressed by integrating the fixtures within the architecture. The downlights have a SoftGlow finish to limit direct glare and are placed between ceiling panels to complement the architectural narrative. Group relamping concerns are mitigated by specifying a similar overhead fixture throughout the whole space and identical 54 watt T5 lamps in the two fluorescent fixtures.

ASHRAE/IESNA 90.1

A 16% improvement of energy use over the ASHRAE/IES Standard 90.1 – 2010 is achieved with the proposed solution. By treating the reveal ceiling (F3) and wall fixtures (L3) as decorative fixtures (1640 watts consumed for 3200 watts available), the lecture hall utilizes 3311 watts overall. Other ASHRAE requirements are met by utilizing scene and user control. Most of the energy savings is due to the use of LED fixtures. Specifying these fixtures warrants careful consideration of color rendering, color constancy, and flicker. These issues are addressed by choosing higher-end fixtures and LED manufacturers.

Energy Consumption (ASHRAE/IESNA 90.1 – 2010) – Lecture Hall		
Category	Allowable	Calculated
Area (SF)	-	3200
Input Wattage	3968	3311
Power Density (W/SF)	1.24	1.04

Appendix E provides a detailed COMCHECK report of the mentioned lecture hall lighting design.

ELECTRICAL DESIGN DEPTH + BREADTHS

ELECTRICAL **DEPTH + BREADTHS**

The following section of the report includes prevalent electrical systems calculations and depth analysis. Deliverables include updated panelboards as affected by the new lighting solution, considerations of emergency lighting, a short circuit current calculation for one branch of the one-line diagram, and alternate transformer cost analysis and evaluation.

Introduction

Four Lighting Spaces

Effected Panelboards

Electrical Information

Fixture Layout

Existing Panelboard Schedules

Revised Panelboard Schedules

Emergency Lighting Renderings

Resized Feeder Calculations

Short Circuit Analysis

Depth Topic | Transformer Analysis

Existing System

Proposed Change + Goals

Methodology

Evaluation

INTRODUCTION

FOUR LIGHTING SPACES

The lighting solution addresses four spaces within the NBS Building: the scrim, lobby/lounge, large classroom, and lecture hall. Likewise, it is a goal of the lighting solution to meet energy requirements as mandated by code. The corresponding electrical system should meet the demands of the new lighting solution while minimizing the energy use of the design. In this report, ANSI/ASHRAE/IESNA Standard 90.1 Space-by-Space method is used to quantify the lighting power density of each space.

Furthermore, placing the lighting solution on the appropriate panelboards at the correct capacity will ensure a complete and compliant lighting design. The corresponding panelboard and branch circuits are sized based on the National Electrical Code 2011.

SCRIM

Driven by the over-arching concept of connection and integration through the biomimicry of a deciduous tree, the lighting of the southern scrim is a festive expression of the absence of daylight. The lighting adds visual drama to the NBS Building, signifying its importance and creating a unique nighttime character in response to the unique form of the architecture. The lighting is controlled using a time-schedule as to ensure lights are only used at night during the appropriate hours (sunset to 2 a.m.).

LOBBY/LOUNGE

Lighting in the lower lobby recalls ideas of uneven pressure and transitional pull: organic movement is established by creating a relaxing and pleasant environment, one that accentuates the architecture in a creative manner. Daylighting is a big part of the lighting control narrative; public lighting along the perimeter will be controlled using photosensors. Likewise, lighting behind the ceiling cavity can be shutoff during the day, allowing the ceiling to come alive at night. The space is controlled using a keyed switch and control system.

CLASSROOM

Perhaps the most flexible space, lighting in the classroom is uniform across the workplane by way of a uniquely symmetric lighting layout. Here, overhead lighting must be flexible and responsive to several different variables: north diffuse daylight, occupancy presence, and various lighting scenes (reading/writing, presentation, TV, etc.)

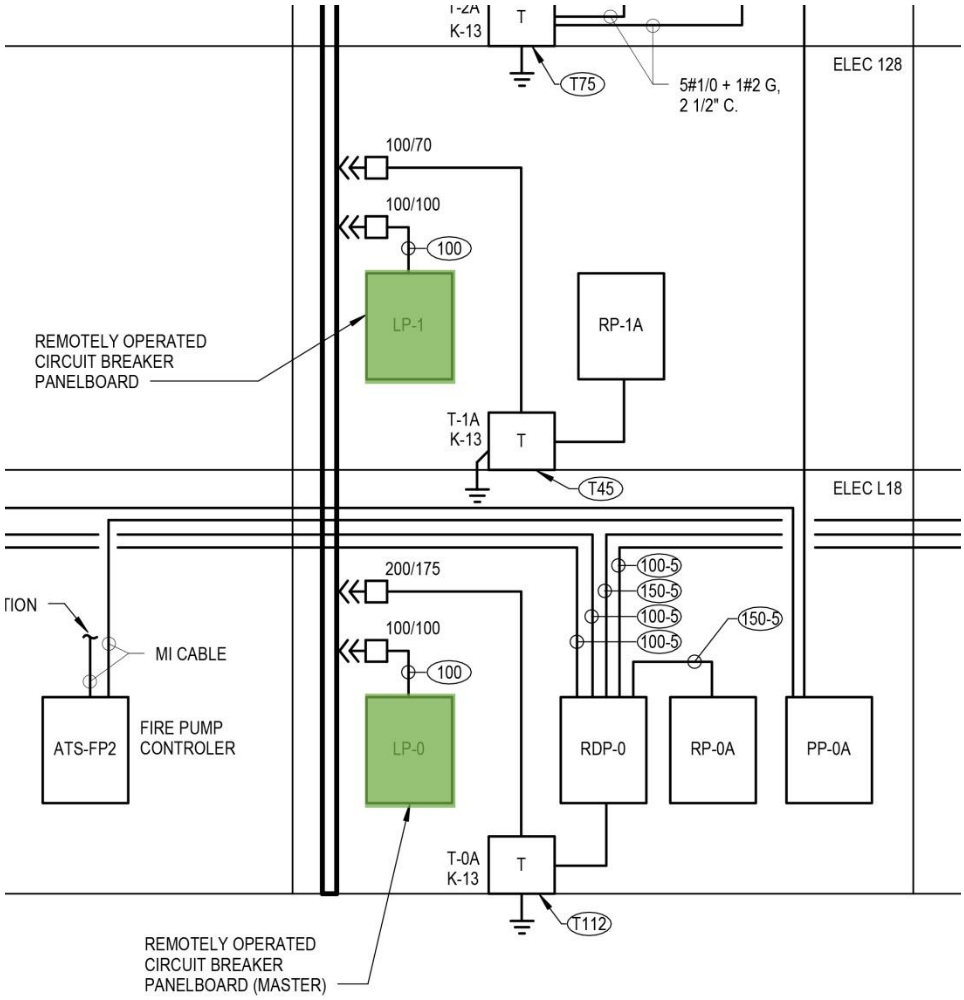
LECTURE HALL

Complimentary of the architectural sense, the lighting in the lecture hall is functional yet creative: the lecture hall becomes a germinated tree root, expanding from the central root and branching out to other cells. Important lighting criteria include limited glare, effective illuminance levels and uniformity, and flexibility. The lighting solution is responsive to the needs of the user, controlled with several scene controls. Multiple layers of light provide functional task light, necessary vertical illuminance, and a decorative expression: this space is certainly the most complex electrically.

EFFECTED PANELBOARDS

The new lighting design affects three panelboards in the NBS Building: LP-0, LP-1, and LP-LS1. All of these are 480/277V, 3PH, 4 wire panelboards. LP-0 and LP-1 are remotely operated circuit breakers (MLO type) while the emergency panelboard LP-LS1 is MCB.

LP-0 services the lecture hall and outdoor lighting (scrim, site, theatrical fixtures). LP-1 services the lobby and classroom lighting. LP-LS1 services the lower, ground, and second floor emergency lighting.



ELECTRICAL INFORMATION

FIXTURE LAYOUT

Refer to Appendix D for wiring diagram and zoning. Reference Appendix E for a detailed COMFEN report of the lighting power densities.

EXISTING PANELBOARD SCHEDULES

The following three panelboard schedules display the existing lighting design and corresponding electrical system. Highlighted in **yellow** are the circuits which will be replaced with the new lighting solution. Using the existing lighting fixture schedule, the appropriate existing VA for each circuit is replaced with the new VA value as defined by the proposed lighting solution.

Panelboard: LP-0

Location: ELEC L18
Supply From: BUS DUCT
Mounting Surface
Enclosure: Type 1

Volts: 480Y/277V
Phases: 3
Wires: 4
Neutral Rating: 100%

A.I.C. Rating: 35,000
Mains Type: MLO
Bus Rating: 100 A

CKT	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	CKT
1	STERILIZER - INSTRUC. CLASS LABS PREP SPACE L06C	50 A	3	10000...	1620...					1	20 A	(EO) LIGHTING - EXTERIOR POLES	2
3						10000...	953 VA			1	20 A	(EO) GENERAL LIGHTING - LOWER LEVEL	4
5								10000...	1640...	1	20 A	(EO) DECORATIVE LIGHTING - LOWER LEVEL	6
7	LIGHTING - L11, L12, L13	20 A	1	2912...	0 VA					1	20 A	(EO) SPARE	8
9	LIGHTING - L05, L06A, L06B, L06C, L07A, L08, ...	20 A	1			1245...	0 VA			1	20 A	(EO) SPARE	10
11	LIGHTING - L40, L50, L59, L54, L51, L41, L52, L53	20 A	1					1200...	0 VA	1	20 A	SPARE	12
13	LIGHTING - L59, L57, L56, L55	20 A	1	2491...	0 VA					1	20 A	SPARE	14
15	LIGHTING - LECTURE HALL L01	20 A	1			2140...	0 VA			1	20 A	SPARE	16
17	LIGHTING - L16A, L17A, L16B, L17B, L14, L15	20 A	1					441 VA	0 VA	1	20 A	SPARE	18
19	SPARE	20 A	1	0 VA	0 VA					1	20 A	SPARE	20
21	SPARE	--	--			0 VA	0 VA			--	--	SPARE	22
23	SPARE	--	--					0 VA	0 VA	--	--	SPARE	24
25	SPARE	--	--	0 VA	0 VA					--	--	SPARE	26
27	SPARE	--	--			0 VA	0 VA			--	--	SPARE	28
29	SPARE	--	--					0 VA	0 VA	--	--	SPARE	30
		Total Load:		17023 VA		14338 VA		13281 VA					
		Total Amps:		62 A		52 A		48 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Equipment	30000 VA	100.00%	30000 VA		
Lighting	14642 VA	100.00%	14642 VA	Total Conn. Load:	44642 VA
Power	0 VA	0.00%	0 VA	Total Est. Demand:	44642 VA
				Total Conn:	54 A
				Total Est. Demand:	54 A

Panelboard: LP-1

Location: ELEC 128
Supply From: BUS DUCT
Mounting Surface
Enclosure: Type 1

Volts: 480Y/277V
Phases: 3
Wires: 4
Neutral Rating: 100%

A.I.C. Rating: 35,000
Mains Type: MLO
Bus Rating: 100 A

CKT	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	CKT
1	LIGHTING - ROOM 101-104, 106, 108-110	20 A	1	1801...	128 VA					1	20 A	(EO) LIGHITNG - GLASS SIGNAGE	2
3	LIGHTING - ROOM 111, 125	20 A	1			1829...	1817...			1	20 A	(EO) LIGHTING - SOUTH FAÇADE	4
5	LIGHTING - ROOM 120, 130, 127, 122-124, 140, 141	20 A	1					1192...	1060...	1	20 A	(EO) LIGHTING - GROUND LEVEL LOBBY/CORRIDOR	6
7	PHOTOCELL POWER; SENSING CKT FOR GTDs	20 A	1	0 AV	4640...					1	20 A	(EO) DECORATIVE LIGHTING - GROUND LOBBY	8
9	SPARE	20 A	1			0 VA	0 VA			1	20 A	(EO) SPARE	10
11	SPARE	20 A	1					0 VA	0 VA	1	20 A	(EO) SPARE	12
13	SPARE	20 A	1	0 VA	0 VA					1	20 A	(EO) SPARE	14
15	SPARE	20 A	1			0 VA	0 VA			1	20 A	(EO) SPARE	16
17	SPARE	--	--					0 VA	0 VA	--	--	SPARE	18
19	SPARE	--	--	0 VA	0 VA					--	--	SPARE	20
21	SPARE	--	--			0 VA	0 VA			--	--	SPARE	22
23	SPARE	--	--					0 VA	0 VA	--	--	SPARE	24
25	SPARE	--	--	0 VA	0 VA					--	--	SPARE	26
27	SPARE	--	--			0 VA	0 VA			--	--	SPARE	28
29	SPARE	--	--					0 VA	0 VA	--	--	SPARE	30
		Total Load:		6569 VA		3646 VA		2252 VA					
		Total Amps:		24 A		14 A		8 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Lighting	12467 VA	100.00%	12467 VA		
				Total Conn. Load:	12467 VA
				Total Est. Demand:	12467 VA
				Total Conn:	15 A
				Total Est. Demand:	15 A

Panelboard: LP-LS1

Location:	ELEC 128	Volts:	480Y/277V	A.I.C. Rating:	14,000
Supply From:	LP-LS4	Phases:	3	Mains Type:	MCB
Mounting	Surface	Wires:	4	Bus Rating:	100 A
Enclosure:	Type 1	Neutral Rating:	100%	MCB Rating:	50 A

CKT	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	CKT
1	T-LS1	30 A	1	100 VA	1072...					1	20 A	LIFE SAFETY - LOWER LEVEL	2
3			1			964 VA	842 VA			1	20 A	LIFE SAFETY - GROUND LEVEL	4
5			1					100 VA	740 VA	1	20 A	LIFE SAFETY - SECOND LEVEL	6
7	SPARE	20 A	1	0 AV	0 VA					1	20 A	SPARE	8
9	SPARE	20 A	1			0 VA	0 VA			1	20 A	SPARE	10
11	SPARE	20 A	1					0 VA	0 VA	1	20 A	SPARE	12
13	SPARE	20 A	1	0 VA	0 VA					1	20 A	SPARE	14
15	SPARE	20 A	1			0 VA	0 VA			1	20 A	SPARE	16
17	SPARE	--	--					0 VA	0 VA	--	--	SPARE	18
		Total Load:		1172 VA		1806 VA		840 VA					
		Total Amps:		4 A		7 A		3 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Lighting	2654 VA	100.00%	2654 VA		
Power	300 VA	100.00%	300 VA	Total Conn. Load:	3818 VA
Mechanical Equipment	864 VA	80.00%	691 VA	Total Est. Demand:	3645 VA
				Total Conn:	5 A
				Total Est. Demand:	5 A

REVISED PANELBOARD SCHEDULES

The following two panelboard schedules display the new lighting design and corresponding electrical system. All lighting circuits are kept under 20A. All lighting is 277V. A continuous load factor (0.8) and future added load factor (0.8) is applied. VA values with * signify decorative lighting.

$$Allowable\ volt - amps\ per\ circuit = 277V * 20A * 0.8 * 0.8 = \mathbf{3545.6\ VA}$$

Fixture Calculations								
Space	Type	Lamp	Quant.	W/fixtures	PF	VA/fixture	Total VA	Circuit
Scrim	L9	LED	10	100	1	100	1000	LP-0-10
	L10	LED	17	145	1	145	2465	LP-0-8
	S1	LED	11	55	1	55	605	LP-0-2
Lobby/Lounge	F1	28W T5	26	32	1	32	832*	LP-1-8
	L1	LED	1	72	1	72	72	LP-1-10
	L2	LED	12	29	1	29	348	LP-1-10
	L3	LED	4	22.9	1	22.9	91.6	LP-1-10
	L4	LED	11	36	1	36	396	LP-1-10
	L5	LED	1	57	1	57	57	LP-1-10
	L11	LED	5	4.8	1	4.8	24	LP-1-10
EL - Lobby	L2	LED	6	29	1	29	174	LP-LS1-4
	L4	LED	2	36	1	36	72	LP-LS1-4

Classroom	F1	28W T5	36	32	1	32	1152	LP-1-3
Lecture Hall	F3	54W T5	22	61	1	61	1342*	LP-0-15
	F4	54W T5	6	61	1	61	366	LP-0-12
	L3	LED	13	22.9	1	22.9	297.7*	LP-0-15
	L6	LED	7	12	1	12	84	LP-0-12
	L7	LED	50	14	1	14	700	LP-0-12
	L8	LED	11	29	1	29	319	LP-0-12
	L8A	LED	30	39	1	39	1170	LP-0-12
EL - Lecture Hall	L7	LED	48	14	1	14	672	LP-LS1-2

The above calculations are used to place the lighting on the correct panelboard and circuit. Loads were placed as best as possible to balance three phases; if to be constructed, it would be noted for electrician to balance panelboard with 10% difference between phases.

Panelboard: LP-0 (Revised)

Location: ELEC L18	Volts: 480Y/277V	A.I.C. Rating: 35,000
Supply From: BUS DUCT	Phases: 3	Mains Type: MLO
Mounting Surface	Wires: 4	Bus Rating: 100 A
Enclosure: Type 1	Neutral Rating: 100%	

CKT	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	CKT
1	STERILIZER - INSTRUC. CLASS LABS PREP SPACE L06C	50 A	3	10000...	1620...					1	20 A	(EO) LIGHTING - EXTERIOR POLES	2
3						10000...	953 VA			1	20 A	(EO) GENERAL LIGHTING - LOWER LEVEL	4
5								10000...	1640...	1	20 A	(EO) DECORATIVE LIGHTING - LOWER LEVEL	6
7	LIGHTING - L11, L12, L13	20 A	1	2912...	2465...					1	20 A	(EO) LIGHTING - SOUTH SUNSCREEN	8
9	LIGHTING - L05, L06A, L06B, L06C, L07A, L08, ...	20 A	1			1245...	1000...			1	20 A	(EO) LIGHTING - OUTDOOR THEATERICAL	10
11	LIGHTING - L40, L50, L59, L54, L51, L41, L52, L53	20 A	1					1200...	2639...	1	20 A	LIGHTING - LECTURE HALL L01	12
13	LIGHTING - L59, L57, L56, L55	20 A	1	2491...	0 VA					1	20 A	SPARE	14
15	DECORATIVE LIGHTING - LECTURE HALL L01	20 A	1			1640...	0 VA			1	20 A	SPARE	16
17	LIGHTING - L16A, L17A, L16B, L17B, L14, L15	20 A	1					441 VA	0 VA	1	20 A	SPARE	18
19	SPARE	20 A	1	0 VA	0 VA					1	20 A	SPARE	20
21	SPARE	--	--			0 VA	0 VA			--	--	SPARE	22
23	SPARE	--	--					0 VA	0 VA	--	--	SPARE	24
25	SPARE	--	--	0 VA	0 VA					--	--	SPARE	26
27	SPARE	--	--			0 VA	0 VA			--	--	SPARE	28
29	SPARE	--	--					0 VA	0 VA	--	--	SPARE	30
		Total Load:		19488 VA		14838 VA		15920 VA					
		Total Amps:		70 A		54 A		57 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Equipment	30000 VA	100.00%	30000 VA		
Lighting	20246 VA	100.00%	20246 VA	Total Conn. Load:	50246 VA
Power	0 VA	0.00%	0 VA	Total Est. Demand:	50246 VA
				Total Conn:	60.4 VA
				Total Est. Demand:	60.4 VA

Panelboard: LP-1 (Revised)

Location:	ELEC 128	Volts:	480Y/277V	A.I.C. Rating:	35,000
Supply From:	BUS DUCT	Phases:	3	Mains Type:	MLO
Mounting	Surface	Wires:	4	Bus Rating:	100 A
Enclosure:	Type 1	Neutral Rating:	100%		

CKT	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	CKT
1	LIGHTING - ROOM 101-104, 106, 108-110	20 A	1	1801…	128 VA					1	20 A	(EO) LIGHITNG - GLASS SIGNAGE	2
3	LIGHTING - ROOM 111, 125	20 A	1			1211…	1817…			1	20 A	(EO) LIGHTING - SOUTH FAÇADE	4
5	LIGHTING - ROOM 120, 130, 127, 122-124, 140, 141	20 A	1					1192…	420 VA	1	20 A	(EO) LIGHTING - GROUND LEVEL CORRIDOR	6
7	PHOTOCELL POWER; SENSING CKT FOR GTDs	20 A	1	0 AV	832 VA					1	20 A	(EO) DECORATIVE LIGHTING - GROUND LOBBY	8
9	SPARE	20 A	1			0 VA	989 VA			1	20 A	(EO) LIGHTING - GROUND LEVEL LOBBY/LOUNGE	10
11	SPARE	20 A	1					0 VA	0 VA	1	20 A	(EO) SPARE	12
13	SPARE	20 A	1	0 VA	0 VA					1	20 A	(EO) SPARE	14
15	SPARE	20 A	1			0 VA	0 VA			1	20 A	(EO) SPARE	16
17	SPARE	--	--					0 VA	0 VA	--	--	SPARE	18
19	SPARE	--	--	0 VA	0 VA					--	--	SPARE	20
21	SPARE	--	--			0 VA	0 VA			--	--	SPARE	22
23	SPARE	--	--					0 VA	0 VA	--	--	SPARE	24
25	SPARE	--	--	0 VA	0 VA					--	--	SPARE	26
27	SPARE	--	--			0 VA	0 VA			--	--	SPARE	28
29	SPARE	--	--					0 VA	0 VA	--	--	SPARE	30
		Total Load:		2761 VA		4017 VA		1612 VA					
		Total Amps:		10 A		15 A		6 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Lighting	8390 VA	100.00%	8390 VA		
				Total Conn. Load:	8390 VA
				Total Est. Demand:	8390 VA
				Total Conn:	10.1 A
				Total Est. Demand:	10.1 A

Panelboard: LP-LS1 (Revised)

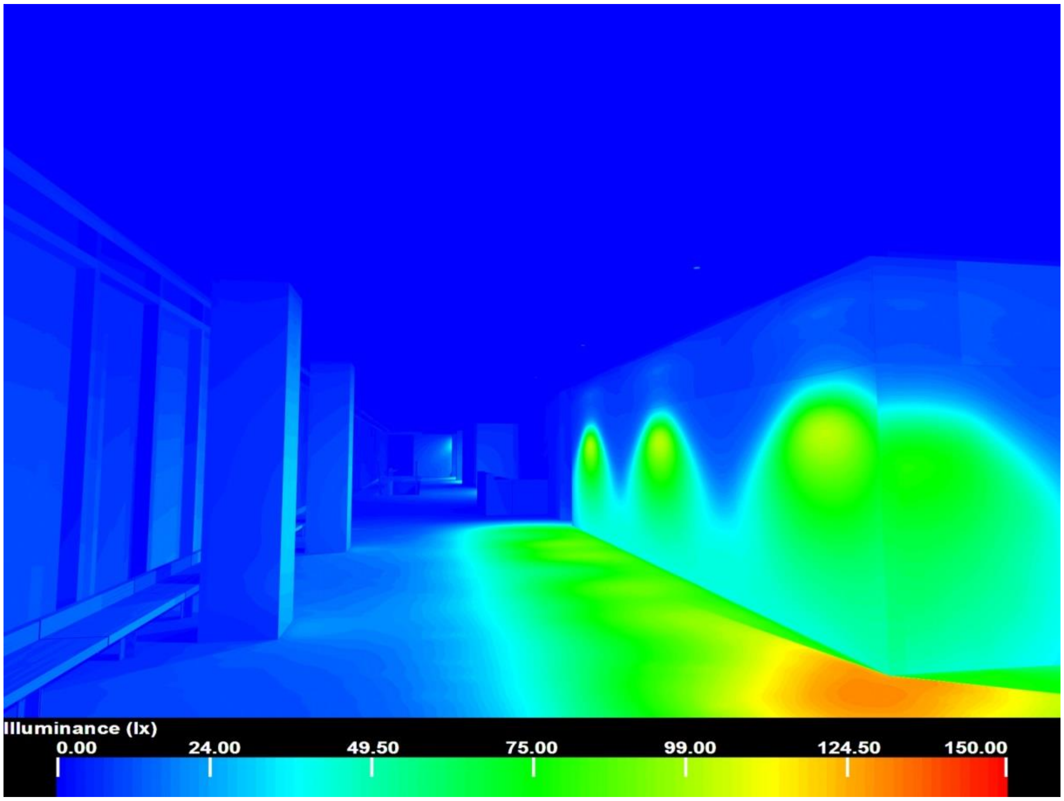
Location:	ELEC 128	Volts:	480Y/277V	A.I.C. Rating:	14,000
Supply From:	LP-LS4	Phases:	3	Mains Type:	MCB
Mounting	Surface	Wires:	4	Bus Rating:	100 A
Enclosure:	Type 1	Neutral Rating:	100%	MCB Rating:	50 A

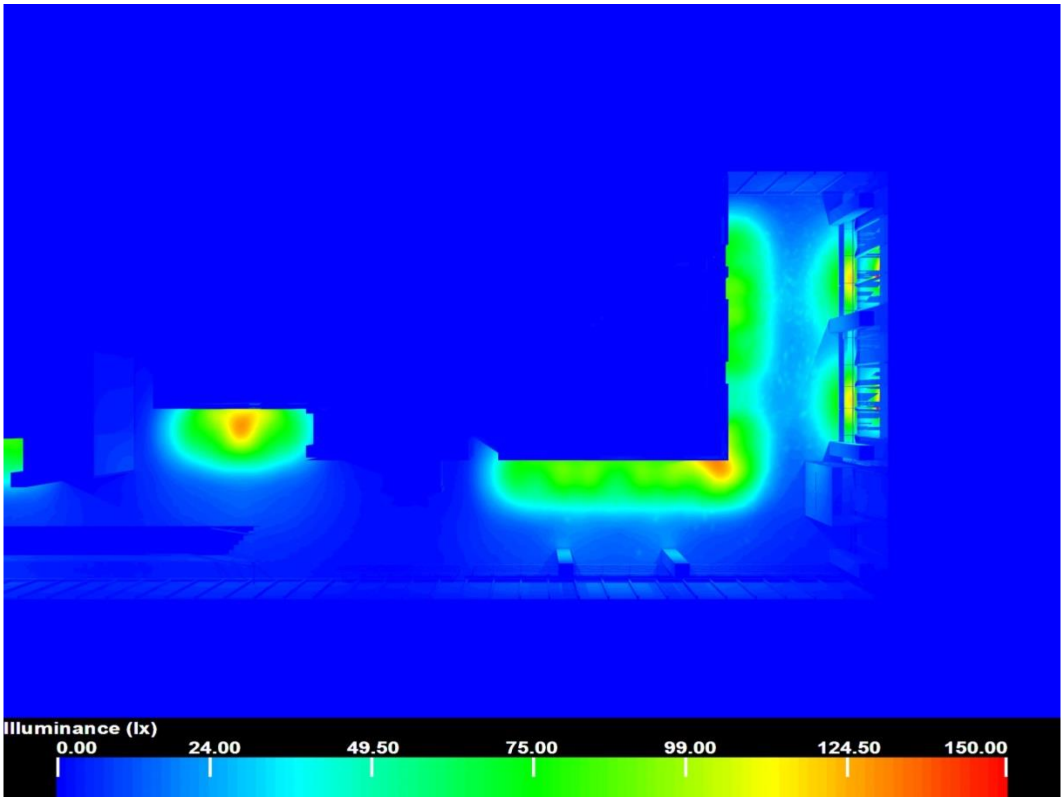
CKT	Circuit Description	Trip	Poles	A		B		C		Poles	Trip	Circuit Description	CKT
1	T-LS1	30 A	1	100 VA	1114…					1	20 A	LIFE SAFETY - LOWER LEVEL	2
3			1			964 VA	928 VA			1	20 A	LIFE SAFETY - GROUND LEVEL	4
5			1					100 VA	740 VA	1	20 A	LIFE SAFETY - SECOND LEVEL	6
7	SPARE	20 A	1	0 AV	0 VA					1	20 A	SPARE	8
9	SPARE	20 A	1			0 VA	0 VA			1	20 A	SPARE	10
11	SPARE	20 A	1					0 VA	0 VA	1	20 A	SPARE	12
13	SPARE	20 A	1	0 VA	0 VA					1	20 A	SPARE	14
15	SPARE	20 A	1			0 VA	0 VA			1	20 A	SPARE	16
17	SPARE	--	--					0 VA	0 VA	--	--	SPARE	18
		Total Load:		1214 VA		1892 VA		840 VA					
		Total Amps:		4 A		7 A		3 A					

Load Classification	Connected Load	Demand Factor	Estimated Demand	Panel Totals	
Lighting	2782 VA	100.00%	2782 VA		
Power	300 VA	100.00%	300 VA	Total Conn. Load:	3946 VA
Mechanical Equipment	864 VA	80.00%	691 VA	Total Est. Demand:	3946 VA
				Total Conn:	4.7 A
				Total Est. Demand:	4.7 A

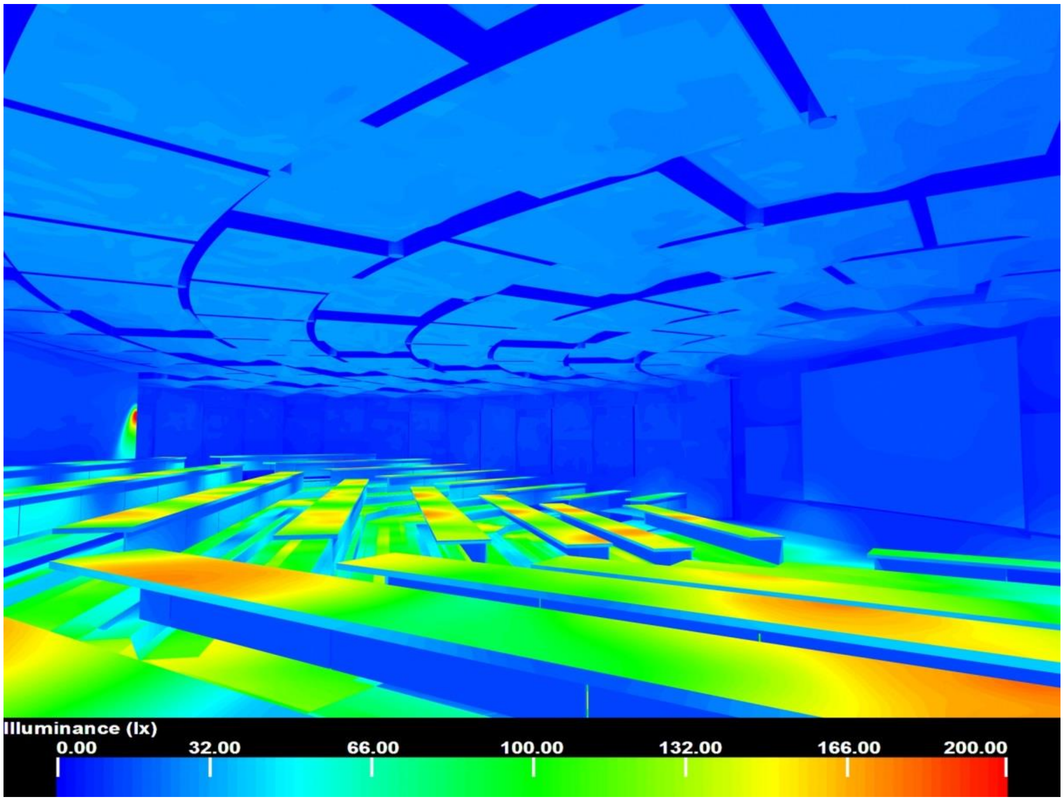
EMERGENCY LIGHTING RENDERINGS

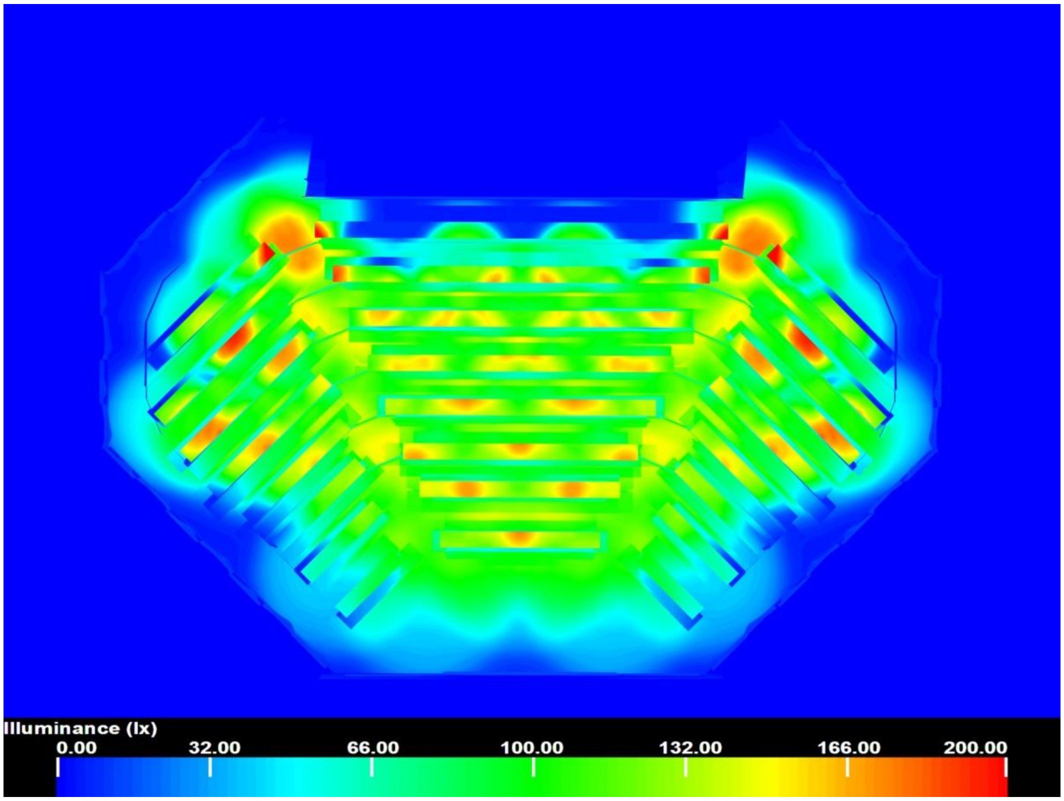
LOBBY/LOUNGE





LECTURE HALL


Illuminance (lx)
0.00
32.00
66.00
100.00
132.00
166.00
200.00

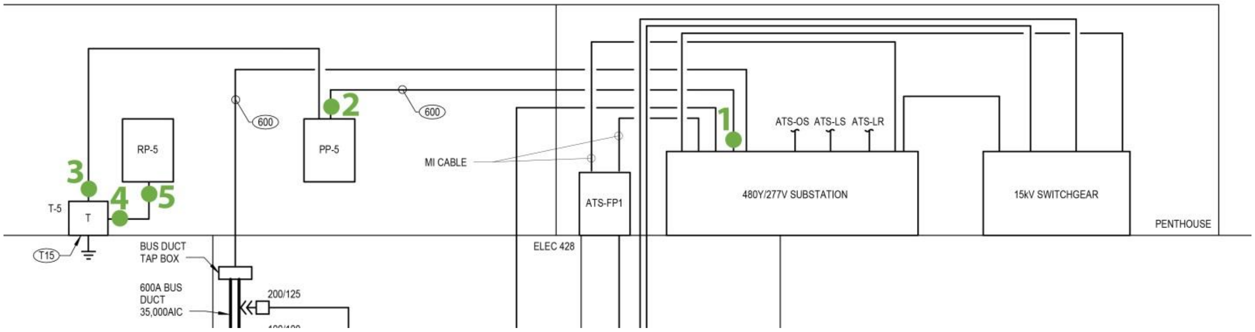

Illuminance (lx)
0.00
32.00
66.00
100.00
132.00
166.00
200.00

RESIZED FEEDER CALCULATIONS

Since all lighting is conservatively kept under 20A per circuit, all lighting branch circuits have 2#12+#12G in 2/3" conduit. Likewise, the new lighting solution does not increase the loads of any of the panelboards significantly. Importantly, feeders are generally sized to NEC *Table 220.12 General Lighting Loads by Occupancy*; since the new solution does not exceed these unit loads (VA/SF), feeders are sized properly as is.

SHORT CIRCUIT ANALYSIS

A point-to-point method short circuit analysis is completed for one branch of the existing one-line diagram. The calculations are shown below, assuming an infinite bus on transformer primary since power is supplied by campus (reference: Cooper Bussmann Short Circuit Current Calculations):



SHORT-CIRCUIT ANALYSIS															
Fault Point	Panel/Transformer	Source (Fault Point)	Source I (amps)	Conduit Type	Wire/Bus Size	Wire/Bus Type	'C' Value	E (volts)	L (ft)	XFMR (%Z)	Multiplier	I_{sc}	f	M	I_{sc}
1	1500 kVA XMRS	--	--	M	2 set 4 #350 kcmil	CU	19704	480	60	3.5	28.57	51542.9	0.2832	0.7793	**40168.48**
2	PP-5 (before)	1	40168.48	M	2 set 4 #350 kcmil	CU	19704	480	75	--	--	40168.5	0.2758	0.7838	**31483.77**
3	T-5 (before)	2	31483.77	M	1 set 3 #10	CU	981	480	12	--	--	31483.77	1.3897	0.4185	**13175.05**
4	T-5 (after)	3	13175.05	M	1 set 4 #4	CU	3806	208	--	2.0	--	13175.05	14.6043	0.0641	**844.32**
5	RP-5	4	844.32	M	1 set 4 #4	CU	3806	208	5	--	--	844.32	0.0107	0.9894	**835.41**

All corresponding electrical equipment have AIC ratings that exceeded the short-circuit calculations above—the design is sufficient.

DEPTH TOPIC | **TRANSFORMER ANALYSIS**

EXISTING SYSTEM

Since the NBS Building houses laboratory equipment, the electrical system is quite robust and reliable. In this regard, a main 15kV switchgear receives campus power at 13.2 kV which is first stepped-down with two unit-substation transformers rated at 1500 kVA. The 480/277V system is transferred throughout the building to various smaller low-voltage transformers on every floor. These smaller transformers then service the corresponding floor and panelboards. This setup introduces relatively more transformers within the building footprint.

PROPOSED CHANGE + GOALS

It is advantageous to consider changing all dry-type NEMA-TP1 Standard low-voltage distribution transformers to dry-type NEMA Premium transformers (higher energy efficiencies with added cost). In the same way, changing both unit-substation transformers from dry-type to vegetable-based liquid-filled is both cost effective and energy efficient. Given these parameters, several goals outline the electrical depth:

1. Compute payback period if all NEMA Standard distribution transformers are replaced with NEMA Premium distribution transformers.
2. Analyze if replacing dry-type unit-substation transformers (UST) with liquid-filled transformers is worth the added risk.

METHODOLOGY

Below the process used to determine simple payback period is outlined.

STEP 1

It is necessary to first understand the existing system. Referring to the one-line diagram, it is apparent that the electrical system uses several smaller distribution points instead of one large distribution hub which then services the various panelboards.

All NBS distribution transformers are cast coil dry-type transformers. Dry-type transformers are traditionally used in building applications to minimize the impact of environmentally detrimental fluids and potential fire safety issues; these transformers sacrifice energy efficiency, sound level, and ease of recycling (*Transformer Technology: Liquid-Type vs. Dry-Type*, Cooper Power Systems). Specifically, cast-coil transformers provide great mechanical strength (*Cast Coil Transformers*, GE Industrial Systems).

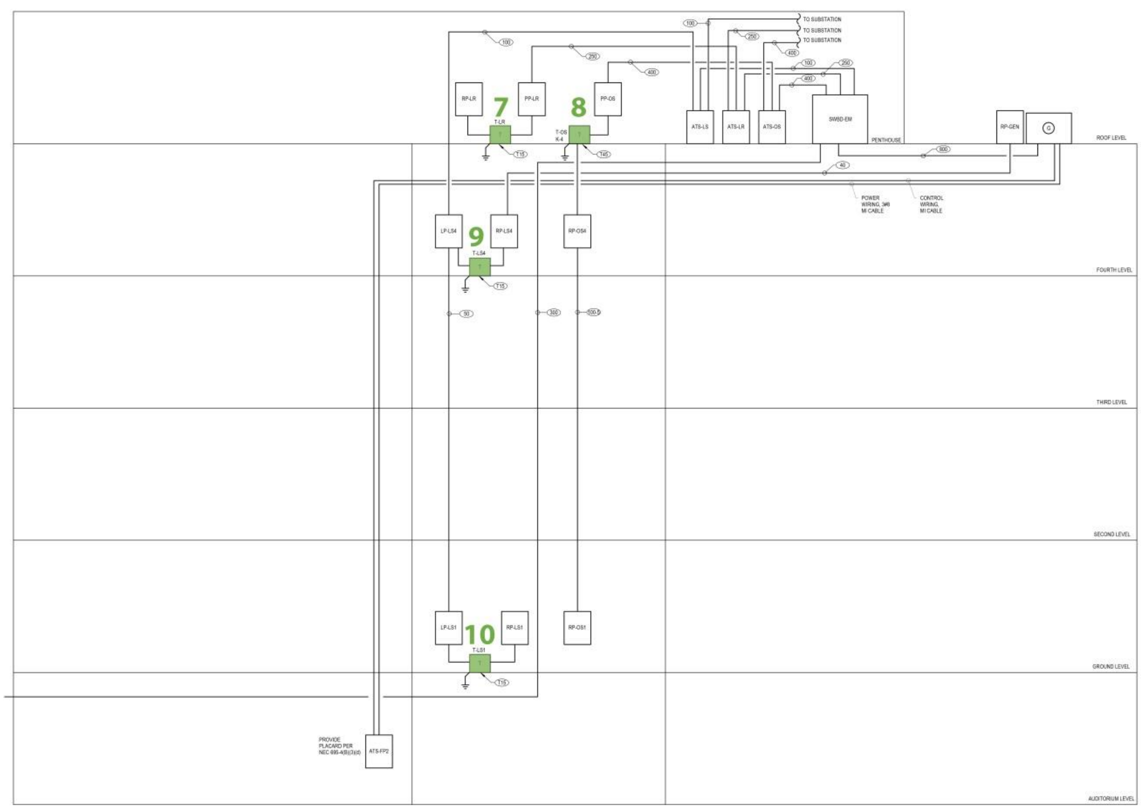
Transformer Schedule

Tag	Primary Voltage	Secondary Voltage	Size	Type	Temp. Rise	Taps	Mounting
TR-1A*	13,200 V 3PH, 4W	480Y/277V 3PH, 4W	1500 kVA	Dry	115° C	(4) 2.5%	Pad
TR-1B*	13,200 V 3PH, 4W	480Y/277V 3PH, 4W	1500 kVA	Dry	115° C	(4) 2.5%	Pad
T-0A	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	112kVA	Dry	115° C	(4) 2.5%	Pad
T-1A	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	45kVA	Dry	115° C	(4) 2.5%	Pad
T-2A	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	75kVA	Dry	115° C	(4) 2.5%	Pad
T-3A	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	75kVA	Dry	115° C	(4) 2.5%	Pad
T-4A	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	75kVA	Dry	115° C	(4) 2.5%	Pad
T-5	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	15kVA	Dry	115° C	(2) 5.0%	Pad
T-LS1	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	15kVA	Dry	115° C	(2) 5.0%	Pad
T-LS4	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	15kVA	Dry	115° C	(2) 5.0%	Pad
T-LR	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	15kVA	Dry	115° C	(2) 5.0%	Pad
T-OS	480Y/277V 3PH, 4W	208Y/120V 3PH, 4W	45kVA	Dry	115° C	(4) 2.5%	Pad

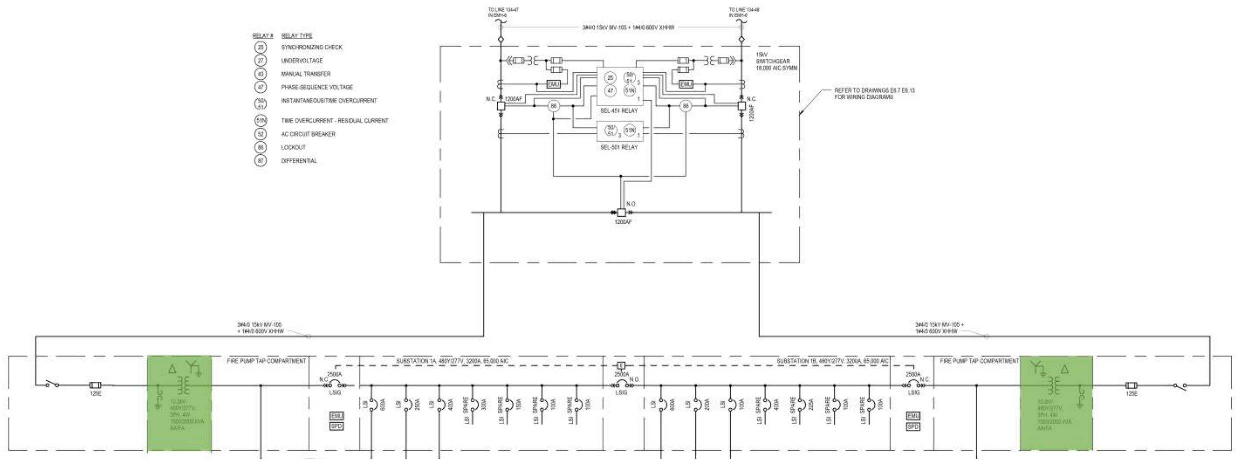
*Transformers located in substation are integral to the unit.

NORMAL POWER LOW-VOLTAGE TRANSFORMERS

EMERGENCY POWER LOW-VOLTAGE TRANSFORMERS



UNIT-SUBSTATION TRANSFORMERS



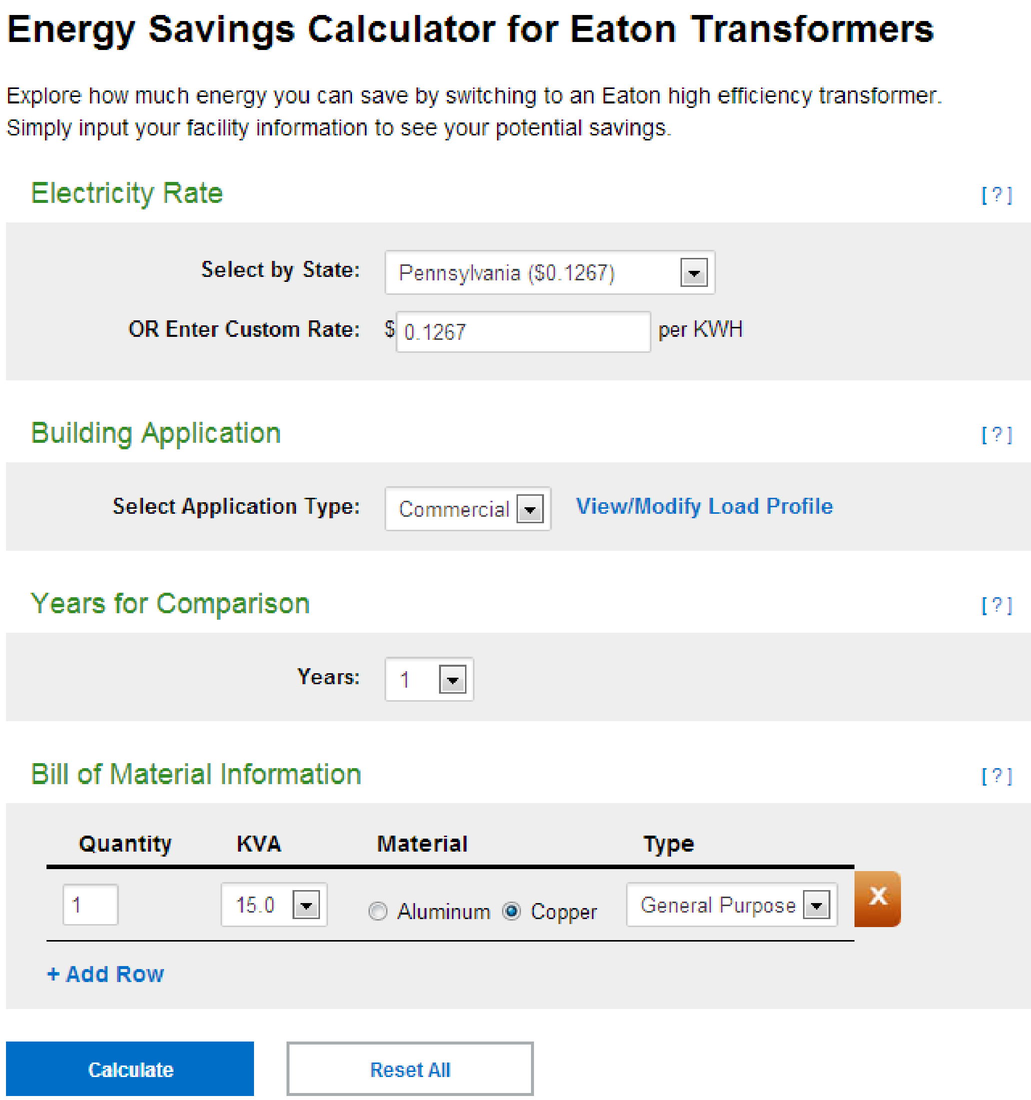
STEP 2 (Distribution Transformer)

Establish NEMA TP-1 and NEMA Premium dry-type efficiencies (reference: *Distribution Transformers*, DOE) for distribution transformers.

Number	XFMR	Level	kVA	System	Phase	Dry-Type Efficiency	
						NEMA TP-1	NEMA Premium
1	T-5	Penthouse	15	480-208Y/120V	3PH	0.9700	0.9790
2	T-4A	Forth	75	480-208Y/120V	3PH	0.9800	0.9860
3	T-3A	Third	75	480-208Y/120V	3PH	0.9800	0.9860
4	T-2A	Second	75	480-208Y/120V	3PH	0.9800	0.9860
5	T-1A	Ground	45	480-208Y/120V	3PH	0.9770	0.9839
6	T-0A	Lower	112.5	480-208Y/120V	3PH	0.9820	0.9874
7	T-LR	Penthouse	15	480-208Y/120V	3PH	0.9700	0.9790
8	T-OS	Penthouse	45	480-208Y/120V	3PH	0.9770	0.9839
9	T-LS4	Forth	15	480-208Y/120V	3PH	0.9700	0.9790
10	T-LS1	Ground	15	480-208Y/120V	3PH	0.9700	0.9790

STEP 3 (Distribution Transformer)

Using *Energy Savings Calculator* (http://es.eaton.com/transformercalc/index.php#calc) from Eaton Electric, calculate the total loss of each transformer type for each specified rating. Hereby, it is assumed Eaton Transformers are specified. A commercial building profile is used for the calculation as well as the cost of electricity as stated by *DOE/EAI-0226*.



Number	XFMR	kVA	Total Loss (kWh)	
			NEMA TP-1	NEMA Premium
1	T-5	15	1000.00	692.77
2	T-4A	75	2370.00	1570.00
3	T-3A	75	2370.00	1570.00
4	T-2A	75	2370.00	1570.00
5	T-1A	45	3190.00	2350.00
6	T-0A	112.5	4400.00	3290.00
7	T-LR	15	1000.00	692.77
8	T-OS	45	3190.00	2350.00
9	T-LS4	15	1000.00	692.77
10	T-LS1	15	1000.00	692.77

STEP 4 (Distribution Transformer)

Set initial costs for each NEMA rating with respect to kVA rating (Eaton Customer Support, Pricing).

Number	XFMR	kVA	Initial Cost ($)	
			NEMA TP-1	NEMA Premium
1	T-5	15	$ 4,206.00	$ 5,680.00
2	T-4A	75	$ 8,830.00	$ 11,920.00
3	T-3A	75	$ 8,830.00	$ 11,920.00
4	T-2A	75	$ 8,830.00	$ 11,920.00
5	T-1A	45	$ 6,506.00	$ 8,412.00
6	T-0A	112.5	$ 13,175.00	$ 16,474.00
7	T-LR	15	$ 3,941.00	$ 5,680.00
8	T-OS	45	$ 6,506.00	$ 8,412.00
9	T-LS4	15	$ 4,206.00	$ 5,680.00
10	T-LS1	15	$ 4,206.00	$ 5,680.00

STEP 5 (Distribution Transformer)

Calculate life cycle cost of each rated transformer by multiplying the total loss noted above (kWh) by energy costs ($/kWh).

Number	XFMR	kVA	Energy Cost ($/kWh)	Energy Life Cycle Costs ($)	
				NEMA TP-1	NEMA Premium
1	T-5	15	$ 0.1267	$ 126.70	$ 87.77
2	T-4A	75	$ 0.1267	$ 300.28	$ 198.92
3	T-3A	75	$ 0.1267	$ 300.28	$ 198.92
4	T-2A	75	$ 0.1267	$ 300.28	$ 198.92
5	T-1A	45	$ 0.1267	$ 404.17	$ 297.75
6	T-0A	112.5	$ 0.1267	$ 557.48	$ 416.84
7	T-LR	15	$ 0.1267	$ 126.70	$ 87.77
8	T-OS	45	$ 0.1267	$ 404.17	$ 297.75
9	T-LS4	15	$ 0.1267	$ 126.70	$ 87.77
10	T-LS1	15	$ 0.1267	$ 126.70	$ 87.77

STEP 6 (Distribution Transformer)

Compute annual energy savings of using NEMA Premium transformer by taking difference between energy life cycle costs.

Number	XFMR	kVA	Energy Life Cycle Costs ($)		Annual Energy Savings
			NEMA TP-1	NEMA Premium	
1	T-5	15	$ 126.70	$ 87.77	$ 38.93
2	T-4A	75	$ 300.28	$ 198.92	$ 101.36
3	T-3A	75	$ 300.28	$ 198.92	$ 101.36
4	T-2A	75	$ 300.28	$ 198.92	$ 101.36
5	T-1A	45	$ 404.17	$ 297.75	$ 106.43
6	T-0A	112.5	$ 557.48	$ 416.84	$ 140.64
7	T-LR	15	$ 126.70	$ 87.77	$ 38.93
8	T-OS	45	$ 404.17	$ 297.75	$ 106.43
9	T-LS4	15	$ 126.70	$ 87.77	$ 38.93
10	T-LS1	15	$ 126.70	$ 87.77	$ 38.93

STEP 7 (Distribution Transformer)

Calculate simple payback period (in years) by taking difference in initial costs divided by annual energy savings.

$$Simple\ Payback\ Period = \frac{Initial\ Cost\ Difference}{Annual\ Energy\ Savings}$$

Number	XFMR	kVA	Initial Cost ($)		Annual Energy Savings	Payback (years)
			NEMA TP-1	NEMA Premium		
1	T-5	15	$ 4,206.00	$ 5,680.00	$ 38.93	**37.9**
2	T-4A	75	$ 8,830.00	$ 11,920.00	$ 101.36	**30.5**
3	T-3A	75	$ 8,830.00	$ 11,920.00	$ 101.36	**30.5**
4	T-2A	75	$ 8,830.00	$ 11,920.00	$ 101.36	**30.5**
5	T-1A	45	$ 6,506.00	$ 8,412.00	$ 106.43	**17.9**
6	T-0A	112.5	$ 13,175.00	$ 16,474.00	$ 140.64	**23.5**
7	T-LR	15	$ 3,941.00	$ 5,680.00	$ 38.93	**44.7**
8	T-OS	45	$ 6,506.00	$ 8,412.00	$ 106.43	**17.9**
9	T-LS4	15	$ 4,206.00	$ 5,680.00	$ 38.93	**37.9**
10	T-LS1	15	$ 4,206.00	$ 5,680.00	$ 38.93	**37.9**

STEP 7 (UST)

Calculate the payback period of changing a unit-substation transformer from cast-coil dry-type to liquid-filled (vegetable-based) with the same 1500 kVA rating. The following process is based on the method as noted in *Considerations in Application and Selection of Unit Substation Transformers* by Charles J. Nochumson.

Process			Cast-Coil	Vegetable-Based
A	**Initial Costs**		$ 51,511.71	$ 34,341.14
B	**Total Load Losses (W)**		20000	12400
C	**No-Load Losses (W)**		4000	1900
D	**I^2R Losses @ Full Load**		16000	10500
E	**For LF1: I^2R Losses**	0.2667	1137.78	746.67
F	**For LF1: Total Losses**		5137.78	2646.67
G	**Rate 1: $/kWh**	$ 0.1267	--	--
H	**LF1 hrs/yr @ R1**	8760	$ 5,702.38	$ 2,937.51
I	**Total Operating Cost**		$ 5,702.38	$ 2,937.51
Operating Cost Difference (Savings)				$ 2,764.86
Initial Cost Difference				$ 17,170.57
Payback (years)				**0.00**

A: initial cost of transformers noted in *Considerations in Application and Selection of Unit Substation Transformers* (2001), adjusted for inflation using CPI Inflation Calculator from the Bureau of Labor Statistics.

B: total-load losses (W) of transformer obtained from Eaton Consulting Application Guide, *Secondary Unit Substations* (2011), reference Appendix G.

C: no-load losses (W) of transformer obtained from Eaton Consulting Application Guide, *Secondary Unit Substations* (2011), reference Appendix G.

D: I^2R Losses = Total Losses (B) – No Load Losses (C)

E: Load Factor Losses for working hours = (I^2R Losses)*LF1 = (D)*0.2667.

LF1 is fraction of load kVA over the nameplate kVA. Here, each 1500 kVA transformer can be expected to experience 400 kVA of load daily.

F: Total Losses for LF1 = No Load Losses (C) + Load Factor Losses (E)

G: Rate of electricity in Pennsylvania (reference *DOE/EAI-0226)*.

H: Annual Cost of Operation = [Total Losses (F)/1000]*Hours of operation*Rate (G)

Hours of operation is assumed 24 hours a day, 7 days a week all year (8760 hrs).

H: Total Operating Cost = Annual Cost of Operation (H)

The **payback period for using a vegetable-based fluid unit-substation transformer is essentially zero** because the initial cost is less and one saves on annual operating costs.

EVALUATION

Given various sized distribution transformers and the robust electrical system, a transformer analysis highlights several key considerations. Seen above, by switching to NEMA Premium transformers from NEMA TP-1 Standard transformers, one does save energy; however, the added cost of using Premium transformers is too high so that a reasonable payback of 10 to 13 years is exceeded (on piece of equipment to operate at least 30 years). Only the 45 kVA transformer provided a payback in 18 years, still a bit much.

It can be inferred that NEMA Premium transformers offer the most payback for larger rated transformers (greater than 112.5 kVA); the added cost for more efficient transformers is simply not worth it for smaller kVA-rated dry-type transformers. It is recommended to not upgrade the NEMA-TP1 Standard Rating dry-type low-voltage transformers to NEMA Premium Rated low-voltage dry-type transformers.

Opposing, changing the dry-type cast-coil UTS to a liquid-filled (vegetable-based) transformer is worth it financially, offering a lower initial cost and more energy savings. The environmentally-friendly vegetable-based transformer is **$17,171 less** than the specified cast-coil transformer and saves the owner **$2,765 every year** in operating costs (48.5% less total load losses). It is important to note there are several other factors that should be discussed when choosing a transformer.

Cast-coil transformers offer reduced environmental contamination and zero risk of leakage of flammable substances. These transformers are non-flammable and self-extinguishing with a high resistance to short circuits. Cast-coil transformers are also capable of withstanding severe rolling and vibrating conditions.

A major reason dry-type transformers are heavily used is less associated fire-risk, an expensive safety and insurance issue; however, liquid-filled transformers provide several advantages. Liquid-filled transformers are general more efficient than dry-type transformers; likewise, they have usually have longer life expectancy and better overload capacity.

In particular, the mentioned change would introduce vegetable-based fluids not conventional mineral oil, silicone, or hydrocarbon fluids. Vegetable-based fluids are available as UL listed and Factory Mutual approved as less-flammable. Under arching conditions, vegetable oil based fluids provide only 20% of the gas and combustion products of mineral oil and less gas and combustion products than hydrocarbon and silicone products.

Transformers with vegetable-based fluids can be overloaded with less loss of life than presently available fluids. While vegetable-based fluid transformers require liquid confinement (curbing)—adding 1% to 10% to initial costs of installation—dry-type transformers have added cost over liquid-type transformers for increased air conditioning and soundproofing (reference: *Considerations in Application and Selection of Unit Substation Transformers* by Charles J. Nochumson).

Moreover, rapid biodegradation and non-toxicity characteristics are steering several utilities to vegetable oil-based transformers because they are more environmentally safe than other transformer fluids (*Utilities Turning to Vegetable Oil-Based Transformer Fluids*, Patrick McShane, Cooper Power Systems). Vegetable-based fluids (FR3 or Biotemp Environmentally Friendly fluids) meet the requirements of being 'fire safeguard' as specified by Section 15 of the National Electrical Safety Code and of being a less-flammable liquid as defined by the National Electrical Code, Section 450-23. Hereby, the associated fire-risk is minimized while still providing sufficient energy savings.

Concluding, it would be beneficial that the existing cast-coil unit-substation transformers are replaced with vegetable-based fluid transformers of the same rating. A lower initial cost, higher energy efficiency, and advancements in fire-safety, make it a viable option. However, the choice is ultimately at the discretion of the building owner, so concerns of safety and following industry standard may drive the owner away from the less expensive and advantageous option which offers immediate payback.

INTEGRATED DAYLIGHTING, MECHANICAL, ARCHITECTURAL DEPTH + BREADTHS

DEPTH + BREADTHS **INTEGRATION**

INTRODUCTION

Goals of sustainability, energy concerns, and improved building technologies have encouraged a great level of building system integration to design a space that is comfortable for the occupants and conscious of its effect on the environment. The following sections describe several depth and breadth topics relating to the Neural and Behavioral Sciences Building. Importantly, the integration of informed daylighting and energy efficient design provides the staple for the purpose of this analysis: the effects of introducing a Kalwall + Lumira Aerogel technology to the East Block curtain wall façade.

PURPOSE + GOALS

The specifics of the project are discussed in the next sections. Here, however, the goals of the depth and breadths are outlined:

1. Use parametric design and optimization algorithms to inform the design, essentially providing a fluid workflow between architecture, daylighting, and mechanical engineering.
2. Improve daylighting within the East Block office plan on a typical floor.
3. Improve or sustain the existing energy demand profile of perimeter offices through detailed energy modeling and optimization.
4. Provide a more collaborative and open work space for graduate students.
5. Investigate the effects of an open-office floor plan versus a divided floor plan.
6. Learn and implement the process of parametric design and optimization.
7. Highlight the importance of using these parametric technologies within the building industry, specifically how it applies to graduates of the Architectural Engineering program.

PRELIMINARY WORKFLOW

Several stand-alone programs are used to first understand the existing site conditions and NBS building. *COMFEN* (LBNL) is utilized to provide weather data concerning the particular site (Philadelphia). *Trace 700* (Trane) is used to determine the appropriate R-values of the existing curtain wall façade and metal panel construction. These values are used later in the design process. Finally, *Ecotect* (Autodesk) provides a visual analysis of contextual shadowing and annual solar irradiation.

DESIGN WORKFLOW

Parametric design is not a new concept; it is, however, just beginning to inform the design of buildings and building systems. Not only can the parametric design process be used to create visually interesting architectural designs, it can be used to easily inform daylighting systems, structural systems, energy models, etc. Several platforms for this process of design are available. For the purposes of this analysis, *Rhino* software with several plug-ins is used due to its availability and flexibility.

Rhino is often used by architects for spatial modeling and rendering. Upon graduation, it is a goal to be able to communicate effectively with architects on a familiar platform to produce better design projects. Hereby, *Rhino* is used as the platform for which daylighting, energy modeling, and architectural changes are investigated.

DIVA for *Rhino*, a daylighting analysis tool, interfaces well with existing architectural models. *DIVA*, developed by Christoph Reinhart (MIT Architecture), uses the *Radiance* and *Daysim* protocols to calculate different daylighting results. *DIVA* is used for an entire floor daylighting study and as a plug-in to *Grasshopper*—a parametric modeling platform which plugs into *Rhino*.

Grasshopper provides a functional and flexible interface for designers to visual code, design, and analyze multiple solutions. *DIVA* is used as plug-in through *Grasshopper* to read *Rhino* geometry and generate daylighting results. *VIPER*, the *DIVA* thermal analysis component, is used in *Grasshopper* to generate energy models for a selected space. *VIPER* is driven by an *Energy+* calculation engine—*Energy+* is commonly used by mechanical engineers for energy modeling. Through *Grasshopper*, *DIVA* and *VIPER* can communicate effectively, using similar geometry defined in *Rhino*, to evaluate daylighting and energy performance of several different solutions.

Finally, *Galapagos*, an optimization engine within *Grasshopper* is used to leverage the power of improved computer technology: an optimization algorithm based on parametric design allows for multiple self-generated and smart iterations of several design solutions. Time can be spent working on other topics while the computer finds the optimal design (as instructed by the designer).

BREADTH TOPIC **ARCHITECTURE**

A strong motivation for the integrated breadths and MAE depth topic is defined by improved architectural design. The following section pertains to important information about the architecture and interior design. Other considerations including acoustical impacts and structural changes are mentioned. Applicable renderings are shown.

Introduction

- Location + Architectural Concept
- Purpose
- Contextual Consideration

Existing Architecture

- Exterior and Interior Layout
- Renderings

Proposed Architecture

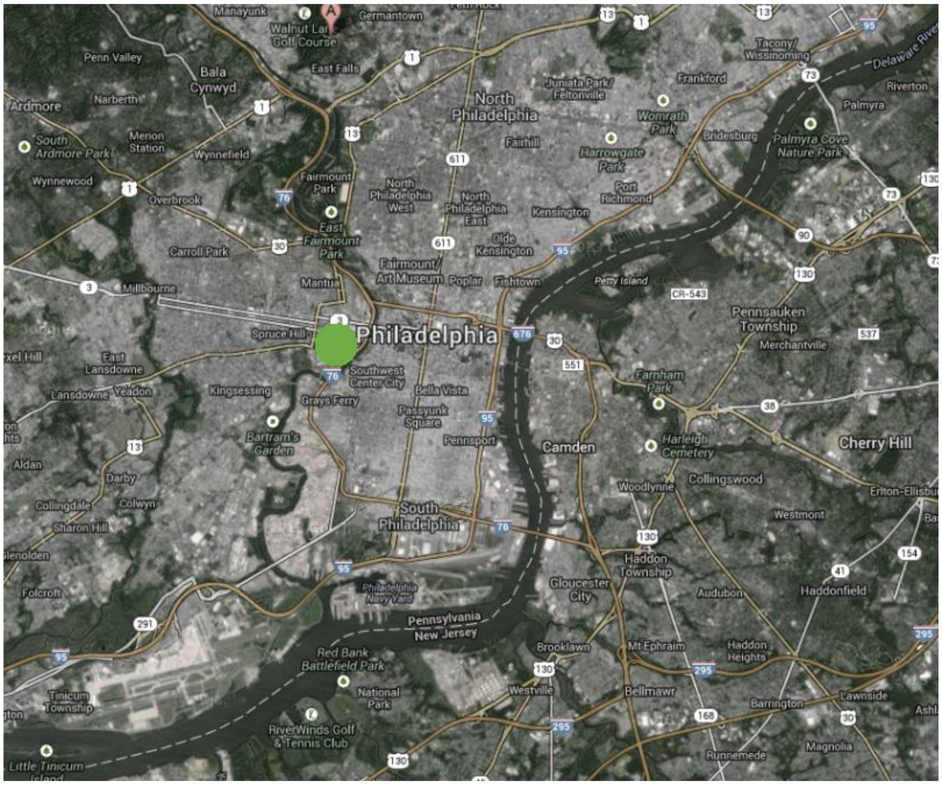
- Exterior and Interior Layout
- Renderings
- Considerations

Conclusion

INTRODUCTION

LOCATION + ARCHITECTURAL CONCEPT

The Neural and Behavioral Sciences Building is located in the heart of University of Pennsylvania's campus in Philadelphia, PA. The main architectural feature sunscreen faces south.



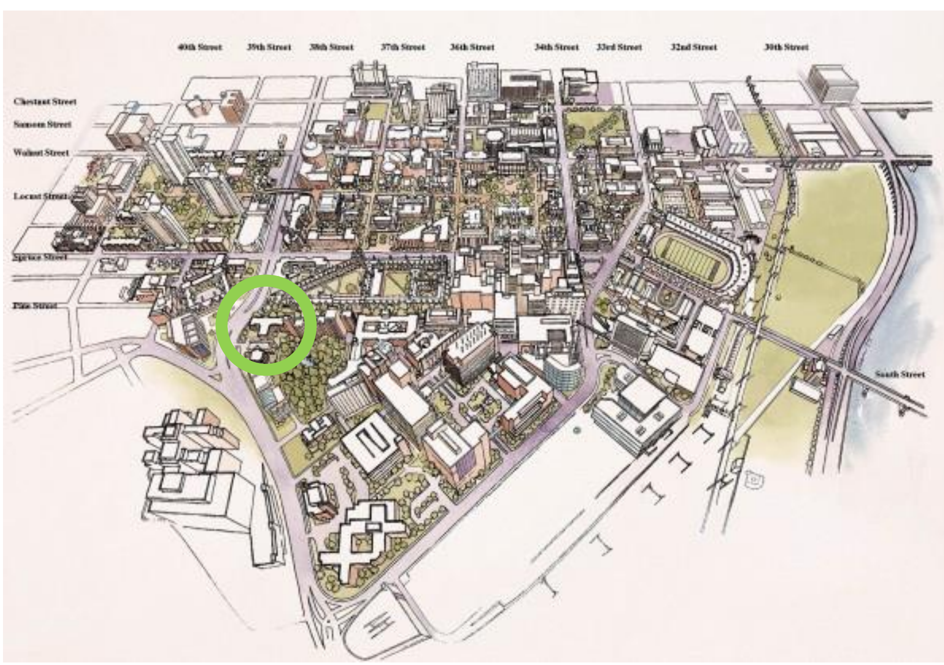
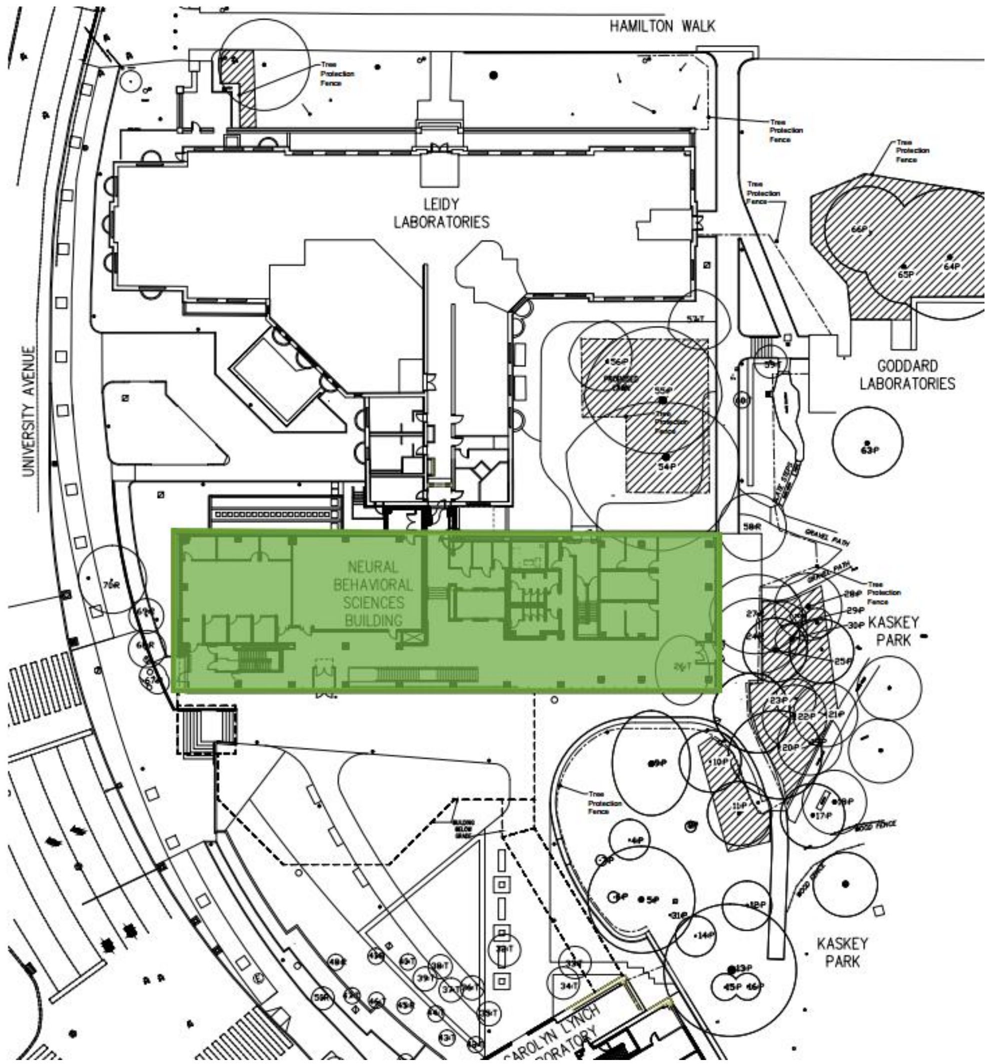


Fig. 22: www.mappery.com



The new Neural and Behavioral Sciences (NBS) building creates a cohesive street front and inviting place for students and faculty. The NBS building, roughly 77,000 SF in size, will contain research and instructional laboratories, a 174-seat lecture hall, and office space. The building will adjoin the existing Leidy laboratories to the north at the lower through third floor levels. Likewise, the building will be connected to the existing Lynch Laboratories Building to the south via an underground tunnel at the lower level.

PURPOSE

The Eastern Block of the NBS building houses primarily graduate and faculty students. The block is cantilevered over the main entrance to the building and not covered by the prominent sunscreen to the south. At the moment, a mixture of clear and diffuse exterior glazing within a metal panel system surrounds the floor area on the south, east, and west side.

SOUTHWEST RENDERING (Existing)

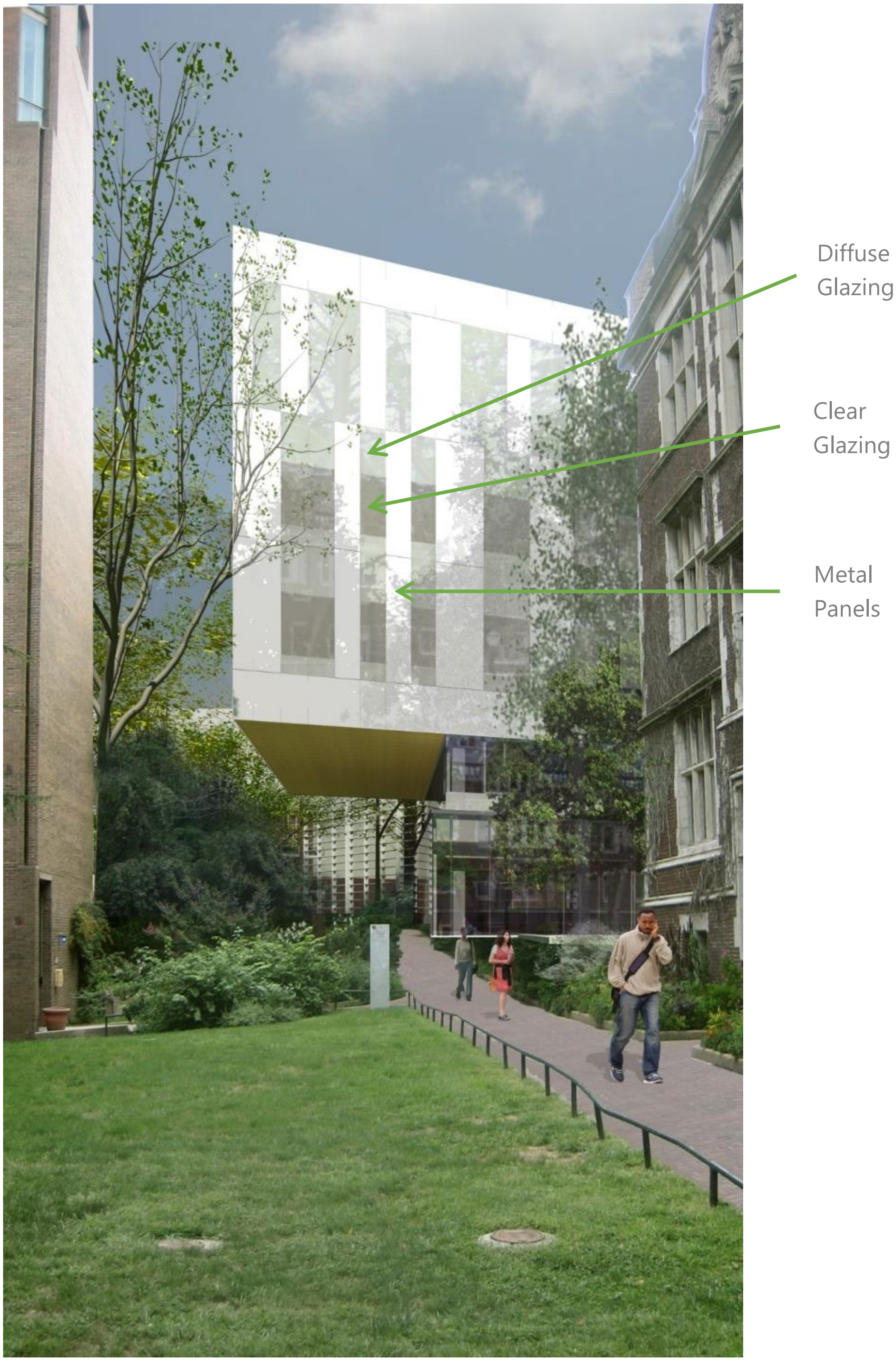
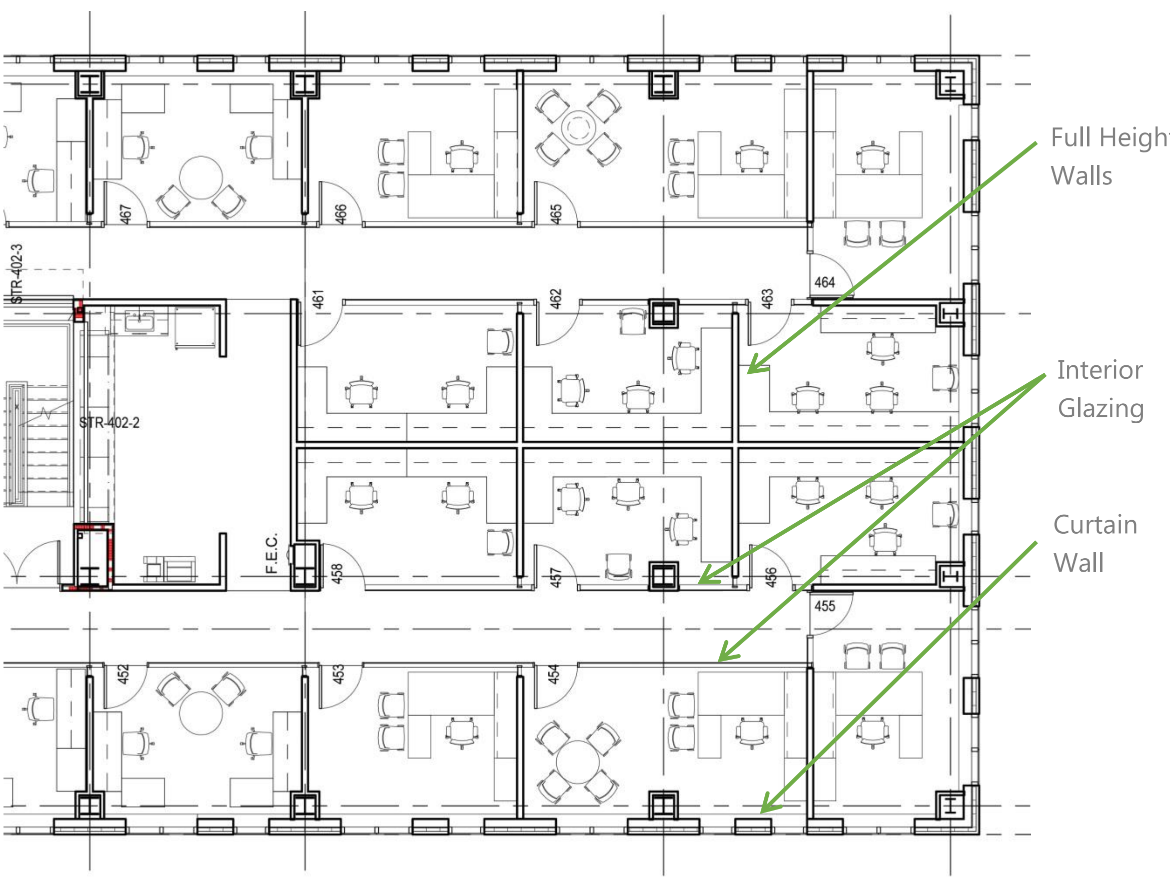


Fig. 23: East Block rendering, courtesy of SmithGroupJJR

NORTHWEST RENDERING (Existing)

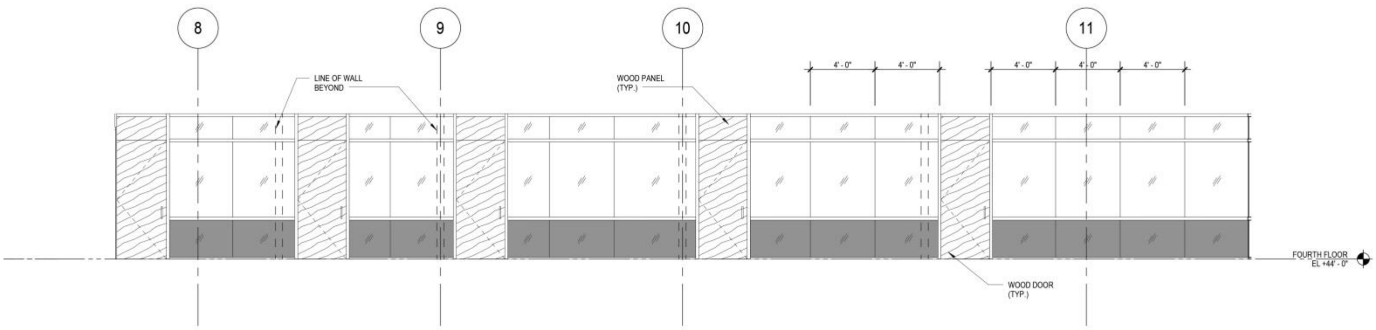
Fig. 24: Main entrance rendering, courtesy of SmithGroupJJR

FLOOR PLAN

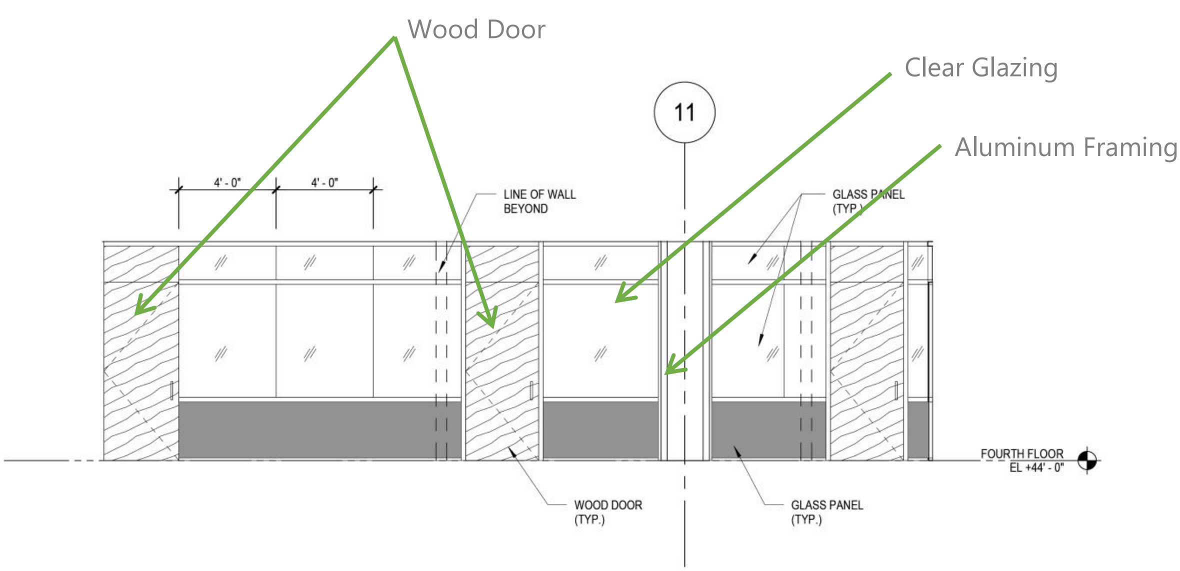


Faculty offices are placed around the perimeter while graduate students sit in the interior floor space. The graduate offices are full height walls. In the two main corridors, interior glazing is used instead of solid walls along both the faculty office and graduate student sides. The entire floor space includes dropped acoustic ceiling tiles at 9'6" above the floor. Mechanical equipment is used and standard fluorescent pendants are used to illuminate the space.

INTERIOR ELEVATION



52 CORRIDOR C-408
SCALE: 1/4" = 1'-0"



48 CORRIDOR C-406
SCALE: 1/4" = 1'-0"

Although there is interior glazing, full height interior partitions create a separate and stagnant space within the graduate student area. Furthermore, two to three graduate students are forced to share a room with limited views to the outside or across the floor plan. This setup is similar to that found at the Engineering Units B second floor. The space feels separated and unproductive; collaboration is hindered by the interior design. This is largely due to the lack of natural light and direct view outside—at least a view to the presence of daylight is lacking.

At first, rearranging and opening the floor plan seemed like a viable option, allowing light to spill into the interior zones. However, privacy and noise concerns limited the deconstruction of faculty office partitions; likewise, faculty often prefer exterior windows and programmatically require more room.

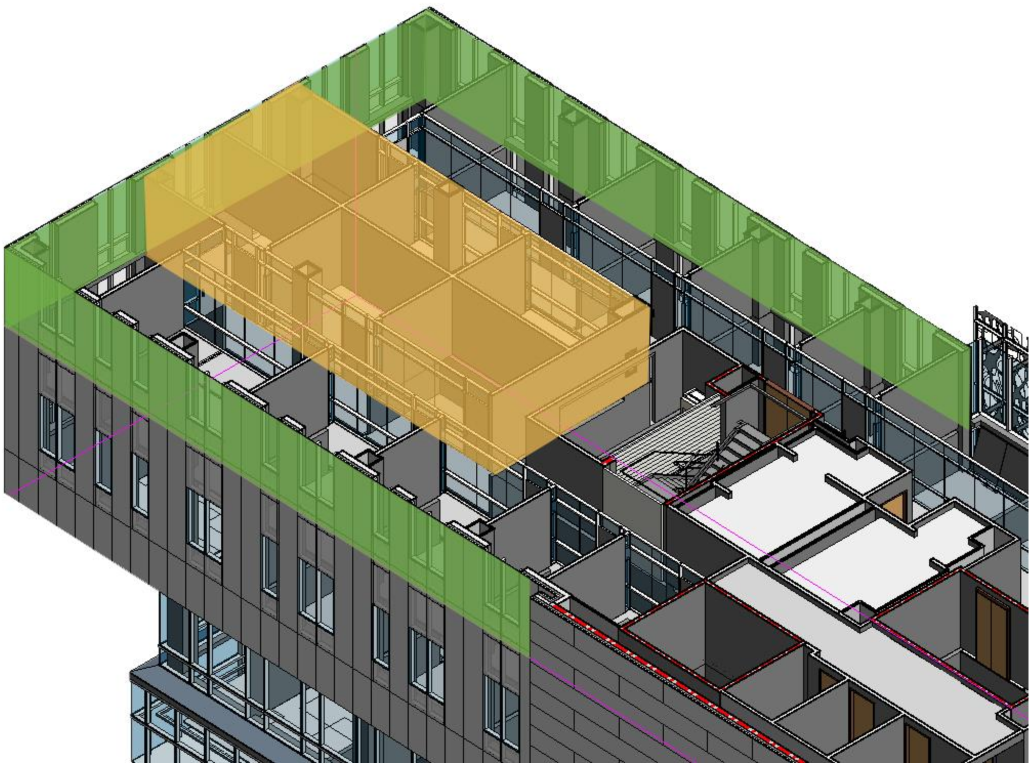


Fig. 25: East Block section

The proposed architectural change will keep the faculty offices where they exist currently. However, the interior graduate student space will become an open floor plan with an exposed ceiling system (orange above). The exterior wall will introduce Kalwall (green above), removing the existing diffuse glazing while maintaining views through the clear glazing. The aim is to provide for more daylight into the interior space while not adversely increasing glare (see daylighting depth). The interior space will feel more open, now an environment for effective collaboration and productivity.

CONTEXTUAL CONSIDERATIONS

Placement and design of the building allows the structure to become a unifier and connector for other nearby buildings which are all part of the Neural and Behavioral Sciences neighborhood. This idea is conceptually apparent in the organic and connective architectural design. The massing of the NBS building is simple yet effective—the east end is a white metal and glass faculty office block, which cantilevers into the garden to help minimize excavation impact on roots and simultaneously provide a protected entry porch below. The west end is a copper clad lab block.

Architecturally, the prepatinated copper enclosing the west lab block references the greens of biology, thus adding variety to the mix of buildings in the neighborhood which are all built in red and brown brick. The white metal and glass contrasts with the green copper and trees to improve readability of the massing.

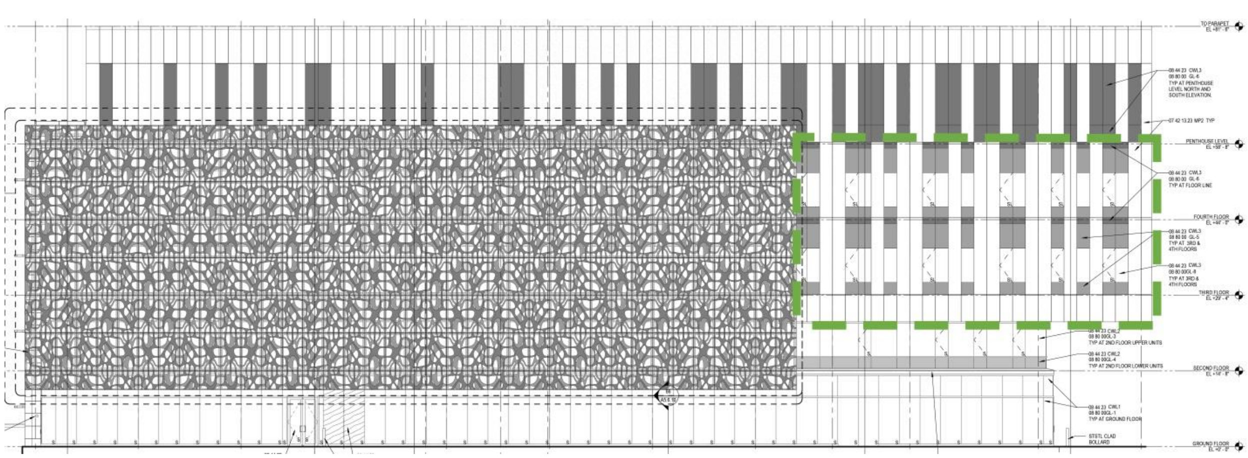
Changing the south sunscreen is a large architectural notion that would otherwise deter from the overall concept as described by the original architect. Furthermore, adding an exterior element of daylighting control would visually take away from the sunscreen. Hereby, changing the materiality of the vertical plane along the East Block allows the sunscreen to dominate the architectural expression. The massing of the building remains contemporary, organic, and transparent. Interior layout alterations do not effect of the contextual relationship of the building to the surrounding campus: in fact, it is a goal of the proposed architecture to encourage more collaboration and connection.

EXISTING ARCHITECTURE

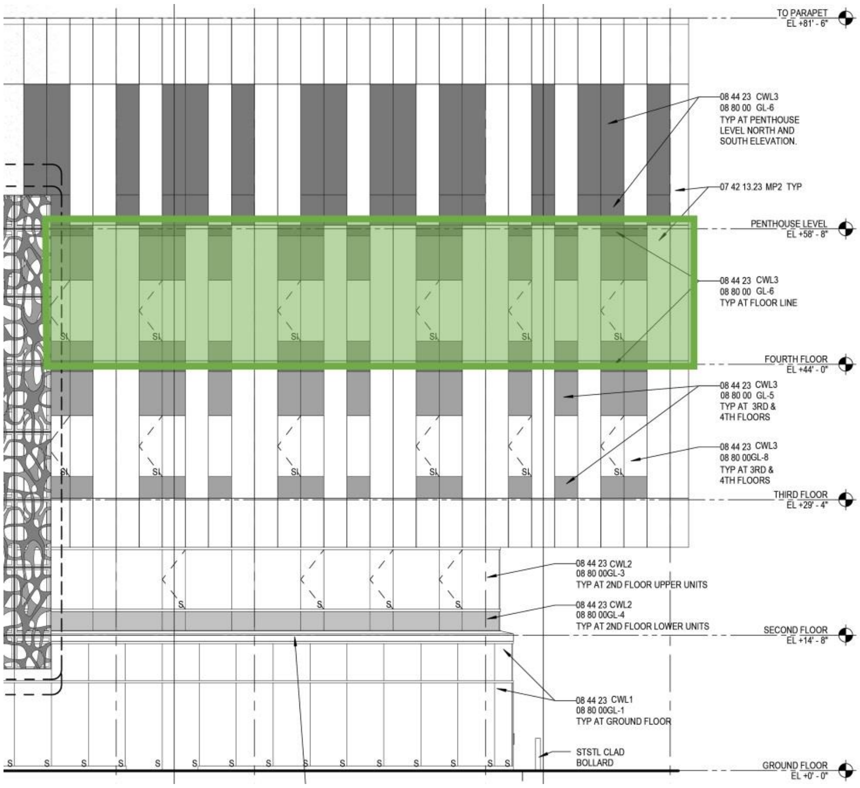
EXTERIOR AND INTERIOR LAYOUT

The exterior consists of composite metal panels and a curtain wall system. The curtain wall system is comprised of clear glazing and diffuse glazing. This is typical on the south, east, and west facades.

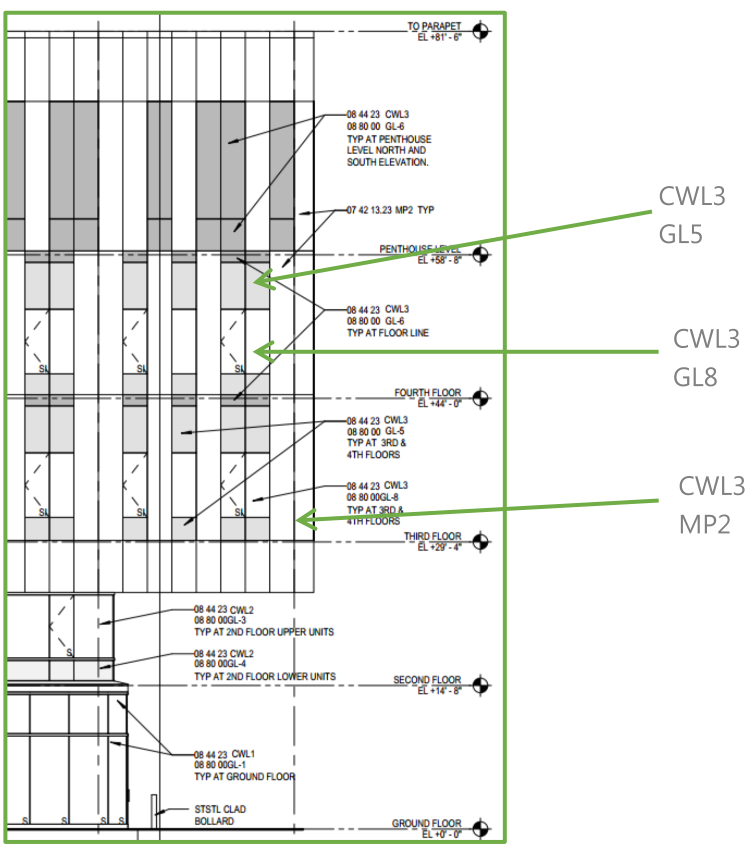
SOUTH ELEVATION



SOUTH ELEVATION DETAILED



SOUTH ELEVATION DETAILED

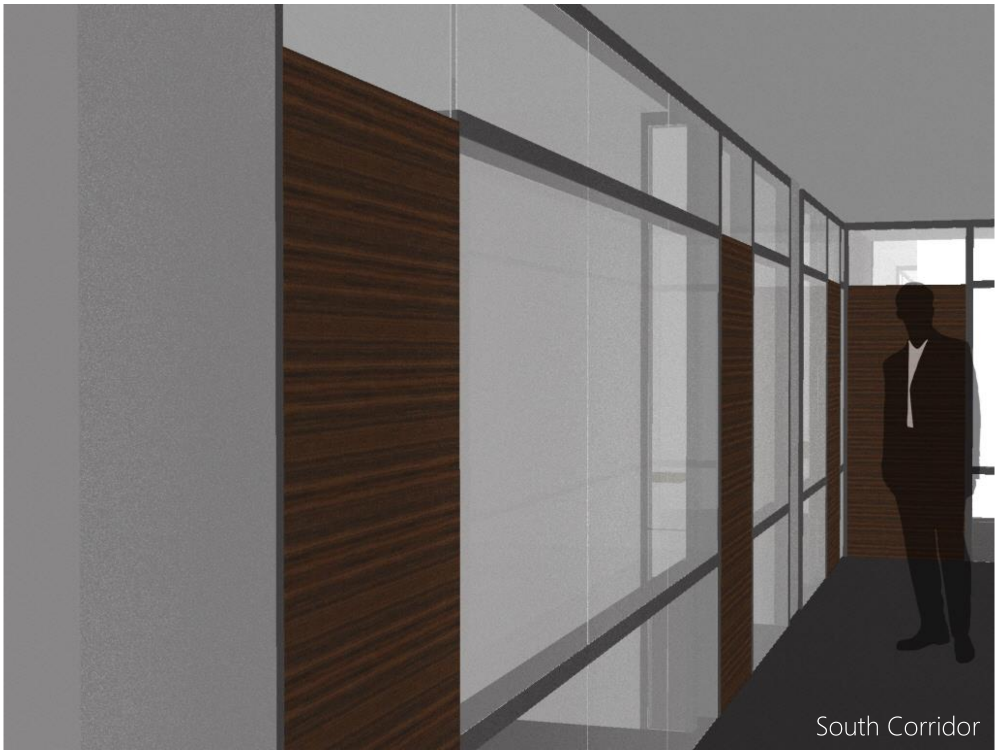


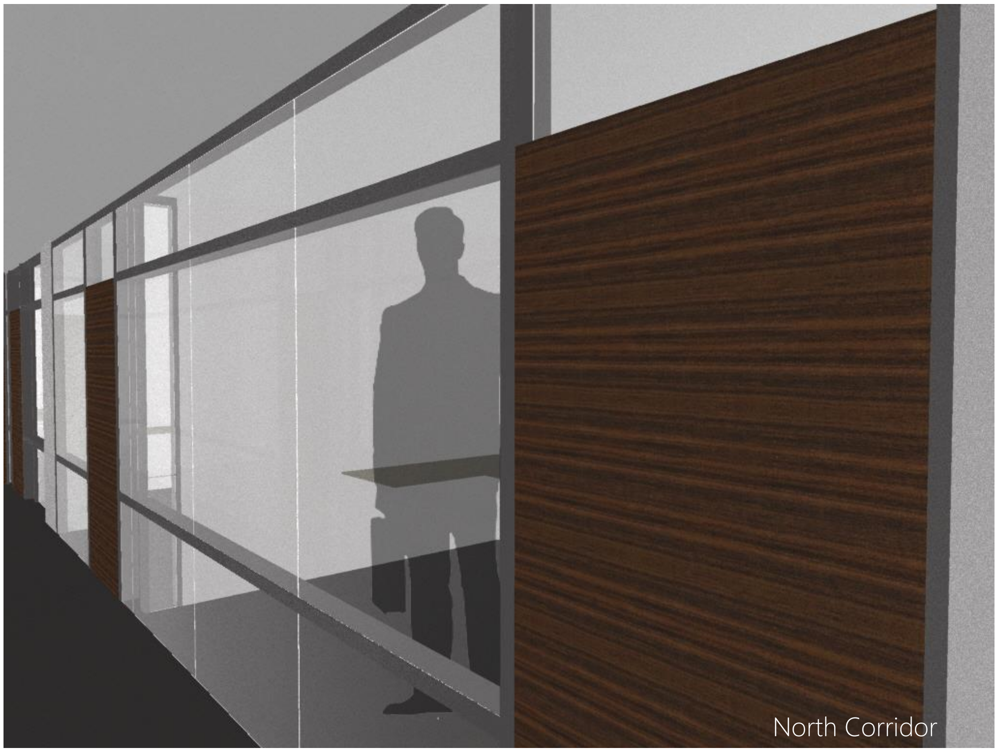
Construction and Materials		
Item	Description	Important Quality
MP2	Composite Metal Panel	3-coat fluoropolymer pearl white aluminum, 40% reflective
GL5	Diffuse Glazing	49% visible transmittance, insulating silkscreen, 0.30 U-Value
GL8	Clear Glazing	38% visible transmittance, low-e, 0.28 U-Value

The interior space is composed of perimeter faculty offices, interior graduate students' offices, and a common kitchen. Full height walls are used to separate graduate student offices and interior glazing is installed along the parallel corridors (refer to Purpose of Architecture Breadth above).

RENDERINGS

Below are schematic level renderings (completed using Rhino Render for ease of workflow) for the existing design. The lighting characteristics are not accurate (refer to the daylighting depth for Radiance images and accurate lighting character of space). These renderings show the massing of the space, overall appearance, and colors.


South Corridor



PROPOSED ARCHITECTURE

EXTERIOR AND INTERIOR LAYOUT

In an effort to maximize diffuse daylight deep into the interior office space, partitions are replaced with collaborative workstations. An exposed ceiling system creates a lofty office that allows daylight to fill the space. Below is an example of the type of workstation that will be implemented in the space (credit to Steelcase.com).

Fig. 26: Open-office furniture system, www.steelcase.com

In order to maximize useful and effective daylight, Kalwall is introduced into the curtain wall system. The current diffuse glazing (GL5) is replaced with the translucent panel system. In order to minimize negative energy effects on the immediate perimeter faculty offices, Kalwall + Lumira Aerogel is specified: this system provides good daylighting with reliable thermal insulation. Kalwall + Lumira provides diffuse daylight without shadows, glare, or hotspots. The thermal insulation means the product can replace the curtain wall at approximately the same R-15 value (see Mechanical Breadth for in-depth material analysis and energy models).

For the purposes of this study, the Kalwall material will have 15% light transmission with an R-20 value. A random distribution of fibers within the panels completely diffuse natural light both clear and cloudy days. Clear glazing will remain as designed to allow for unimpeded views to the exterior. Moreover, these windows are operable feature a controlled shading system. The amount of Kalwall will be optimized to allow for maximum daylight in the faculty offices and more importantly, deep into the open office space (refer to Daylighting Depth for optimization and daylighting calculations).

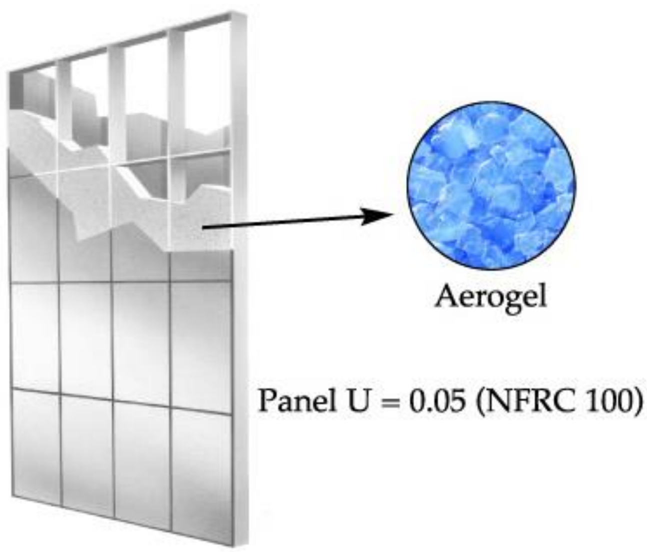


Fig. 27: Kalwall + Lumira Aerogel, www.kalwall.com

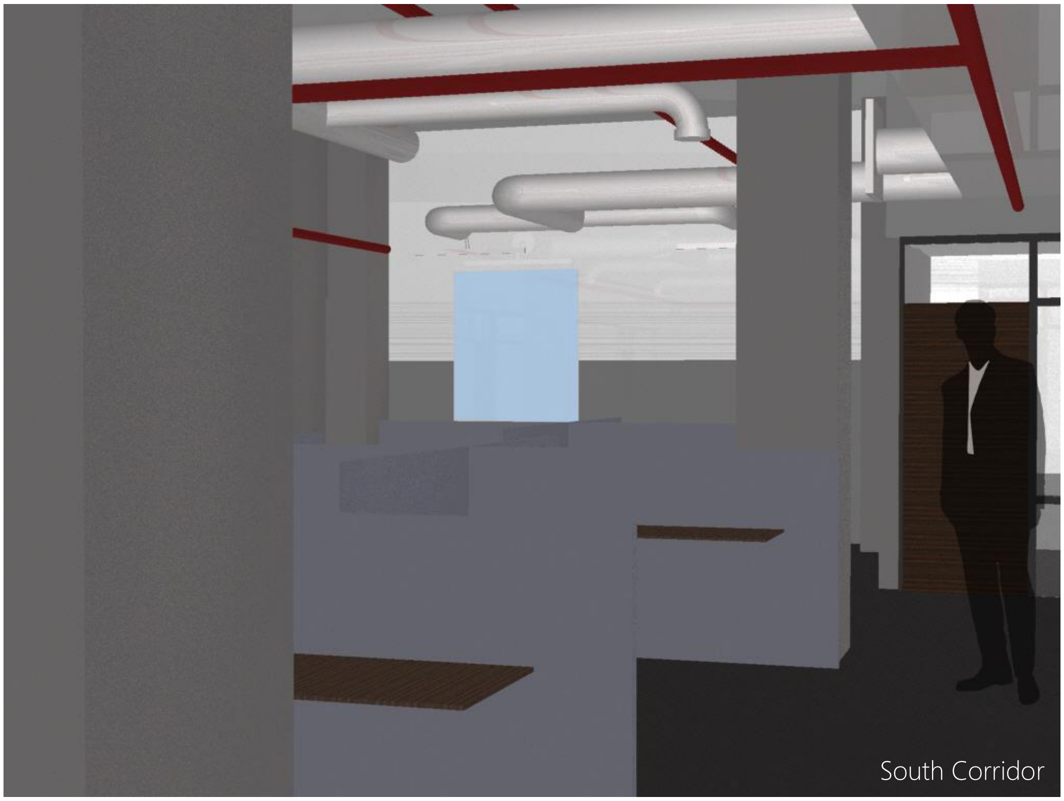
Other important considerations are addressed with the Kalwall + Lumira technology. The Kalwall product is UV stable and maintains integrity. An inclusion of a continuous glass veil erosion barrier under the external face sheet encapsulates fibers and this mitigates unsightly degrading. Moreover, since superficial coatings or "gel coats" are not applied to the face of the Kalwall, yellowing and loss of light transmission is prevented. According to a study reported by Structura Curtainwall Engineering, Kalwall showed no noticeable color change after five years of South Florida sun.

Kalwall has been classified with lifetime of 25 years regarding durability (ETA-07/0244). Regarding impact resistance, Kalwall meets requirements as defined by the American code US Standard UL-972: Kalwall is sufficient in handling soft and hard body impacts including vandalism and large missile impact tests. As studied, Kalwall would generally meet the NFPA definition of "Limited Combustibility" in relation with fire resistance. Kalwall + Lumira Aerogel achieves a 34 dB R_w Weighted Noise Reduction rating and weighs no more than 4.5 pounds per square foot (psf).

Importantly, panels are prefabricated to the exact size and configuration for each project. Hereby, flexibility in design as informed by parametric modeling is possible. Finally, it is expected that vertical Kalwall facing North or East with average exposure is to be maintained every 15 to 20 years: wash with soapy water and clear water rinse.

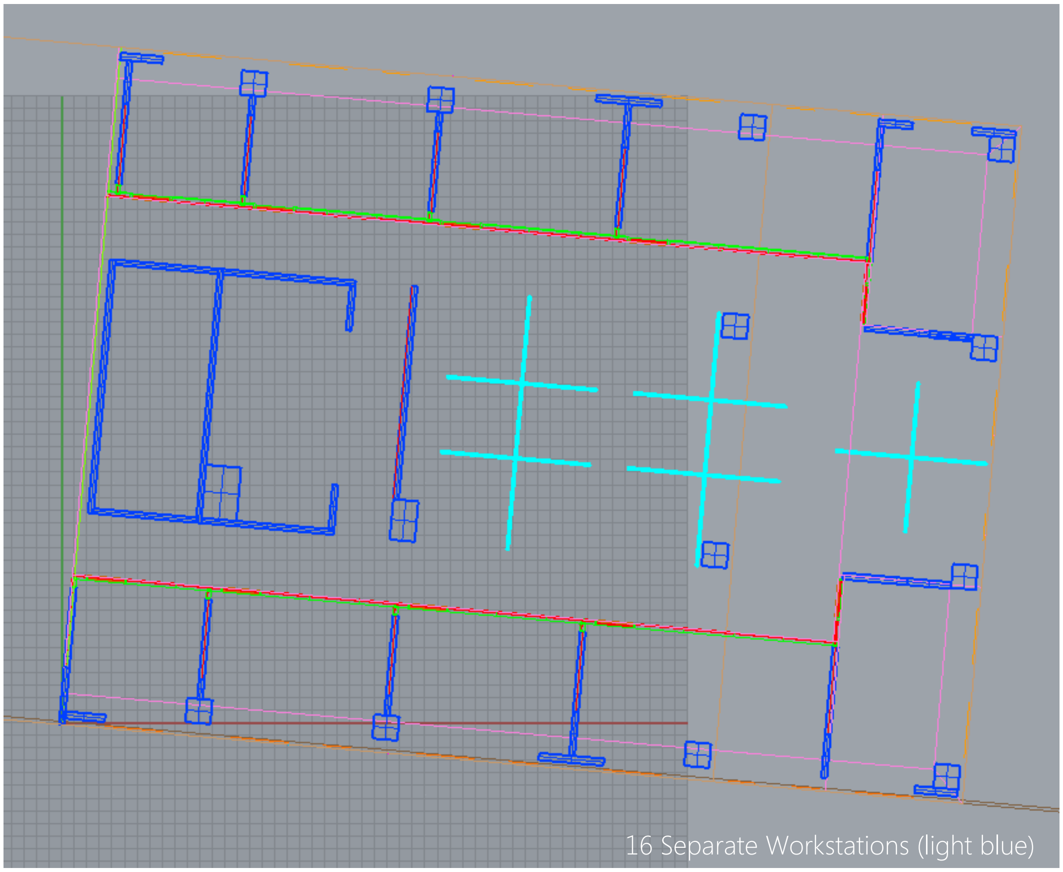
RENDERINGS

Below are schematic level renderings (completed using Rhino Render for ease of workflow) for the proposed design. The lighting characteristics are not accurate (reference daylighting depth for Radiance images and accurate lighting character of space). These renderings show the massing of the space, overall appearance, and colors.



South Corridor


North Corridor


16 Separate Workstations (light blue)

CONSIDERATIONS

There are several important architectural and interior design considerations when changing the floor plan dramatically. Foremost, privacy is an important programmatic element and should thus be accounted for. The proposed design maintains faculty offices at the original locations with existing interior glass walls; privacy and direct exterior views remain within the faculty offices.

Privacy among the graduate students changes little. The new design does call for a completely open space whereas the original design implements several smaller rooms with two or three students per space. Privacy is not jeopardized, outweighed largely by the now more inviting space.

Acoustics is an issue that would need further study. For the purposes of this study, acoustics were not studied in detail. Potentially more noise will not adversely affect the faculty offices. As a function of the work of graduate students, noise is not a critical concern throughout a school day. Increased conversation may occur: this is more positive than negative in this case. All exposed and redesigned mechanical equipment and duct work have ratings of NC-30 or less (see Mechanical Breadth). This rating is generally acceptable in office spaces.

Finally, Kalwall is relatively not too heavy. At 4.5 psf, the weight of the Kalwall will not adversely impact the existing structural system as the existing curtain wall system weighs approximately the same (5 psf).

Reference the breadth and depth conclusion for a cost analysis of the proposed architectural changes.

CONCLUSION

Collaboration is a major goal of the overall architectural concept. Hereby, the proposed open-office design will encourage further collaboration and productivity. The new design provides every graduate student on the floor with their own respective 6'x6' workstation. This facilitates an effective and private work space while encouraging cross-communication. The now exposed ceiling space is architectural spacious and inviting: no longer are the graduate student offices a gloomy place to work. Views, natural light, and production are abundant.

An optimized exterior wall construction of Kalwall, metal panels, and clear glazing increases daylight in the interior space while maintaining the overall annual energy demand as previously designed.

MAE DEPTH **DAYLIGHTING**

Advanced parametric analysis of daylighting as it relates to Kalwall construction optimization is used to inform the architectural changes and energy models. In this section, goals of improved daylighting are discussed, existing conditions are evaluated, the parametric design process is explained and examined, and several daylighting results are reported. Radiance renderings of the original and proposed design are shown to visually explain the performance of natural light in the space.

Introduction
- Goals
- Methodology + Integration

Existing Conditions

Original Design
- Introduction
- Materials + Setup
- Results

Proposed Design
- Introduction
- Materials + Setup
- Parametric Optimization
- Results

Conclusion

INTRODUCTION

GOALS

Physical changes to the space are addressed in the Architectural Breadth section. As stated, it is advantageous to create a more spacious and naturally-lit interior office space. The daylighting depth investigates and addresses several goals:

1. Improve daylighting within the interior office zones.
2. Create parametric model with various adjustable parameters using integrative *Grasshopper* technology.
3. Optimize amount of Kalwall relative to metal panel construction for best daylighting design.

METHODOLOGY + INTEGRATION

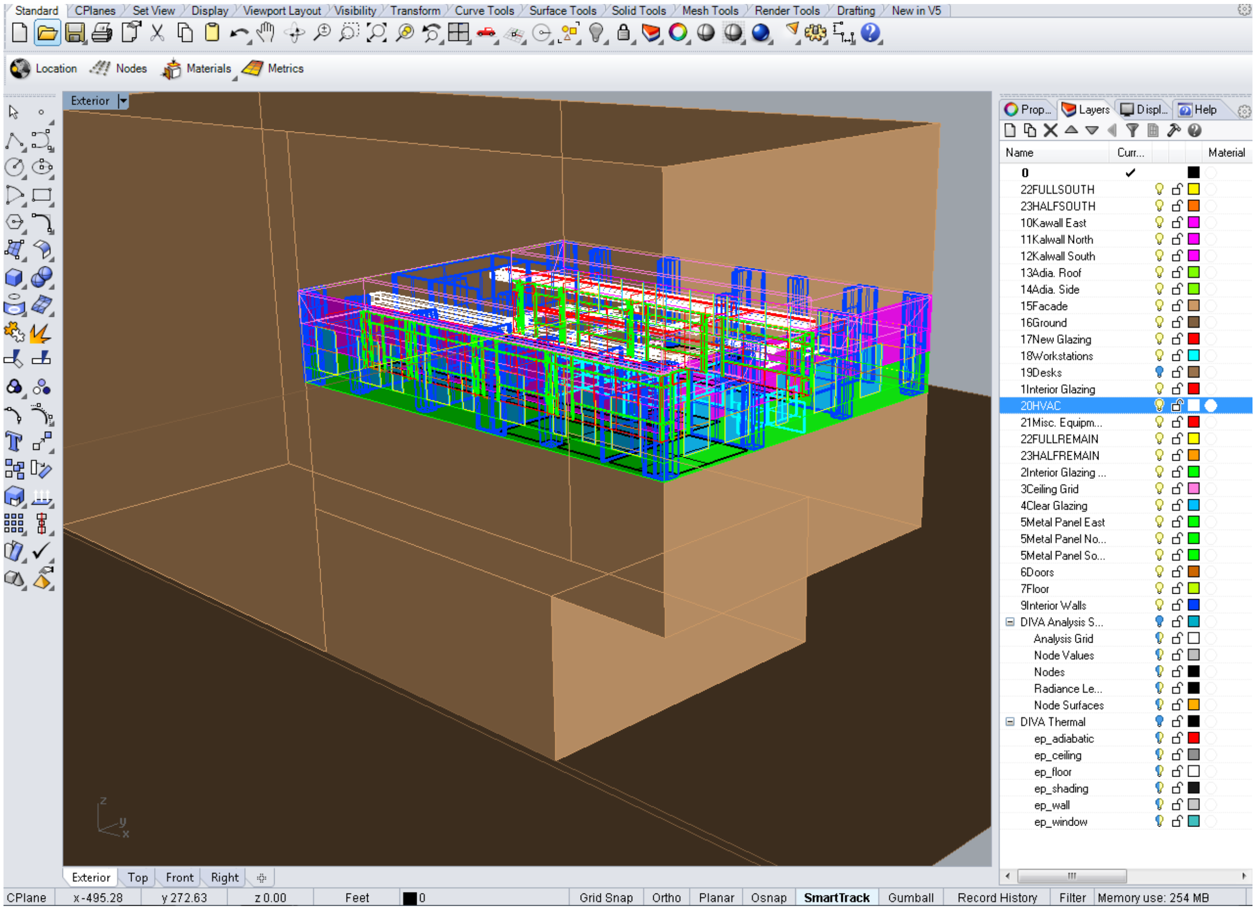
Integration between depths and breadths requires an effective platform for sharing information and prevalent model data. Without describing the computer software in excessive detail, the following methodology explains the parametric process and its impact on the final design. Simply put, by utilizing plug-ins to the *Rhino* architectural model, it is interesting to change the space for improved daylighting and see the architectural effect immediately. This workflow highlights both daylighting and mechanical aspects of the design.

STEP 1

Perform preliminary study of existing site conditions to determine daylighting characteristics of location.

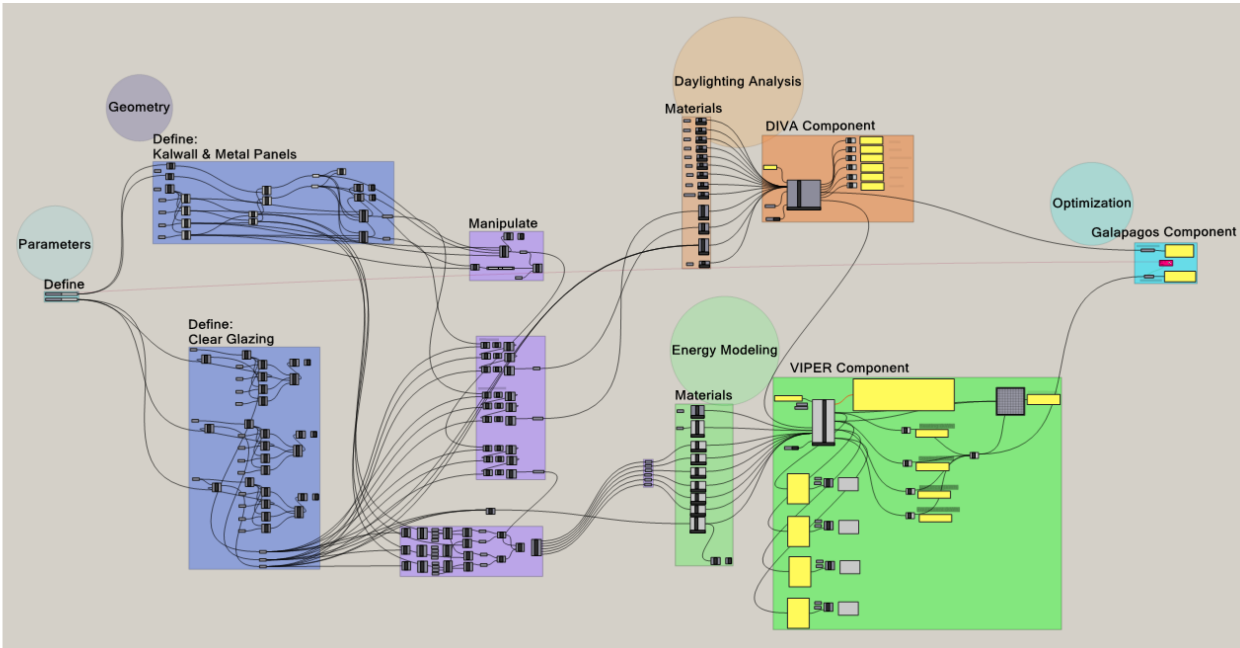
STEP 2

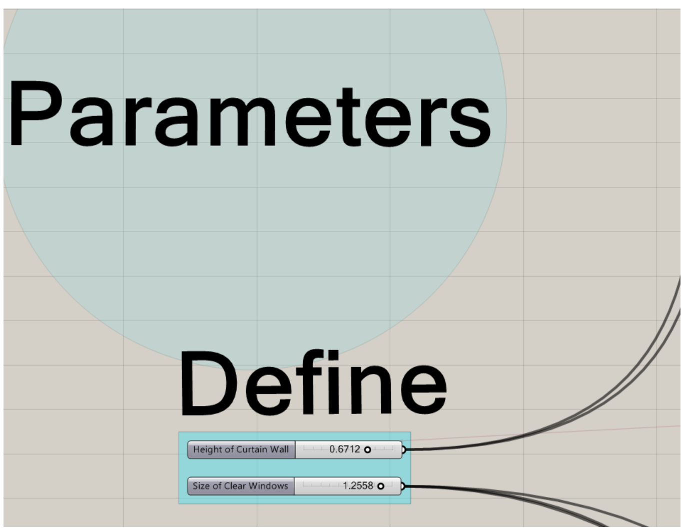
Import 3D model into *Rhino* software for daylighting analysis. Four different models are created: a full floor model (originally design), a full floor model (proposed design), simplified floor plan with detailed typical southern room (original design), and a simplified floor plan with detailed typical southern room (proposed design).

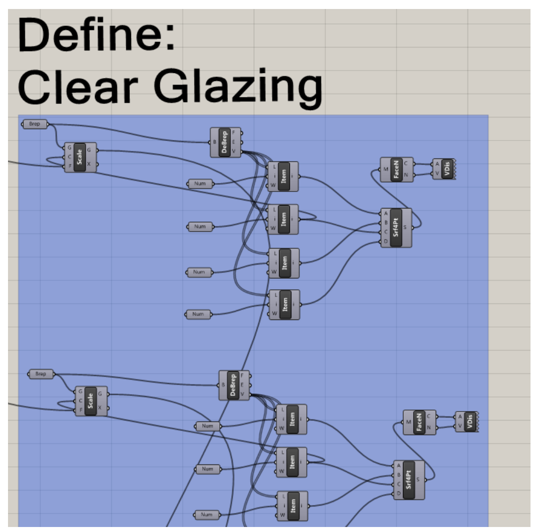


STEP 3

Construct *Grasshopper* workflow: reference architectural geometry and set up parameters. It is important for parametric modeling that the parameters are established early in the design process as it will influence the overall *Grasshopper* workflow. For this project, two main parameters were established: **size of clear windows and amount of Kalwall (defined by height from ceiling).** In this study, the size of the clear windows remained constant at 100% of the original size. The option to investigate the effect of larger or smaller glazing is available; however, due to confounding variables—to make a reasonable subjective design choice in the given time required some simplification—**only the height of the Kalwall was iteratively investigated**.

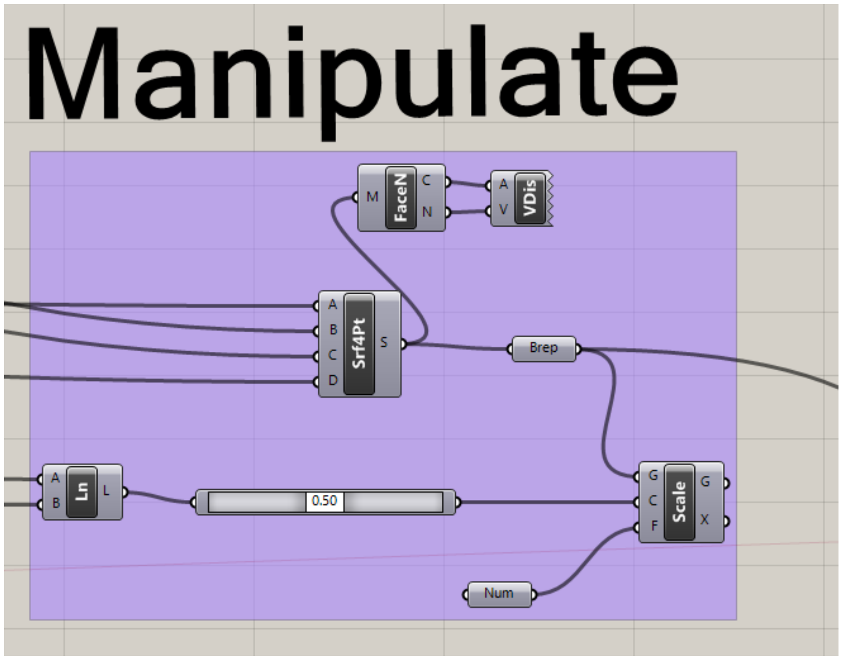


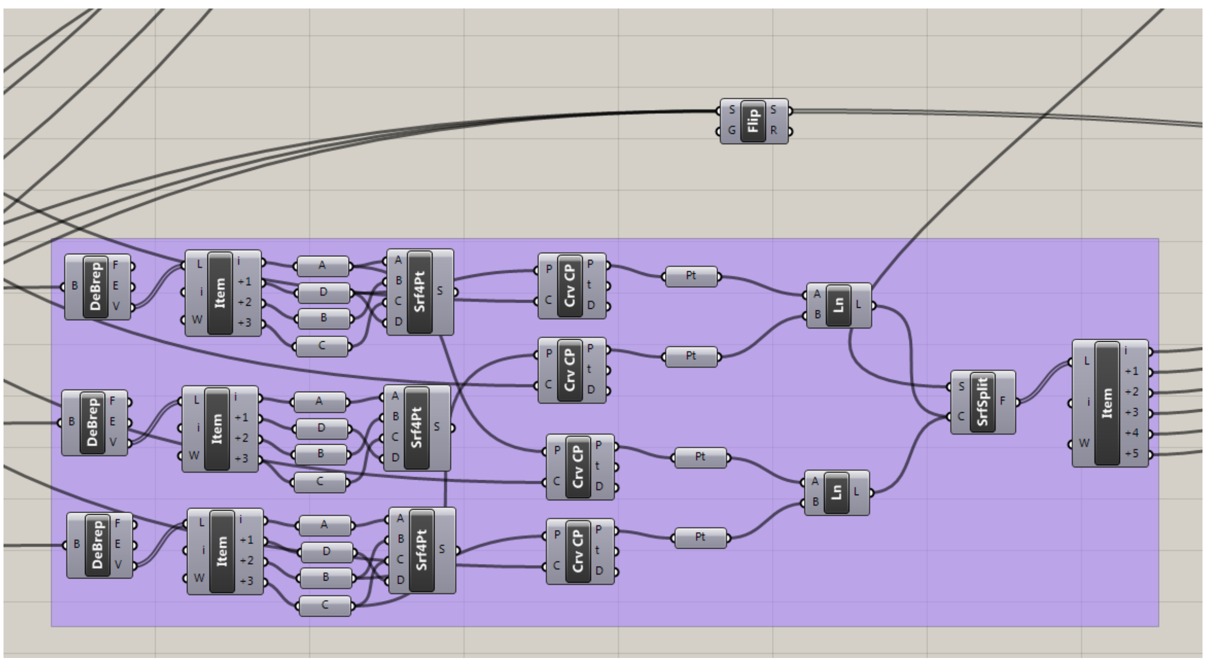




STEP 4

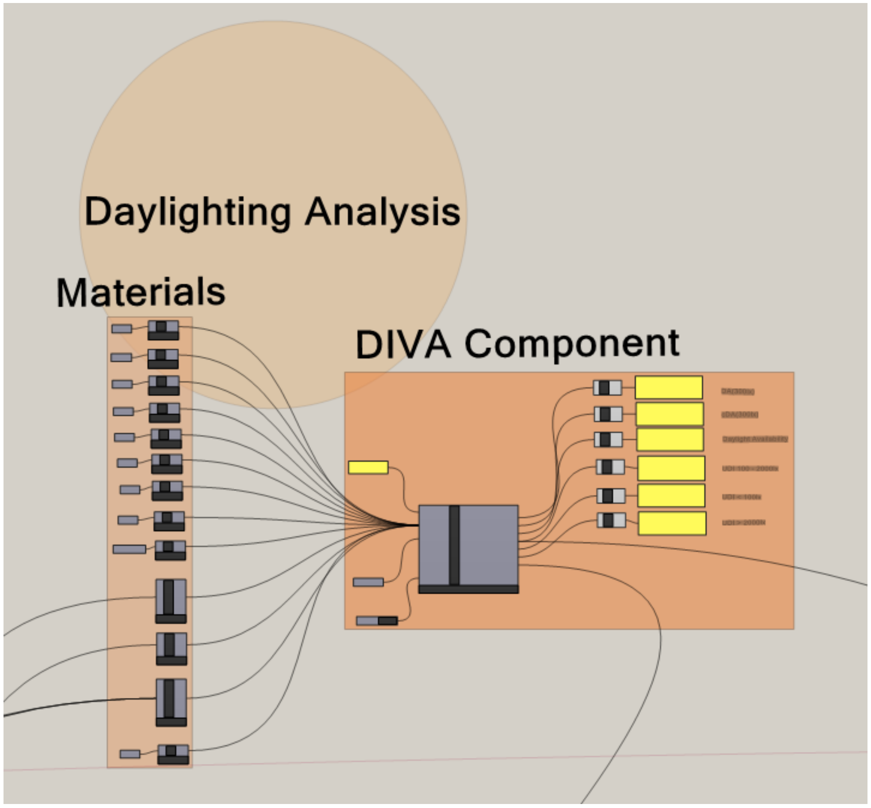
Manipulate geometry to allow for accurate parametric adjustments. These steps involve placing clear windows within their respective gap in the Kalwall and metal panel construction. Referencing the appropriate points in space allows for easy manipulation of data structure; these data structures coincide with physical geometry. Conceptually, aligning data, statistics, and lists to the modeling geometry allows parameters to accurately influence the analysis.

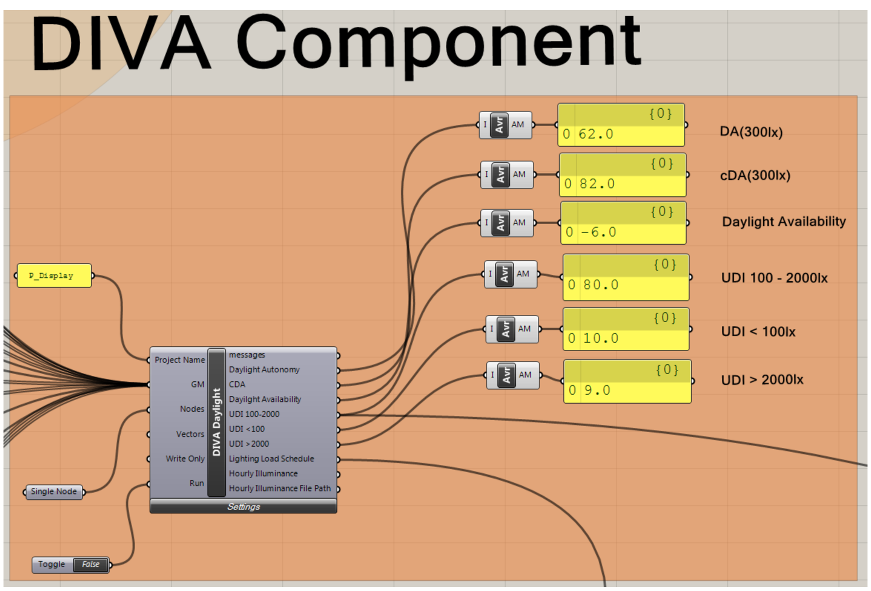




STEP 5

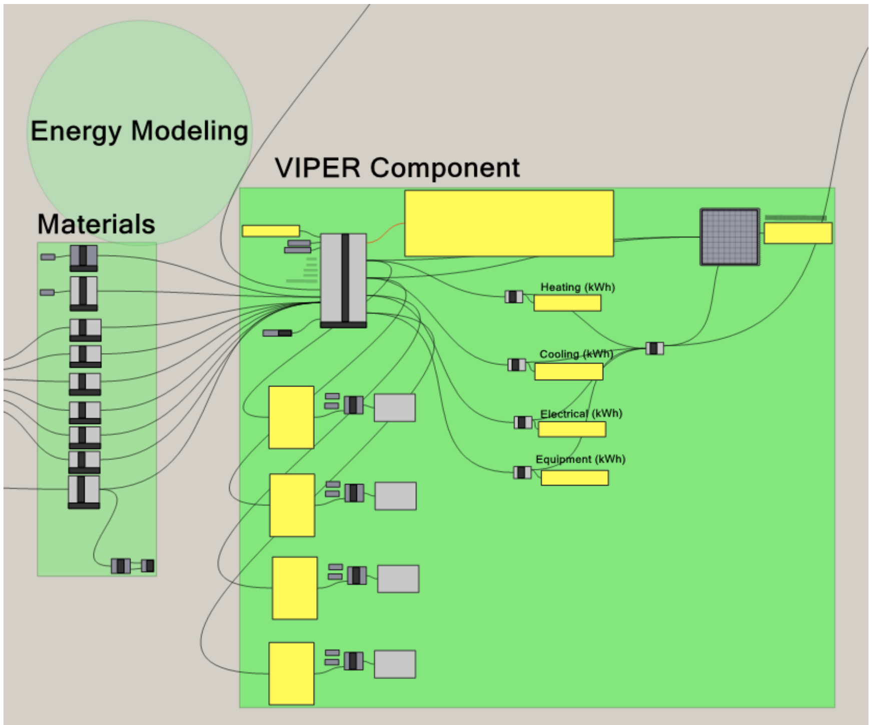
Develop daylighting analysis by assigning Radiance materials to the reference geometry. All materials written in text file with .rad format with the appropriate reflectances, transmissive values, etc. The material then pipes into the *DIVA* component where simulation parameters are established. This analysis relies primarily on climate-based metrics. The lighting load schedule (an .ill file) feeds into the *VIPER* component (step 6 below) which uses the *DIVA* data to calculate the influence of electrical energy use.

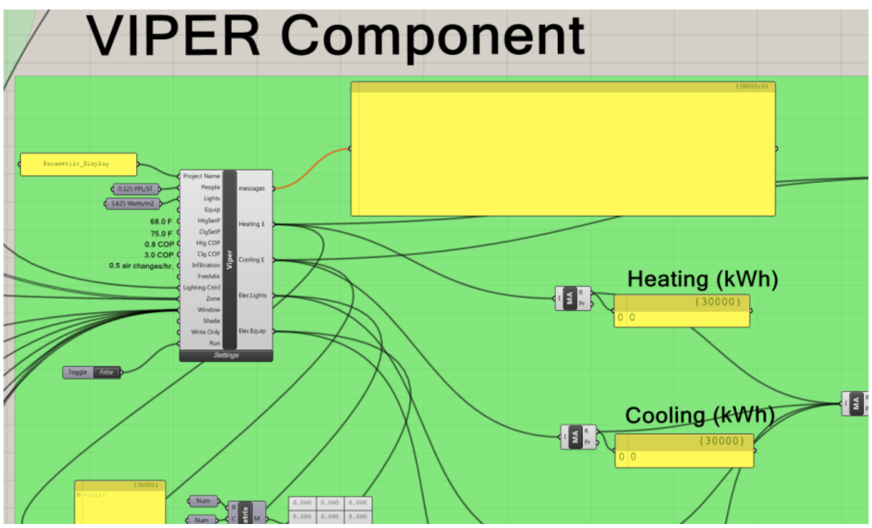




STEP 6

Similarly to the *DIVA* component, construct a *VIPER* energy analysis structure. *VIPER* uses an *Energy+* engine and thus *Energy+* materials. Default materials were used where appropriate. Material properties for Kalwall, metal panels, diffuse glazing (GL5), and clear glazing (GL8) are written in *Energy+* format (see Mechanical Breadth for more details about component setup).

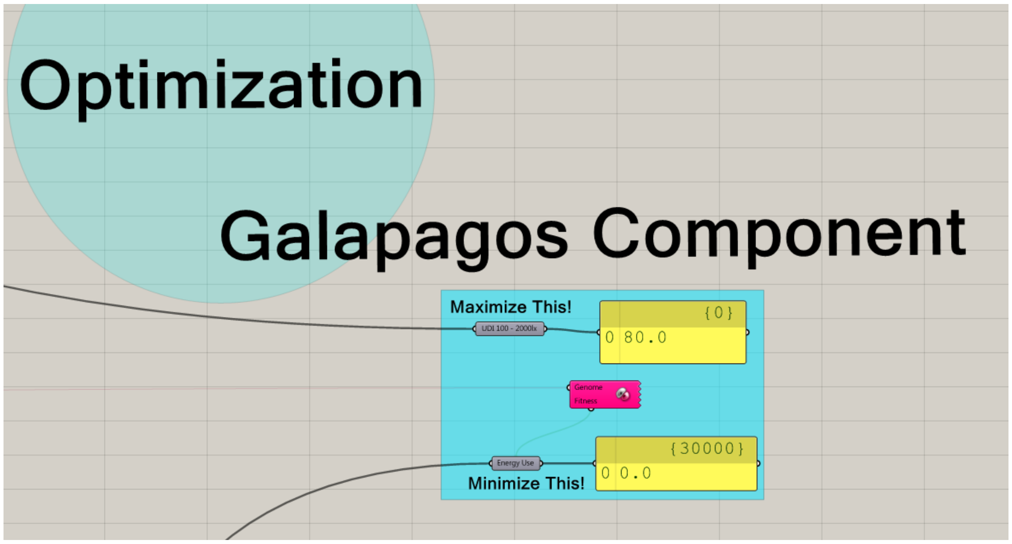




As a limitation to *VIPER*, only a single zone can be studied at a time. Reasonable assumptions had to be made to complete the study and parametrically relate several changing variables. These are limitations and assumptions are noted in the Mechanical Breadth section of this report.

STEP 7

Implement the use of an Evolutionary Optimization engine, *Galapagos*, to inform the design.



Simply put, *Galapagos* utilizes the idea of a *Fitness Landscape*. In Evolutionary Computing there exists several variables or *genes*. By changing *Gene A*, the state of the model changes and it either becomes better or worse. Basically, as *Gene A* changes, the fitness of the entire model goes up or down. However, for every value of *A*, it is possible to vary *Gene B*, resulting in better or worse *combinations of A and B*.

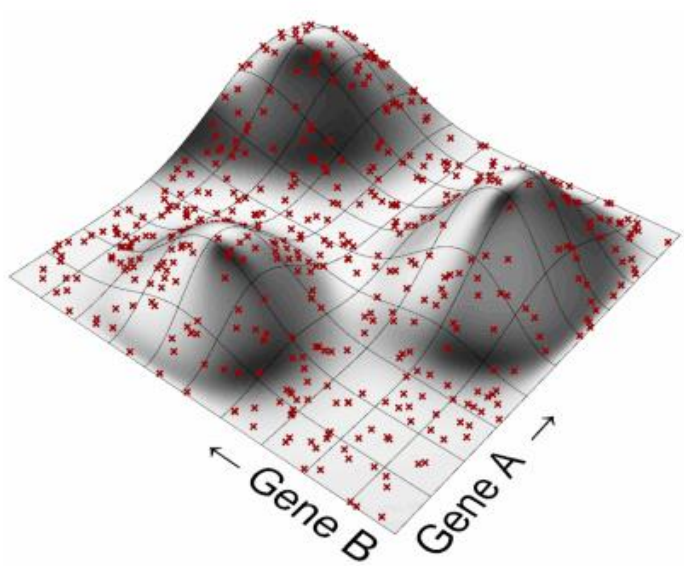


Fig. 28: Evolutionary Optimization, www.grasshopper3d.com

Every combination of A and B results in a particular fitness. This fitness is expressed as the height of the Fitness Landscape. It is the job of the solver to find the highest peak in this landscape (referenced http://www.grasshopper3d.com/profiles/blogs/evolutionary-principles).

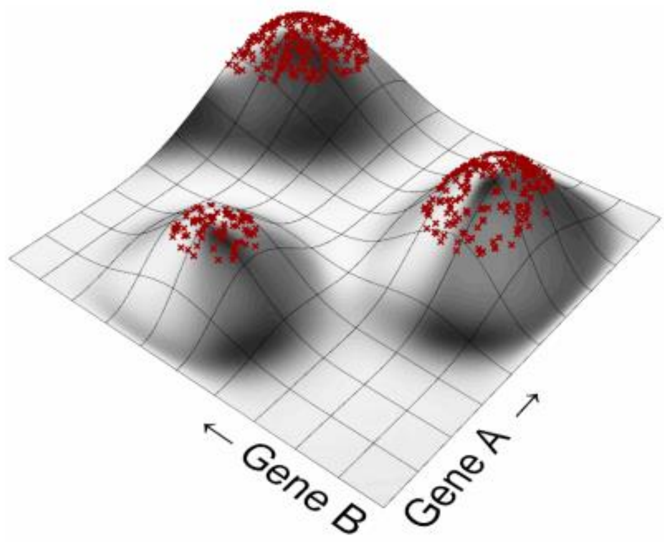


Fig. 29: Evolutionary Optimization, www.grasshopper3d.com

As a function of Evolutionary Algorithms, ensuring correct parameters and accurate daylighting and energy analysis will help derive a solution: a solution is not guaranteed using one of these solvers if "pre-defined" values are not accurate. As a result, *Galapagos* was used in preliminary investigations to calculate the amount of Kalwall needed to minimize only one value (total energy use, kWh) by changing only one parameter (percentage/height of Kalwall).

User-input is often needed to assess non-relatable variables, here UDI 100 – 2000 lux and total energy use: manually adjusting the Kalwall height parameter iteratively—hence altering the model geometry in both the *DIVA* and *VIPER* component—until an optimal solution is achieved is required. This process and results are explained later in this depth. It is important to note that the Mechanical Breadth is a large factor in this mentioned process. Integration requires overlap; a complete understanding of the breadth and depth is accomplished by not dissecting the parts but instead describing them simultaneously.

STEP 8

Once optimal height of Kalwall is determined, model the corresponding geometry in the full floor model. Run a *DIVA* for *Rhino* simulation (different than *DIVA* in *Grasshopper*). *DIVA* in *Rhino* has more options including shading and lighting controls but does not support parametric design. Finally, compare data between the original and proposed design.

EXISTING CONDITIONS

UPenn's new NBS building is located in Philadelphia, PA and faces southwest by approximately 5° (from due south). This orientation mandates a southern façade treatment—seen by the unique sunscreen.

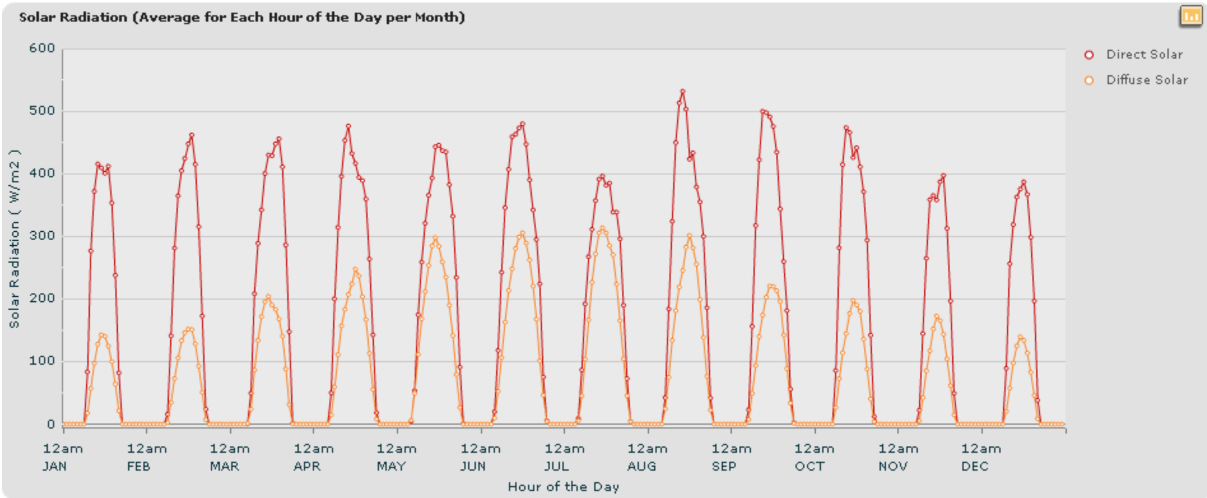
Directly to the north is the existing Leidy Laboratory which has little effect on the East Block office space. Immediately to the east of the building site is a large urban park, Kaskey Park. Trees in this region do not greatly affect the sun's impact on the building façade. Current landscaping design does have 20' – 30' trees located near the southeast corner of the site. For the purposes of this study, the one or two trees that would interfere with direct sunlight would be moved to a different location nearby.

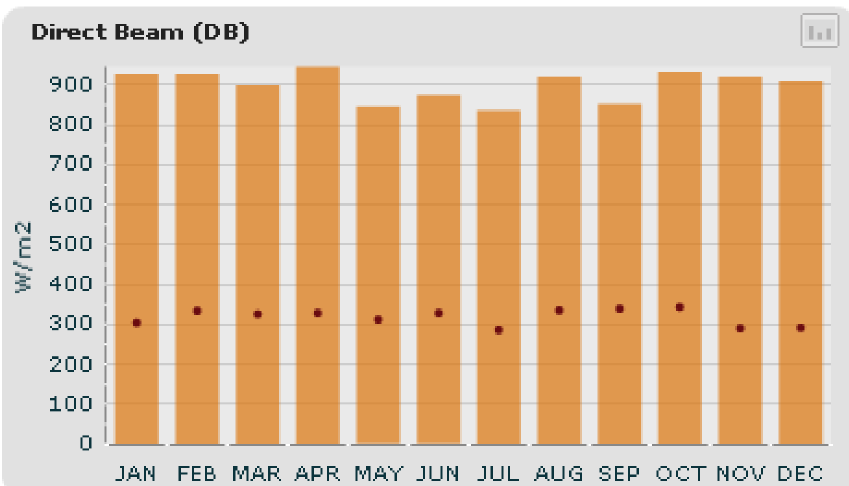
It is a goal to not only design the public corridors for effective daylighting but also design occupied office space for excellent daylighting. The office space has walls along the south, east, and west façade. It is advantageous to consider the architectural changes mentioned.

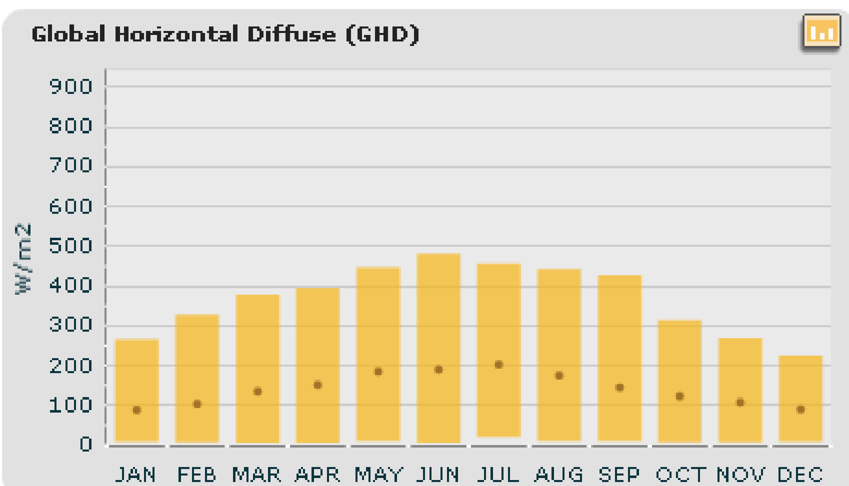
Fig. 30: Existing site, www.google.com

COMFEN

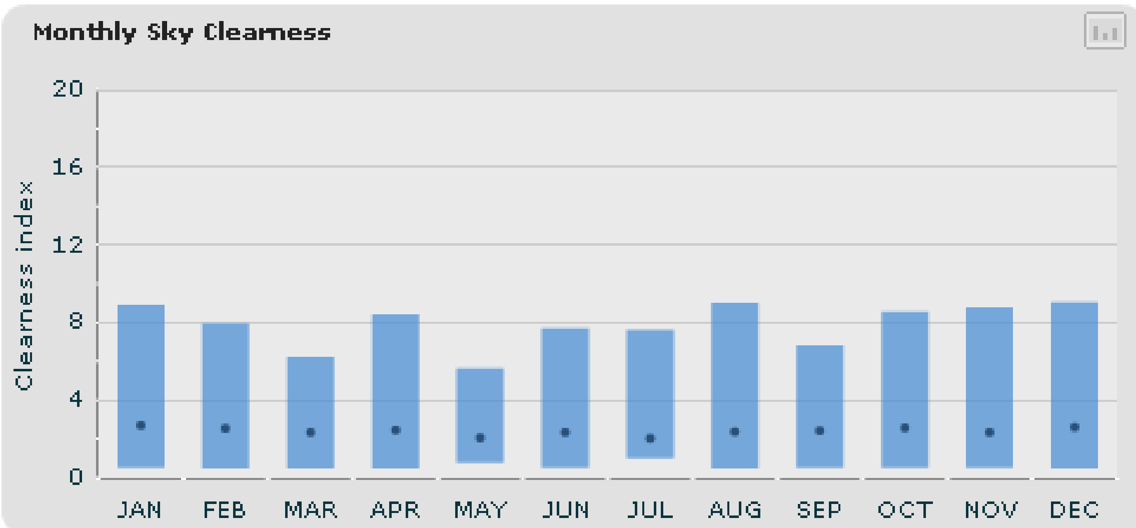
Design conditions for Philadelphia, PA are displayed in graphs generated by LBNL's COMFEN.







The above graphs illustrate that a façade facing directly south receives between 800 to 900 W/m^2 of direct solar irradiation steadily throughout the year. Slightly more diffuse light occurs during the summer months. Kalwall is most effective with direct sun but is also useful with diffuse light. It is likely that the Kalwall panels are most effective in the summer months and will diffuse light comfortably into the open-office space.

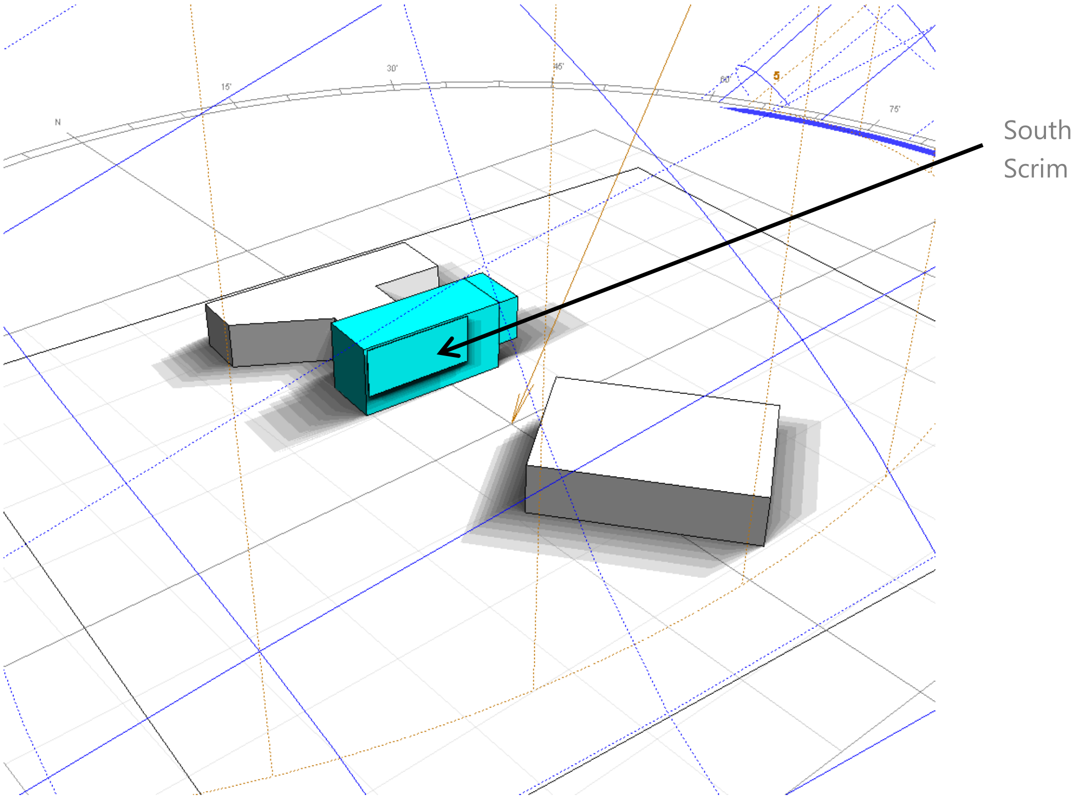


An investigation of sky clearness shows moderately steady clearness throughout the year, around a clearness index of 8. Philadelphia can be approximated to have 93 sunny days per year, 112 partly cloudy days per year, and 160 cloudy days per year. Kalwall is reported to perform well even in overcast conditions; the application of Kalwall in this location is appropriate and warrants a thorough analysis.

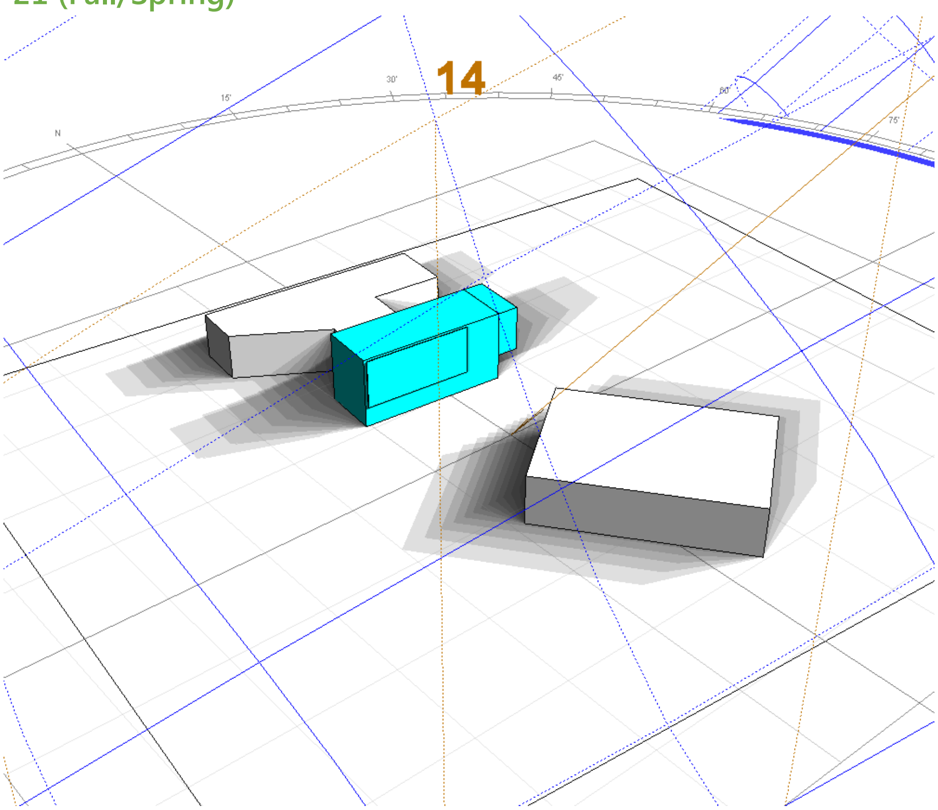
ECOTECT

Contextual shading and solar irradiation striking the façade of a building is an informative and telling statistic for daylighting analysis. Here, *Ecotect* is used to evaluate site shadowing and solar irradiation (as it relates to the solar radiation charts above). Below is the shadow range (snapshots every hour throughout the day) for three days of the year: June 21, September 21, and December 21. The view is of the southern façade (NBS Building colored in blue).

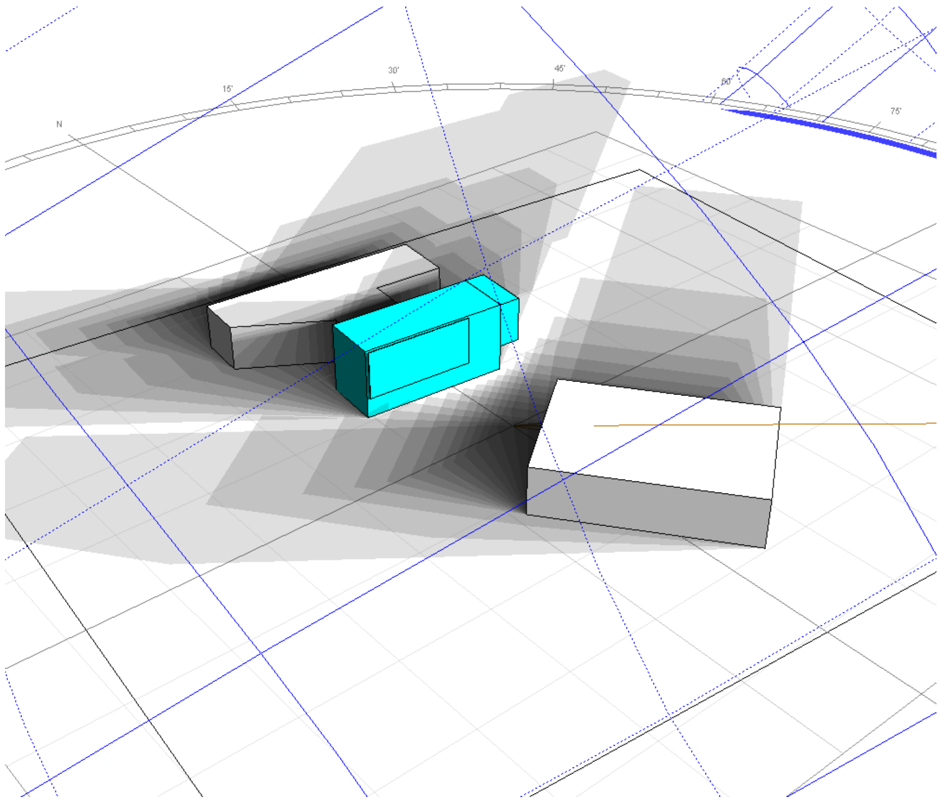
June 21 (Summer)



September 21 (Fall/Spring)



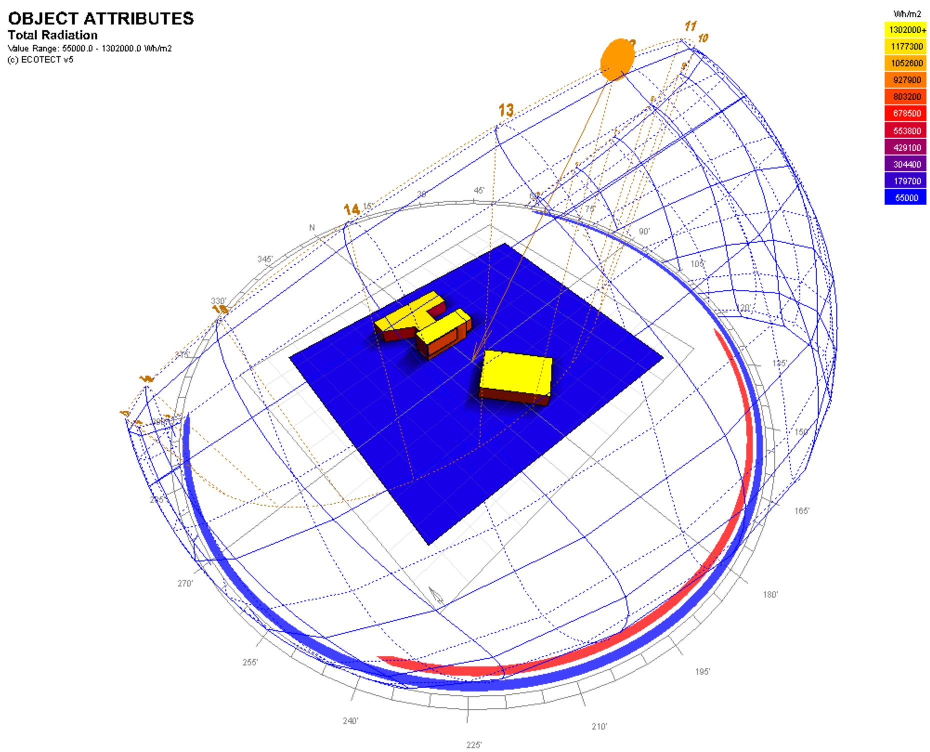
December 21 (Winter)

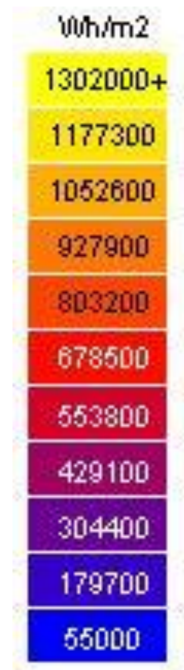


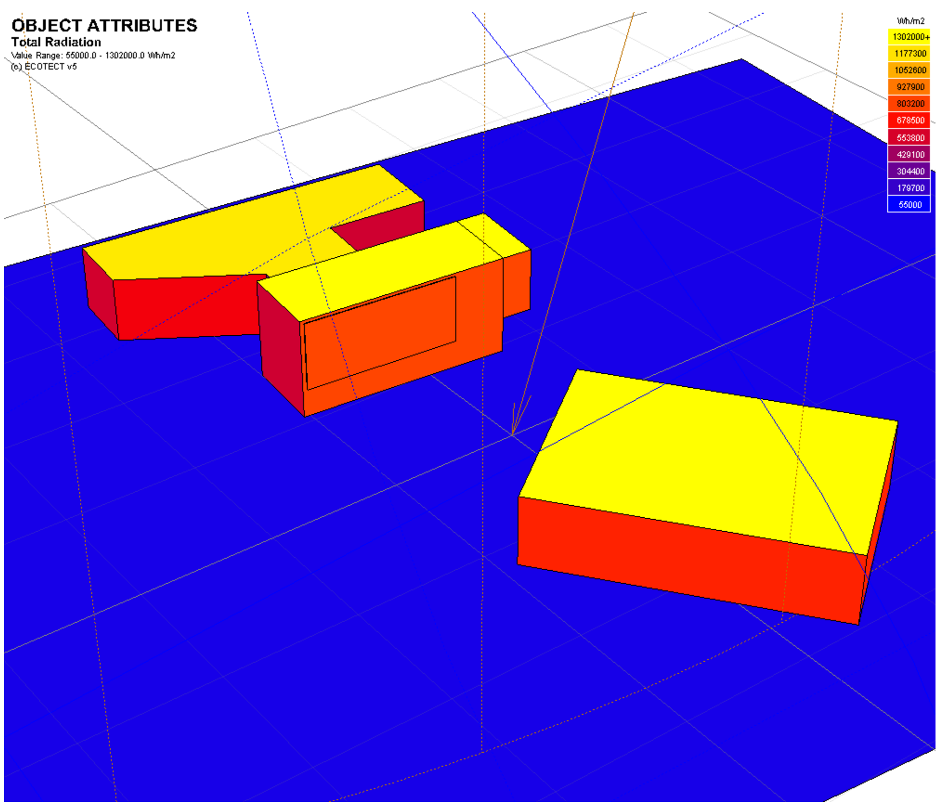
As seen above, contextual shading is rarely present on the southern façade of the building. Even at very low profile angles, as in the winter, the southern façade is exposed to the direct sun often. The east façade (right of the blue building) receives early morning sun. The north side receives primarily diffuse daylighting; the Kalwall on the north side is shaded by the building itself (some direct sun in summer months strikes north façade).

Displayed in the incident solar radiation map below, the southern facade experiences approximately 930 kWh/m^2 of annual solar radiation. The east facing side of the office has 500 kWh/m^2 of incident solar radiation while north side has less, as expected: 310 kWh/m^2. It is anticipated that the Kalwall will perform well along the southern façade as the material as the potential to diffuse plenty of direct sun. The north and east sides are more limiting in the sun potential however, early morning sun is important because of low angle sun (however, better energy performance along north façade). A diffusing panel like Kalwall mitigates issues of sunlight penetration. Any sun penetration is identical between the original and proposed design as the size and properties of the clear glazing remains constant.

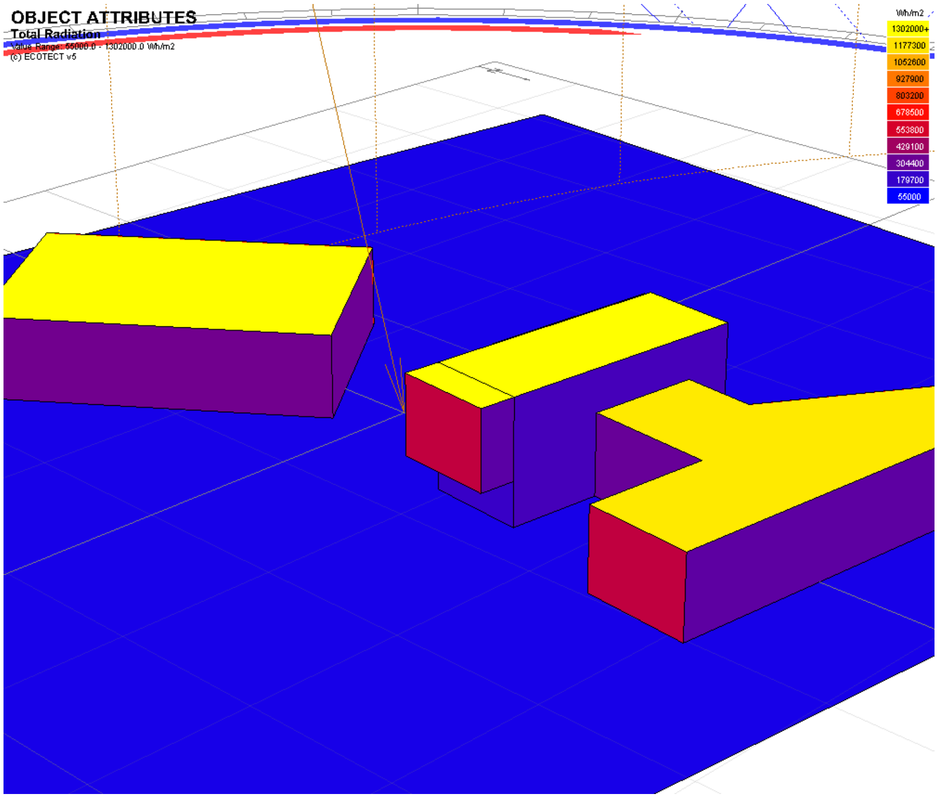
South Façade

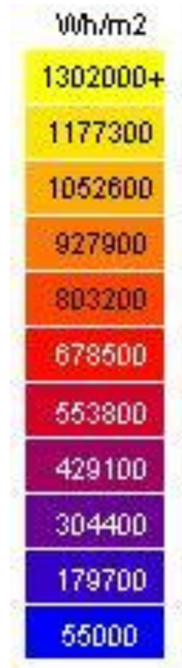






East and North Facades





ORIGINAL DESIGN

INTRODUCTION

Referring to the architectural breadth earlier in this report, the existing design utilizes clear and diffuse glazing within a metal panel curtain wall system as the primary method of daylighting. Interior walls constructed of glazing increase daylight levels further into the space. Diffuse glazing (GL5) sits both below and above the clear windows (GL8). Noted later, the portion of diffuse glazing below the clear window (below a workplane height of 2.5 feet) is not beneficial for daylighting purposes and thus removed.

Fig. 31: East Block renderings, courtesy of SmithGroupJJR

Full height walls limit graduate students' views and personal connections to natural light; these are also removed.

MATERIALS + SETUP

For accurate *DIVA* calculations, Radiance materials are created to mimic the specified construction. Diffuse glazing is a trans material with 49% visible transmittance. Clear glazing is glass material with 38% visible transmittance. Interior ceilings, walls, and floor are 80%, 50%, and 20% reflective respectively. Interior glazing has a visible transmittance of 98% while the exterior metal panels are 40% reflective. A ground with 20% reflectivity and entire building mass façade (35% reflective) is constructed and included in the model.

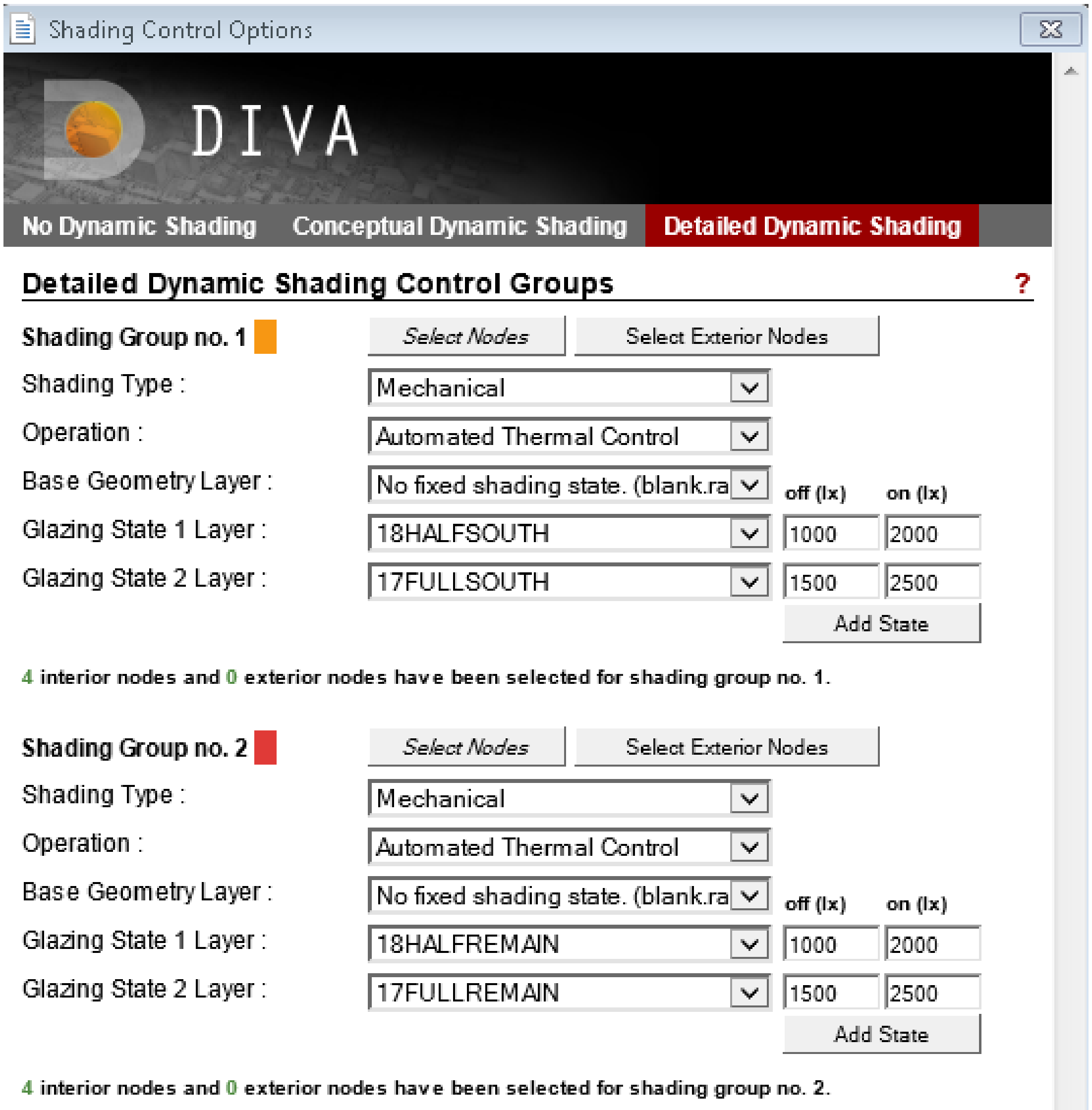
There exist seven node groups within the original design simulation. These nodes are 2.5' above the finished floor and have a grid spacing of 2'. An occupancy file between 8 a.m. to 6 p.m. is used: spaces are occupied a total of 3650 hours per year.

Two automatically controlled shading conditions are implemented on top of the base case (fully open window). Roller shades are Eggshell (model 1566) 59% reflective (3% openness factor) MechoShades modeled as a trans material. The shades are controlled using sensor points located where a person would sit and work. Two shading groups exist for simplification.

All southern shades are controlled using a typical office sensor point (**4 orange nodes**). The east and northern shades are controlled using a typical north office sensor point (**4 red nodes**). Creating shading groups for every office would exponentially complicate the model; the important factor is that the shading conditions stayed constant between the original design simulation and the proposed design simulation.

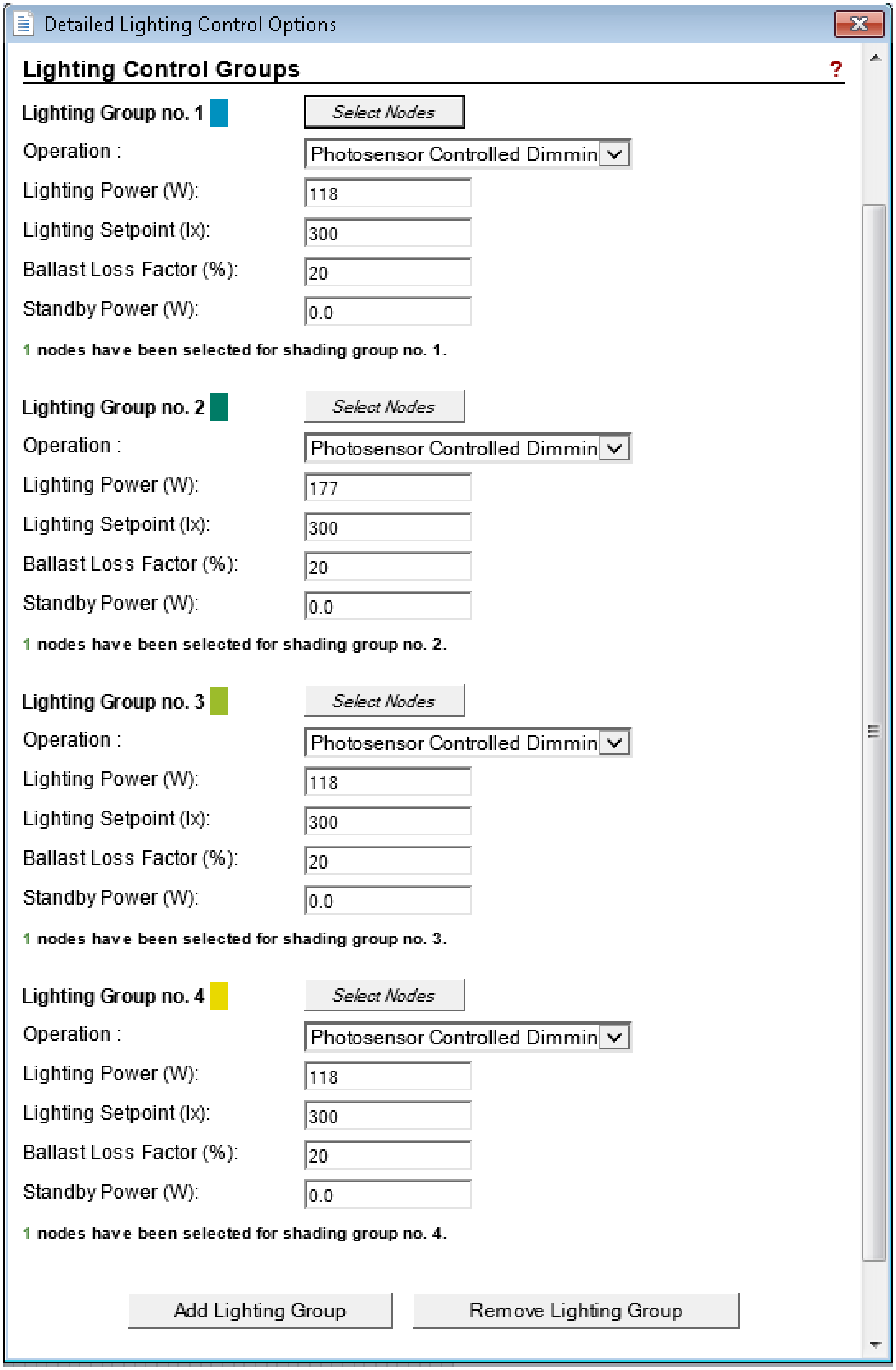
As seen below, shades come down half way when the chosen node point receives more than 2000 lux. The shades come down completely when that same point receives more than 2500 lux.

Lighting controls use a photo-sensor controlled dimming system. Here, the lighting system is ideally commissioned; photocells dim (open-loop) the active lighting until the total workplane illuminance (daylight & electric light) reaches the target illuminance. The minimum light output is 1%. The lighting can be switched on/off by the occupant at the door.

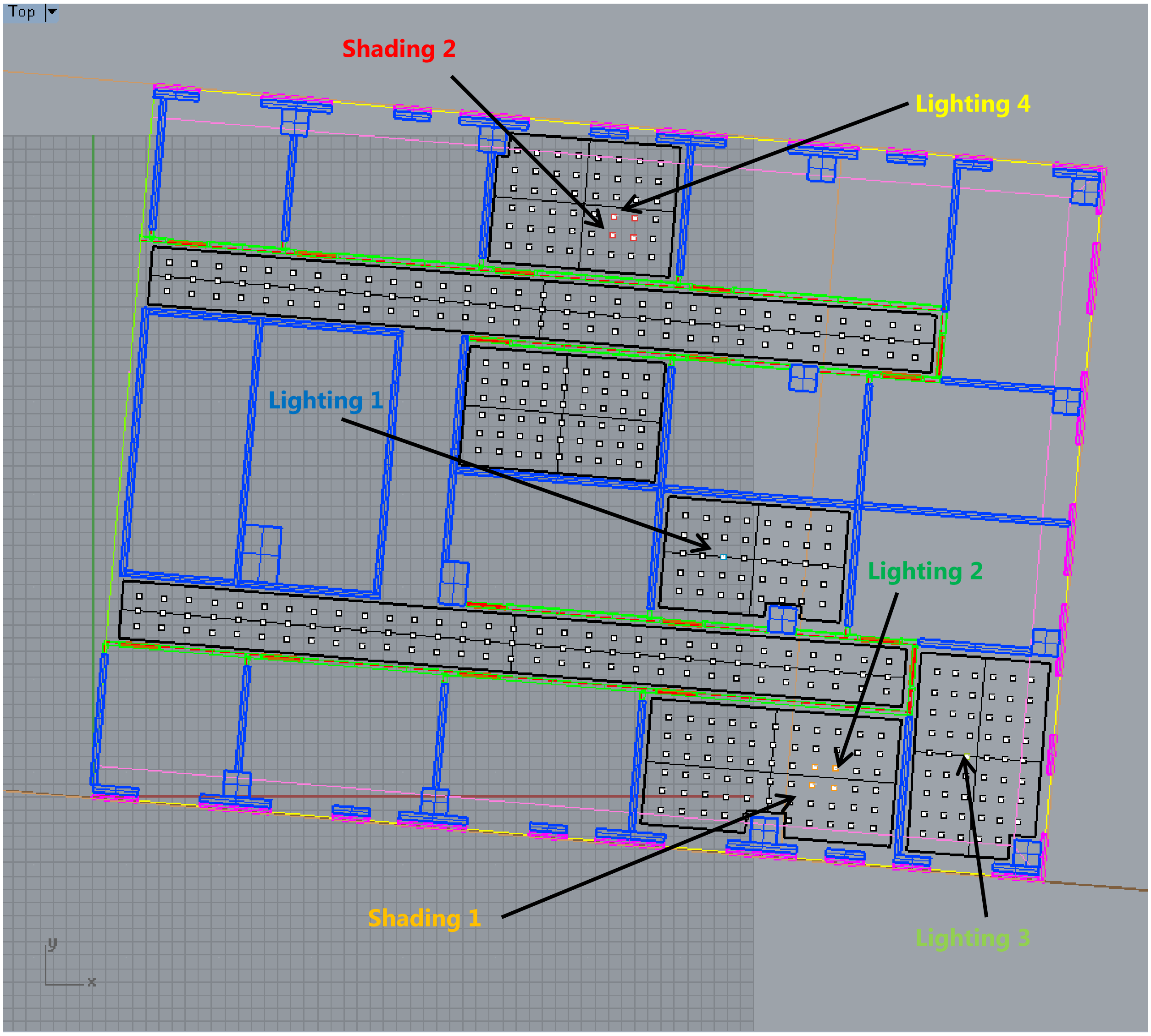


Every space utilizes the lighting wattage as specified in the fixture schedule. DIVA assumes that all watts consumed provide the target lux at the selected nodes (such as at nighttime). Four lighting zones are used in both the original and proposed design. These zones include an interior office space along southern corridor (**blue node**), typical southern facing faculty office (**teal node**), southeast corner faculty office (**green node**), and typical northern facing faculty office (**yellow node**).

Identical shading and lighting controls are used in both the original design and proposed design simulations. This eliminates confounding variables and allows for a reasonable comparison between the two situations. Likewise, all material properties remained identically expect where new materials such as Kalwall is introduced.


Detailed Lighting Control Options
Lighting Control Groups
?
Lighting Group no. 1
Select Nodes
Operation :
Photosensor Controlled Dimmin
Lighting Power (W):
118
Lighting Setpoint (lx):
300
Ballast Loss Factor (%):
20
Standby Power (W):
0.0
1 nodes have been selected for shading group no. 1.
Lighting Group no. 2
Select Nodes
Operation :
Photosensor Controlled Dimmin
Lighting Power (W):
177
Lighting Setpoint (lx):
300
Ballast Loss Factor (%):
20
Standby Power (W):
0.0
1 nodes have been selected for shading group no. 2.
Lighting Group no. 3
Select Nodes
Operation :
Photosensor Controlled Dimmin
Lighting Power (W):
118
Lighting Setpoint (lx):
300
Ballast Loss Factor (%):
20
Standby Power (W):
0.0
1 nodes have been selected for shading group no. 3.
Lighting Group no. 4
Select Nodes
Operation :
Photosensor Controlled Dimmin
Lighting Power (W):
118
Lighting Setpoint (lx):
300
Ballast Loss Factor (%):
20
Standby Power (W):
0.0
1 nodes have been selected for shading group no. 4.
Add Lighting Group
Remove Lighting Group

FLOOR PLAN SHADING AND LIGHTING CONTROL SETUP



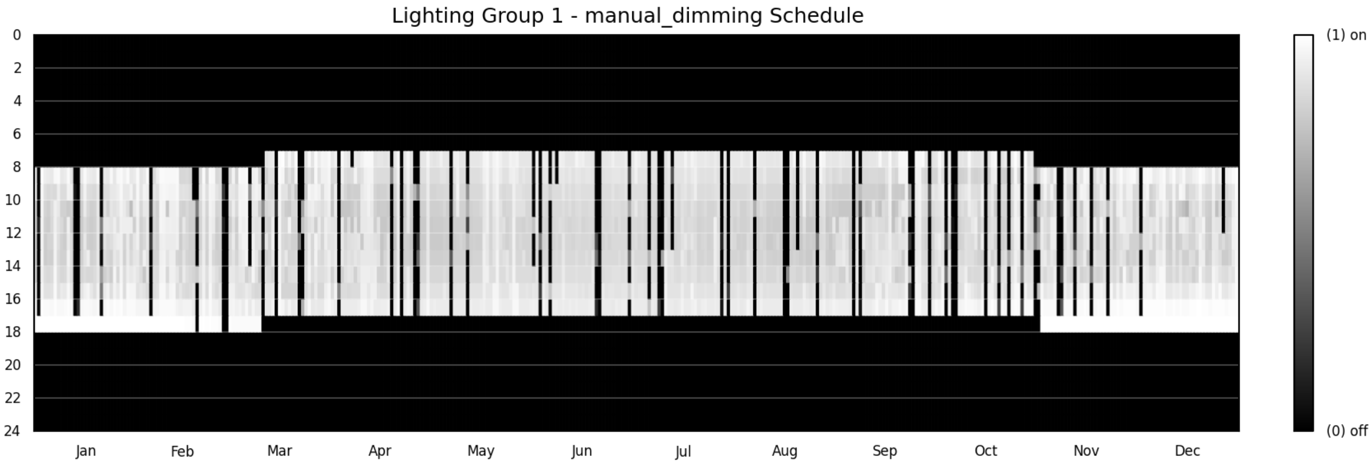
RESULTS

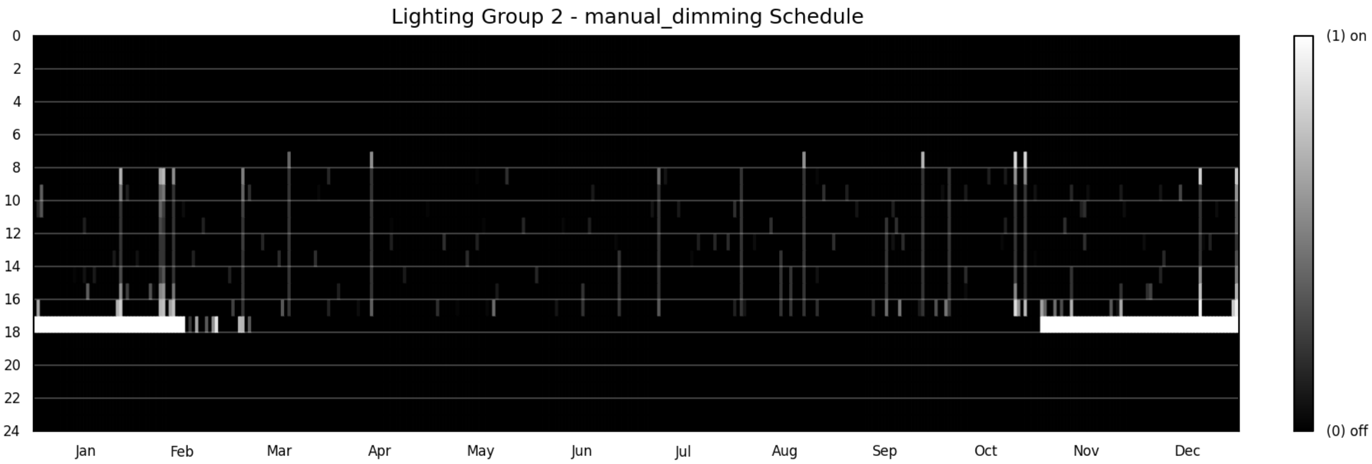
Several different daylighting metrics define the base case for accurate comparisons. Below the node groups are defined and the metrics reported. Both continuous daylight autonomy (cDA_{300lux}) and Spatial Daylight Autonomy (sDA_{300lux}) provides useful information for comparison. Useful Daylight Illuminance 100 – 2000 lux (UDI) is used in the parametric model and reported for a typical southern office space only (see Proposed Design section below). This metric was not run for the full floor plan as the two mentioned metrics provide a solid base for comparison.

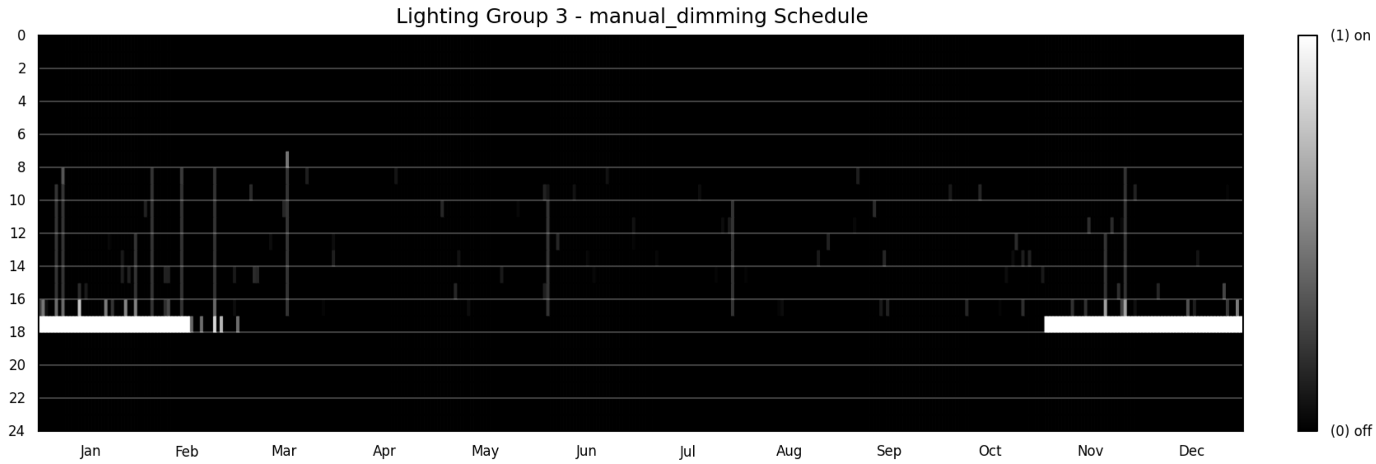
LIGHTING GROUPS

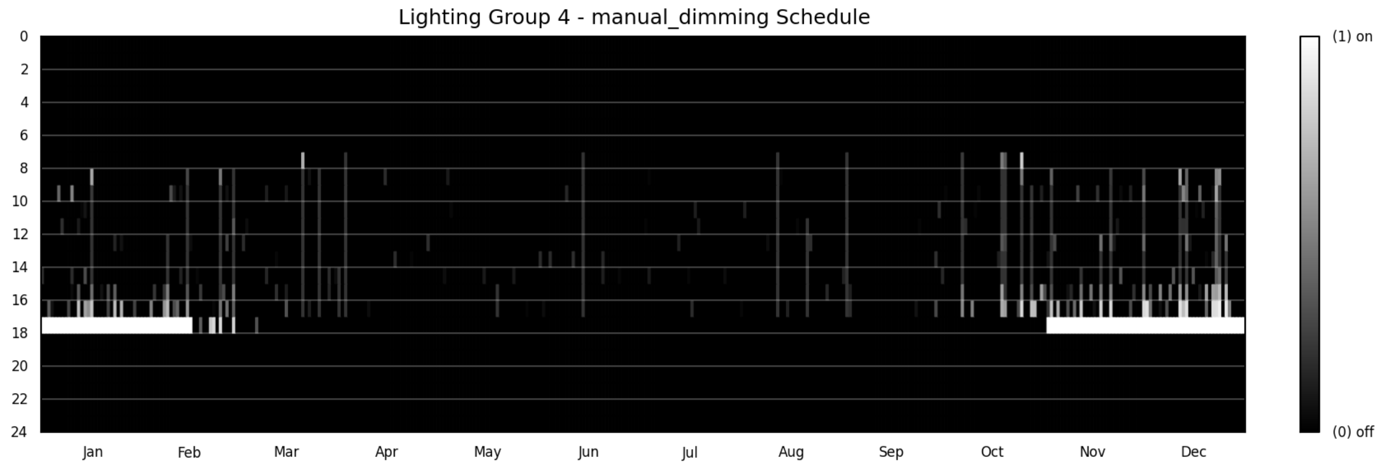
Using the established parameters mentioned, the electric lighting use is reported. All groups are controlled using a manual on/off switch; the dimming system is an ideally commissioned photosensor-control with a ballast loss factor of 20%.

Annual Electric Lighting Use	
Lighting Group	Energy Use
Lighting Group 1	330.5 kWh
Lighting Group 2	32.6 kWh
Lighting Group 3	16.6 kWh
Lighting Group 4	25.5 kWh





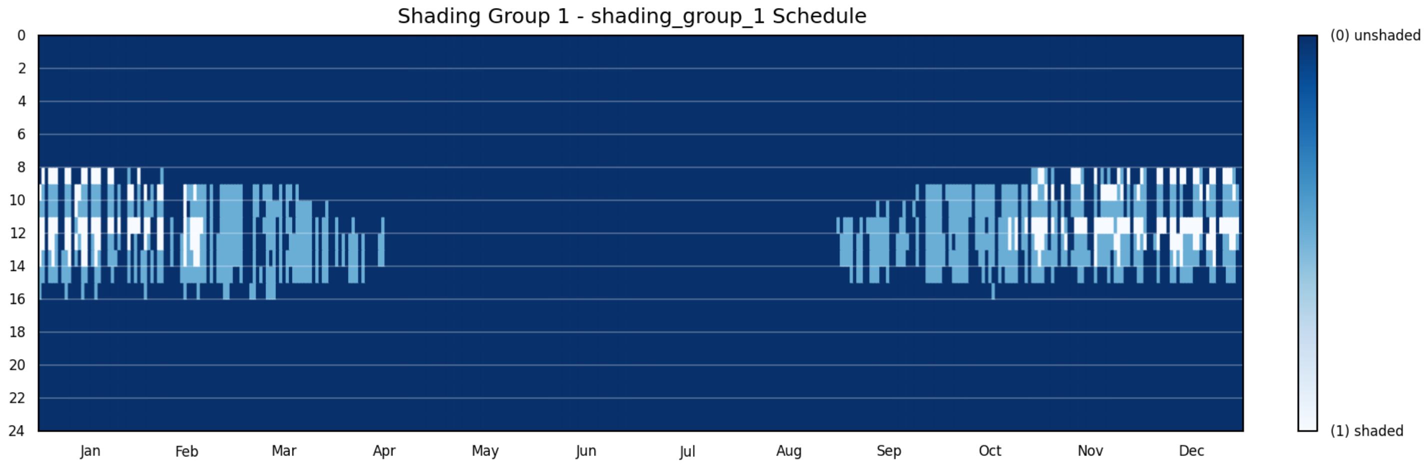


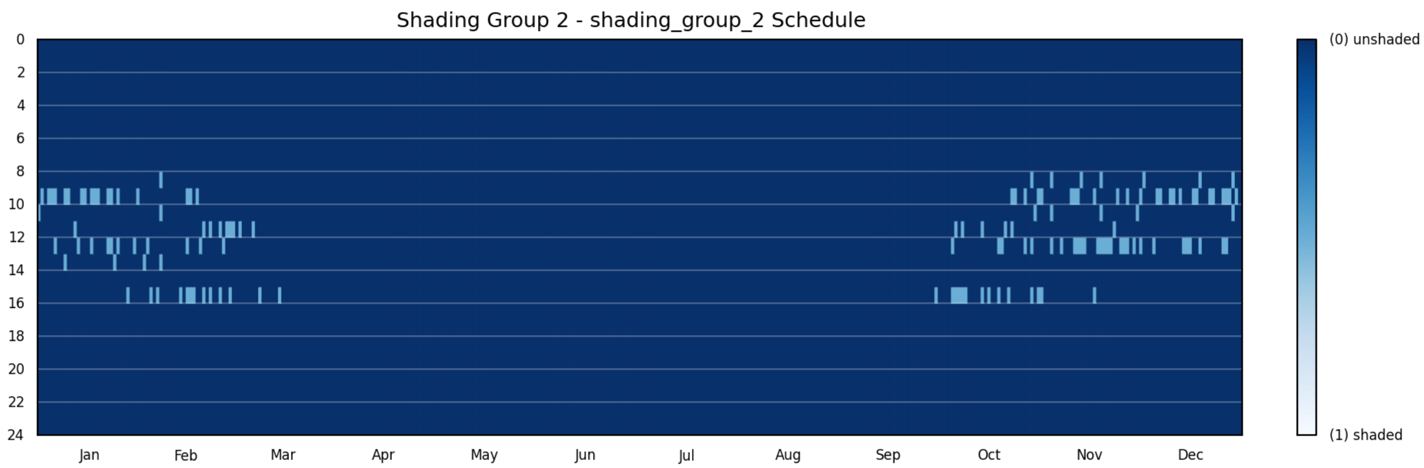


SHADING GROUPS

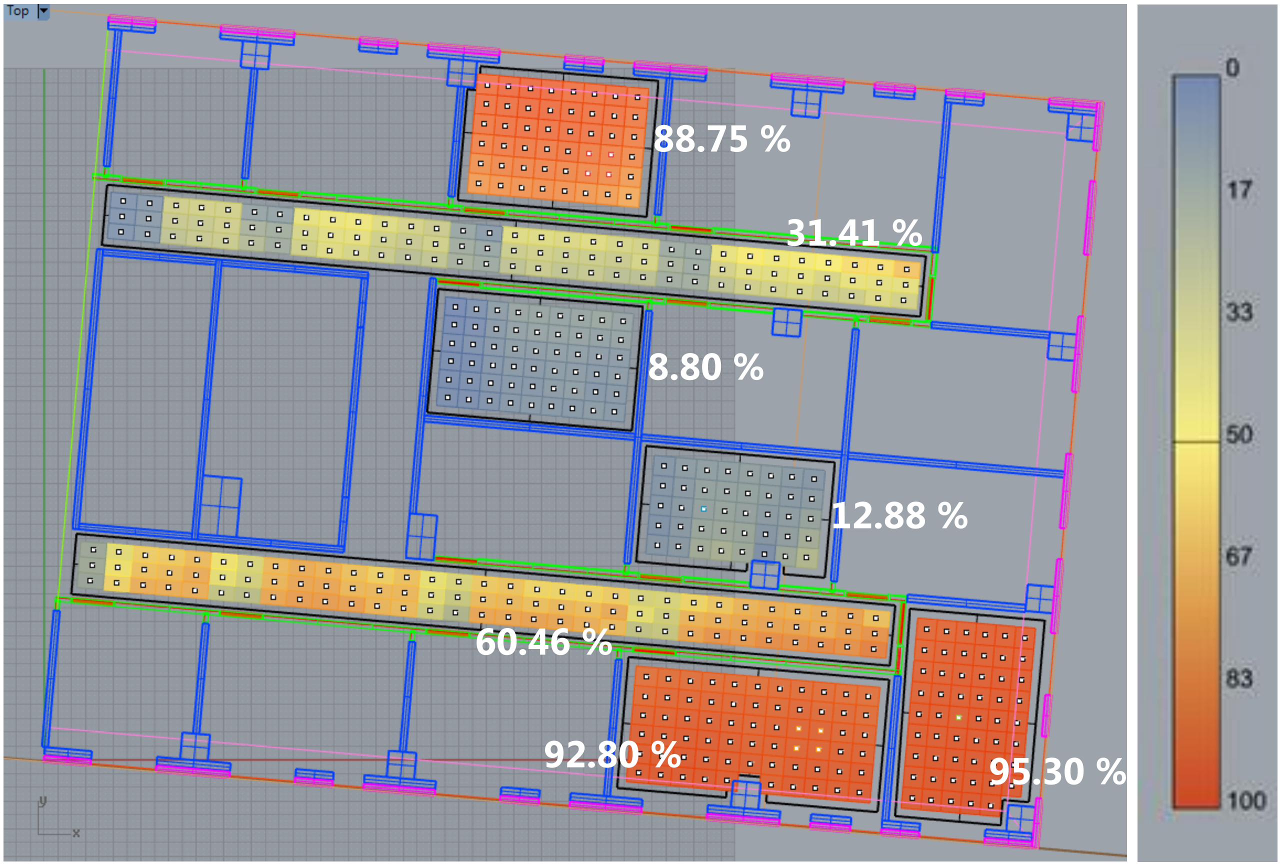
Shading group 1 (south) is open 76% of the occupied hours. Shading group 2 (east and north) is open 96% of the occupied hours. Conservative values were chosen as the set-points for these shading groups; the time open does seem high but assuming the calculation engine of *DIVA* is correct, these are the correlated shading schedules.

In the graphs below, dark blue represents the open condition. White represents shades fully down and light blue represents shades halfway down. As seen, shades are used primarily along the southern facade in the winter months when the profile angle is low and sun penetration can occur deep into the space.


Shading Group 1 - shading_group_1 Schedule
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
(0) unshaded
(1) shaded

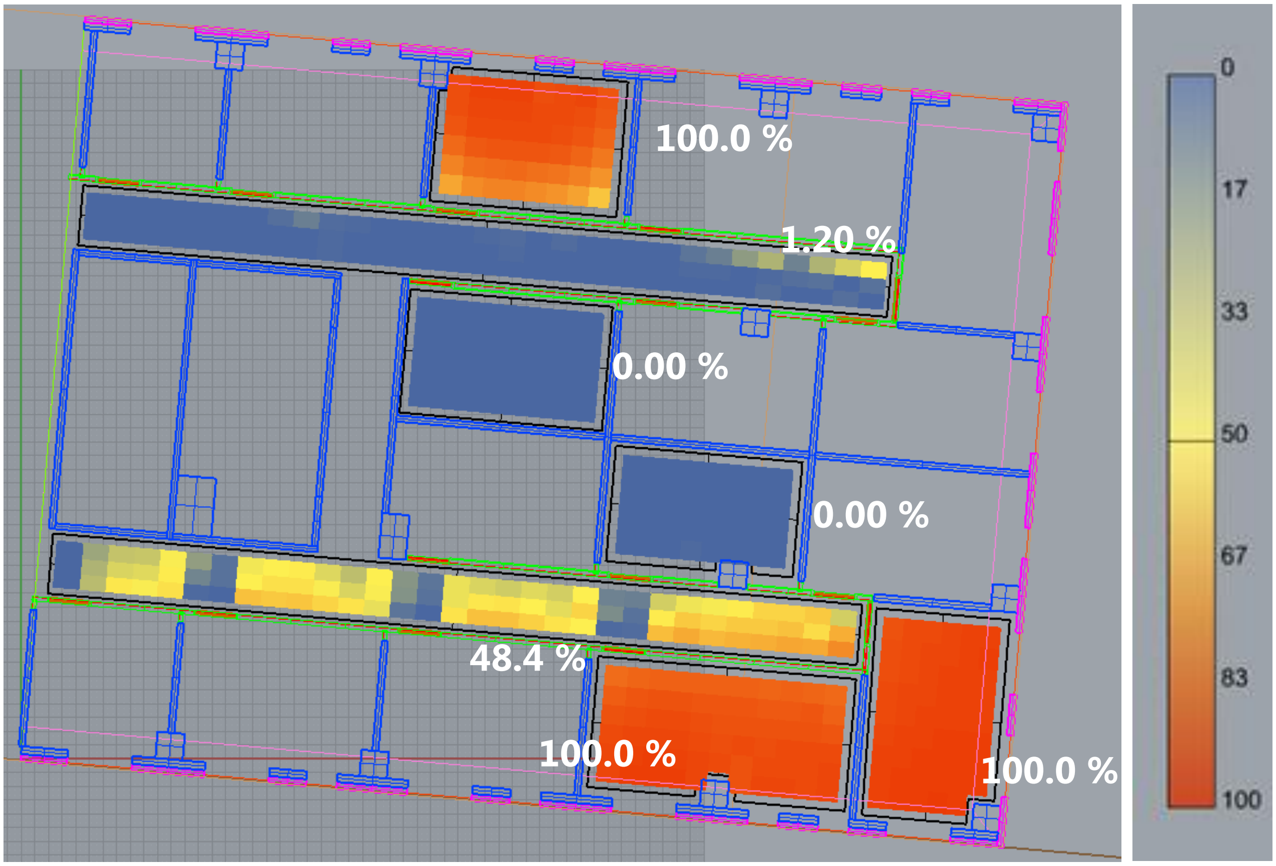

Shading Group 2 - shading_group_2 Schedule
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
(0) unshaded
(1) shaded

CONTINOUS DAYLIGHT AUTONOMY 300 LUX (ORIGINAL DESIGN)



Continuous Daylight Autonomy 300 lux	
Node Group (Zone)	cDA (%)
1 South Grad Office	12.88 %
2 South Corridor	60.46 %
3 South Faculty Office	92.80 %
4 Southeast Faculty Office	95.30 %
5 North Grad Office	8.80 %
6 North Corridor	31.41 %
7 North Faculty Office	88.75 %

SPATIAL DAYLIGHT AUTONOMY 150 LUX (ORIGINAL DESIGN)

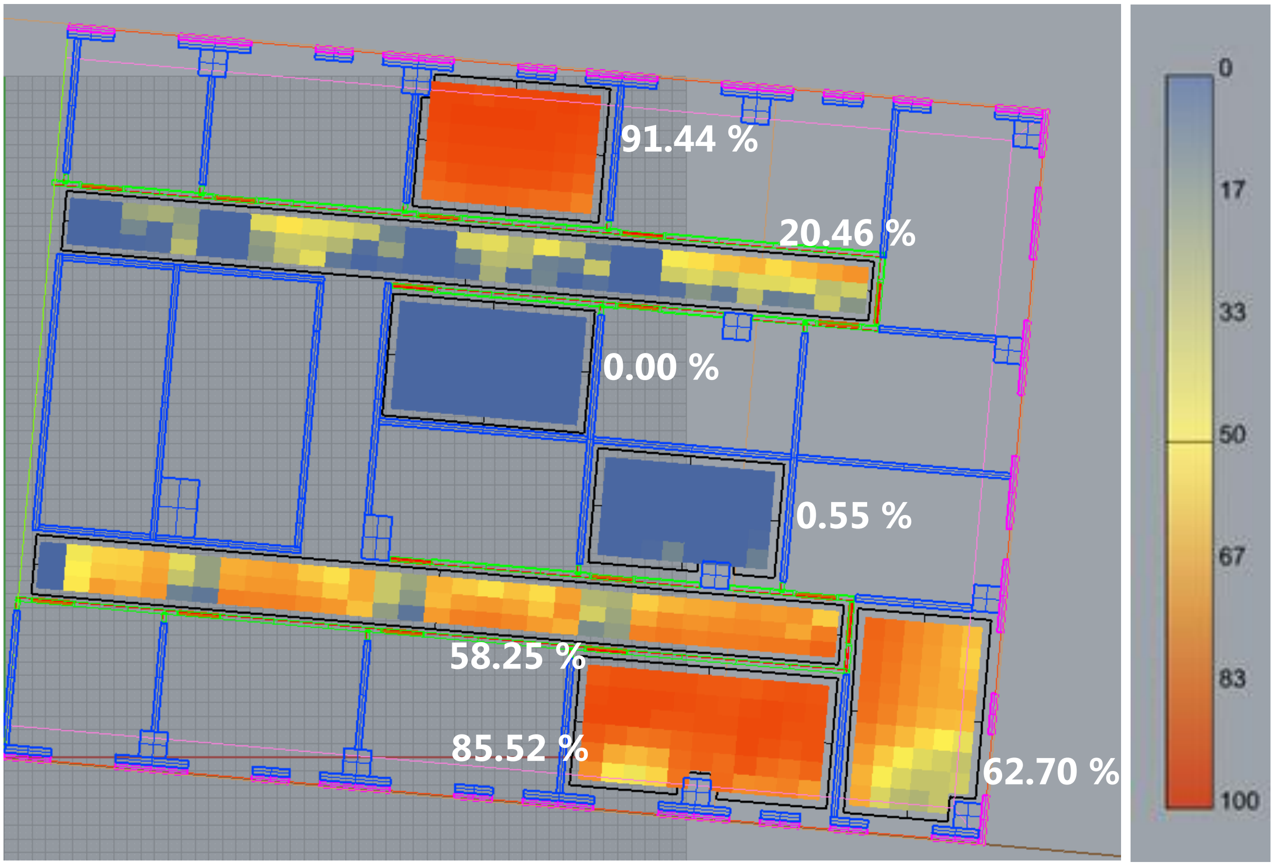


Spatial Daylight Autonomy 150 lux	
Node Group (Zone)	sDA (%)
1 South Grad Office	0.00 %
2 South Corridor	48.40 %
3 South Faculty Office	100.00 %
4 Southeast Faculty Office	100.00 %
5 North Grad Office	0.00 %
6 North Corridor	1.20 %
7 North Faculty Office	100.00 %

SDA_{150lux} is the percentage of nodes within each zone that has a DA_{150lux} value greater than 50%.

Note, unlike the IES method where full shades are used if more than 2% of nodes saw direct daylight, the above spatial daylight autonomy is based on using the actual prescribed shading algorithm. This is consistent with the proposed design solution as well.

USEFUL DAYLIGHT ILLUMINANCE 100 – 2000 LUX (ORIGINAL DESIGN)



Useful Daylight Illuminance 100 – 2000 lux	
Node Group (Zone)	UDI (%)
1 South Grad Office	0.55 %
2 South Corridor	58.25 %
3 South Faculty Office	85.52 %
4 Southeast Faculty Office	62.70 %
5 North Grad Office	0.00 %
6 North Corridor	20.46 %
7 North Faculty Office	91.44 %

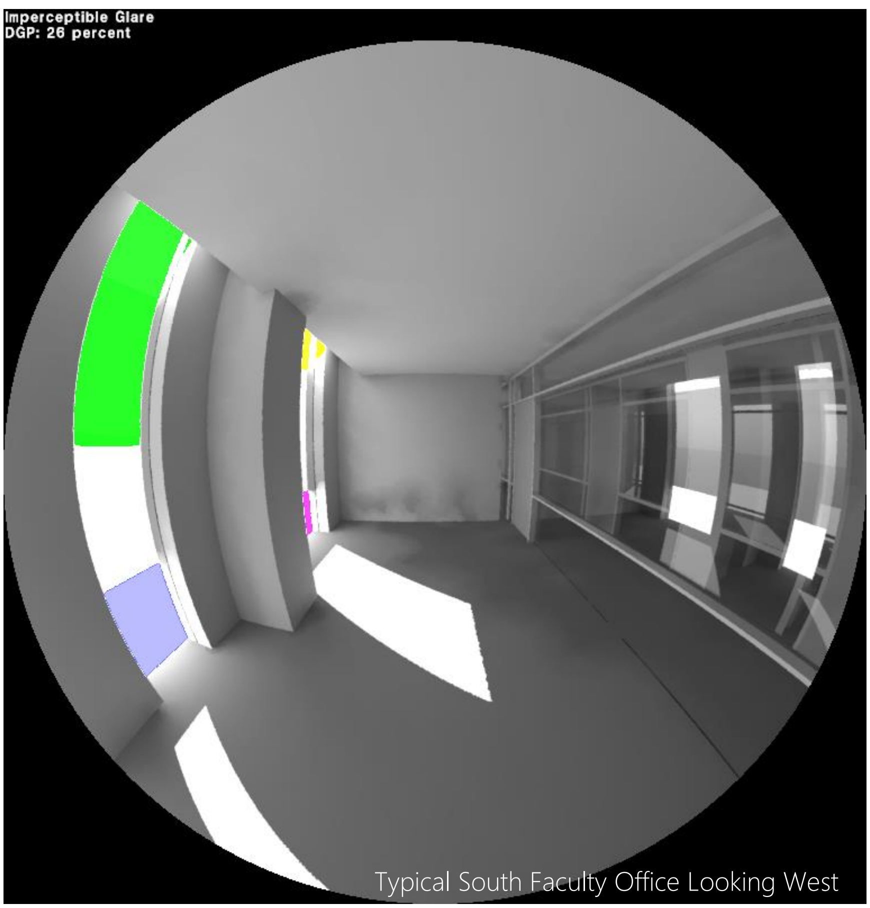
RADIANCE VISUALIZATION

Below are several radiance images that portray daylighting within the space on September 21 at 9 a.m. View dependent discomfort glare (DGP) is also shown below. The rendering shows areas of high contrast, i.e. potential glare sources, the percentage of DGP at a given hour of the day, and the glare category (either imperceptible glare, perceptible glare, disturbing glare, or intolerable glare).


South Corridor


North Corridor

Typical South Faculty Office Looking South



Typical South Faculty Office Looking West

PROPOSED DESIGN

INTRODUCTION

As described in the architectural breath, the proposed design introduces Kalwall + Lumira Aerogel construction to the office plan. Diffuse glazing (GL5) is removed from the facades while the clear glazing (GL8) and same shading conditions remain. The question logically arises: *what percentage of the exterior wall construction should be Kalwall?* To address his problem, parametric design and optimization is used on a typical southern facing faculty office. The optimized design is then implemented in the full floor plan simulation and compared directly to the original design—daylight performance in the interior space is studied.

MATERIALS + SETUP

All materials used in the original design simulation are identical in the proposed design simulation (reference section above for more information). Some new materials were added to the proposed design. Workstations have a 50% reflectance diffuse surface. Exposed HVAC equipment has an 80% reflective white paint to maximize exposed cavity reflections.

Most importantly, Kalwall material properties are obtained from Christoph Reinhart at *Daysim*. Properties imply trans material characteristics with more advanced settings for a realistic diffusing profile. For reference, the material data is attached below (reference: Alstan Jakubiec, diva4rhino.com/forum/topics/Kalwall-material):

```
# material name: KalwallTranslucent15nano
# material type: translucent panel
# manufacturer: Kawall Inc, NH, USA
# author: Christoph Reinhart
# date: October 2006
# comment: This is a validated Radiance model of a translucent sandwiched panel
#with a direct normal transmittance of ~15%.
#     The Radiance model is based on integrating sphere measurements taken at
#          the Fraunhofer Institute for Solar Energy Systems. A description of the
#underlying model can be found under:
#        Reinhart C F, Andersen M, "Development and validation of a Radiance
#model for a translucent panel", Energy and Buildings 38:7 pp. 890-904, 2006
#
#     The model requires that the following two files are being added to a
#directory included
#          in your RAYPATH variable, e.g.: C:\Radiance\lib or C:\Daysim\lib
```

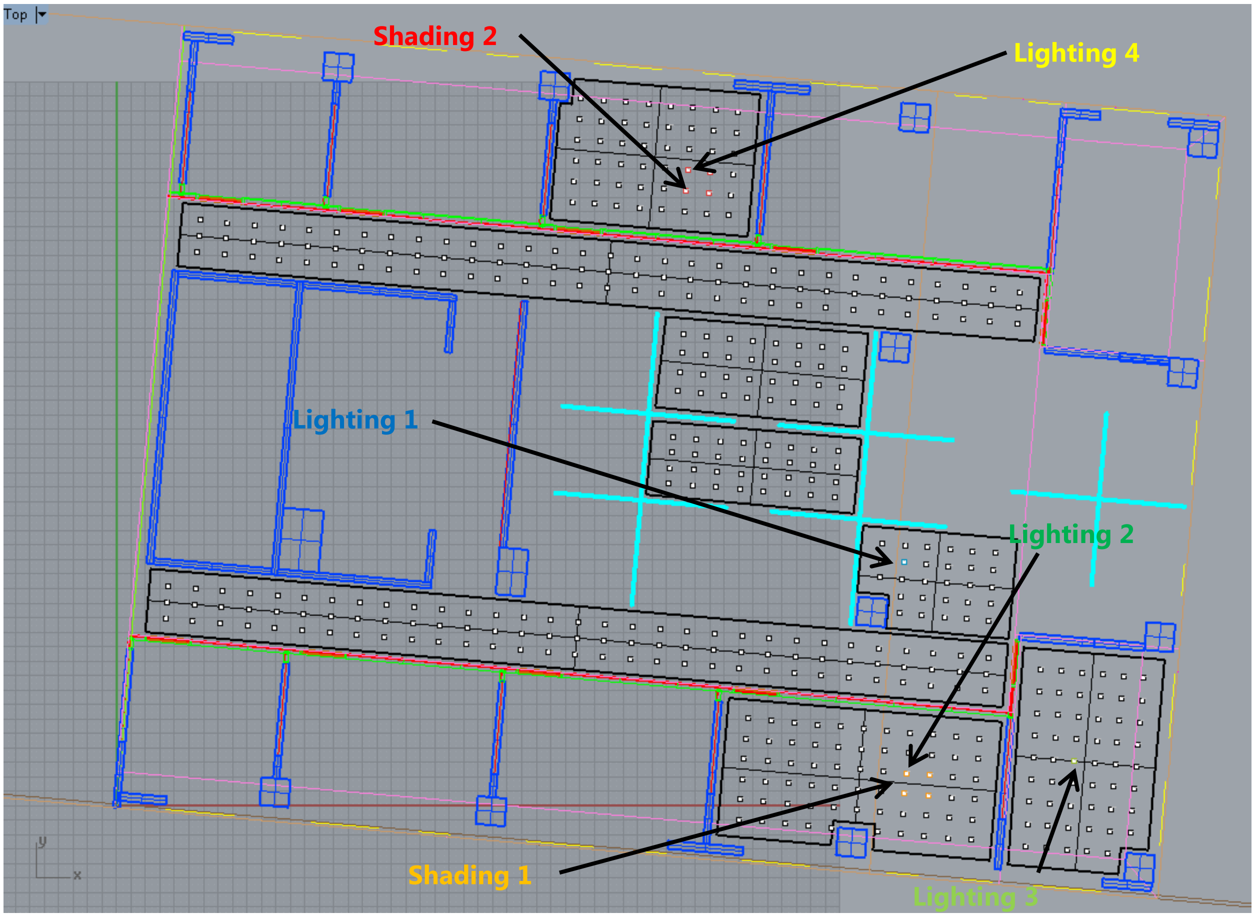
```
#       rang.cal & KalwallTranslucent15nano.dat
#
# RADIANCE 'transdata' model of a translucent panel assuming
# Rd = Cr = Cg = Cb = 0.21 (diffuse reflectance)
# Rs = A4 = 0.08 (specular reflectance)
# Sr = surface roughness = 0
# Td = direct direct hemispherical transmittance = 0.1440
# Ts = transmitted specularity (ideal diffuser) = 0
# A6 = (Td+Ts)/(Rd+Td+Ts) = 0.5333 = 0.406746028
# A1 = A2 =A3 = Rd/((1-Rs)*(1-A6)) = 0.384760794
# St = A6*A7*(1-A1)*A4 = 0

void transdata KalwallTranslucent15nano
4 noop KalwallTranslucent15nano.dat rang.cal rang
0
6 0.384760794 0.384760794 0.384760794 0.08 0.406746028 1
# A1 A2 A3 A4 A6 1
```

Likewise, shading calibrations are identical to the original design. Lighting is adjusted slightly to work with the open office workstations. It is assumed the same wattage will be needed in the graduate student area; pendants can now be shared between workplanes essentially remaining in original location—new lighting layout not required.

The proposed design includes an eighth node group (center workstation) for added reliability in comparison.

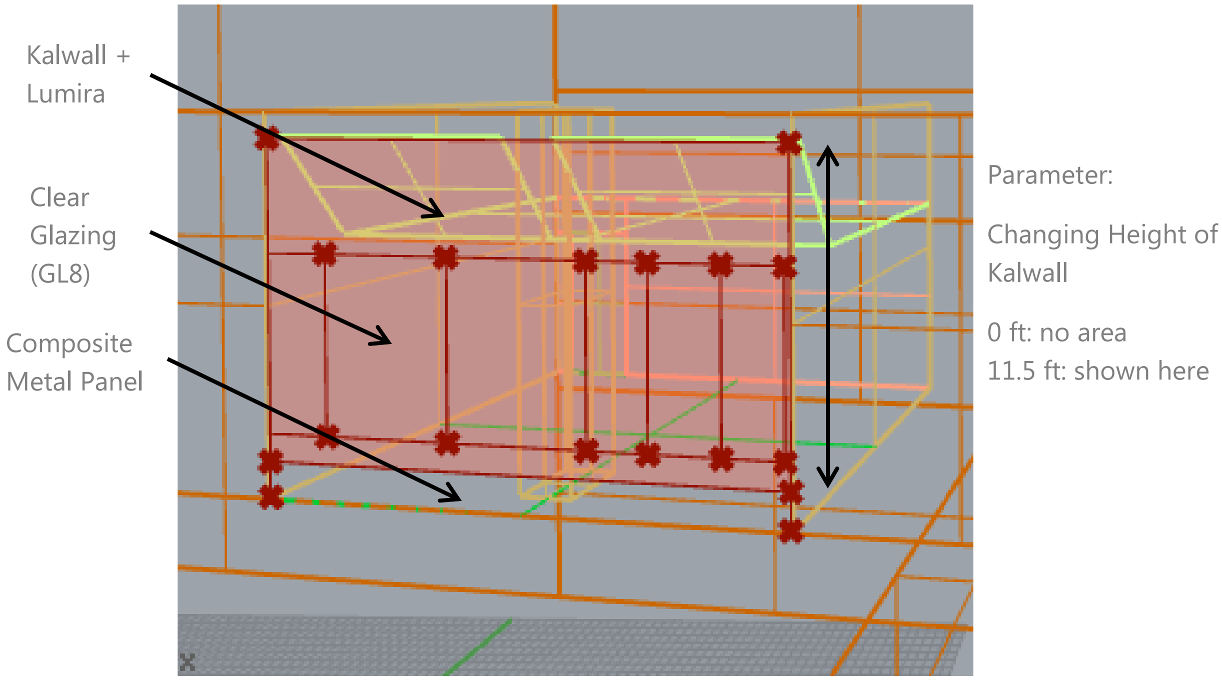
FLOOR PLAN SHADING AND LIGHTING CONTROL SETUP



PARAMETRIC OPTIMIZATION

Described in the Methodology portion of this depth, *Grasshopper* is used to parametrically model a southern-facing faculty room. The ultimate goal was to subjectively and accurately predict the optimal percentage of Kalwall on the building façade to maximize Useful Daylight Illuminance 100 – 2000 lux and minimize overall annual energy use (kWh). The amount of Kalwall (active parameter/genome) is expressed as the height of Kalwall from the top of the ceiling down. The lower half of the wall is then the existing metal panel system. Clear glazing remained and was accounted for.

A model is first tested for the original design to set a base condition. A parametric model for the proposed design is then studied. Both models use their respective *DIVA* materials as defined in the materials section of this report. Thermal properties are discussed in the Mechanical Breadth section—for completeness, parametric energy analysis will be discussed here. Integrated data between daylighting and energy use is important in order to establish a relative relationship between differently weighted metrics.

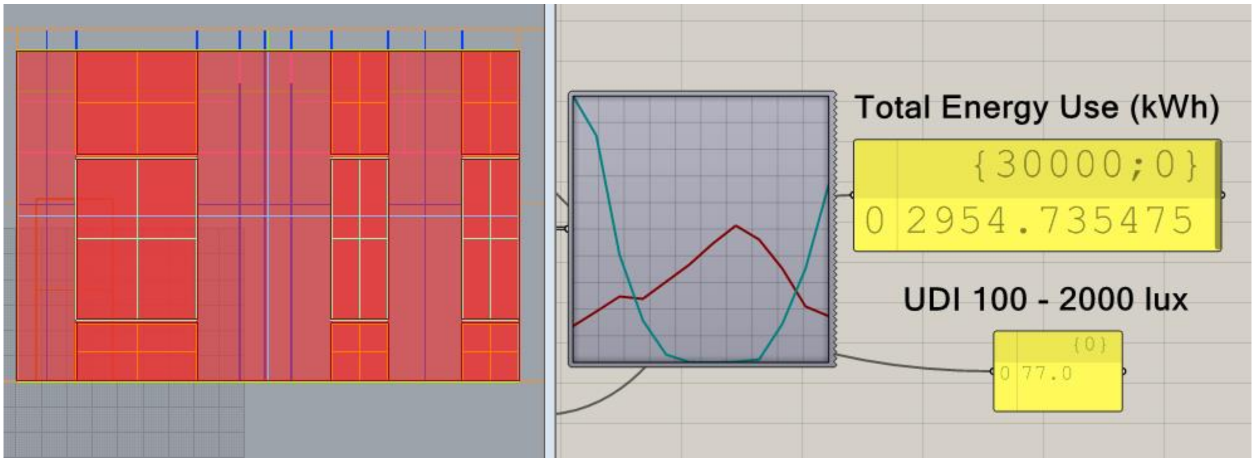


For daylighting, a single node point was located where someone can be expected to sit and do work. To control excessive daylight and restrict change in data to the percentage of Kalwall, full shades are applied for all occupied hours. Likewise, lighting is controlled similarly as described before. In this space, 135 watts of electric lighting (photosensor dimming) provides 300 lux at the workplane.

Climate-based data is used to generate UDI, DA_{300lux}, cDA_{300lux}, hourly illuminance data, and a lighting load schedule. The lighting load schedule is linked to the *VIPER* component of *Grasshopper* where it is used in the energy calculation; hereby, integration occurs, using the parallel geometry and real-world daylighting data to inform the energy profile. All of the above simulation parameters are identical between the original and proposed design models.

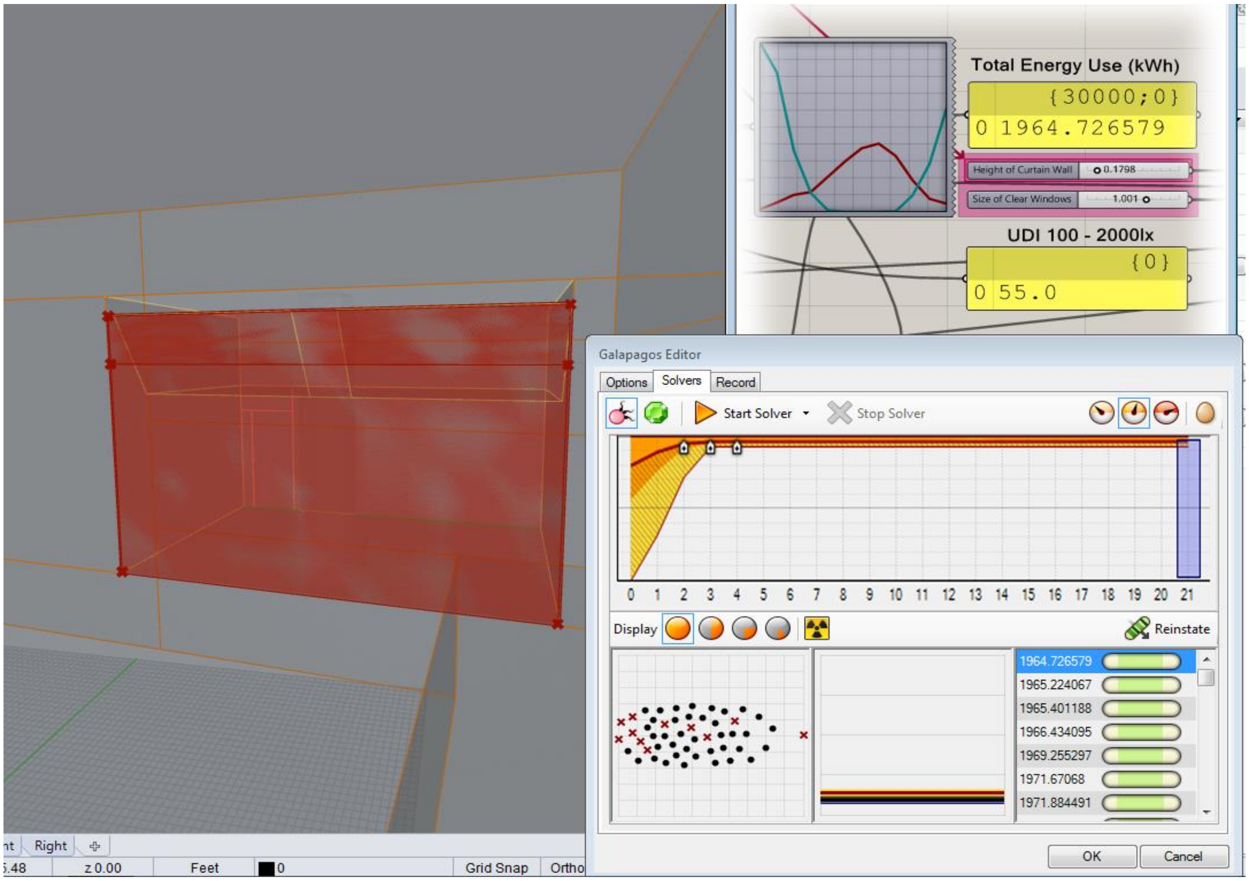
ORIGINAL DESIGN (BASE CASE)

Seen here is the UDI 100 – 2000 lux and total annual energy use of the original architectural design. The UDI is **77%** and the total energy use is **2954.74 kwH.**



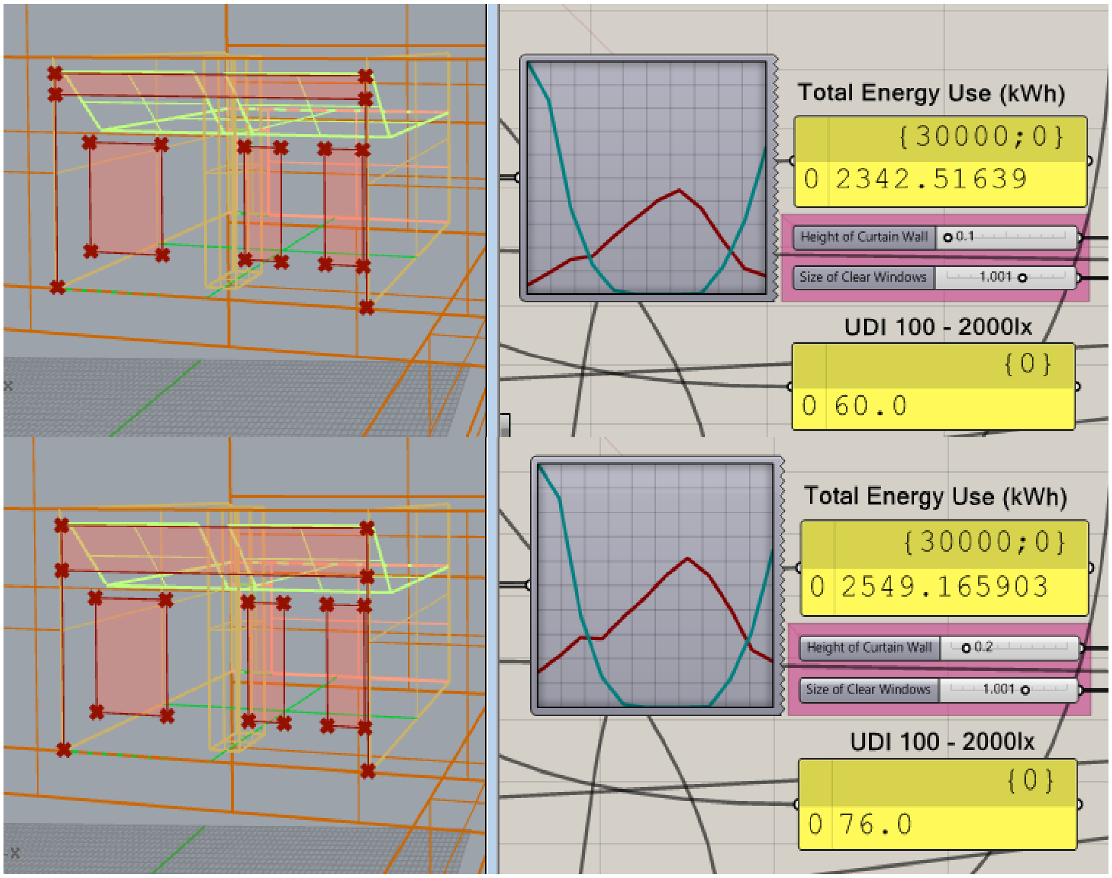
PROPOSED DESIGN (OPTIMIZED CASE)

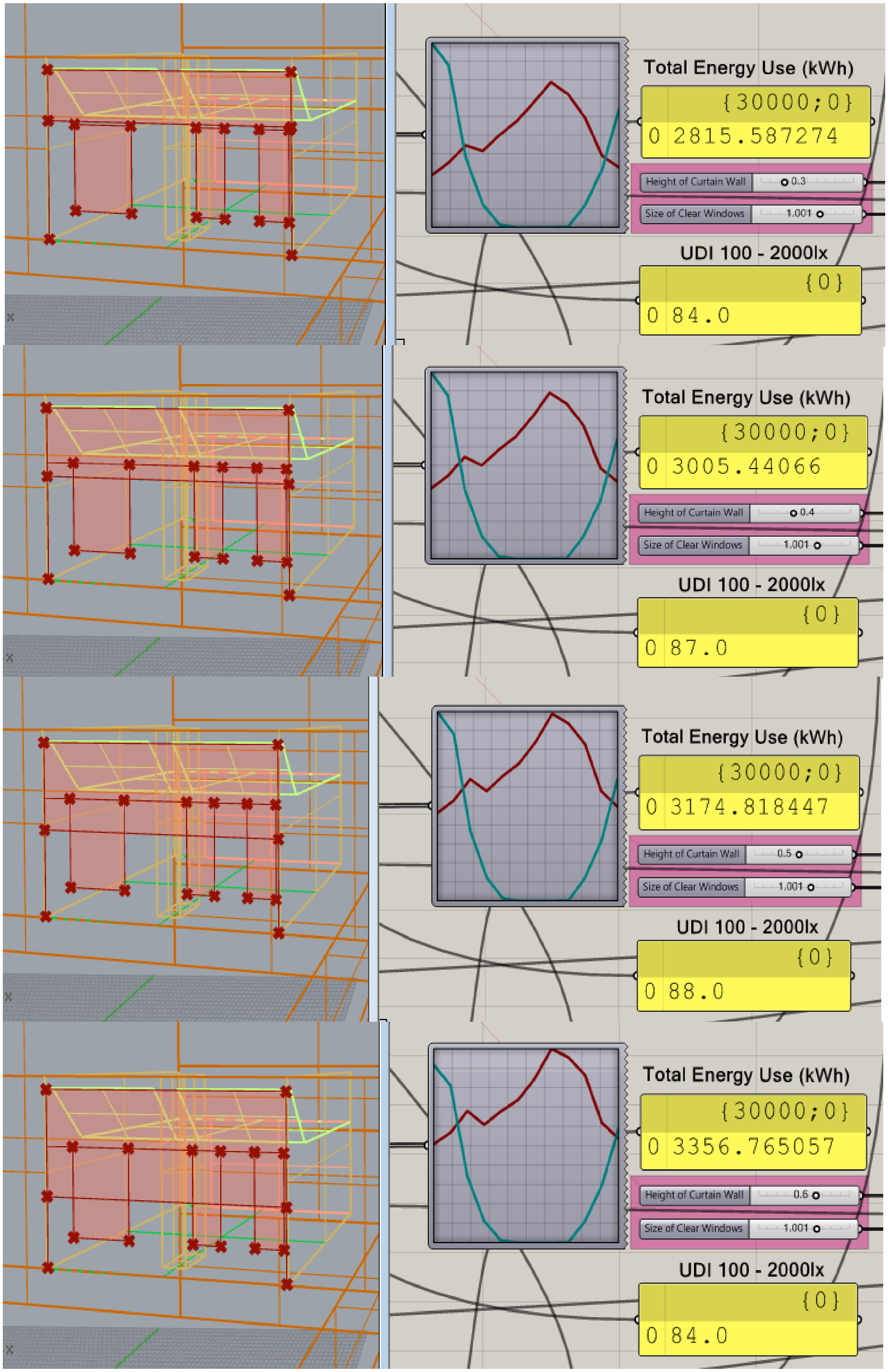
A quick Evolutionary Solver calculation using *Galapagos* is first used to estimate the optimal position of the Kalwall. This case is simplified: no clear glazing or shading is used. The Kalwall is optimized only for minimal annual energy use.

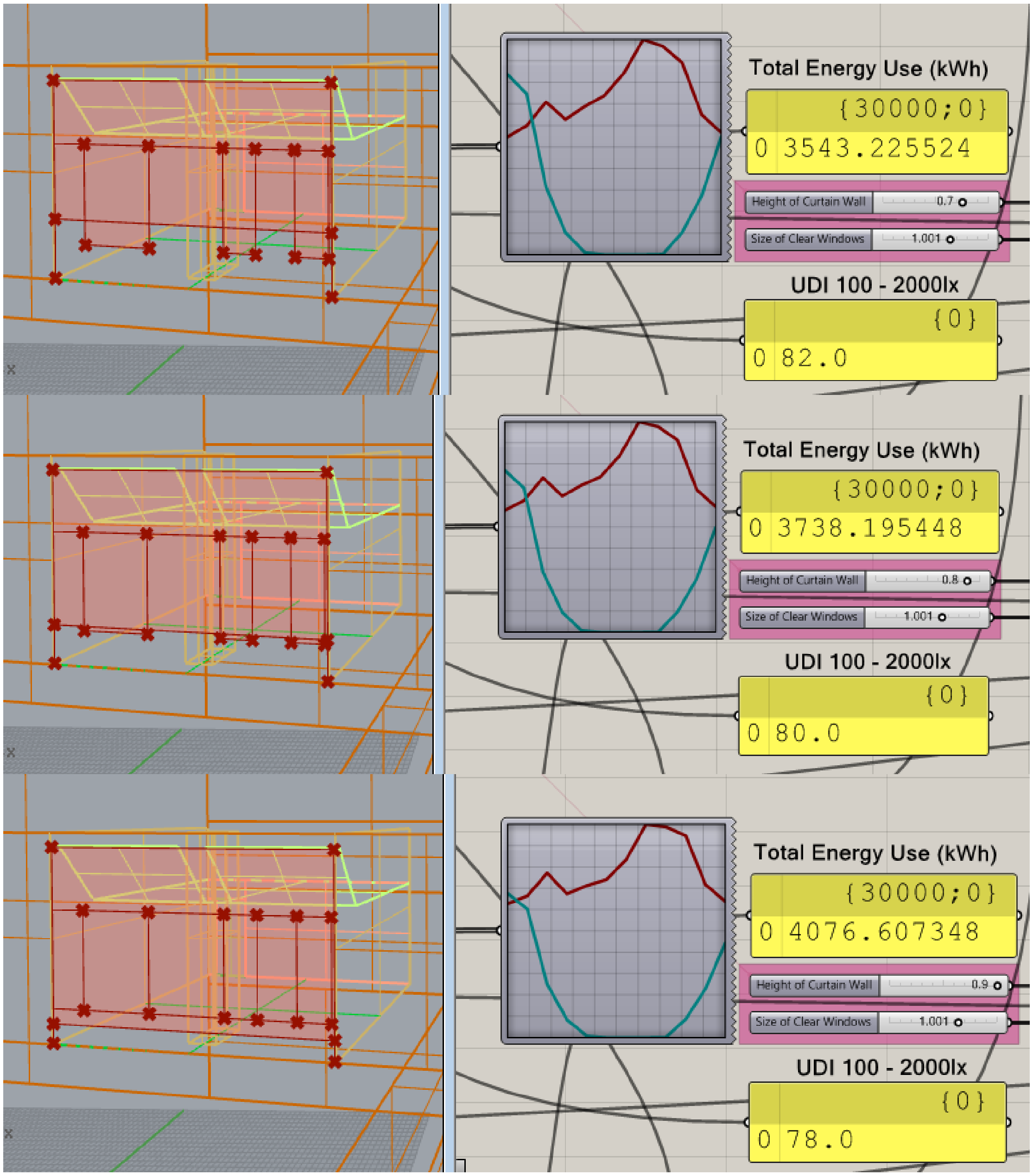


The graphic above illustrates that *Galapagos* quickly found an optimal solution. That is, Kalwall at 2.30 feet from the top horizontal line (about 18% of the vertical area) yields a minimal energy use of 1965 kWh but a low UDI at 55. Keeping in mind that although this is a simplified case, 18% of Kalwall in this scenario would not yield increased daylight deeper into the interior office space. Hereby, an optimized solution needs to be studied further—manual optimization.

Next, a detailed optimization that balances maximum UDI and minimum energy use is conducted. Manual parametric control means that the user changes the variable (height of Kalwall) and recalculates the solutions. Parametric modeling makes the process extremely flexible and fast. Starting at 10% Kalwall, incrementally increasing in 10% steps, the data is collected.

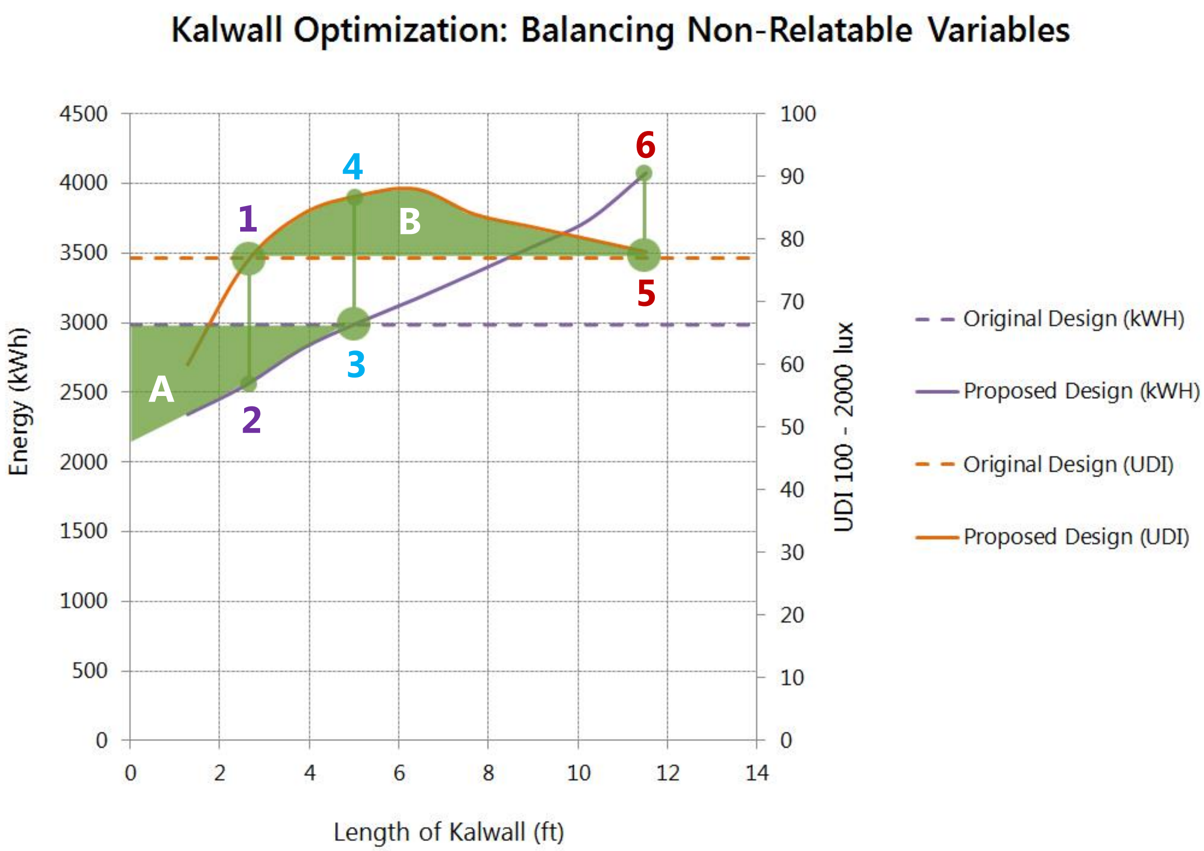



Total Energy Use (kWh)
{30000;0}
0 2815.587274
Height of Curtain Wall 0.3
Size of Clear Windows 1.001
UDI 100 - 2000lx
{0}
0 84.0
Total Energy Use (kWh)
{30000;0}
0 3005.44066
Height of Curtain Wall 0.4
Size of Clear Windows 1.001
UDI 100 - 2000lx
{0}
0 87.0
Total Energy Use (kWh)
{30000;0}
0 3174.818447
Height of Curtain Wall 0.5
Size of Clear Windows 1.001
UDI 100 - 2000lx
{0}
0 88.0
Total Energy Use (kWh)
{30000;0}
0 3356.765057
Height of Curtain Wall 0.6
Size of Clear Windows 1.001
UDI 100 - 2000lx
{0}
0 84.0



Through the progression, one can notice a peak UDI value near 50% Kalwall. On the other hand, energy use steadily increases as the amount of Kalwall increases. The reasoning for this is discussed in the Mechanical Breadth.

Given the original design data and the proposed design "stepped" data, a graph comparing several variables is generated. This graph serves as the foundation of reasoning to the proposed design; by making informed subjective decisions, a designer is able to make better conclusions regarding the proper solution.



Area A: proposed design demands less annual energy (kWh) than original design

Area B: proposed design produces better UDI 100 – 2000 lux than original design

Point 1: proposed design and original design yield same UDI 100 – 2000 lux

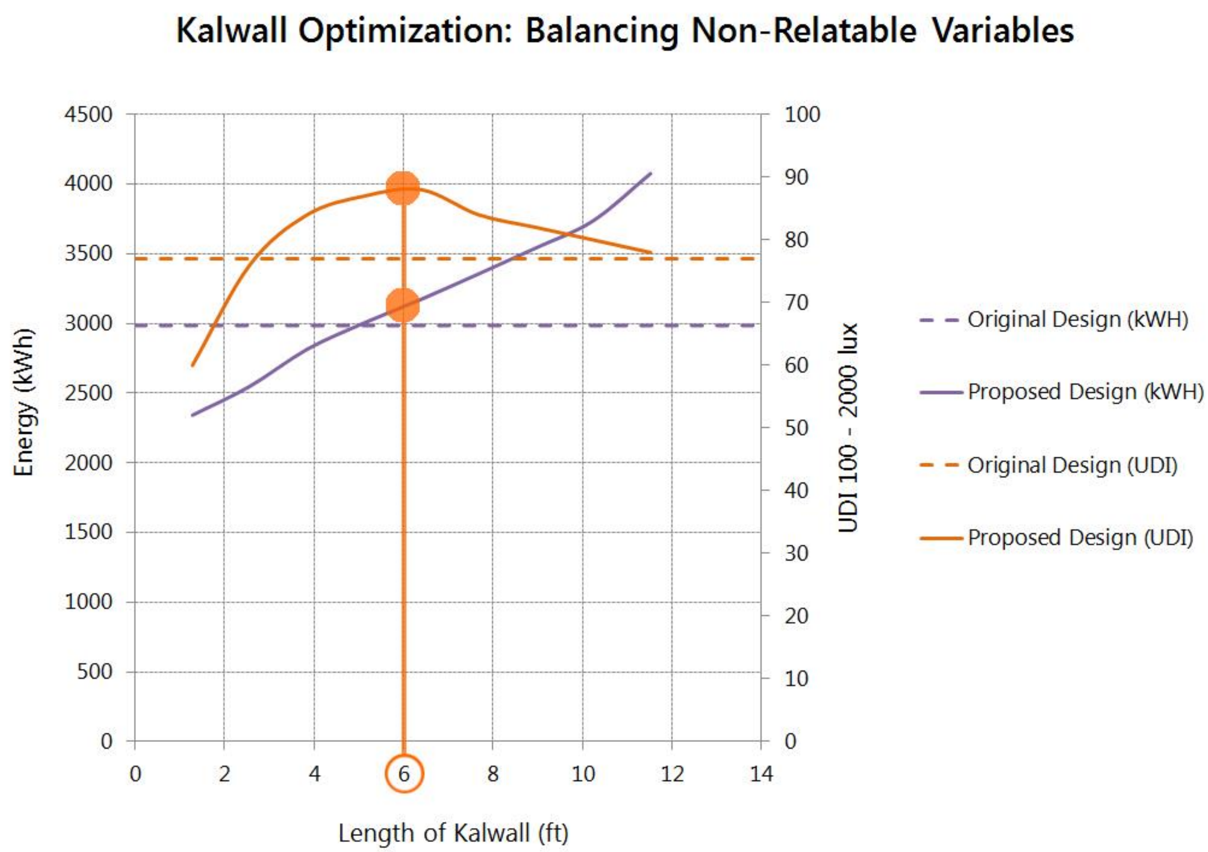
Point 2: proposed design uses 500 kWh less energy than original design

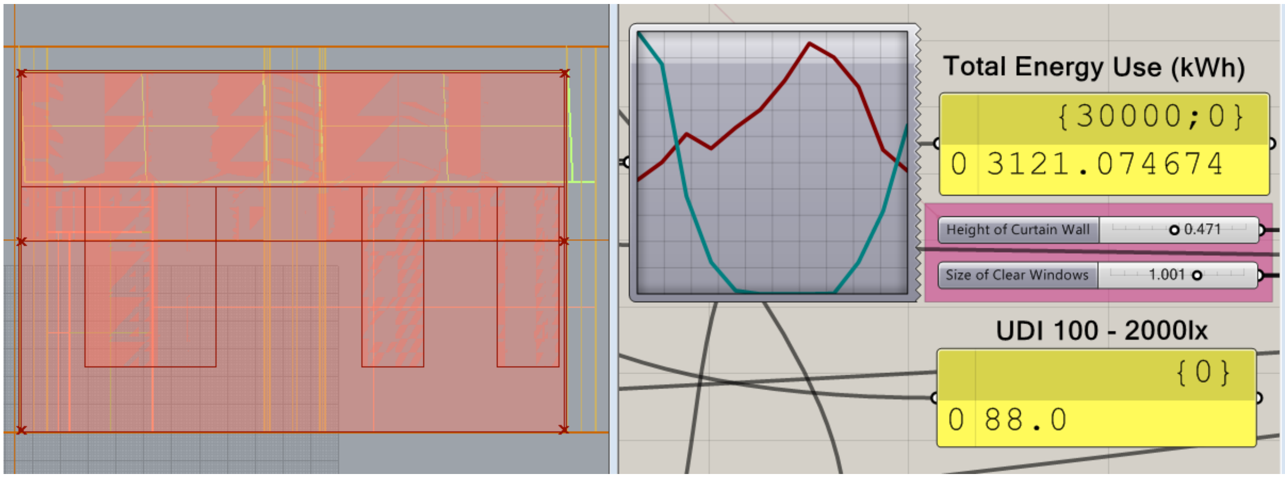
Point 3: proposed design and original design yield same annual energy use (kWh)

Point 4: proposed design yields 10% more UDI 100 – 2000 lux than original design

Point 5: proposed design and original design yield same UDI 100 – 2000 lux

Point 6: proposed design uses 1100 kWh more energy than original design.





Referencing the data above, a subjective decision implies that the optimal amount of Kalwall lies somewhere between 4 and 6.5 feet. *An important goal of the architectural change remains increasing daylighting deep into the interior office space*. Hereby, a design that yields more UDI and little added energy use (approximately 166 kWh more) is desired.

At 6 feet of Kalwall (47% of vertical surfaces area), energy use is maintained relative to the original design while daylighting is improved. This solution's effect on the interior office space is discussed below.

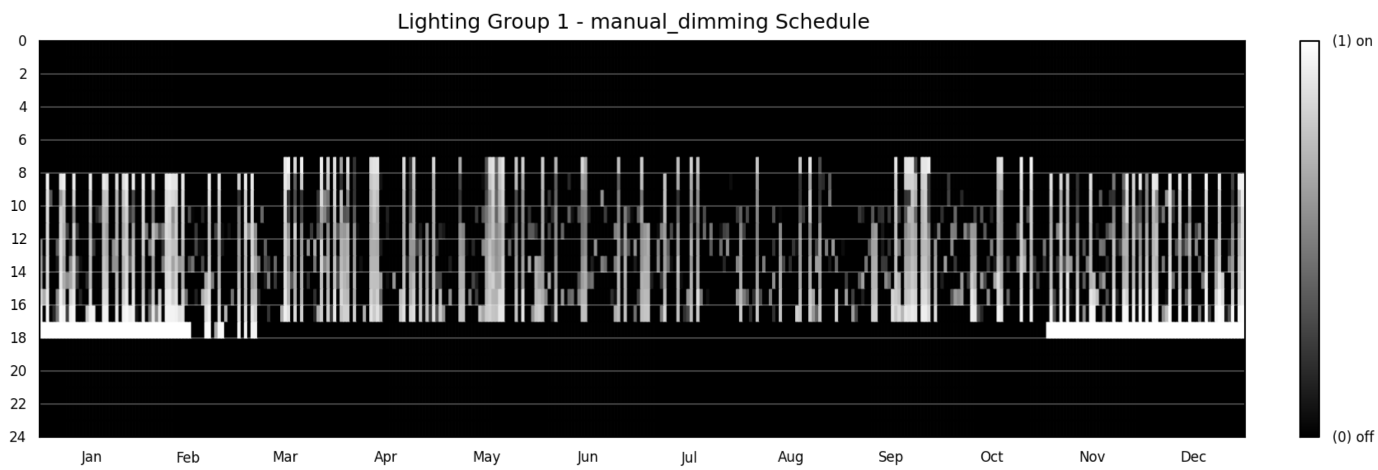
RESULTS

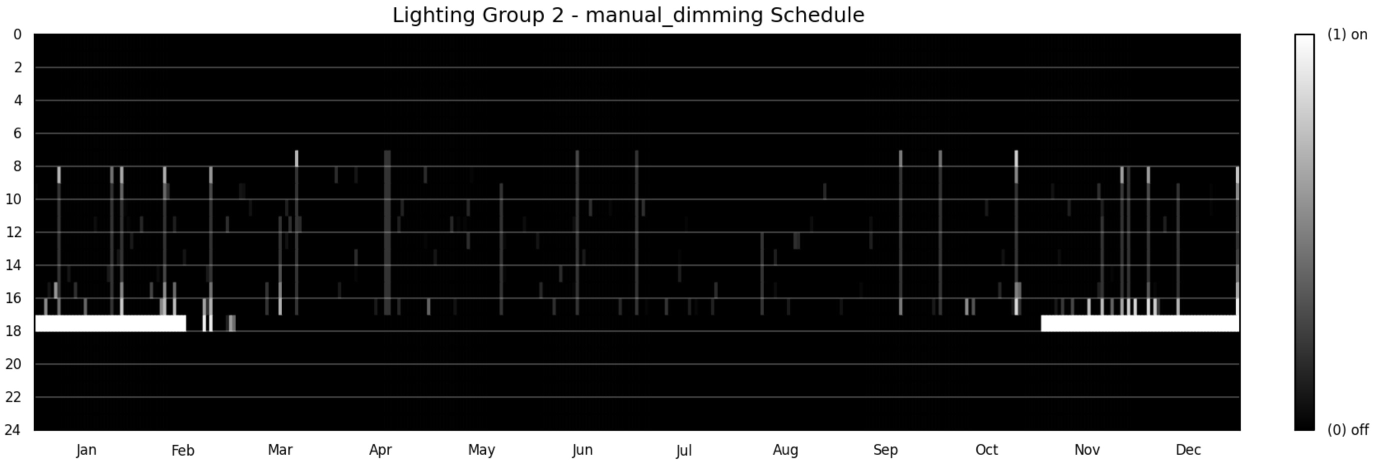
Using the information gathered from the optimization processes, Kalwall is modeled at the appropriate height around the entire floor plan. Similar daylighting metrics to the original design is then evaluated.

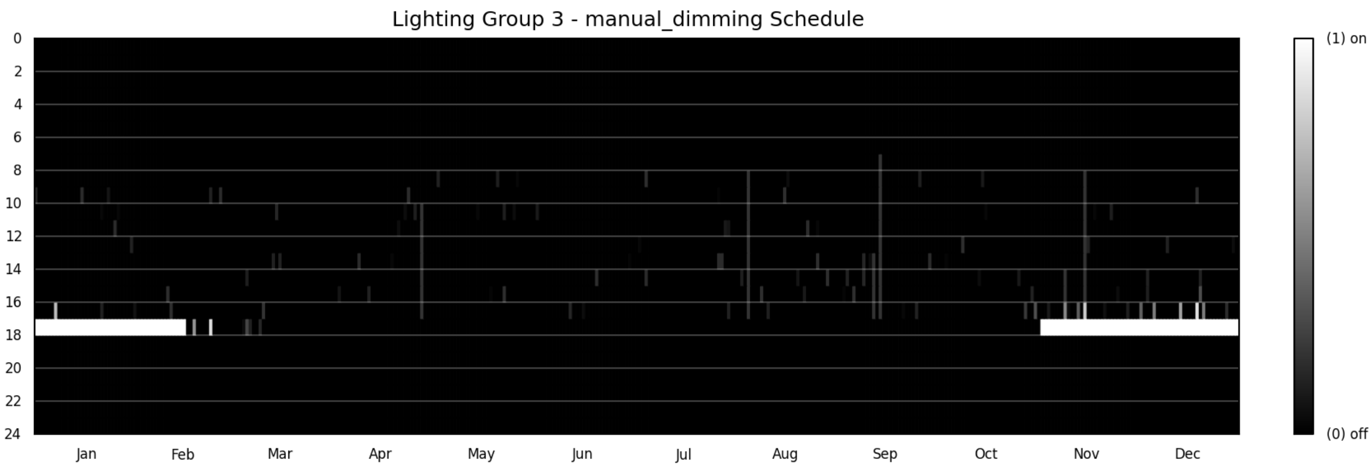
LIGHTING GROUPS

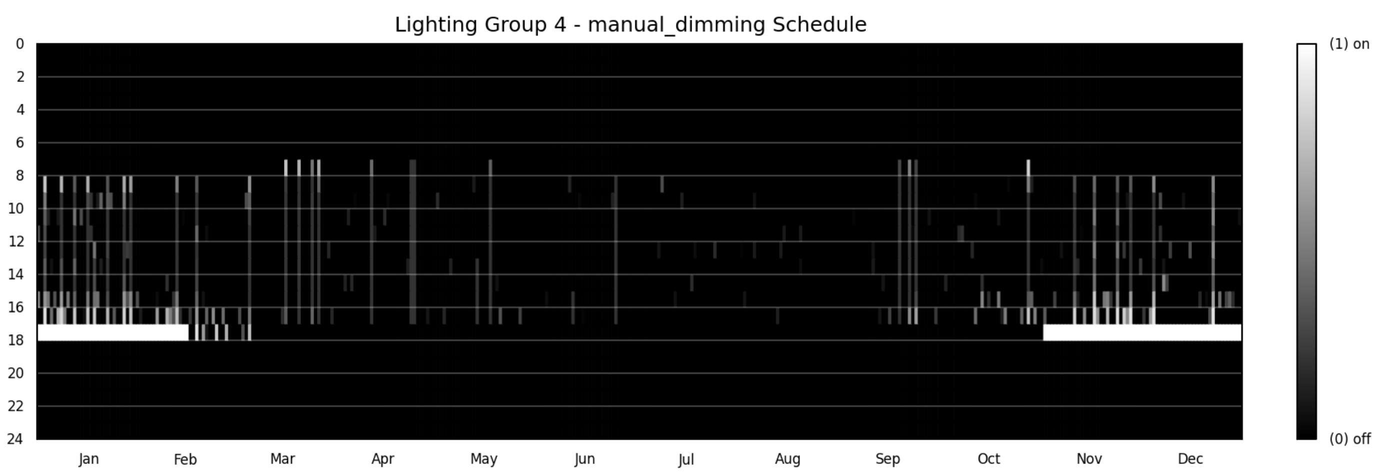
Seen below, less lighting is needed at lighting group 1, while the remaining lighting energy use remains relatively constant between the original and proposed design.

Annual Electric Lighting Use	
Lighting Group	Energy Use
Lighting Group 1	117.9 kWh
Lighting Group 2	32.4 kWh
Lighting Group 3	15.6 kWh
Lighting Group 4	27.4 kWh




Lighting Group 2 - manual_dimming Schedule
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
(1) on
(0) off

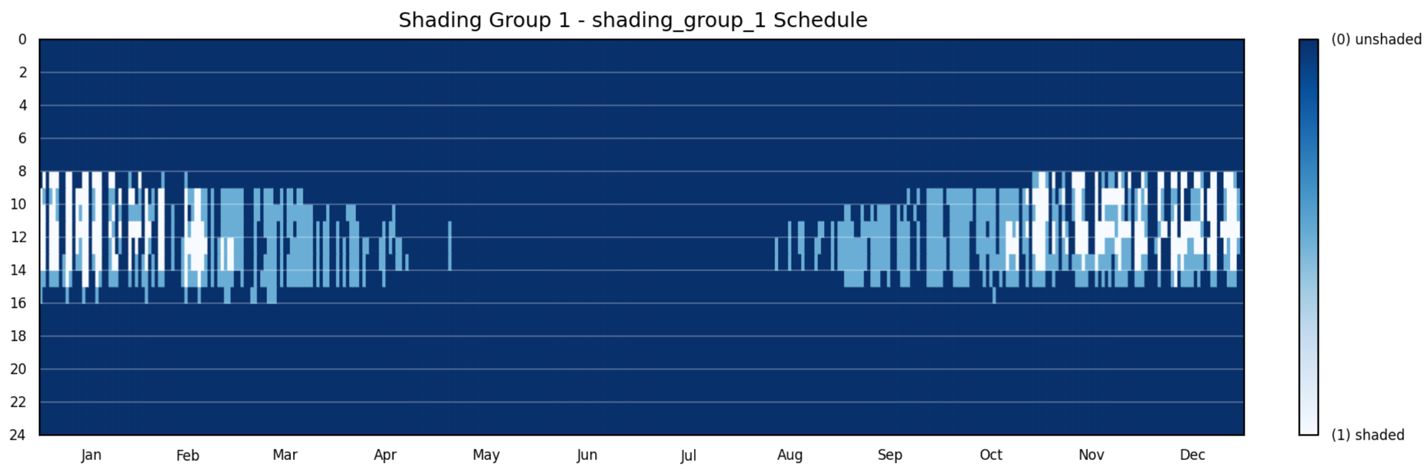

Lighting Group 3 - manual_dimming Schedule
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
(1) on
(0) off

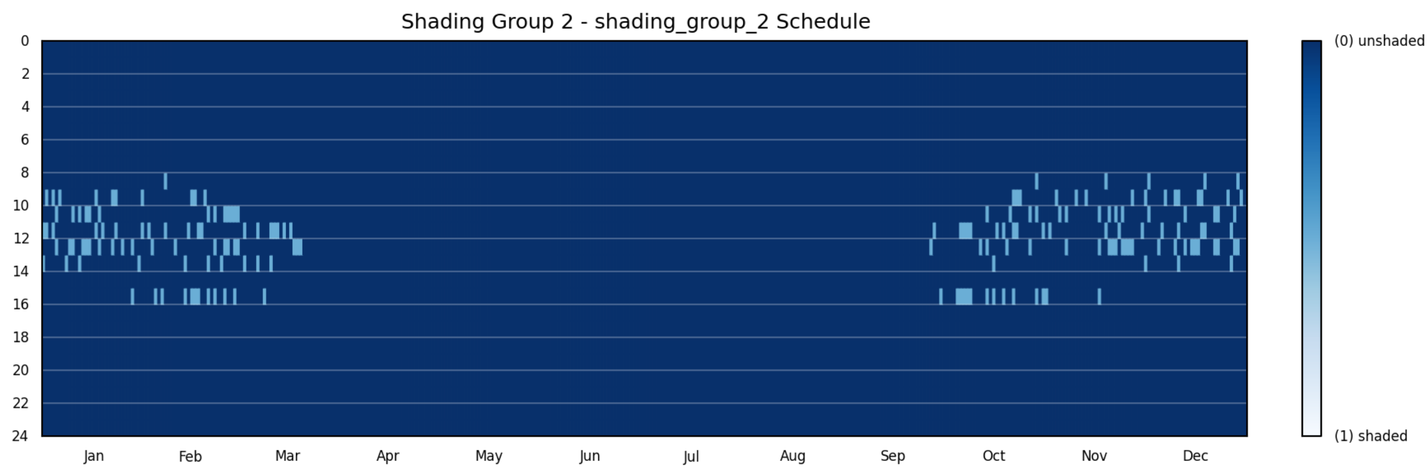

Lighting Group 4 - manual_dimming Schedule
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
(1) on
(0) off

SHADING GROUPS

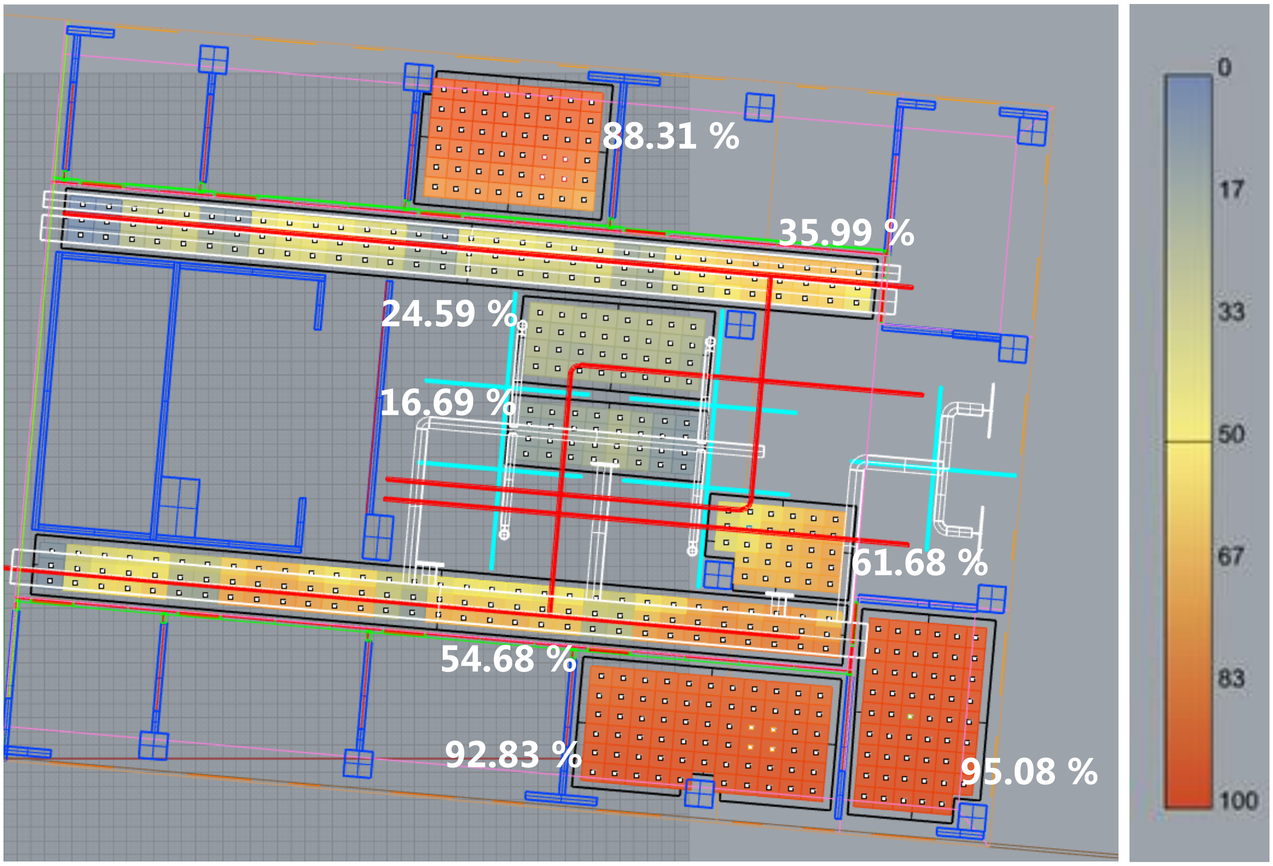
Shading group 1 (south) is open 74% of the occupied hours. Shading group 2 (east and north) is open 95% of the occupied hours. Shading between the original and proposed design did not change drastically. The diffusing Kalwall controls the amount of light that enters the space, still preventing excessive illuminance at the shading setpoints.

In the graphs below, dark blue represents the open condition. White represents shades fully down and light blue represents shades halfway down. As seen, shades are used primarily along the southern facade in the winter months when the profile angle is low and sun penetration can occur deep into the space.



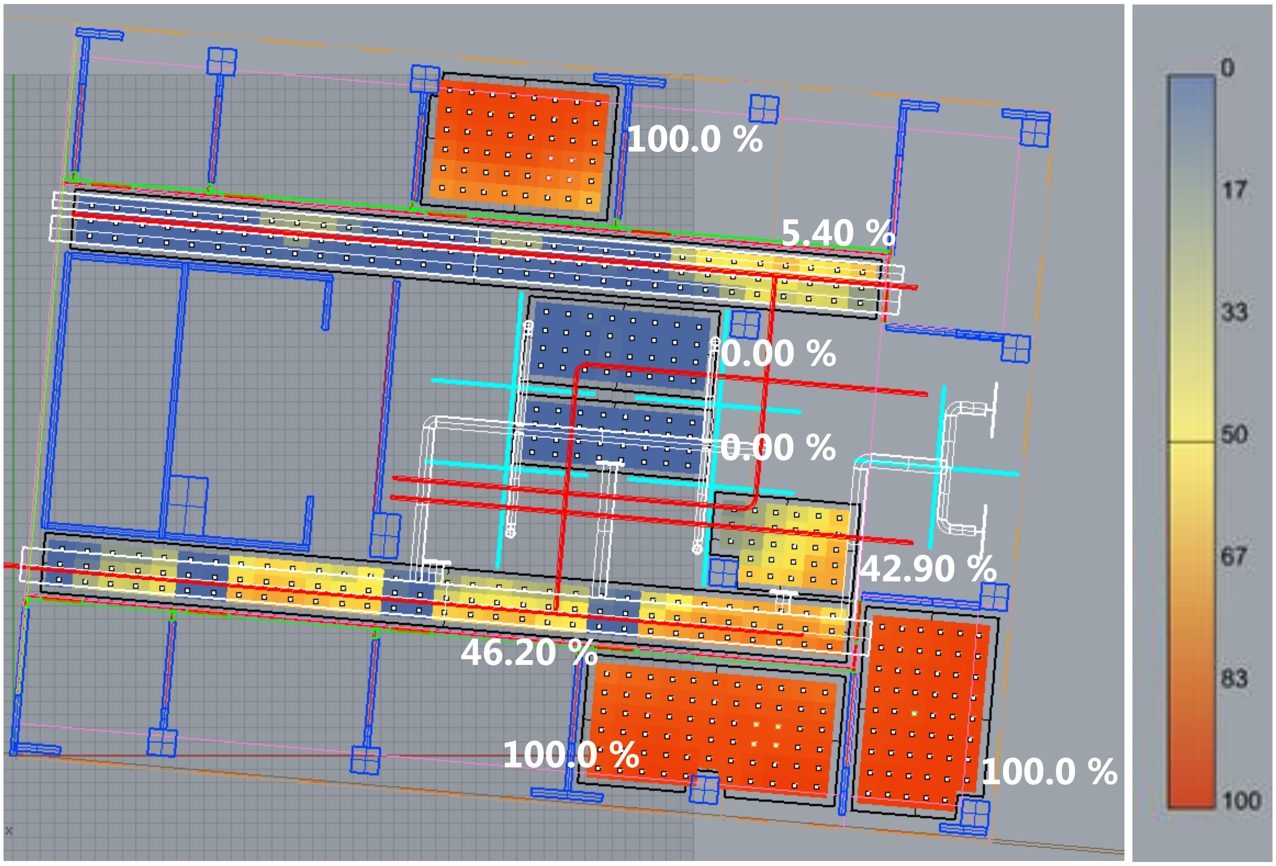


CONTINOUS DAYLIGHT AUTONOMY 300 LUX (PROPOSED DESIGN)



Continuous Daylight Autonomy 300 lux	
Node Group (Zone)	cDA (%)
1 South Workstation	61.68 %
2 South Corridor	54.68 %
3 South Faculty Office	92.83 %
4 Southeast Faculty Office	95.08 %
5 North Workstation	24.59 %
6 North Corridor	35.99 %
7 North Faculty Office	88.31 %
8 Center Workstation	16.69 %

SPATIAL DAYLIGHT AUTONOMY 150 LUX (PROPOSED DESIGN)

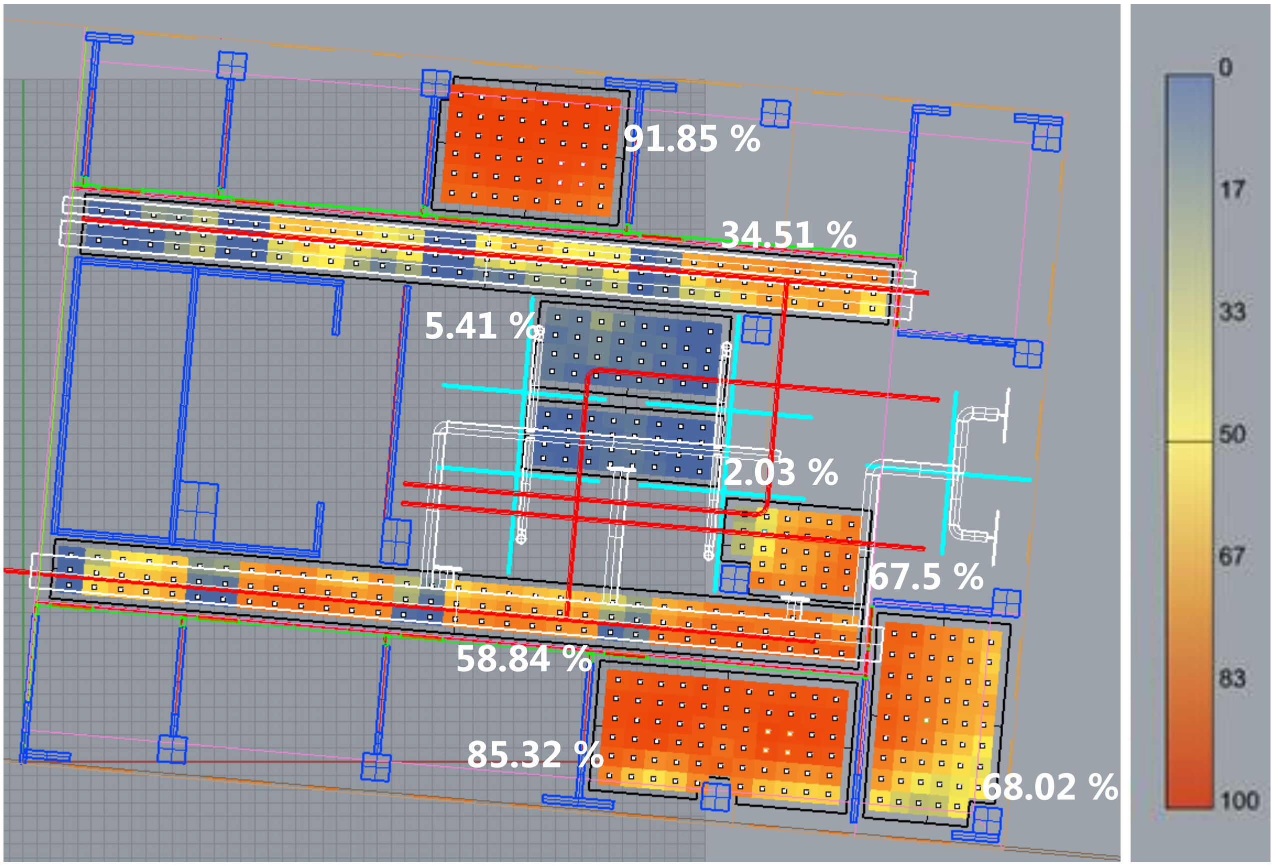


Spatial Daylight Autonomy 150 lux	
Node Group (Zone)	sDA (%)
1 South Workstation	42.90 %
2 South Corridor	46.20 %
3 South Faculty Office	100.00 %
4 Southeast Faculty Office	100.00 %
5 North Workstation	0.00 %
6 North Corridor	5.40 %
7 North Faculty Office	100.0 %
8 Center Workstation	0.00 %

SDA$_{150lux}$ is the percentage of nodes within each zone that has a DA$_{150lux}$ value greater than 50%.

Note unlike the IES method where full shades are used if more than 2% of nodes saw direct daylight, the above spatial daylight autonomy is based on using the actual prescribed shading algorithm. This is consistent with the proposed design solution as well.

USEFUL DAYLIGHT ILLUMINANCE 100 – 2000 LUX (PROPOSED DESIGN)



Useful Daylight Illuminance 100 – 2000 lux	
Node Group (Zone)	UDI (%)
1 South Workstation	67.5 %
2 South Corridor	58.84 %
3 South Faculty Office	85.32 %
4 Southeast Faculty Office	68.02 %
5 North Workstation	5.41 %
6 North Corridor	34.51 %
7 North Faculty Office	91.85 %
8 Center Workstation	2.03 %

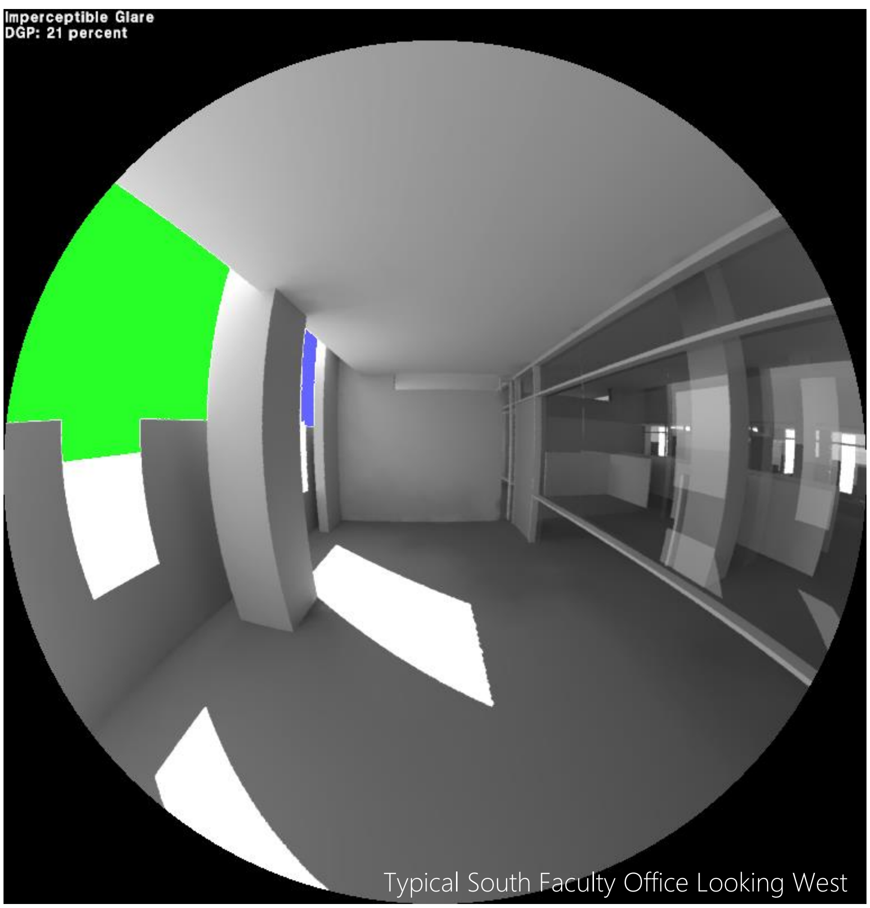
RADIANCE VISUALIZATION

Below are several radiance images that portray daylighting within the space on September 21 at 9 a.m. View dependent discomfort glare (DGP) is also shown below. The rendering shows areas of high contrast, i.e. potential glare sources, the percentage of DGP at a given hour of the day, and the glare category (either imperceptible glare, perceptible glare, disturbing glare, or intolerable glare).

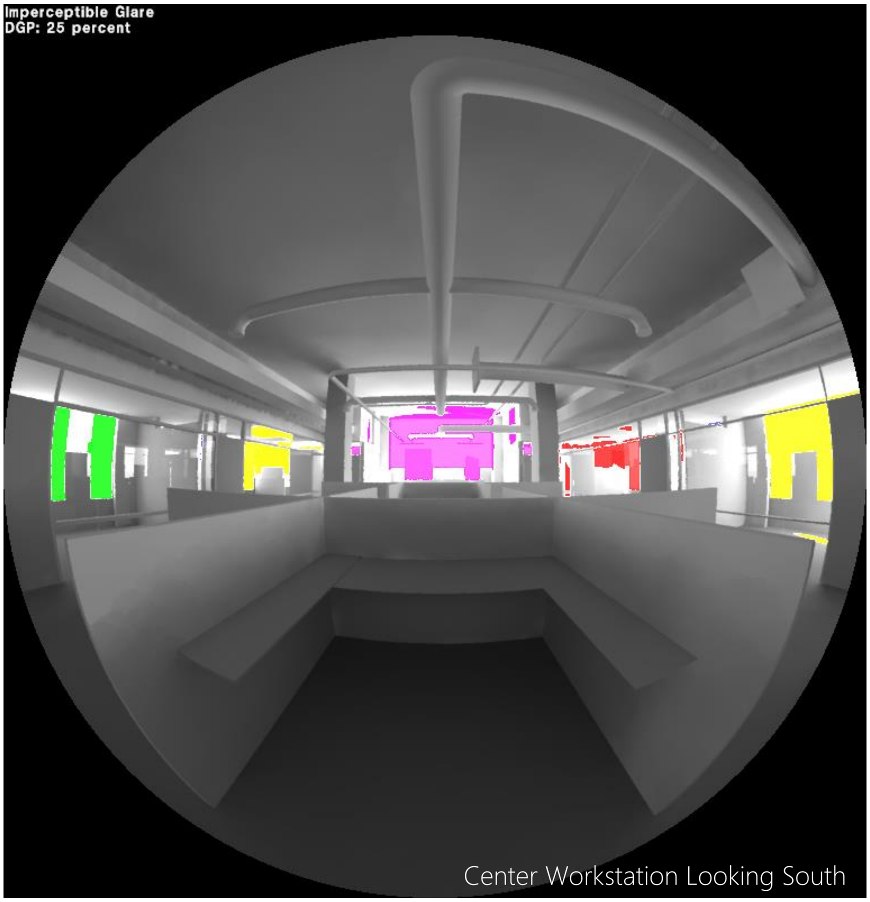

South Corridor


North Corridor

Typical South Faculty Office Looking South



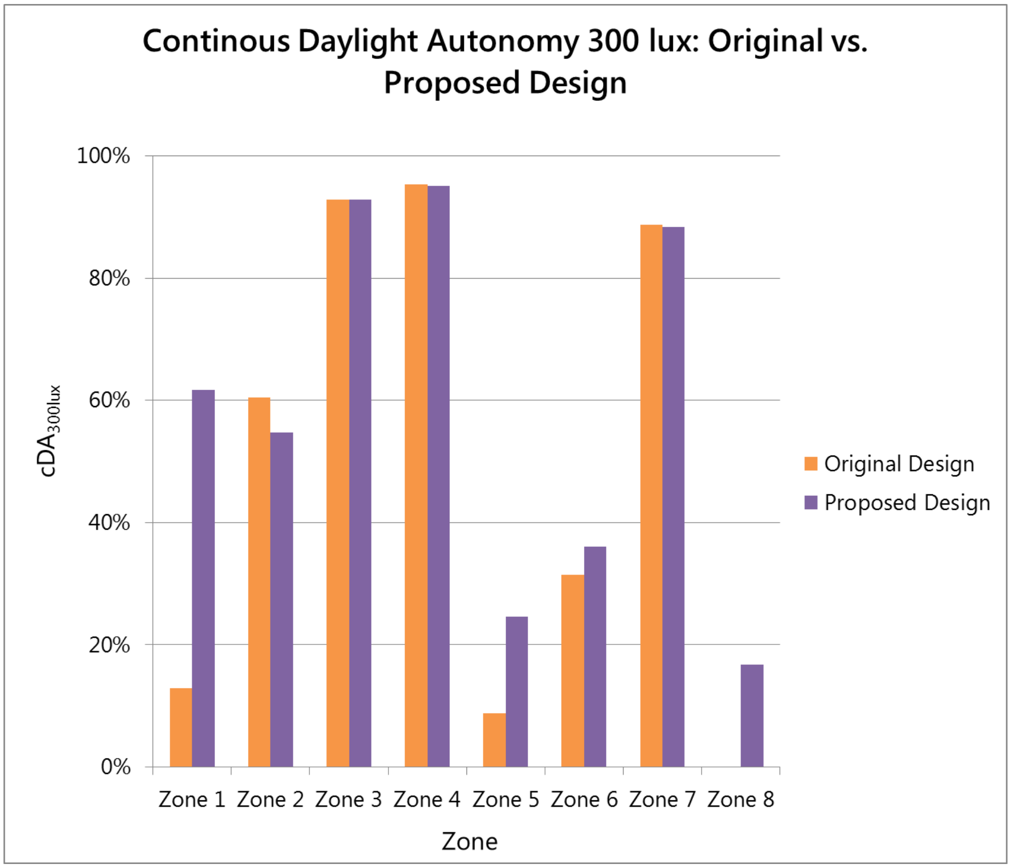
Typical South Faculty Office Looking West



Center Workstation Looking South

CONCLUSION

Informed by parametric design, a proposed solution that introduces 48% Kalwall on the exterior façade yields several improvements over the original design. First, comparing continuous daylight autonomy between the two designs, the proposed design saw increases in cDA for interior spaces. While the perimeter spaces remained constant throughout the architectural change, a typical southern graduate student office (zone 1) saw a **48.8% increase** in cDA 300 lux. This corresponds to saving 212 kWh of electrical energy for that same zone. Further, a typical northern graduate student office (zone 5) is expected to have a **15.8% increase** in continuous daylight autonomy. It is interesting to note that the center workstation space (zone 8) yields **16.7% cDA** despite its central location on the floor plan: energy savings is thus achievable even deep into the space.

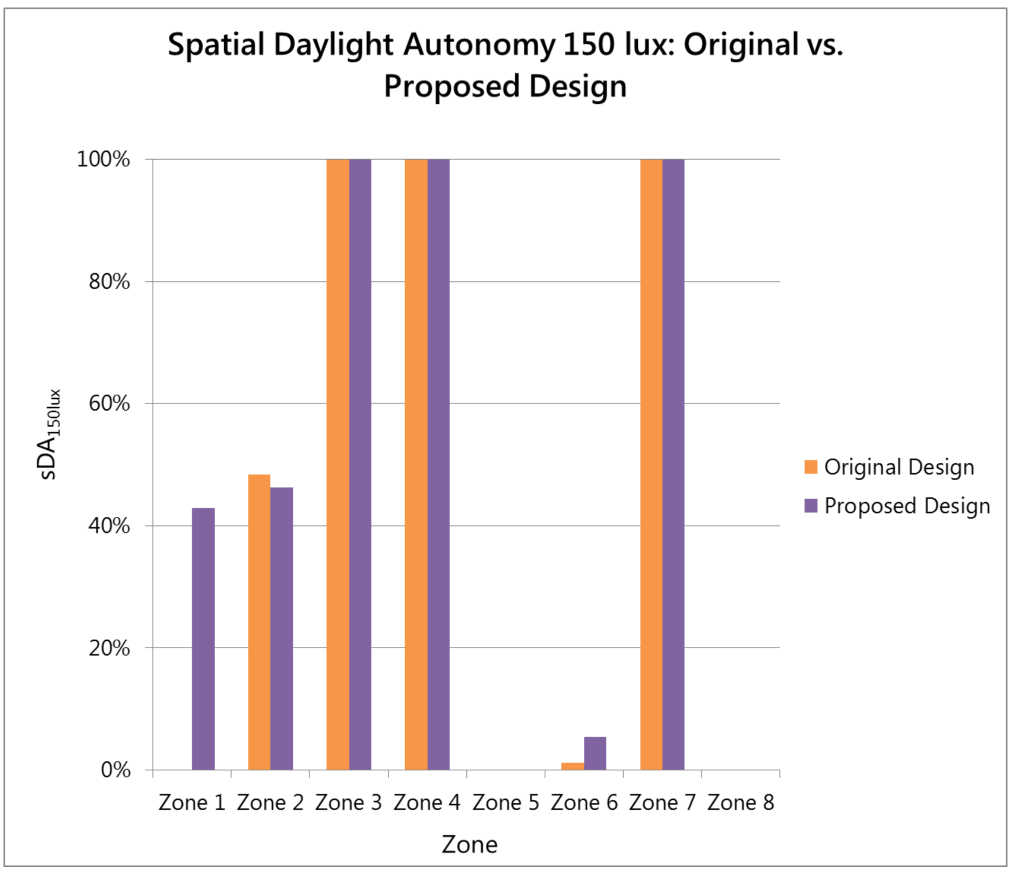


In a separate condition, annual electrical energy use is compared between the original and proposed designs. A worst case scenario is tested: shades fully down in all perimeter spaces. This is done to mimic energy simulation in *VIPER* where shades are used. Six open-loop photosensors are placed ideally on the workplane (in six different interior office spaces) looking in the +Z direction. Despite being open-loop, the protocol does not capture electric lighting illuminance be it there are no IES files in the DIVA model (see description of lighting procedure earlier in this section of the report). Lighting savings are thus a function of daylight provided at each photosensor node.

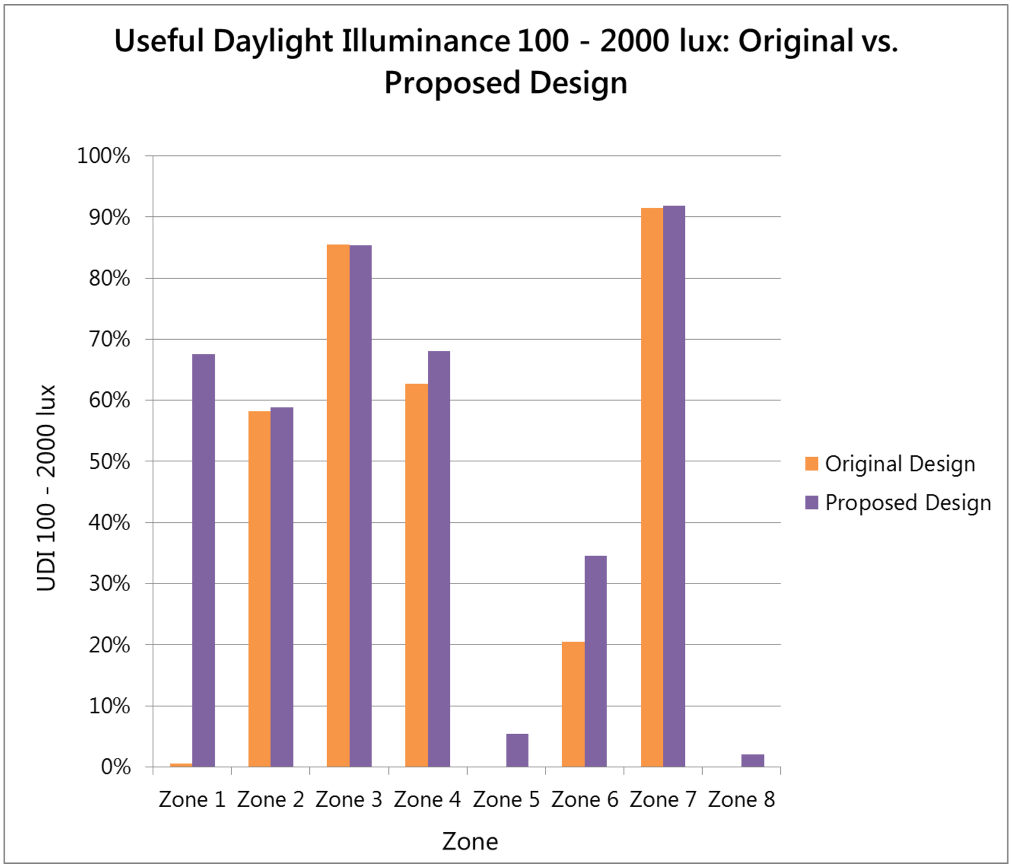
Photosensors have a stand-by power of 2 watts. Ballast loss is 20% for all lighting in both models. Each specified node controls a 118 watt fixture, providing a target illuminance of 300 lux. The original and proposed solutions exhibit the same simulation conditions, effectively comparing kWh of electric energy. The difference is multiplied by cost of electricity in Pennsylvania, $0.1267/kWh (*DOE/EAI-0226*). The proposed Kalwall + Lumira solution offers a total $110.01 energy savings per year for graduate student lighting.

Annual Grad. Area Electrical Savings with Kalwall + Lumira Proposed Design		
Room	Energy Savings (+)/Loss(-)	Annual Cost Difference
Room 456 (SE Workstation)	130.3 kWh	$ 16.51
Room 457 (S Workstation)	112.0 kWh	$ 14.19
Room 458 (SW Workstation)	233.3 kWh	$ 29.56
Room 461 (NW Workstation)	122.8 kWh	$ 15.56
Room 462 (N Workstation)	246.4 kWh	$ 31.22
Room 463 (NE Workstation)	23.5 kWh	$ 2.98
Annual Energy Savings		**$ 110.01**

Spatial daylight autonomy at 150 lux offers significant improvement especially in the south graduate student office (**increase of 42% sDA**). The north faculty office did see a slight 5% improvement in sDA_{300lux}. Worth noting, both designs yield high sDA values for the perimeter offices. Plenty of daylighting is available in those spaces and provides for maximum energy savings; furthermore, the illuminance values are beneficially and yield high UDI values, noted below.



Investigating UDI 100 – 2000 lux for the same spaces, although there is an abundant amount of daylight, the performance of the space (regarding a comfortable range of daylight illuminance) is generally comfortable. All the lighting zones experience an increase in "good" UDI. Most notably, the interior south office space has a UDI of 67.5% with the proposed design whereas the original design yields only 0.6% UDI (**67% improvement**). Similarly, the north workstation area increases UDI by **5.4%** while the north corridor has a **14.1% increase** in UDI. Perimeter spaces match in UDI meaning although the Kalwall and open office design provides better daylighting in the interior space, the faculty offices do not experience "excessive" daylighting (UDI > 2000 lux).



The visual environment created by the new façade and open-office workspace is comfortable and inviting. In a typical southern faculty office, DGP (discomfort glare probability) is 22% with Kalwall. This number is calculated at 2:00 p.m. on Sept. 21, a condition which could lead to potential issues when facing west in the office—the glare metric is view dependent, as the image is from the working perspective. At **22% DGP, the glare experienced is imperceptible**; 15% visible transmittance Kalwall diffuses daylight well as to prevent problematic glare. For the same viewpoint at the same time, the original design facilitated 26% DGP, more than the Kalwall design but also imperceptible.

Glare experienced in the open office space—facing east from a central workstation) can also be expected to be **imperceptible at 25% DGP** (calculation done at 9:00 a.m. on Sept. 21). Again, the solution lends to the idea that the Kalwall effectively diffuses uncomfortable daylight. By keeping clear glazing, occupants can experience a direct view to the exterior, operate the windows for ventilation, and use shades when daylighting is a problem; even with shades, the Kalwall solution will provide museum like daylight in the space, to comfortably provide energy savings will limiting problematic visual sensations.

Implementing Kalwall + Lumira Aerogel improved daylighting significantly for the interior spaces while maintaining comfortable illuminance along the perimeter zones. Energy modeling of the proposed design implies the new solution will nearly match the original design's energy use. Mentioned thermal components and results are discussed in the next section.

BREADTH TOPIC **MECHANICAL + ENERGY ANALYSIS**

The following section describes the East Office block as it pertains to energy use and HVAC layout. Deliverables include an account of modeled material properties, a detailed *Energy+* summary of the original and proposed design, verification of appropriately sized equipment, schematic plans for a redesigned HVAC layout, and cost implications.

Introduction
    Goals
    Methodology + Integration
Existing Conditions
Original Design
    Wall Construction
    Energy Use
    Mechanical Layout
Proposed Design
    Wall Construction
    Energy Use
    Equipment Resizing
    Mechanical Layout
Conclusion

INTRODUCTION

GOALS

Designing for improved daylighting without consideration to the energy impact on the space is ineffective. The best overall solution provides improved daylighting while mitigating added energy use; through parametric modeling, mechanical systems integration with daylighting and architecture yields a solution that is energy conscious and comfortable. Hereby, a mechanical breadth allows the designer to evaluate integrated variables which often oppose one another. Several goals follow:

1. Provide a solution that improves upon or matches the energy use of the original design.
2. Integrate energy modeling with daylight analysis; allow for parametric control as it relates to energy simulations.
3. Architecturally simplify the overhead HVAC equipment to provide a visually pleasing and uncluttered exposed ceiling in the open-office space.

METHODOLOGY + INTEGRATION

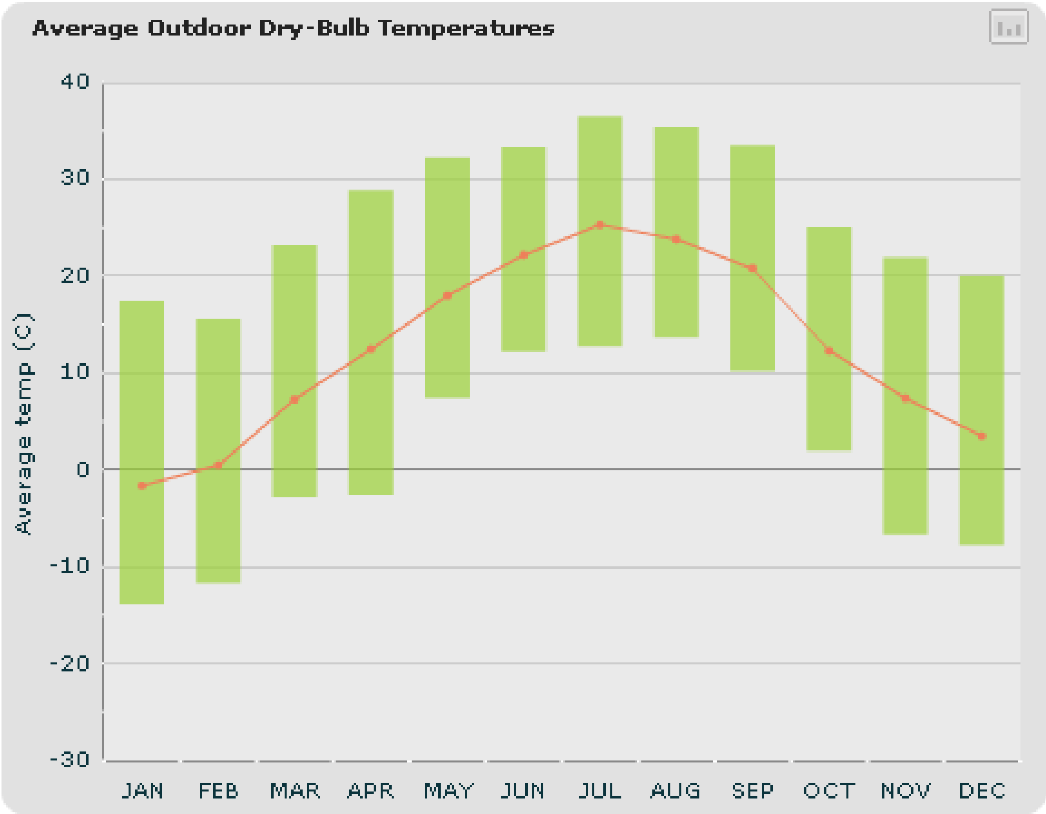
Referencing the methodology (step 6) as described in the Daylighting Depth, *VIPER* is used to compute the energy use of a typical southern facing faculty office. Through *Grasshopper*, *VIPER* analyzes real-time geometry alterations and provides the designer with constant feedback. *DIVA* for daylighting is commonly linked with VIPER through shared geometry but also more directly: actual lighting load schedules generated through daylighting analysis are linked to *VIPER* and thus included in the *Energy+* calculations. "In effect, this allows one to test the relative effect of different daylighting and controls strategies on the energy consumption of a typical daylit space." (diva4rhino.com).

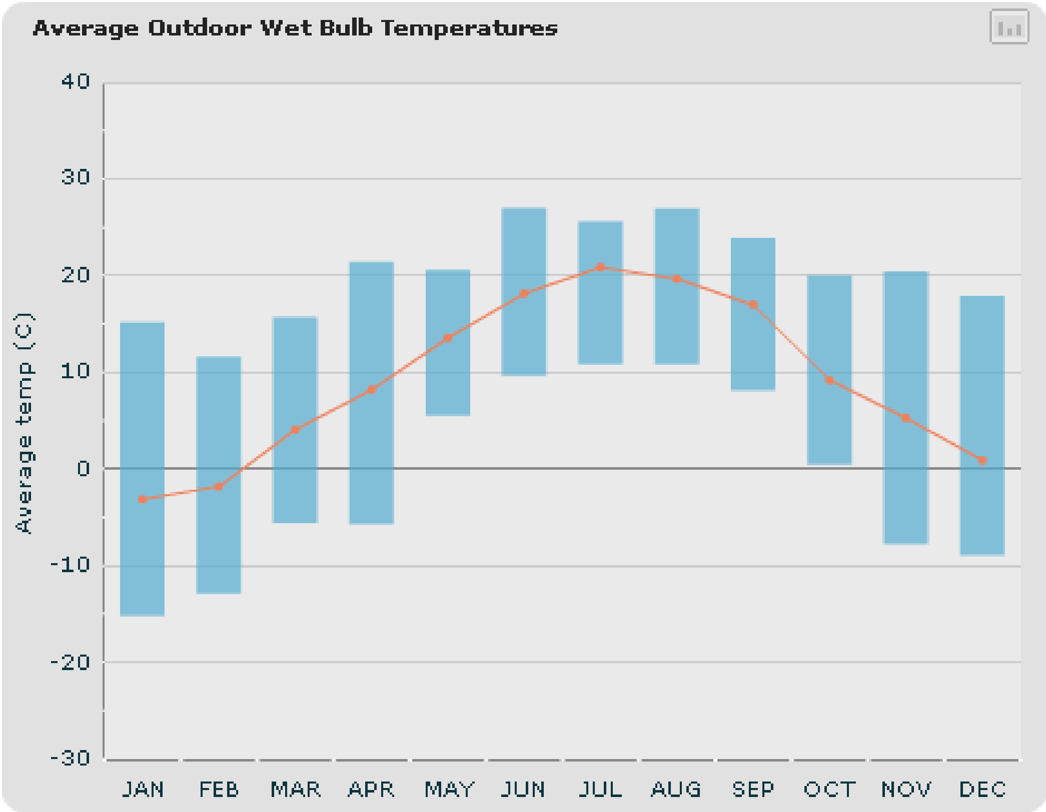
All geometry is built in *RHINO* and referenced in *Grasshopper* for use in the *Energy+* engine. For further detail on the overall workflow or parametric design process, see Daylighting Depth.

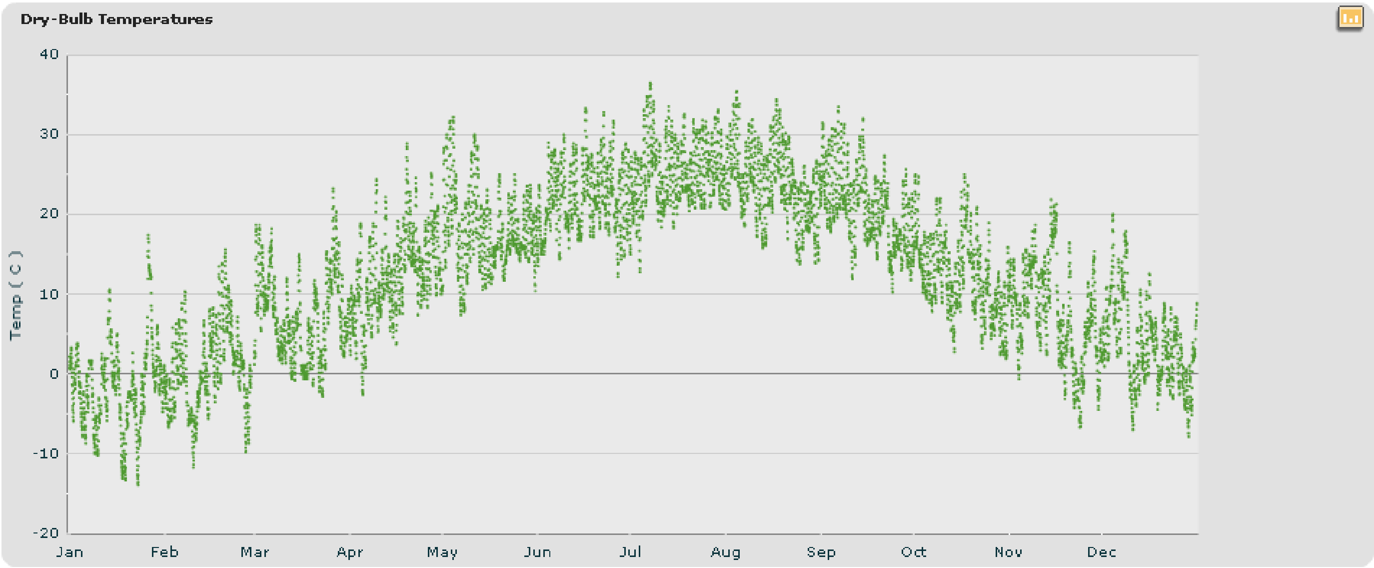
EXISTING CONDITIONS

External research of Philadelphia climate suggests that the NBS Building is located in a heating dominated zone (reference: http://www.degreedays.net/).

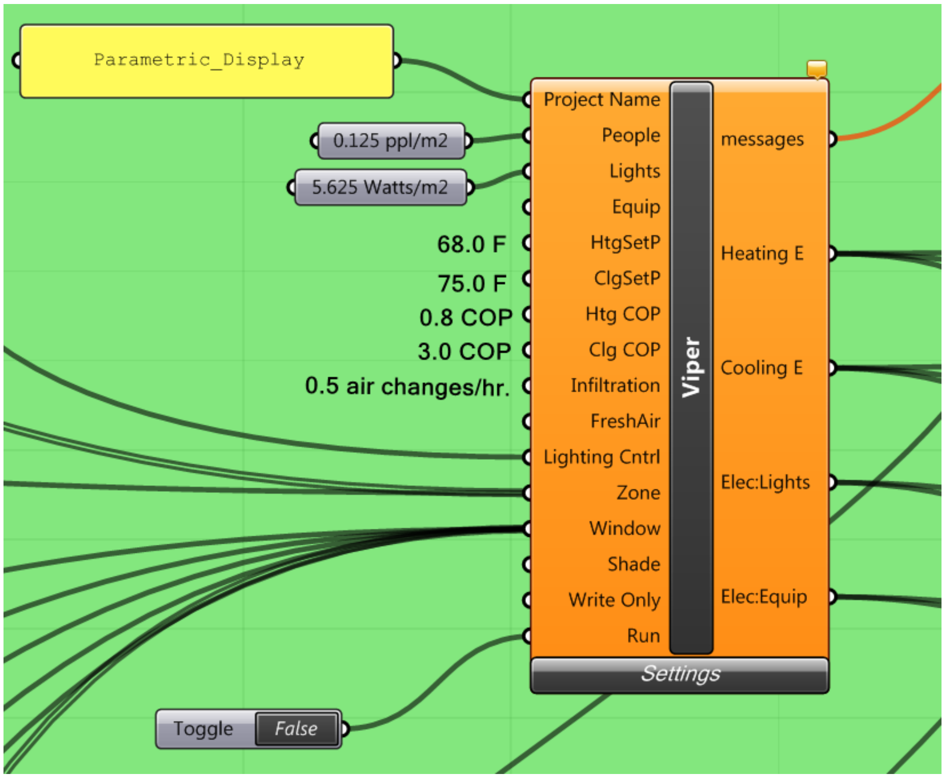
Heating + Cooling Degree Days, Philadelphia INT Airport	
HDD/CDD	Degree Days
Heating (@ 65°F)	5164
Cooling (@ 50°F)	3949


Average Outdoor Dry-Bulb Temperatures
40
30
20
10
0
-10
-20
-30
Average temp (C)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC


Average Outdoor Wet Bulb Temperatures
40
30
20
10
0
-10
-20
-30
Average temp (C)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC



Besides daylighting conditions, COMFEN also provides important information pertaining to the potential thermal performance of a building. Charts illustrate that Philadelphia, PA experiences a range of temperatures throughout the year. Good exterior wall insulation will guarantee that heat does not easily escape in the winter and heat does easily enter the space during the summer. Since Philadelphia is heating dominated, some solar gain is beneficial if controlled, as it allows for passive heating.



Information above helps to establish accurate thermal design parameters. When modeling the spaces, a heating set point of 75° F and a cooling set point of 68° F are used. An office profile is selected for internal load calculations while lighting inputs are gathered directly from *DIVA*. To encompass variable occupancies in the space (faculty, faculty and student, multiple faculty), it is assumed 0.125 people/ft^2 occupancy.

Appropriate material properties are applied directly in *Grasshopper*. Thermal properties for the façade are custom-made *Energy+* materials that are attached in the materials directory. For model simplification, interior walls, ceilings, and floors are modeled as adiabatic surfaces: these surfaces do not transfer heat since there is no temperature difference across the boundary. These surfaces will store and release heat only at the inside face of the surface. This condition is the same for the original and proposed energy models.

ORIGINAL DESIGN

WALL CONSTRUCTION

While most surfaces in the *VIPER* model are appropriately defined using default material constructions, the façade required detailed R-Value calculations to ensure accurate energy modeling. R-Value calculations for clear glazing, diffuse glazing, and the metal panels are shown here. *Energy+* materials are reported using the metric system; therefore, all final values are reported as conductivity in W/m-K. All thicknesses are 0.1 meters (m) for mathematical simplicity.

CLEAR GLAZING

$$U = 0.28 \frac{BTU}{hr * ft^2 * °F}$$

$$U = 0.28 \frac{BTU}{hr * ft^2 * °F} * 5.678263 \frac{\frac{W}{m^2 * K}}{\frac{BTU}{hr * ft^2 * °F}} = 1.59 \frac{W}{m^2 * K}$$

$$U = 1.70 \frac{W}{m^2 * K} = \frac{k}{0.1} \quad \therefore \quad \boldsymbol{k = 0.159 \frac{W}{m * K}} \quad \therefore \quad \boldsymbol{R - 3.6\ (US)}$$

DIFFUSE GLAZING

$$U = 0.3 \frac{BTU}{hr * ft^2 * °F}$$

$$U = 0.3 \frac{BTU}{hr * ft^2 * °F} * 5.678263 \frac{\frac{W}{m^2 * K}}{\frac{BTU}{hr * ft^2 * °F}} = 1.70 \frac{W}{m^2 * K}$$

$$U = 1.70 \frac{W}{m^2 * K} = \frac{k}{0.1} \quad \therefore \quad \boldsymbol{k = 0.170 \frac{W}{m * K}} \quad \therefore \quad \boldsymbol{R - 3.3\ (US)}$$

METAL PANEL

To accurately predict the R-value of the metal panel construction, wall details are referenced to create a Trace 700 wall construction assembly.

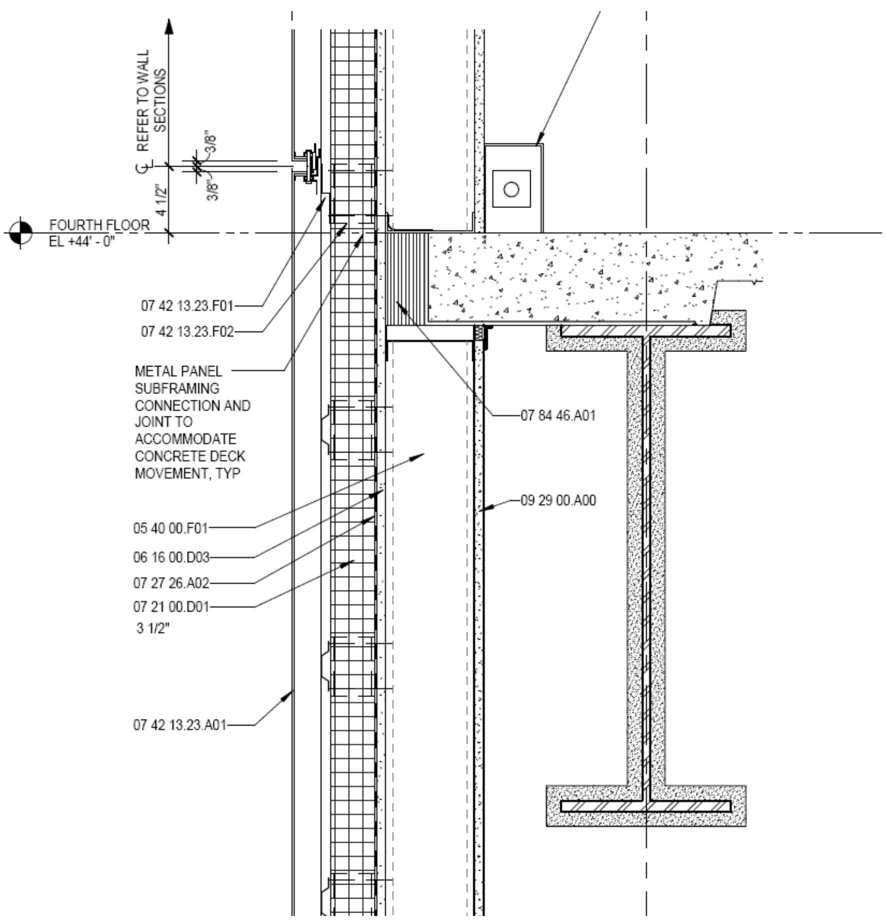
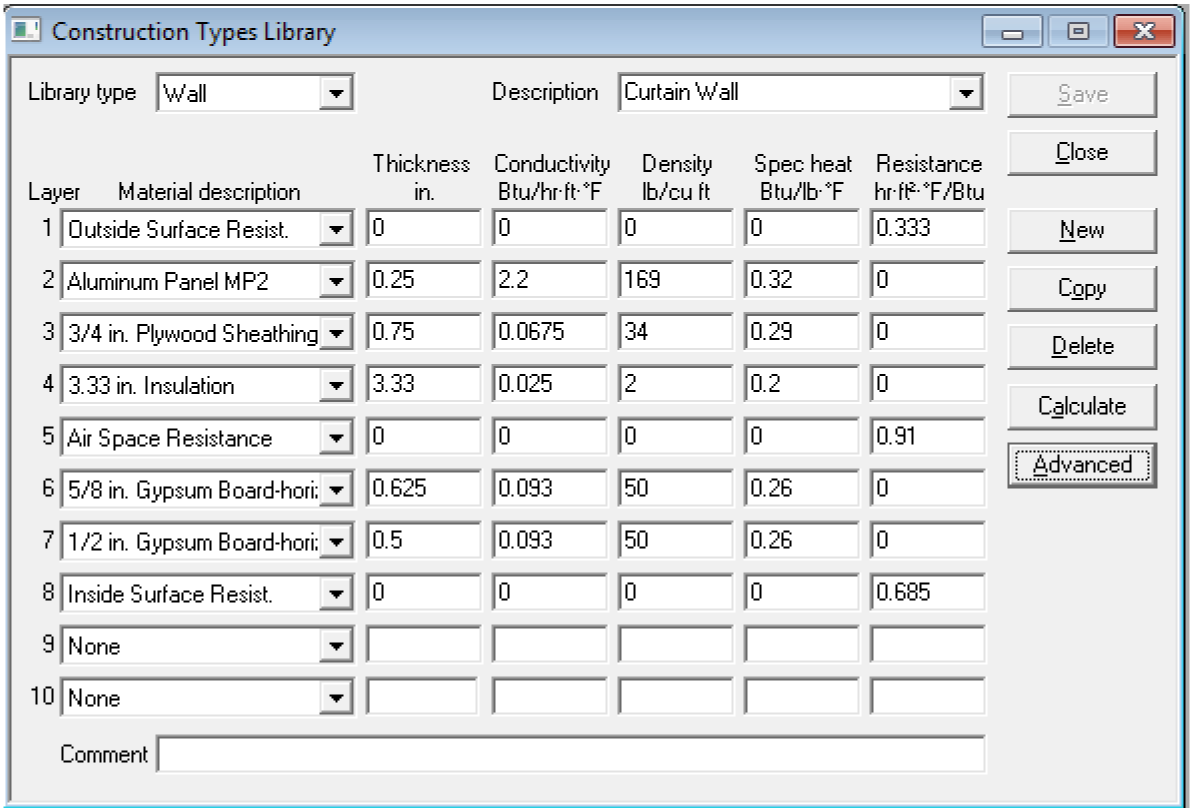
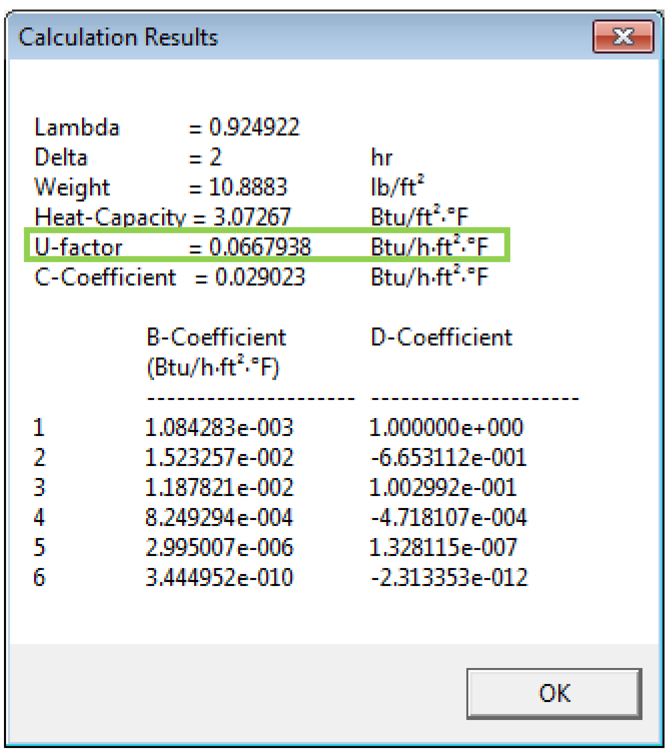


Fig. 32: MP2 Wall Detail, courtesy of SmithGroupJJR


Construction Types Library
Library type Wall
Description Curtain Wall
Save
Close
New
Copy
Delete
Calculate
Advanced
Layer Material description
Thickness in.
Conductivity Btu/hr·ft·°F
Density lb/cu ft
Spec heat Btu/lb·°F
Resistance hr·ft²·°F/Btu
1 Outside Surface Resist. 0 0 0 0 0.333
2 Aluminum Panel MP2 0.25 2.2 169 0.32 0
3 3/4 in. Plywood Sheathing 0.75 0.0675 34 0.29 0
4 3.33 in. Insulation 3.33 0.025 2 0.2 0
5 Air Space Resistance 0 0 0 0 0.91
6 5/8 in. Gypsum Board-hori: 0.625 0.093 50 0.26 0
7 1/2 in. Gypsum Board-hori: 0.5 0.093 50 0.26 0
8 Inside Surface Resist. 0 0 0 0 0.685
9 None
10 None
Comment


Calculation Results
Lambda = 0.924922
Delta = 2 hr
Weight = 10.8883 lb/ft²
Heat-Capacity = 3.07267 Btu/ft²·°F
U-factor = 0.0667938 Btu/h·ft²·°F
C-Coefficient = 0.029023 Btu/h·ft²·°F
B-Coefficient (Btu/h·ft²·°F) D-Coefficient
1 1.084283e-003 1.000000e+000
2 1.523257e-002 -6.653112e-001
3 1.187821e-002 1.002992e-001
4 8.249294e-004 -4.718107e-004
5 2.995007e-006 1.328115e-007
6 3.444952e-010 -2.313353e-012
OK

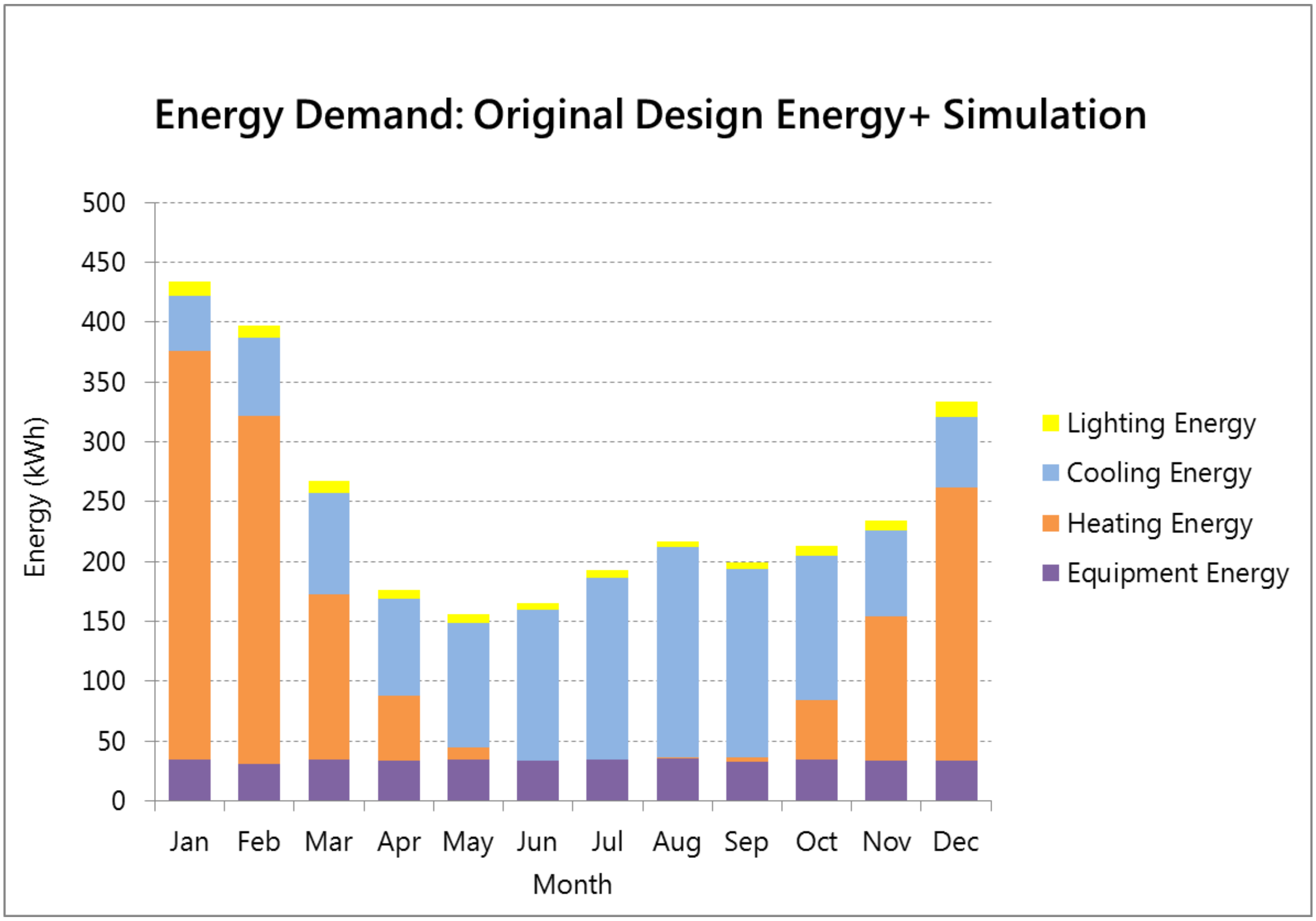
$$U = 0.0667938 \frac{BTU}{hr * ft^2 * °F}$$

$$U = 0.0667983 \frac{BTU}{hr * ft^2 * °F} * 5.678263 \frac{\frac{W}{m^2 * K}}{\frac{BTU}{hr * ft^2 * °F}} = 0.379 \frac{W}{m^2 * K}$$

$$U = 0.379 \frac{W}{m^2 * K} = \frac{k}{0.1} \quad \therefore \quad \boldsymbol{k = 3.79 \frac{W}{m * K}} \quad \therefore \quad \boldsymbol{R - 15\ (US)}$$

ENERGY USE

According to the *VIPER* simulation model, a typical southern office space uses a total of **2954.74 kWh** annually.

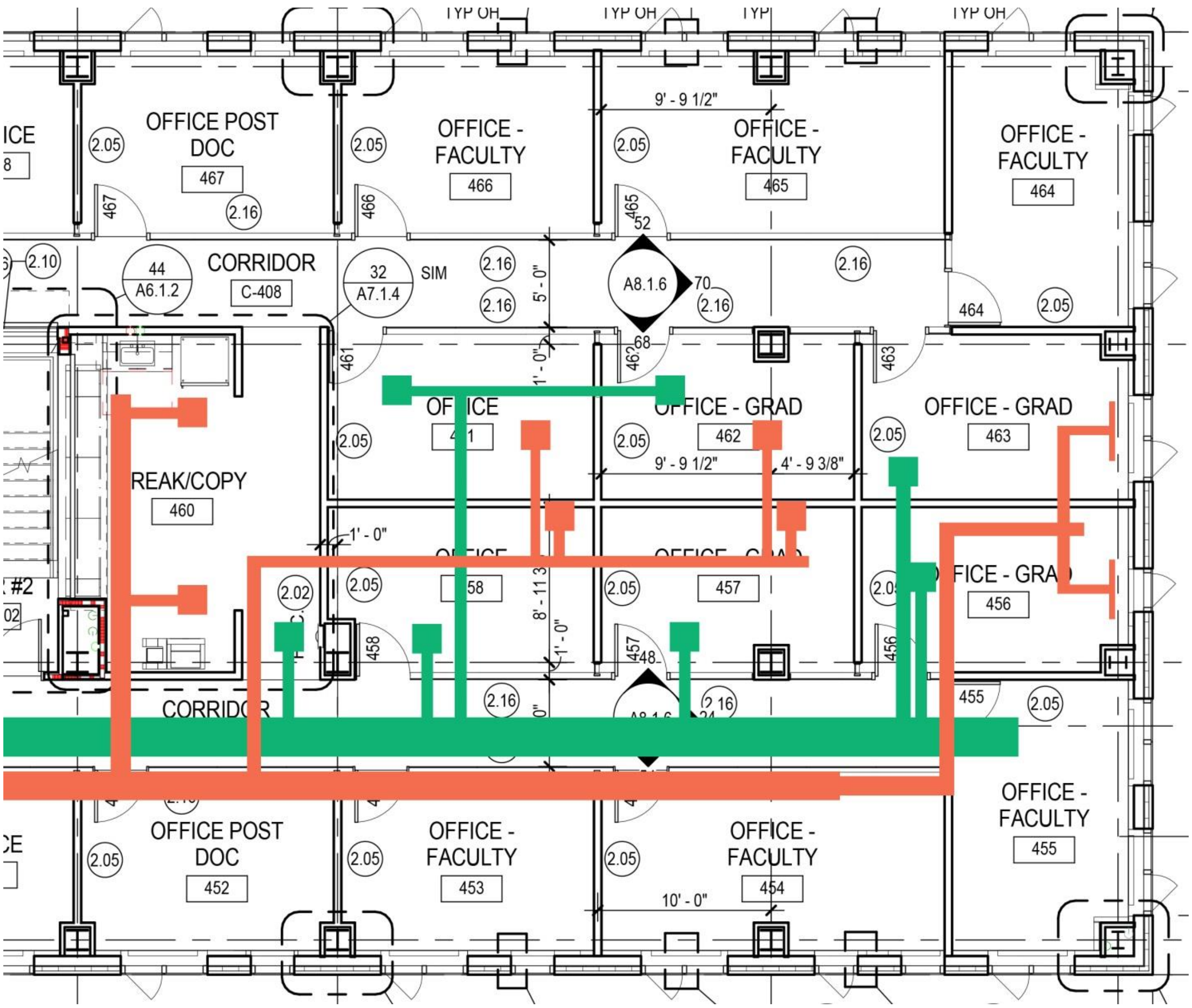


As expected, in the winter months, the heating load dominates whereas in the summer, the cooling load dominates. Equipment load remains constant throughout the year while the lighting is a function of the daylighting and *DIVA* schedule.

Energy Use for Original Design	
Type of Energy Use	Annual Use (kWh)
Equipment	404.44
Heating	1206.22
Cooling	1241.76
Lighting	102.31

MECHANICAL LAYOUT

Below is an existing plan view of the HVAC equipment servicing the graduate student area. Supply air is marked in **orange** while return air is marked in **teal**.



PROPOSED DESIGN

WALL CONSTRUCTION

In the proposed design, all materials remain the same; diffuse glass and some metal panels are replaced with Kalwall + Lumira Aerogel. This construction is specified to have a US U-Value of 0.05 BTU/hr-ft^2-°F (R-20 US).

KALWALL + LUMIRA

$$U = 0.05 \frac{BTU}{hr * ft^2 * °F}$$

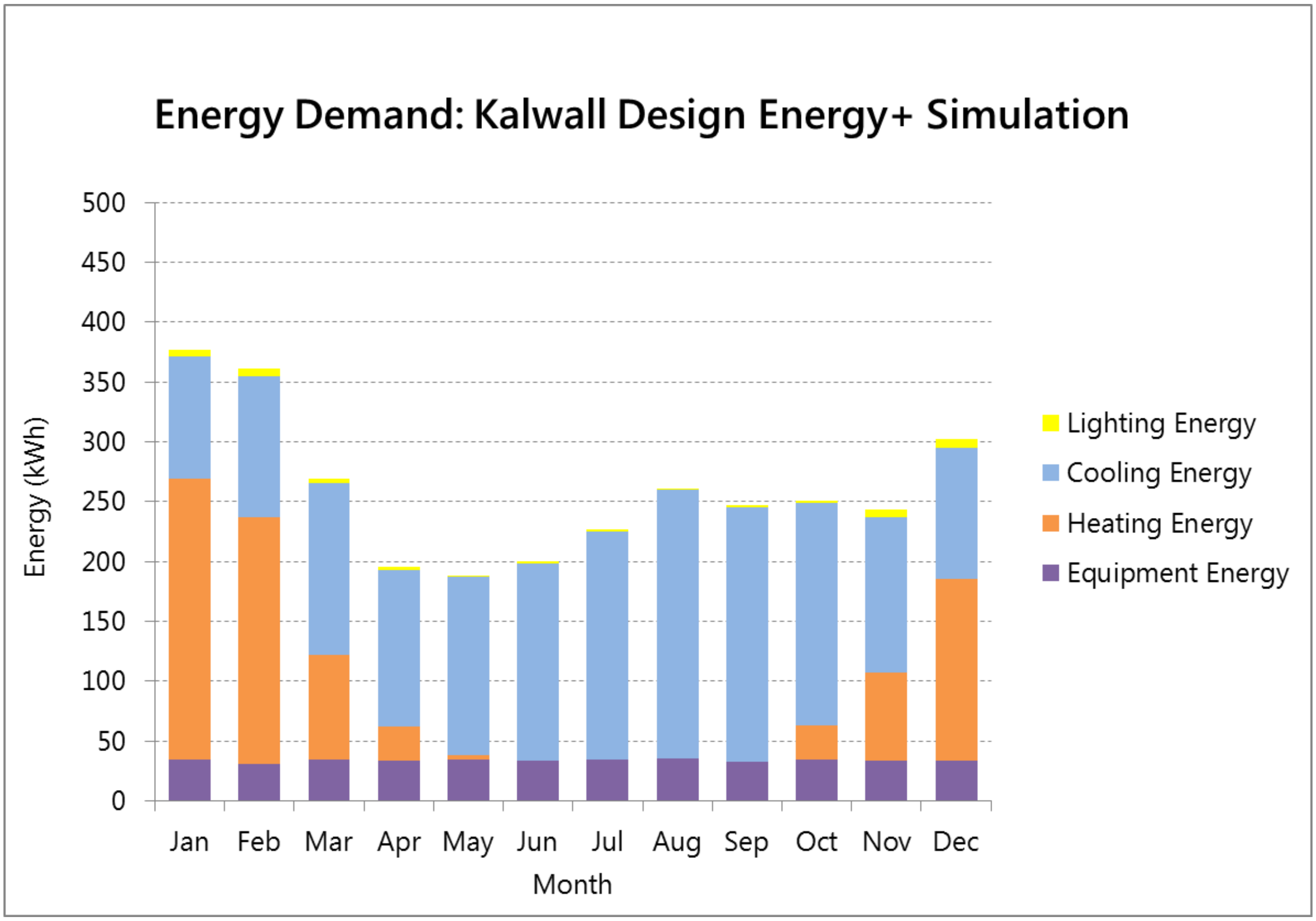
$$U = 0.05 \frac{BTU}{hr * ft^2 * °F} * 5.678263 \frac{\frac{W}{m^2 * K}}{\frac{BTU}{hr * ft^2 * °F}} = 0.284 \frac{W}{m^2 * K}$$

$$U = 0.284 \frac{W}{m^2 * K} = \frac{k}{0.1} \quad \therefore \quad \boldsymbol{k = 0.0284 \frac{W}{m * K}} \quad \therefore \quad \boldsymbol{R - 20\ (US)}$$

An R-value for Kalwall effectively matches the R-value of the existing metal panel system. By using Lumira Aerogel, it is possible to increase daylighting in the space while improving energy use—essentially eliminating the need for secondary thermal system aside translucent panels. The actual data is provided below; the relationship between added daylight and cooling load is interesting and warrants investigation.

ENERGY USE

Upon optimization for minimum energy use based on subjective reasoning (see Parametric Optimization in Daylighting Depth), a typical southern office space with Kalwall uses a total of **3121.07 kWh** annually.

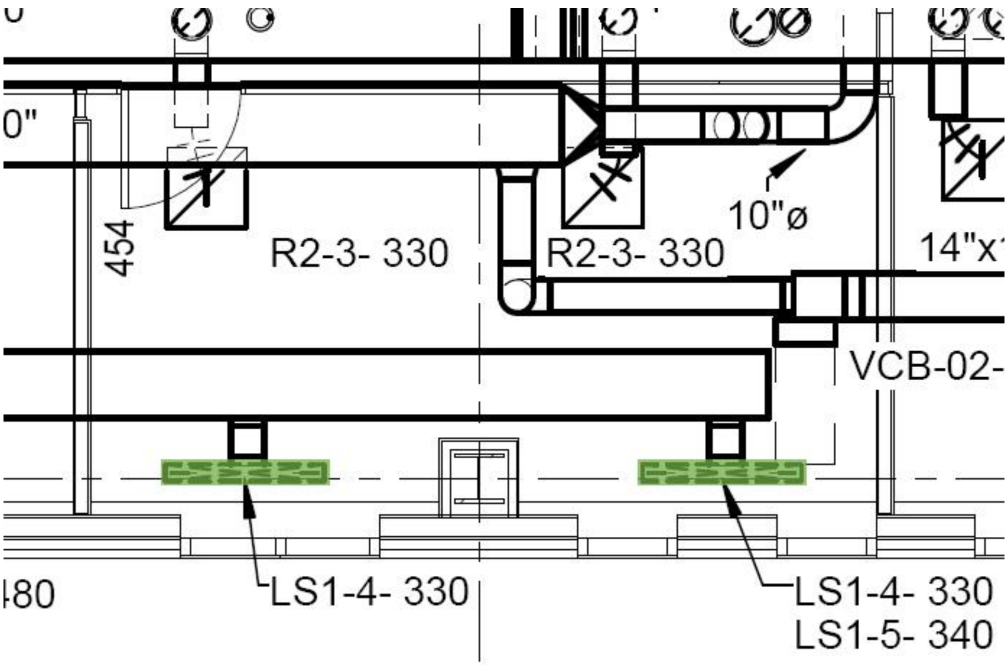


The graph above illustrates several important points: the proposed solution adds significant cooling load to the space especially in the late summer/early fall months. The Kalwall solution performs best in April and May when temperatures outside are moderately mild and the sun provides ample daylight but not excessive solar gain.

Energy Use for Proposed Design	
Type of Energy Use	Annual Use (kWh)
Equipment	404.44
Heating	814.65
Cooling	1861.22
Lighting	40.77

EQUIPMENT RESIZING

To resize the linear diffusers which supply heating and cooling to the office space, a linear relationship between maximum kWh (either extreme summer day for cooling or extreme winter day for heating) and cfm as specified in the mechanical drawings (660 total cfm) is established. The equipment is sized for the worst case scenario: for the original and proposed design, the highest kWh value for the extreme days is used to create the relationship.



Peak Energy Use for Original Design		
Type of Energy Use	Extreme Summer Day (kWh)	Extreme Winter Day (kWh)
Heating	0.00	**9.00**
Cooling	7.85	2.72

Peak Energy Use for Proposed Design		
Type of Energy Use	Extreme Summer Day (kWh)	Extreme Winter Day (kWh)
Heating	0.00	5.22
Cooling	**9.60**	6.40

$$\frac{9.00\ kWh}{660\ cfm} = \frac{9.60\ kWh}{X\ cfm}$$

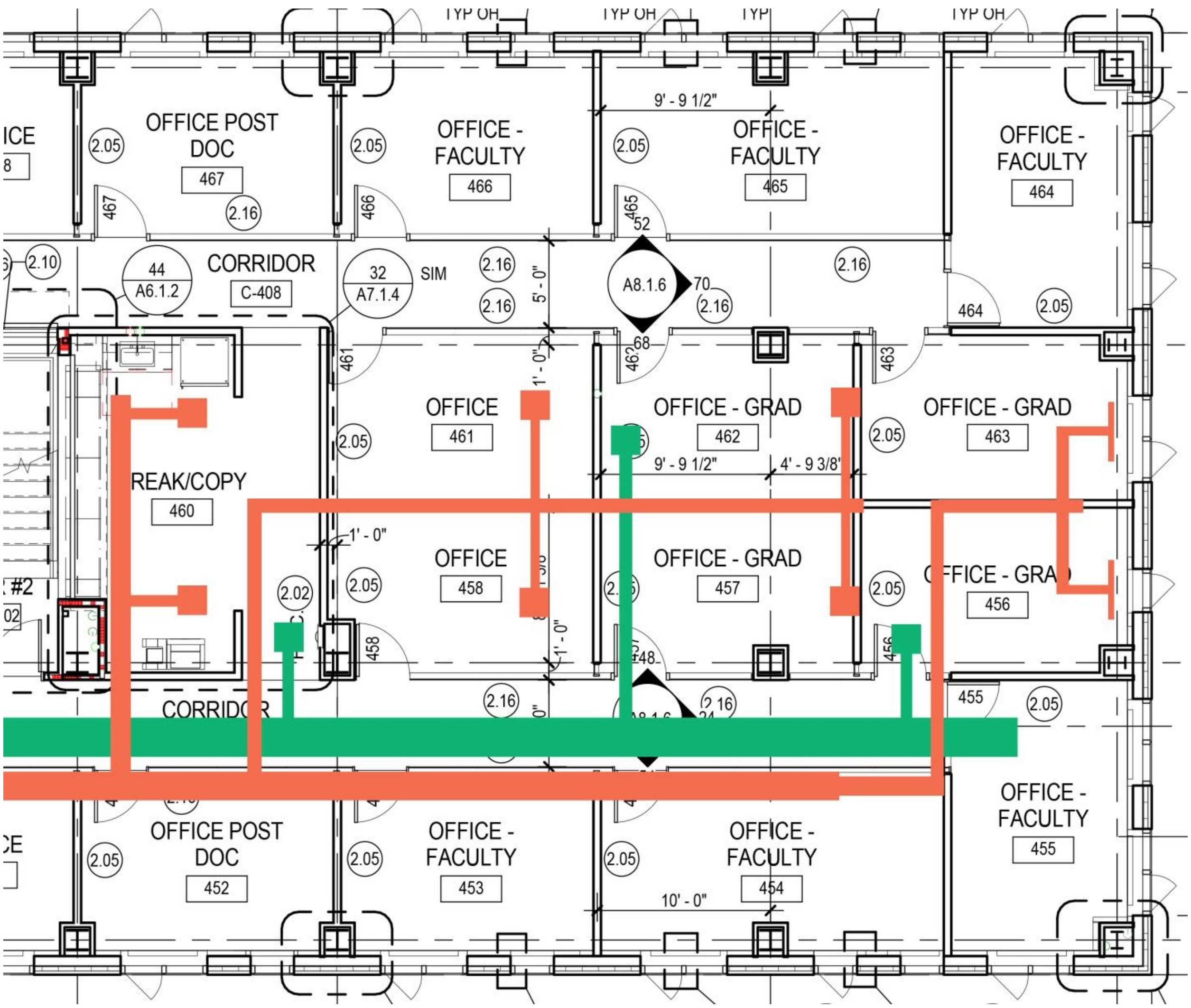
$$\boldsymbol{X(proposed\ design) = 704\ cfm\ total}$$

Therefore, each linear diffuser requires 352 cfm, a 12 cfm increase in capacity. The volume control box that services these two linear diffusers has a design airflow of 1140 cfm and minimum 230 cfm airflow. The added 24 cfm in the office does not significantly affect the comfort of the space.

For heating, steam is supplied by the campus steam distribution system. Chilled water is likewise supplied by the campus; hereby, chillers or boilers do not need to be resized as the campus can handle the capacity demand of the building spaces. Considering the little change in energy use between the proposed and original design, this concept is reaffirming.

MECHANICAL LAYOUT

Below is a revised plan view of the HVAC equipment servicing the graduate student area. Supply air is marked in **orange** while return air is marked in **teal**.



By opening the interior office zones, the HVAC system is able to be simplified. While the supply air ductwork and diffusers remain the same size, they are relocated and round instead of rectangular. The existing system is used to calculate the overall cfm of the supply system. The revised system then uses round diffusers and duct work that can handle the previous cfm capacity.

The return air system is simplified as well: the total cfm is calculated and used to guide the redesign. Here, however, three grilles were removed and ductwork shortened as the return air system could service a shared zone. Essentially, each ductwork run and return grille accounts for two previously installed grilles (double cfm rating).

All diffusers and grilles have a NC-30 rating or lower to minimize irritable noise in the office space. Likewise, ductwork is painted white to maximize daylighting and create a lofty impression in the space.

A detailed cost comparison between the old and new HVAC layout yields savings. Upon resizing and relocating the ductwork, diffusers, and grilles, one can expect to **save $1058.29** (reference Appendix F). The system remains quite and effective, now exposed and made an architectural element.

CONCLUSION

Although the new solution does not increase energy use significantly (**only 5.6%**) there are some interesting comparisons worth noting.

Energy Use Comparison of Typical South Faculty Office			
Type of Energy Use	Annual Use (kWh)		
	Original Design	Proposed Design	Difference
Equipment	404.44	404.44	0.00
Heating	1206.22	814.65	- 391.57
Cooling	1241.76	1861.22	+ 619.46
Lighting	102.31	40.77	- 61.54
Total	**2954.74**	**3121.07**	**+ 166.35**

While the equipment energy use does not change between the original and proposed design, other types of energy use do change. The annual heating load decreases by 391.6 kWh as the Kalwall provides for more passive heating. This is helpful in a heating dominated space such as in Philadelphia, PA. Relating, the lighting load is expected to decrease by 61.5 kWh: more readily available daylighting means less electric lighting (based on photosensor open-loop ideally commissioned calibration—a common variable between both designs).

Interestingly, the 619.5 kWh increased cooling load outweighs the savings experience with heating and lighting. Throughout the year, the Kalwall solution introduces more diffuse daylighting solar gain into the office. A quick simulation focusing on a typical northern office shows the proposed solution saves annual energy. The original design uses 2933.9 kWh while the proposed design uses 2494.2 kWh (**15% improvement**). *While a south office typically uses more energy with the proposed design, a north office uses less energy annually.*

A cost analysis is done using the reported energy savings for typical south and north faculty office. Ratios of area are used to determine the energy savings or losses for a respective south or north facing office relative to the two conditions studied above (office space along the east is assumed no decrease or increase in energy use because of its position relative to the north and south offices). Difference in energy use (kWh) is calculated for each zone and multiplied by the annual cost of electricity in Pennsylvania: approximately $0.1267/kWh (*DOE/EAI-0226*).

Annual Energy Savings with Kalwall + Lumira Proposed Design		
Room	Energy Savings (+)/Loss(-)	Annual Cost Difference
South Room 451	- 86.96 kWh	-$ 11.02
South Room 452	- 113.42 kWh	-$ 14.37
South Room 453	- 120.98 kWh	- $ 15.33
South Room 454*	- 166.35 kWh	- $ 21.08
South Room 455	- 124.76 kWh	- $15.81
North Room 464	329.78 kWh	$ 41.78
North Room 465*	439.71 kWh	$ 55.71
North Room 466	319.79 kWh	$ 40.52
North Room 467	299.80 kWh	$ 37.98
North Room 468	229.85 kWh	$ 29.12
Annual Energy Savings		**$ 127.52**

*Indicates zone that was actually modeled in *VIPER*.

With the Kalwall + Lumira solution, one **saves $127.52 per year**; this parallels the optimization point found through parametric design where the subjective decision lends to increased daylighting and minimal change in energy use (refer to parametric optimization in Daylighting Depth).

BREADTH + DEPTH **CONCLUSION**

The integrated architecture breadth, mechanical breadth, and daylighting depth is summarized. This portion of the report includes an assemblies and energy savings cost analysis and an overall evaluation of the proposed design.

Summary

Costs Analysis
Evaluation

SUMMARY

COST ANALYSIS

An assemblies estimate cost comparison between the original and proposed designs provides insight to the expenses incurred by adding Kalwall + Lumira Aerogel. All cost data obtained from *RS Means Assemblies Cost Data 2014*.

Exterior Wall Redesign				
Material	Unit	Bare Material	Bare Labor	Bare Total
Sandwich panel, 22 Ga. Galv., both sides 2" insulation, enamel exterior, polyvinylidene flouride exterior finish	SF	$ 14.10	$ 6.25	$ 20.35
GL-5 (Clear) - Glazing Panel, insulating, 1" thick, 1/4" float, clear	SF	$ 18.25	$ 14.30	$ 32.55
GL-5 (Diffuse) - Glazing Panel, insulating, 1" thick, 1/4" float, light and heat relfective glass, tinted	SF	$ 34.50	$ 12.60	$ 47.10
Kalwall + Lumira (Aerogel)	SF	$ 50.00	$ 30.00	$ 80.00

Exterior Wall Redesign	
Material	Total Cost
Original Design	$ 81,604.15
Proposed Design	$ 92,078.35
Additional Costs (Material + Labor)	**$ 10,474.20**

In the same manner, an assemblies estimate of replacing the original design's interior office space with the proposed design's open-office space is reported. This includes removing walls, ceilings, desks, and doors and installing workstation furniture. The savings generated by simplifying the mechanical system is included in the price difference. All cost data obtained from *RS Means Assemblies Cost Data 2014*.

Interior Redesign				
Material	Unit	Bare Material	Bare Labor	Bare Total
5/8" FR drywall, no base layer, 2-1/2" @ 16" O.C., 5/8" regular drywall	SF	$ 1.15	$ 3.44	$ 4.59
Interior glazed opening, aluminum tube finish, 1/4" float, 12'x4' opening size	Opng.	$ 1,725.00	$ 1,175.00	$ 2,900.00
Wood Door/Wood Frame, hollow core/flush, 3'0"x7'0"	Ea.	$ 340.00	$ 250.00	$ 590.00
Acoustic Ceiling, 5/8" fiberglass board, 24"x24", tee, suspended	SF	$ 2.35	$ 1.86	$ 4.21
Office workstations (16)	Ea.	$ 2,500.00	$ 200.00	$ 2,700.00
Misc. Office Equipment (Tables)	Ea.	--	--	$ 500.00
Savings due to renovated mechanical layout	--	--	--	$ 1,129.55

Interior Redesign	
Material	Total Cost
Original Design	$ 45,877.37
Proposed Design	$ 46,378.64
Additional Costs (Material + Labor)	**$ 501.27**

Given the total amount of incurred costs and annual energy savings from both the daylighting depth and mechanical breadth, a simple payback analysis illustrates the amount of time the owner can expect to see any financial benefit from investing in Kalwall + Lumira Aerogel. A payback period between 10 and 13 years is deemed a worthy investment.

Simple Payback Period		
Annual Energy Savings	Total Cost	Payback
$ 237.53	$ 10.975.47	**46 years**

EVALUATION

Despite providing increased beneficial daylighting at minimal impact to the energy load of the space, the optimal proposed Kalwall + Lumira Aerogel design solution and open-office plan is simply too expensive to provide the owner with a justified reason to invest.

Although the proposed design is too expensive, the integrated analysis did meet the goals of the stated proposal. First, parametric design and optimization algorithms were effectively used to inform the design—a fluid workflow between architecture, daylighting, and mechanical engineering was established on a common platform.

Furthermore, daylighting was improved within a typical floor plan within the East Block of the NBS Building. Southern graduate spaces show a 48% improvement in cDA_{300lux} while northern graduate student spaces show a 16% improvement in cDA_{300lux}. Spatial daylight autonomy at 150 lux remained similar between designs; a southern graduate student office, however, saw an 18% improvement in sDA_{150lux}.

"Under-lighting" or "over-lighting" does not occur as UDI 100 – 2000 lux increased with the proposed design. North graduate student spaces improved UDI by 5% to 15%. A south graduate student work area had a 67% improvement in helpful UDI. The probability of discomfort was less with the proposed design than the original, though both are likely imperceptible.

The energy use profile of a typical south office was maintained; energy use only slightly increased by 166 kWh annually while it decreased by 440 kWh per year for a typical north office.

Architecturally, the new interior space fosters collaboration and faculty-student interaction. An open and spacious plan paired with increased useful daylight creates a productive and inviting atmosphere. With the proposed design, every graduate student has their own workspace within a constructive student community. Faculty can maintain their privacy while still getting a perimeter office space.

Acoustic problems are mitigated by specifying NC-30 rated grilles and diffusers. An adjustment to the mechanical layout in the graduate student area provides an uncluttered and organized exposed ceiling system; mechanical equipment along the perimeter does not need major resizing adjustments as the energy use remained similar between designs.

Through this analysis, exploration of parametric design and advanced technologies was possible. The overall parametric process is better understood and can now be readily applied to future daylighting problems. The process allows one to better inform architectural decisions based on daylighting and energy use data: although the initial costs are relatively high and thus yields an extended payback of 46 years, the proposed architecture does provide better daylighting and acceptable energy loads. With an overall project estimated cost of $49,300,000, $10,975 for a more pleasing environment can be justified (0.03% of overall cost).

CONCLUSION

CONCLUSION

SUMMARY

When speaking about the NBS Building, Associate Dean for the Natural Sciences, Richard Schulz, said that "the main objective is to have a place where Penn undergraduates who are life science majors have a place where they can relate to…if you bring people together, there's a higher likelihood of interactions happening among them…"

The lighting solution thus spherically connects the students, architecture, and nature through biomimicry of a deciduous tree. The lighting speaks to the interests of the Natural Science students and reinforces that the new NBS building is the central place for community connection and activity.

The unique southern scrim, lit by several LED narrow beam floodlights, *becomes a festive expression of the absence of daylight much like a leaf changes color in the late fall*—a response to nature and architecture. The surrounding site encourages exploration through the use of theatrical lighting while maintaining safe illumination for occupants of the space. Light from the ground floor lobby, apparent on the illuminated vertical surfaces, spills out from within.

Upon being drawn in, the lobby expresses itself through architecturally conscious lighting: *organic movement parallels a tree's process of transitional pull, highlighting paths of uneven pressure and providing visual direction*. Lighting vertical surfaces and allowing light to fill the space from the periphery creates a pleasant and relaxing space. Placing brightness in areas of importance reinforces way-finding and transition through the space, much like the flowing ceiling visual suggests.

The classroom is fitted with a discontinuous symmetrical layout of fixtures, *providing uniform lighting much like a glowing canopy from above a tree's trunk*. The lighting is organized yet fosters collaboration and interaction. The solution is responsive to daylighting, user occupancy, and scene controls.

Lighting in the lecture hall *captures the essence of a tree's lateral roots—extending from a central point—while transforming the ceiling into a system of central and companion cells*. Here, the lighting provides sufficient illumination for prescribed tasks yet maintains an organic and unique sense. Layers of light illuminate various curved and planar surfaces, allowing light to reveal itself through the architectural forms.

A corresponding electrical system services the new lighting, meeting ASHRAE/IESNA Standard 90.1 requirements. Through an in-depth transformer analysis, it is implied that while using NEMA Premium low-voltage transformers is not financially beneficial, changing cast-coil unit-substation transformers to vegetable-based fluid filled transformers will yield lower annual operating costs at a lower initial cost.

Finally, through parametric modeling and analysis, an architectural solution designed for maximum useful daylight and acceptable energy use is proposed. The proposed Kalwall and open-office design does improve daylighting and energy use relative to several metrics, facilitating $237.53 in energy savings per year. A $10,975.47 incurred cost of the new solution alludes to a simple payback period of approximately 46 years. While this solution is extended beyond 13 years payback, the additional cost of the system is only 0.03% of the overall project cost; this does present the owner with a viable option be it he or she values a more pleasant work environment for occupants.

Indirectly, the process of parametric modeling was proficiently explored and implemented. As far as thesis is concerned, this new skill is certainly beneficial upon graduation. The effectiveness of “visual coding” is hard to learn at first; however, once understood, parametric design and optimization is an extremely powerful and informative method of design. Architectural engineers of any focus would benefit greatly from having the opportunity to learn and implement parametric design techniques: engineers and designers are able to successfully communicate and design *with* an architect, not for one.

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A list of all software used is noted.

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