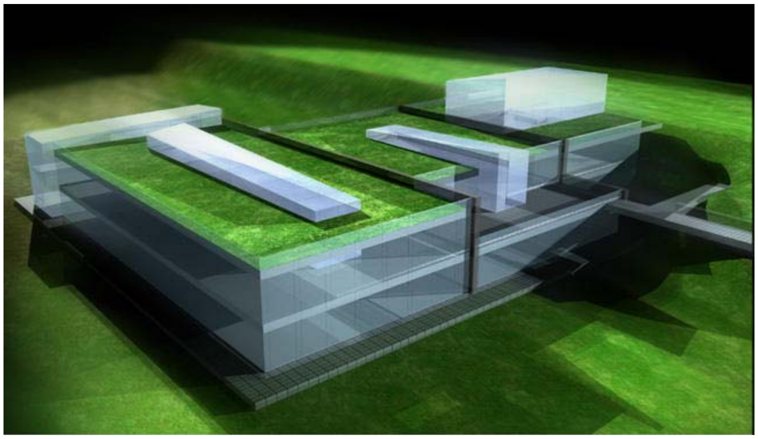

Greenwich Academy Upper School
Lighting/Electrical Redesign

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AE Senior Thesis 2004

The Pennsylvania State University
Department of Architectural Engineering

| Executive Summary

Somewhere in the woods of Connecticut, as forests are being removed to make room for expanding families, there is a building that was built to celebrate its relationship to the natural world. The building is a cube of light, it is a forest of man made wood and steel, it is a garden 40 feet in the air, it is a school. It is the Greenwich Academy Upper School designed by Roger Duffy of Skidmore Owings and Merrill.

I was first attracted to this building when I saw a picture of it while working last summer for the same company that built the school, Turner Construction. The picture was eye-catching, but more confusing to me at the time. It showed a luminous hallway with what looked like a bridge cutting across it, and the whole structure looked to be supported with wood mullions.

I was even more amazed when I found out that the wood columns are the structure, and when I started to hear about the different "green" design aspects that were integrated into the design and the construction, I knew that this was a building that I would really enjoy learning more about.

The lighting is quite interesting also, as there is an LED system in place inside of the mullions, which creates moving spectrums of light throughout the entire building. The system was designed by James Turrell, and I knew that it was apart of the building that really helped to establish its character. So I did not disturb the glowing box that is the main entrance to the school, but I did enjoy the opportunity to try my hand at designing a few other spaces in the building.

First of all is the library, a 4400 square foot space which features one of the more exposed light chambers in the building. The north end of the room is essentially a two-story glass box. The challenging architecture of the building came into in several of the other rooms, and really added to the adventure of remodeling the building systems.

| Executive Summary (cont'd)

As I came to understand each of the spaces, and their place in the overall building, I was able to sort out which criteria were most important to each room. The library required a flexible system to account for the variety of tasks to be performed. This was accomplished by using as many fixtures as there were activities. Next, the science room required high illuminance levels on the horizontal and vertical surfaces. I employed a recessed direct/indirect system to provide these levels, as well as to contribute to the overall sense of openness that the building seems to provide.

Third, I analyzed the main corridor of the building, and switched from a recessed fluorescent system to a cove and downlight solution in order to create general brightness and also points of interest. Finally, since I did not want to disturb the main entrance, I decided to work on the library entrance, which is located near the north end of the building. This space needed strong light levels for security, but also some relaxed areas for visual interest.

Since I had been dealing with the large areas of glazing in several of my chosen spaces, I decided to do a heating and cooling load analysis based on a passive solar storage design of the library's light chamber. The results showed that the change to a more transmissive glass and a stone floor would help reduce energy costs, but may endanger the architectural integrity of the building. I decided to follow up this study with an analysis of the acoustics in the library, to determine what the effects of the direct-gain system would be. The results here were slightly inconclusive, as the reverberation time did not change significantly enough to warrant any kind of change.

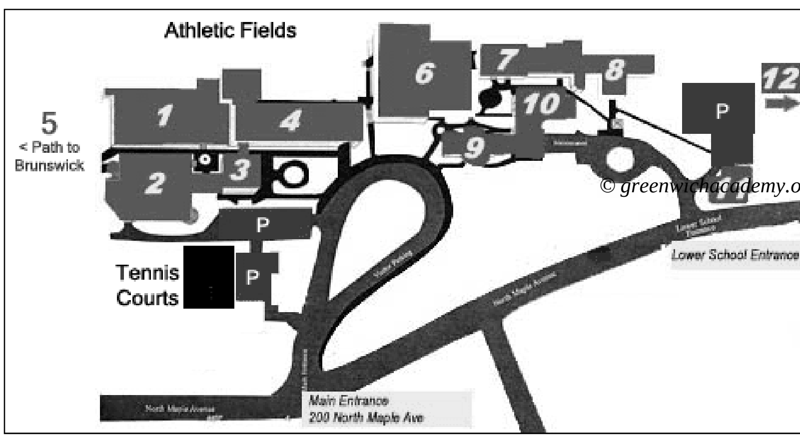
All in all, I had a great experience trying to come up with my own solutions for the spaces, and I can only hope that one day my work might have the same effect on an engineering student.

| Building Introduction

Greenwich Academy

Greenwich Academy is a private educational institution for girls located in Greenwich, CT. The campus is set on 32 acres of rolling terrain, surrounded by wooded areas, and contatinting several ponds and streams. The independent school encompasses grades K-12, and offers recreational facilities as well as classrooms and laboratories.

As a college preparatory day school, GA strives to provide a challenging, comprehensive educational experience with the objective of developing independent women of integrity, courage, and compassion. The tight grouping of buildings is meant to reflect the community established by students, parents, alumnae and faculty, which comes together to better achieve the goals of the institution.

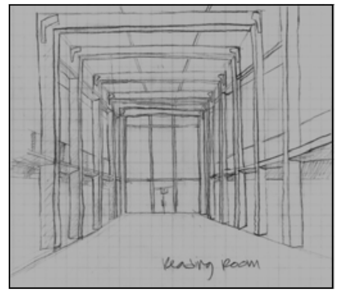


Building Function

The Upper School (number 6 on the map) provides facilities for grades 9-12, and is connected to the Middle (7) and Lower (8) Schools. As a part of the school community, the building serves as both a physical location for classes and meetings, and also as a tool for enabling each student to reach her highest levels of academic achievement as well as interpersonal development.

Architectural Features

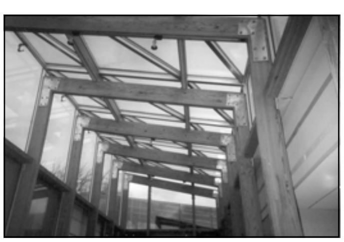




- → School is built into a hillside, entrance is on the top level.
- → Open, weightless design aesthetic applied throughout school.
- → 4 “Light Chambers”; Large, fully glazed boxes that penetrate above the 2nd floor.
- → Fully planted roof for stormwater retention and integration with surroundings.
- → 30% of roof is glazed tops of light chambers, 53% is planted.



- → Glulam columns and mullions.
- → LED light pipes built into mullions.
- → DMX dimming system cycles LED’s through visual spectrum every 15 minutes.
- → 4400 s.f. library with separate entrance and courtyard.
- → Glass and heavy timber is meant to give illusion of “walking through a forest”.




Greenwich Academy Upper School

Greenwich, CT

The Upper School is a 2-story, 50,000 s.f. school for girls in grades 9-12. The building is clad almost entirely in glass curtain walls, and features 4 glass "light chambers" with a total surface area of 5500 sq. ft. A lush landscaped roof covers the structure, and provides a beautiful environment as well as storm water management. Additionally, the building and site were designed and constructed with sustainability in mind.

project team:
owner: Greenwich Academy
architect: Skidmore, Owings and Merrill
CM: Turner Construction Co.
MEP: AKF engineers
landscape architect: Brown/Sardina, Inc.
structural: DiBlasi Associates

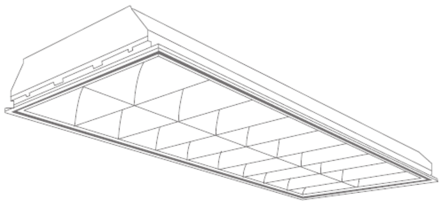
lighting
-DMX Dimming system used for site and roof lighting and at Main Entrance.
-Large Light Chambers penetrate the space and provide daylight to interior.
-Classrooms and Labs are lit with 2'x4' air-handling troffers.

electrical
-Existing campus HV connection feeds 750 KVA transformer.
-3000A 208/120V Main Switchboard.
-Emergency power provided by one 200kW, 208/120V generator located on-site.

structural
-Integrated steel and glulam framing system.
-Planted Roof load includes lightweight soil mixture, rigid insulation, and a 3" concrete slab with waterproofing membrane.

HVAC
-Fan-Driven VAV System.
-3 AHUs with 16,400 CFM min Outdoor Air.
-2 88.4 kW rotary-screw chillers with a combined capacity of 200 tons.
-Integrated wastewater and storm water management systems

matthew fracassini
lighting/electrical
http://www.arche.psu.edu/thesis/2004/mxf276



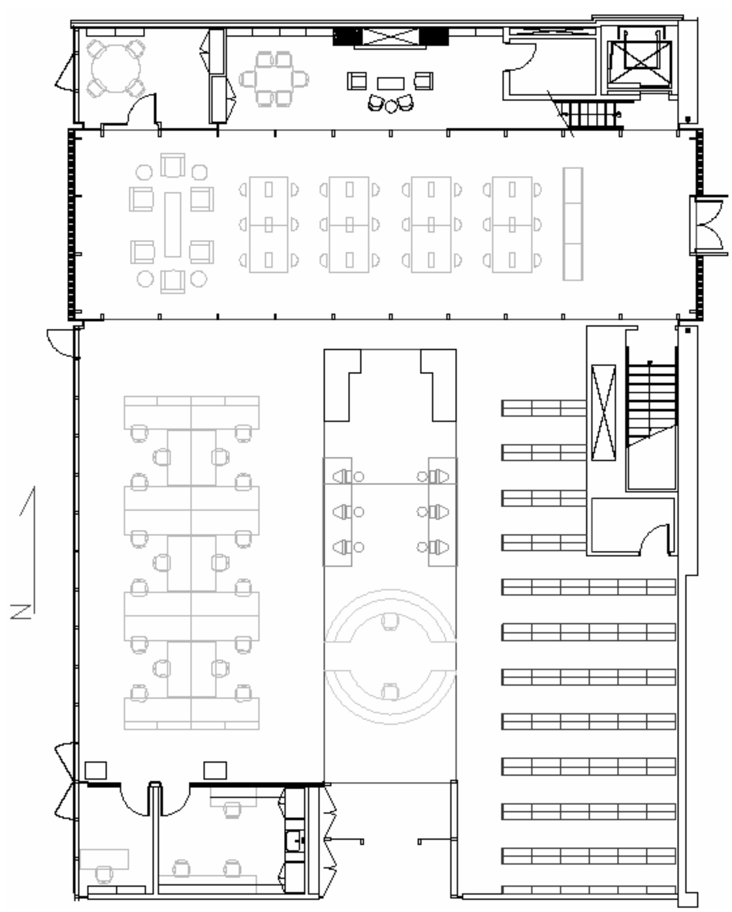
Lighting Redesign
for Greenwich Academy Upper School

| Space #1: Library

size: approx. 65' x 80' x 9' (at Reading Room)
height at Light Chamber #4 is 22'
5340 s.f.

description: The Library encompasses a large Reading Room with several VDT screens at computer terminals, a Learning Center with conference tables and other resources, and a separate Conference Room, Archive Room, and Work Room. I will be focusing on the large open spaces, the Reading Room and Learning Center. Finally, there is a large light chamber located over the north part of the learning center which lets in daylight.

floor plan:



functions:

→ reading
→ browsing vertical stacks
→ writing
→ studying
→ small group conferences
→ VDT use

design criteria:

Reflected Glare: Due to high reflectance on glossy wood tables, positioning of luminaries and distribution patterns must be considered.

Source/Task/Eye Geometry: Again, care must be paid to geometry to reduce reflected glare, but also to compensate for differences between vertical stacks and horizontal tables.

Horizontal Illuminance: Illuminance should be at 40 fc on tables and desks.

Emphasize Open Space: The building feels "open" and "airy" by the nature of the architecture, and the lighting design should contribute to this feeling. This means no protrusions into the space, either by a luminaire or a light pattern.

Color Appearance: Very important in a library with texts, magazines, and other pictures. CRI should not be below 82, CCT should be 3500 or above.

System Flexibility: Different tasks (reading, VDT use, browsing) require either different approaches to lighting each, or a system that can provide for all three tasks.

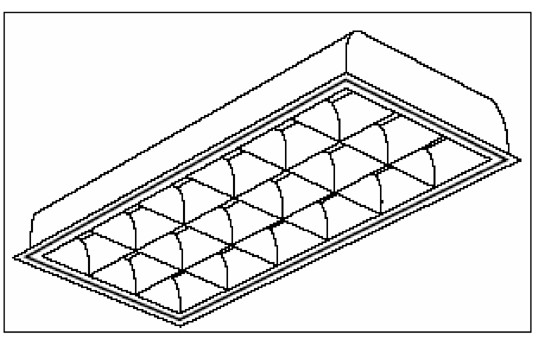
adjectives to describe redesign:

→ open
→ airy
→ focused
→ uniform
→ permanent
→ still
→ silent

functional goals of redesign:

My goals for the design of this space are fairly simple. After looking at the space and the design criteria, I came up with a plan to address the needs of the room. Strong light levels on the horizontal workplanes, a specialized means of lighting the stacks, and a way to avoid reflected glare.

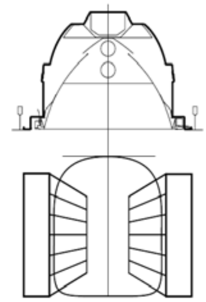
Also, it seemed important that in a room like this, an open library, there should be a sense of permanence and stillness. I thought that the best way to accomplish this was with a highlighted entrance, full of focal points and brightness, surrounded by an evenly lit study area, perfect for quiet reading and studying. I used a fixture similar to those in the existing design, a 2’ x 4’ recessed fluorescent troffer with a parabolic reflector and an 18-cell diffuse baffle. Two 32W T8 lamps, each rated at a CRI of 82 and a CCT of 3500K, shine directly onto the floor and workplane, but the baffles provide enough of a cutoff angle to avoid glare.



This fixture is spaced throughout the western half of the space, to evenly illuminate the shorter bookcases and tables. The VDT screens in the space are used as an electronic card catalog, and are also lit by these fixtures. The luminaire itself is actually designed with this use in mind, and the diffuse louvers and sharp cutoff angle should ensure that reflected glare does not become a problem for student using the screens.

functional goals of redesign: (cont'd)

In between the tall bookcases on the east side of the room, I used a 32W T8 fixture designed especially for use in library stacks. The 1' x 4' fixture features and over-and-under lamp placement with parabolic reflectors and an 8-cell low-iridescent specular louver. The luminaire give the distribution pattern of the lamps a very sharp cutoff, allowing light to reach the floor and illuminate all of the shelves on the way.



At the entrance to the library, there is a large section of hardwood floor and exposed wood beams along the ceiling. This feature is actually a visual extension of the light chamber that is located directly above.

In this portion of the room, I decided to play up the statement that the distinct ceiling makes, and create points of tangible light and shadow. This arrangement is meant to stand in contrast to the uniform lighting system that defines the rest of the space. Each fixture is a track– mounted spotlight with a 50W QR-LP111 low-voltage halogen lamp. The luminaire contains a 120V-12V transformer, and emits a 24° beam angle.

Finally, the fourth fixture used in the design provides light to the tables located inside of light chamber #4. On most days in Connecticut, even if the sky is overcast, there will likely be enough light coming into this part of the room to fully illuminate it. However, with much of the school year during the winter, and the short days that accompany it, a lighting solution may be required here. I chose to use fixtures that would not intrude into the space, but would provide enough light onto the tables roughly 23 feet below. The 70W metal halide lamps are mounted in cylindrical cans and attached to the light chamber mullions.

materials:

Surface	*Material*	*Reflectance (ρ)*
ceiling	Acoustical Ceiling Tile, White	0.86
floor	Low-height tile carpeting	0.11
floor	Laminated Flooring System	0.28
walls	Gypsum Wall Board, painted white	0.72
countertop	Beech Veneer	0.36
stacks	Beech Veneer	0.36
tables	Beech Veneer	0.36
mullions	Glulam Timbers	0.16
glass	double pane 1/4”, gray tint	0.85

luminaire schedule:

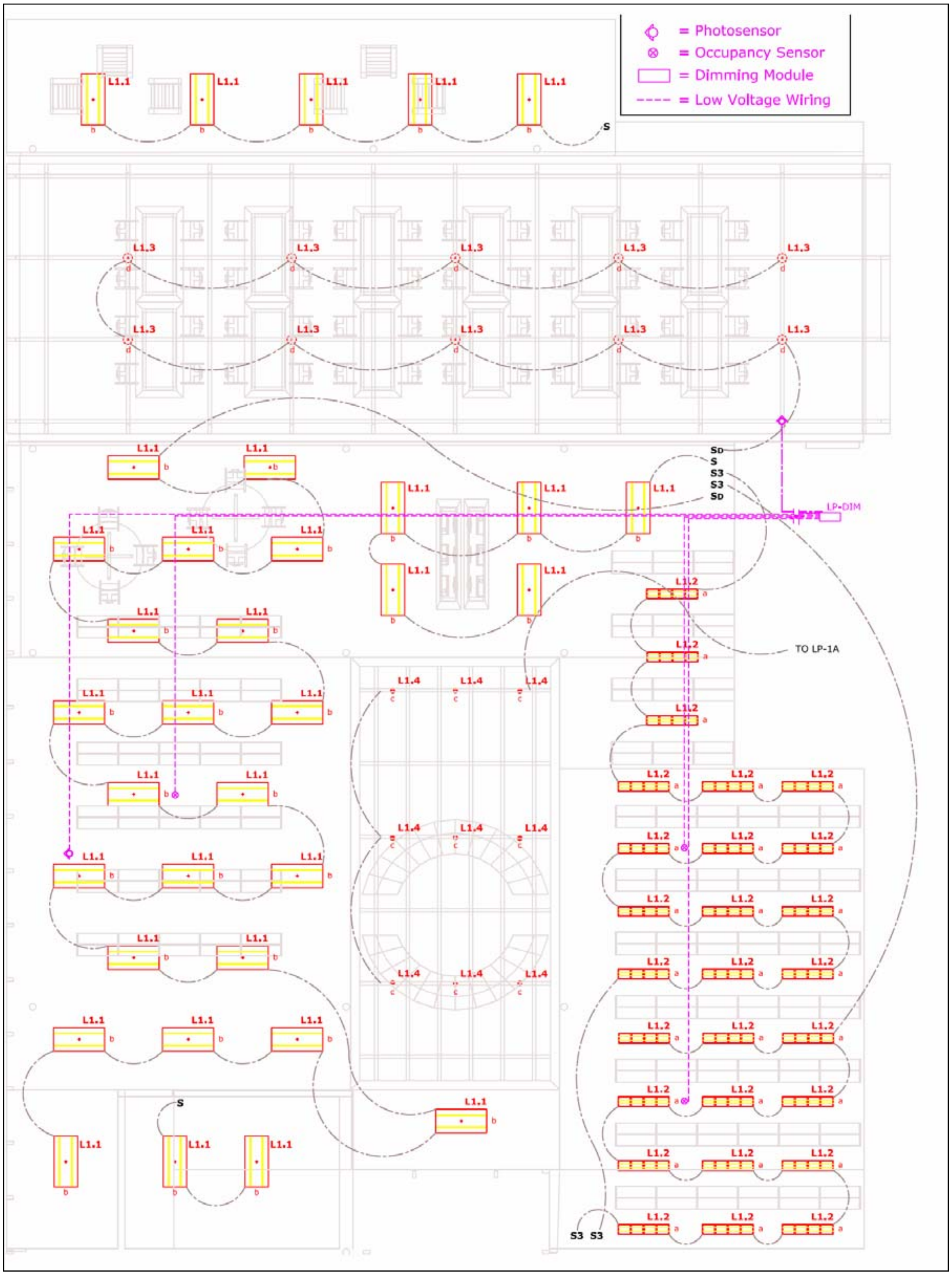
Des.	*Name*	*Lamp*	*Watts*	*BF*	*LLD*	*LDD*	*RSDD*	***LLF***
L1.1	2’ x4’ Louvered Troffer	2 32W T8	59	0.94	0.95	0.83	0.96	**0.711**
L1.2	1’ x 4’ Louvered Troffer	2 32W T8	66	0.94	0.95	0.83	0.96	**0.711**
L1.3	Track Spotlight	50W QR-LP111	53	1.0	0.9	0.86	0.96	**0.743**
L1.4	Cylindrical Downlight	70W HIT-DE-CE	88	1.0	0.91	0.83	0.96	**0.725**

assume: 12 month cleaning cycle
RCR = 1.25
Medium environment

ballast schedule:

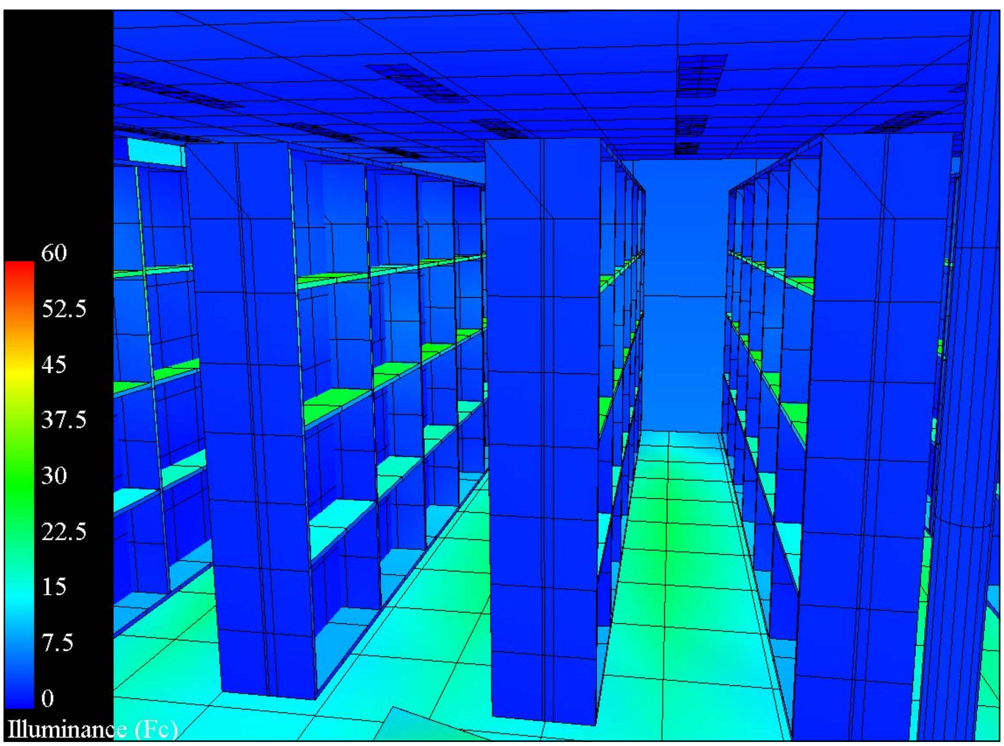
Des.	*Catalog Number.*	*Start Method*	*# of lamps*	*BF*	*Input Power*	*Input Current*	*PF*	*THD %*
a	QT2X32/T8/120ISNSC	IS	2	0.90	59 W	0.51 A	>0.97	<20%
b	QTP2X32/T8/120DIMS B	PS	2	0.94	66 W	0.57 A	>0.99	<10%
c	Low Voltage Track	-	1	1.0	53 W	-	-	-
d	71A5282	HX-HPF	1	1.0	88 w	0.80 A	>0.90	-

RCP:


= Photosensor
= Occupancy Sensor
= Dimming Module
= Low Voltage Wiring
L1.1
L1.2
L1.3
L1.4
LP-DIM
TO LP-1A
S3 S3

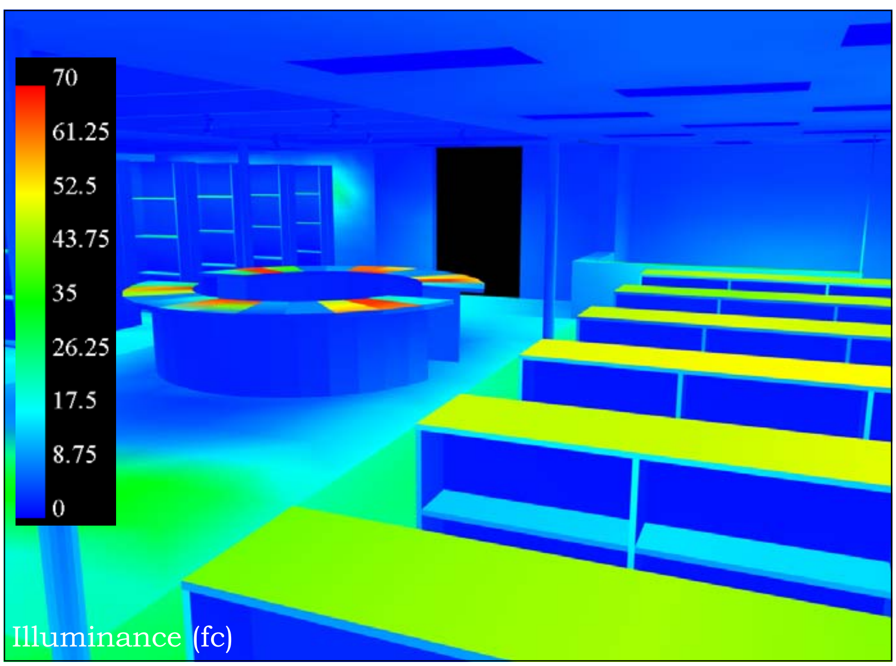
renderings/calcs:

These comparison renderings of the stacks illustrate the even distribution that is provided by the specialized fixtures.



renderings/calcs:

This rendering shows the difference between the uniformly lit bookshelves and the high contrast entrance area.



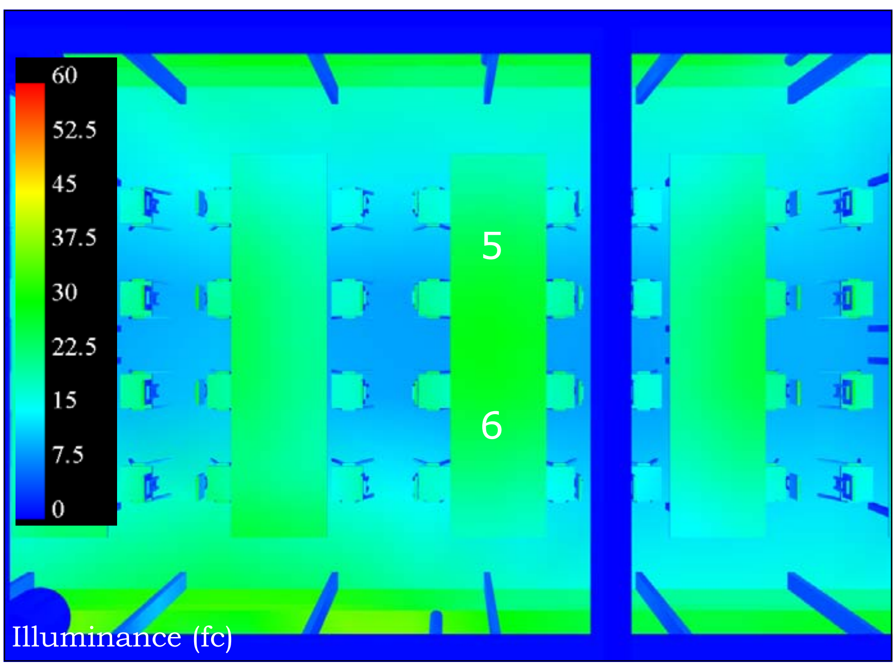
renderings/calcs:

The metal-halide canister lamps provide even distribution and acceptable contrast ratios when little to no sunlight is illuminating the space.

Light Chamber Floor
Illuminance Values(Fc)
Average=12.23
Maximum=21.9
Minimum=8.4
Avg/Min=1.46
Max/Min=2.61

Table #5
Illuminance Values(Fc)
Average=24.99
Maximum=29.2
Minimum=19.4
Avg/Min=1.29
Max/Min=1.51

Table #6
Illuminance Values(Fc)
Average=24.27
Maximum=28.9
Minimum=17.9
Avg/Min=1.36
Max/Min=1.61

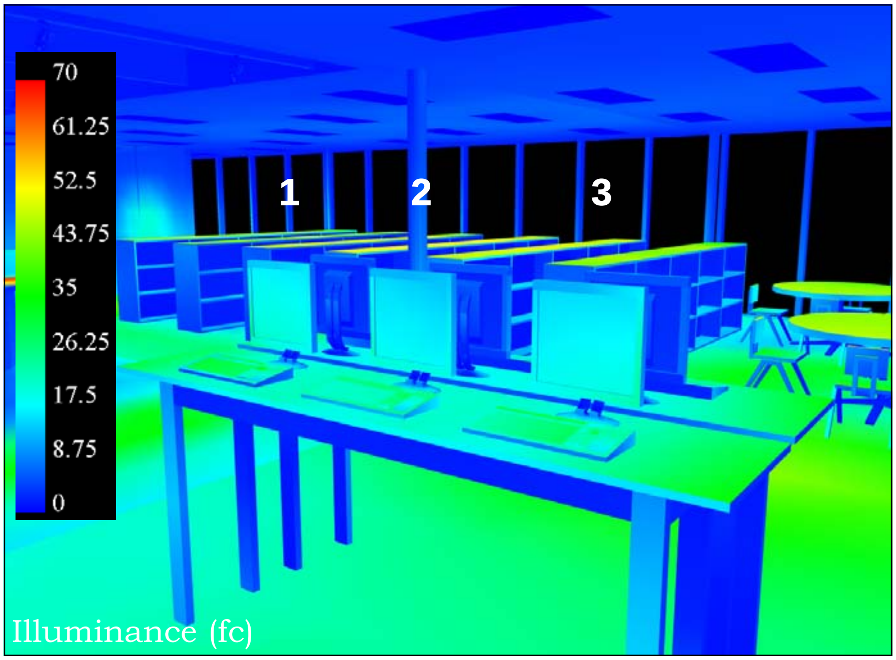


renderings/calcs:

VDT #1
Illuminance Values(Fc)
Average=19.43
Maximum=21.3
Minimum=17.3
Avg/Min=1.12
Max/Min=1.23

VDT #2
Illuminance Values(Fc)
Average=17.73
Maximum=19.9
Minimum=15.3
Avg/Min=1.16
Max/Min=1.30

VDT #3
Illuminance Values(Fc)
Average=18.88
Maximum=21.2
Minimum=16.3
Avg/Min=1.16
Max/Min=1.30

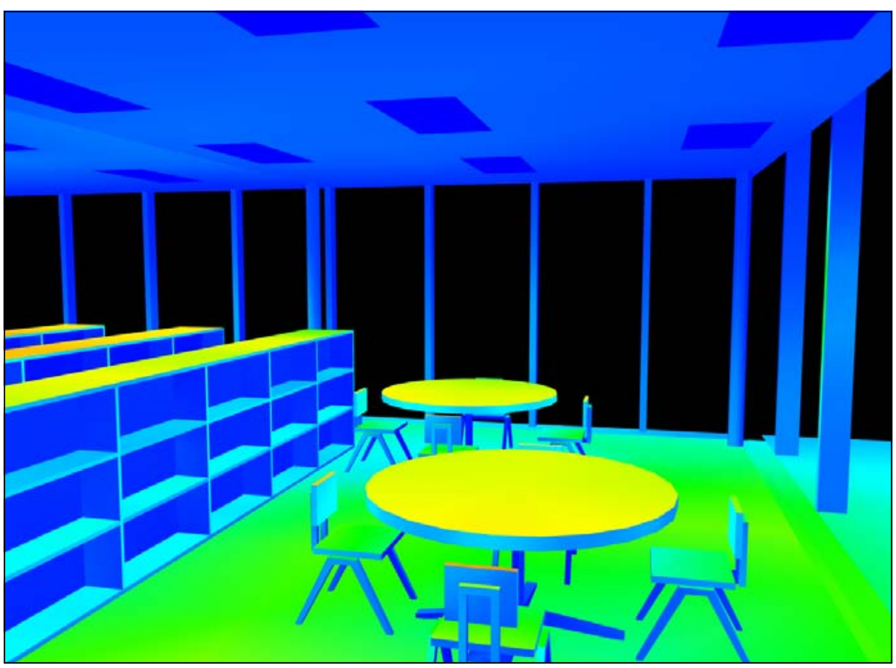


Although the luminaries throw a significant amount of light onto the VDT screens, the narrow angle from lamp to luminaire should keep any reflected glare from being a problem.

The criteria goal of 40 fc on the workplanes was achieved with the use of the fluorescent troffers.

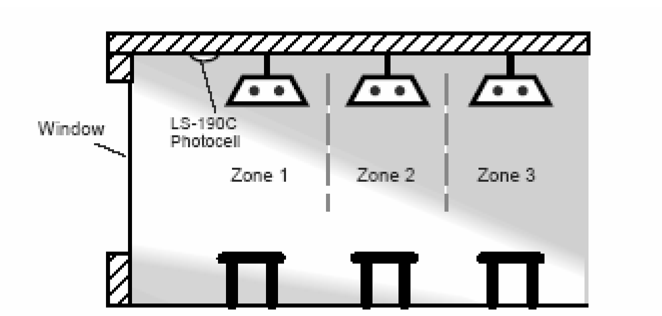
Round Table #1
Illuminance Values(Fc)
Average=48.47
Maximum=53.4
Minimum=42.3
Avg/Min=1.15
Max/Min=1.26

Round Table #2
Illuminance Values(Fc)
Average=49.87
Maximum=53.0
Minimum=47.3
Avg/Min=1.05
Max/Min=1.12



controls:

All of the fixtures in the room are manually switchable from 3 different locations. Each lighting circuit is connected to a centralized time clock, and set to turn off after school hours. Most of the zones have occupancy sensors set up for use of the space after school is out and to reduce energy costs. All circuiting is run to panel LP-1A. Though it was not feasible to show on the reflected ceiling plan, all circuits are also connected to the dimming and central clock panel (LP-DIM).



The control scheme for the room is fairly complex, but is based of simple divisions of the different room zones. Zone 1 is the western half of the room, nearest to the windows, and containing only type L1.1 fixtures. These lights will be controlled by a photosensor dimming system during the day, and by a surface mounted occupancy sensor at night. The tall bookcases on the other side of the room make up Zones 2 and 3. After school hours, the 1’ x 4’ stack lights are controlled by two different occupancy sensors for the two zones.

Zone 4 is the canister lights on the light chamber mullions, and is controlled by a photosensor switching system. The lights will remain off as long as one of the two sensors in the space is detecting light. The circulation desk spotlights are all that is in zone 5, and they will remain on and at full light levels for the duration of daily occupancy. Finally, all other fixtures are controlled by the central clock and manually switchable.

power density:

The total power density is 0.928 W/ft^2. The ASHRAE/IESNA 90.1 power density for a library is 1.5 W/ft^2, which leaves an additional 3054 W for use elsewhere.

conclusions:

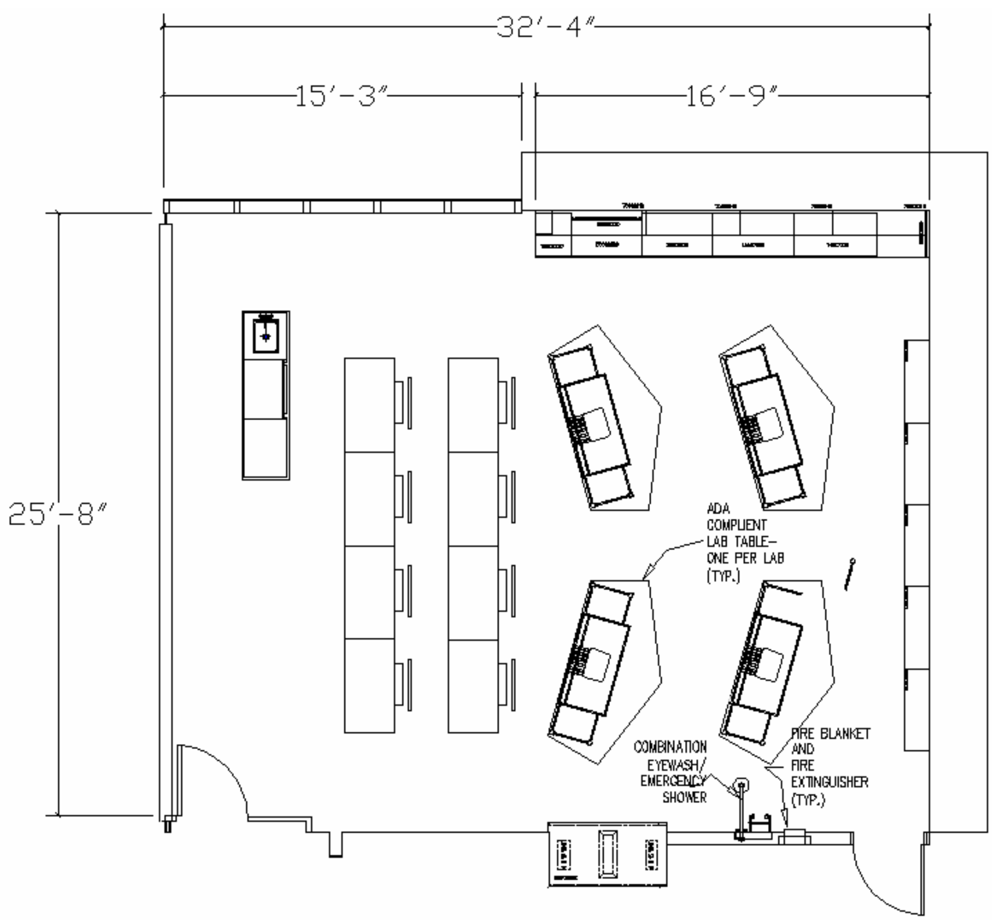
Overall, I was very satisfied with the results of the calculations. The vertical stack light worked exactly as planned, and was not too much of a burden on the power density. The other recessed fixture spread an average of almost 50 fc onto the reading tables and short bookcases. The performance near the VDT screens was adequate, the contrast ratio was not what it should have been (almost 1:1 instead of 2:1), but the luminaire louver and arrangement will keep glare from becoming a problem. Although the levels on the tables were only around 20-30 fc, the space will likely not be used intensively after dark, and even if it is, this illuminance should be reasonable for most visual tasks. This lighting system seemed to be a perfect fit with the goals that I had in mind for the space.

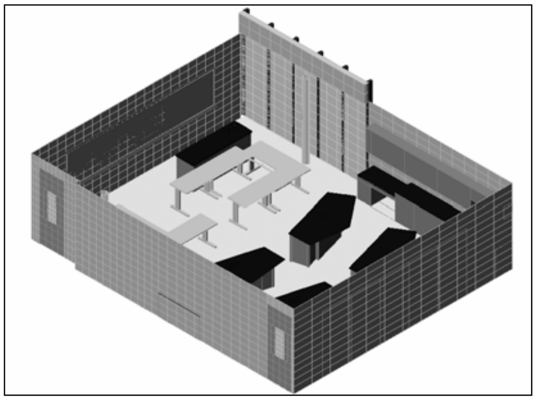
| Space #2: Science Room 1

size: approx. 32' x26' x 9'
853 s.f.

description: The Science Room is the smallest space being redesigned, and also the most simple. The room is basically shaped like a large rectangle, with 9' ceilings, and an entrance in the southwest corner. There is a full height window along the north wall, in the northwest corner. The furniture consists of a teacher's lab desk in the front of the room, several 3' high desks adjacent to the teacher's desk, and 4 large, 4' high lab tables in the rear of the room. Also there, are counters along the remainder of the north wall, and cabinets located along the east wall.

floor plan:





functions:

→ reading → writing
→ observing teacher and whiteboard
→ precise measurements

design criteria:

Light Distribution on Task Plane: Work surfaces must be uniformly lit for optimal performance. Keeping luminaries evenly spaced and properly oriented should provide an even distribution across the space.

Horizontal Illuminance: At least 50 fc should be striking the lab tables and desks for accurate observations.

Vertical Illuminance on Whiteboard: The whiteboard should receive a vertical illuminance of between 30 and 40 fc to be clearly visible from the back of the room.

Color Appearance and Contrast: A lamp with a CRI of 82 and a CCT above 3500 should be able to provide good color appearance. The contrast ratios on the work surface should be between 2:1 and 3:1.

Daylight Integration: The large window along the north wall can deliver a substantial amount of light into the space. Keeping all surfaces bright can help blend the daylight with the electric lighting system.

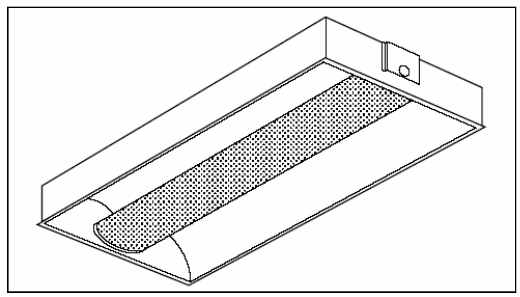
adjectives to describe redesign:

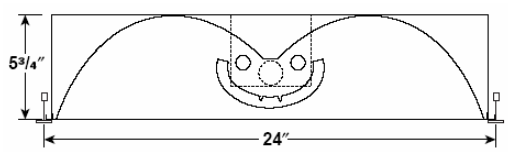
bright, balanced, crisp, clean, open

functional goals of redesign:

As far as goals for a redesign of the space, I think that my ideas can be summed up into 3 distinct aims. First, to keep a bright, open feel to the room. I think the best way to achieve this is to use some kind of indirect lighting system. By throwing light onto the ceiling, the entire room will receive a uniform level of brightness as well as the open environment that is desired. The most common way to achieve this effect is to use some kind of suspended fluorescent light that can direct light up to be reflected off of the ceiling. In this case, with a ceiling height of only 9' and a small floor area, a suspended fixture could cause problems with clutter and also direct glare from the very bright ceiling.

However, there are fixtures made which provide indirect light in a recessed housing. These luminaries use a perforated aluminum shield to direct the downlight component of the two 28W T5 fluorescent bulbs up at the reflector. This painted aluminum reflector then directs the light back down to the workplane. These fixtures should allow the room to keep an open feel, and contribute to that same feeling by brightening up all of the room surfaces.





(See appendix for detailed cut sheets and photometrics for each fixture.)

My second goal for the redesign is to provide at least 50 fc on the workplane. As students attempt experiments and projects, they will need above average light levels on the workplane to make accurate observations. This goal can also be achieved through the use of indirect fixtures. While they do not have a light component shining directly on to the work surfaces, the high reflectance of the ceiling and walls should provide enough reflected light to efficiently light these planes.

Finally, the whiteboard at the front of the room needs to receive an even wash, with light levels high enough to allow viewing from the rear of the room. For this space, the illuminance should be between 30 and 40 fc on the whiteboard, and should not vary by more than 20%. Initially, I placed linear fluorescent wallwashers along the west wall to accentuate the whiteboard, but upon further investigation, it seemed that this was unnecessary. The indirect fixtures provide more than enough vertical illuminance.

luminaire schedule:

Des.	*Name*	*Lamp*	*Watts*	*BF*	*LLD*	*LDD*	*RSDD*	***LLF***
L2.1	2' x4' Indirect Troffer	32W T8 (3)	87	0.90	0.93	0.82	0.87	**0.623**
L2.2	2' Undercabinet Fixture	17W T8	24	1.22	0.95	0.86	0.96	**0.956**

assume: 12 month cleaning cycle
RCR = 3.14
Medium environment

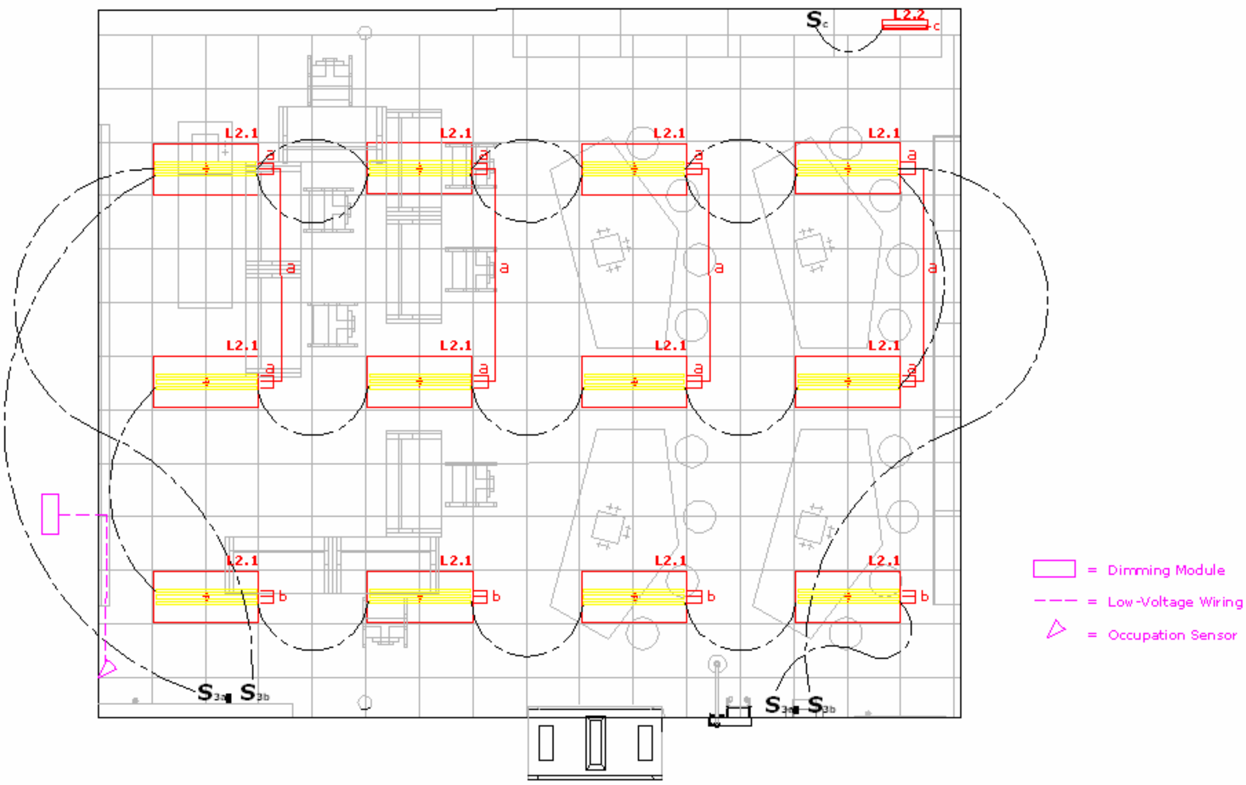
ballast schedule:

Des.	*Catalog Number.*	*Type*	*Start Method*	*# of lamps*	*BF*	*Input Power*	*Input Current*	*PF*	*THD %*
a	QT2X32/120IS	E	IS	2	0.90	59 W	0.51 A	>0.97	<20%
b	QT3X32/120IS	E	IS	3	0.90	87 W	0.77 A	>0.97	<20%
c	REL-1P32-HL-SC	E	IS	1	1.22	24 W	0.21	0.95	<20%

materials:

Surface	*Material*	*Reflectance (ρ)*
ceiling	Acoustical Ceiling Tile, White	0.86
floor	Vinyl Composition Tile, Cream	0.67
walls	Gypsum Wall Board, White paint	0.72
desks	Melamine Resin, Tan	0.86
lab tables	Epoxy Resin, Black	0.30
doors	Oak Veneer	0.48
cabinets	Oak Veneer	0.48
whiteboard	Front: White Marlite	0.90
glass	double pane 1/4", gray tint	0.85

RCP:



renderings/calcs:

renderings/calcs:

The indirect fixtures give an uniform wash of light to all surfaces in the room. But enough light hits the workplanes to create the necessary contrast ratios.

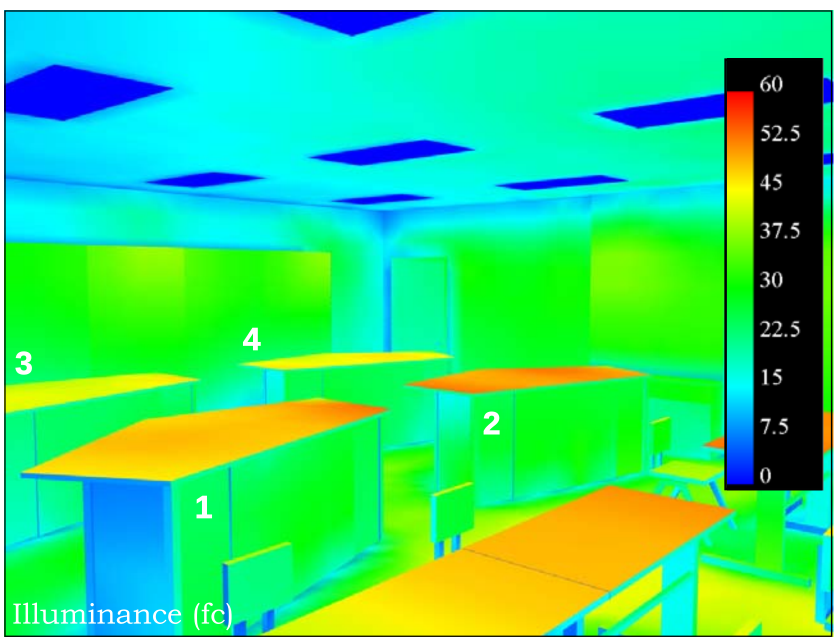
The distribution on the desks is uniform for each workplane, and very close from table to table.

Table #1 Top
Illuminance Values(Fc)
Average=48.94 Maximum=52.9
Minimum=46.6 Avg/Min=1.05
Max/Min=1.14 No.Points=96

Table #2 Top
Illuminance Values(Fc)
Average=51.12 Maximum=52.9
Minimum=44.1 Avg/Min=1.16
Max/Min=1.20 No.Points=96

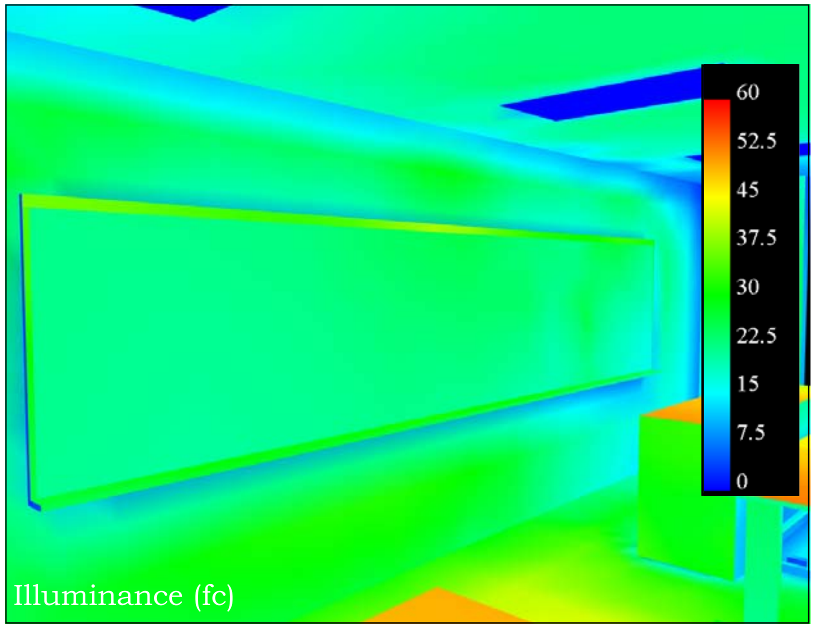
Table #3 Top
Illuminance Values(Fc)
Average=43.36 Maximum=46.8
Minimum=40.9 Avg/Min=1.06
Max/Min=1.14 No.Points=96

Table #4 Top
Illuminance Values(Fc)
Average=44.87 Maximum=46.5
Minimum=40.1 Avg/Min=1.12
Max/Min=1.16 No.Points=96



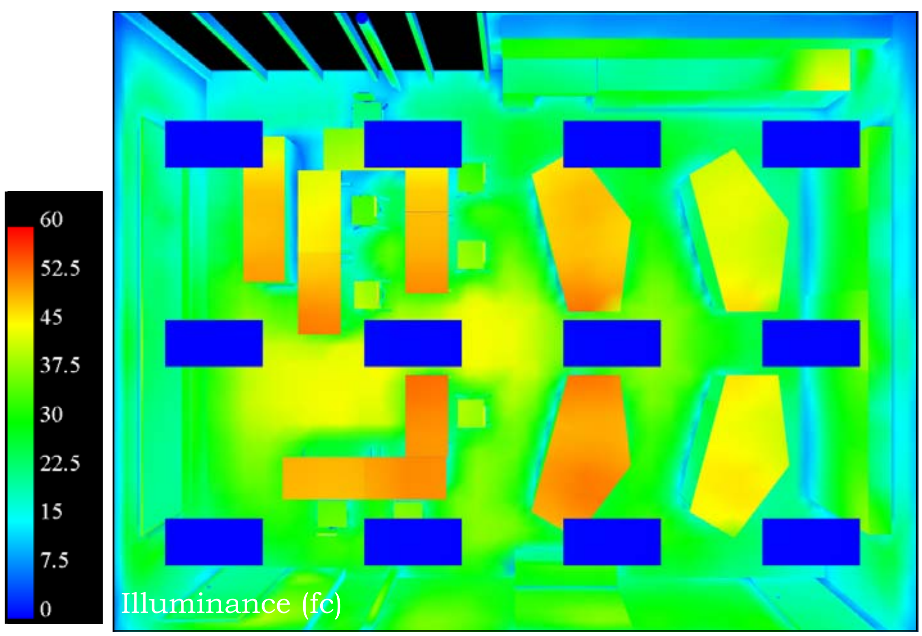
renderings/calcs:

Whiteboard
Illuminance Values(Fc)
Average=33.20 Maximum=39.8
Minimum=22.3 Avg/Min=1.49
Max/Min=1.78 No.Points=245



The whiteboard receives a uniform distribution of light, averaging about 33 footcandles.

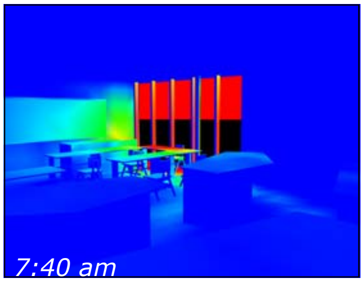
The overall workplane to floor contrast ratio for the space is about 2:1 (50 fc : 24 fc)

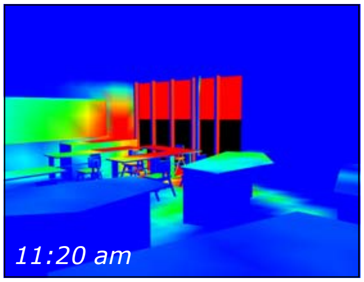


controls:

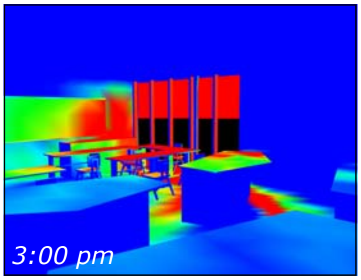
There are 2 major circuits in the Science Room. The first controls all 3 lamps of each fixture in the bottom row, and 2 lamps of each fixture in the other two rows. This circuit is switched manually at two locations in the room, and is also connected to the occupancy sensor and central clock via the dimming panel (LP-DIM). The occupancy sensor will only be operative after the clock shuts the lights down after school hours.

The other circuit controls the remaining lamps, that is, one lamp from each of the fixtures in the top two rows. This circuit is also wired to LP-DIM, switched off by the central clock, and manually switchable in the same two locations. A photosensor-based daylight dimming system was considered to keep the light levels balanced throughout the day. How ever, due to the limited area that is affected during school hours (7am-3pm), it became more practical to employ manual switching on these lamps.





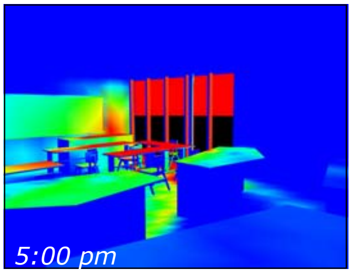
As is illustrated in the renderings to the right, the maximum amount of illuminance due to sunlight in the room does not occur until late in the afternoon. A dimming system seemed superfluous considering that it would usually not be needed until near the end of the school day. Shades are installed between each wood mullion, so that even during periods of brightness, there is alternative to controlling the lighting.



Finally, the small undercabinet light is under complete manual control, as it is installed to be used only when supplemental light is needed on the countertop.

power density:

The power density in the space is 1.251 W/ft^2. The allowable power density for a school classroom from ASHRAE/IESNA 90.1 is 1.6 W/ft2.



conclusions:

As with the library system, I think that this lighting design was the perfect fit for what I wanted to accomplish. The uniform distribution, solid 2:1 contrast ratio and strong light levels on the horizontal and vertical planes. For a further review of the space, please read the conclusions for the next design.

| Space #2: Science Room 1: Alternate Design

luminaire schedule:

Des.	*Name*	*Lamp*	*Watts*	*BF*	*LLD*	*LDD*	*RSDD*	***LLF***
L2.3	2' x4' Indirect Troffer	28W T5 (2)	66	0.94	0.93	0.82	0.87	**0.623**
L2.4	Suspended Indirect	54W T5HO	62	1.0	0.89	0.84	0.86	**0.642**

assume: 12 month cleaning cycle
RCR = 3.14
Medium environment

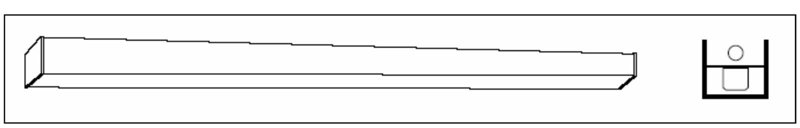
ballast schedule:

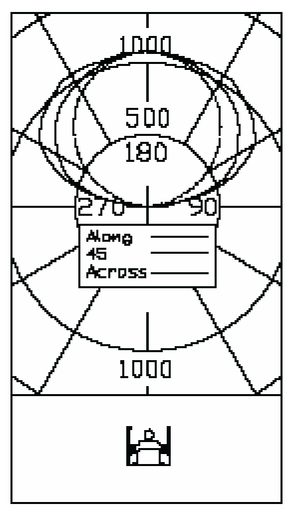
Des.	*Catalog Number.*	*Type*	*Start Method*	*# of lamps*	*BF*	*Input Power*	*Input Current*	*PF*	*THD %*
a	RCN-2M32-MC	E	IS	2	0.98	66	0.5	0.99	<10%
b	QT1X54/120PHO-DIM	E	PS	1	1.0	62	0.54	>0.97	<10%

functional goals:

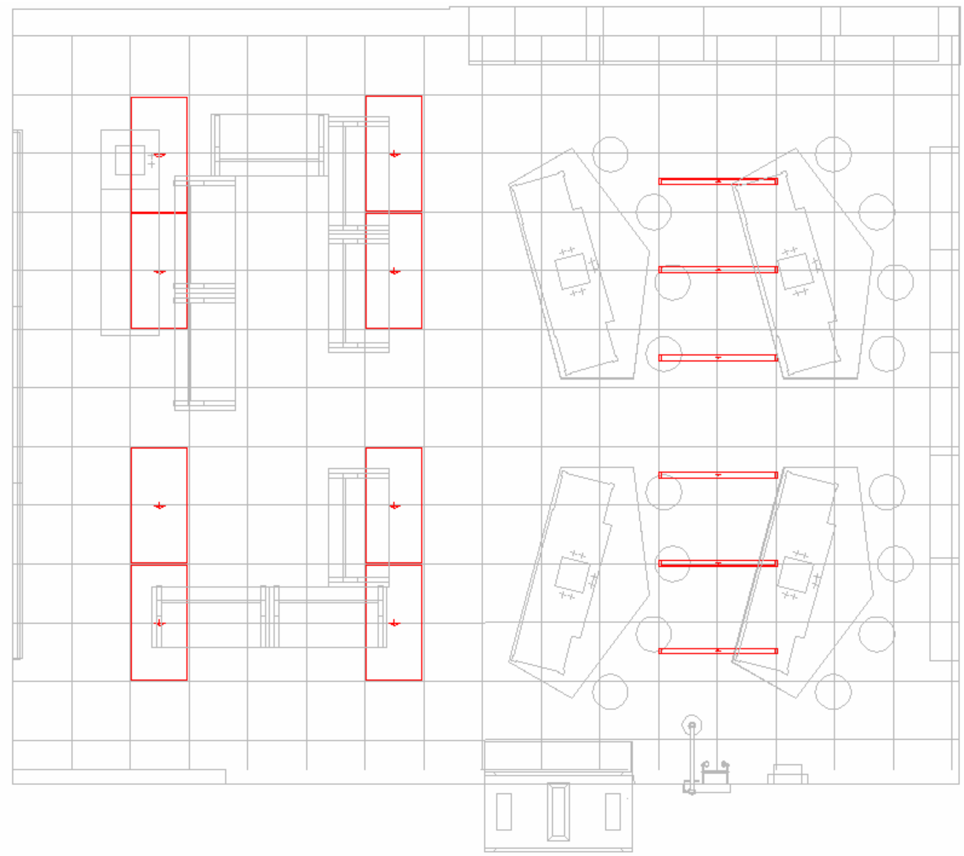
The goals of this design are the same as those for the original design. Keep the room surfaces bright, strong vertical illuminance on the whiteboard, and over 50 fc on the workplanes. This approach uses a more traditional indirect approach, the suspended fixtures in the back of the room have a 100% uplight component. The recessed direct/indirect troffers are similar to those used in the first design, but with more of a downlight component.

This approach should provide higher light levels on most of the surfaces, but may not perform as well in keeping all of the surfaces uniform. In order to counteract this effect, the spacing and orientation of the suspended luminaries is at the optimal arrangement for even distribution.





RCP:

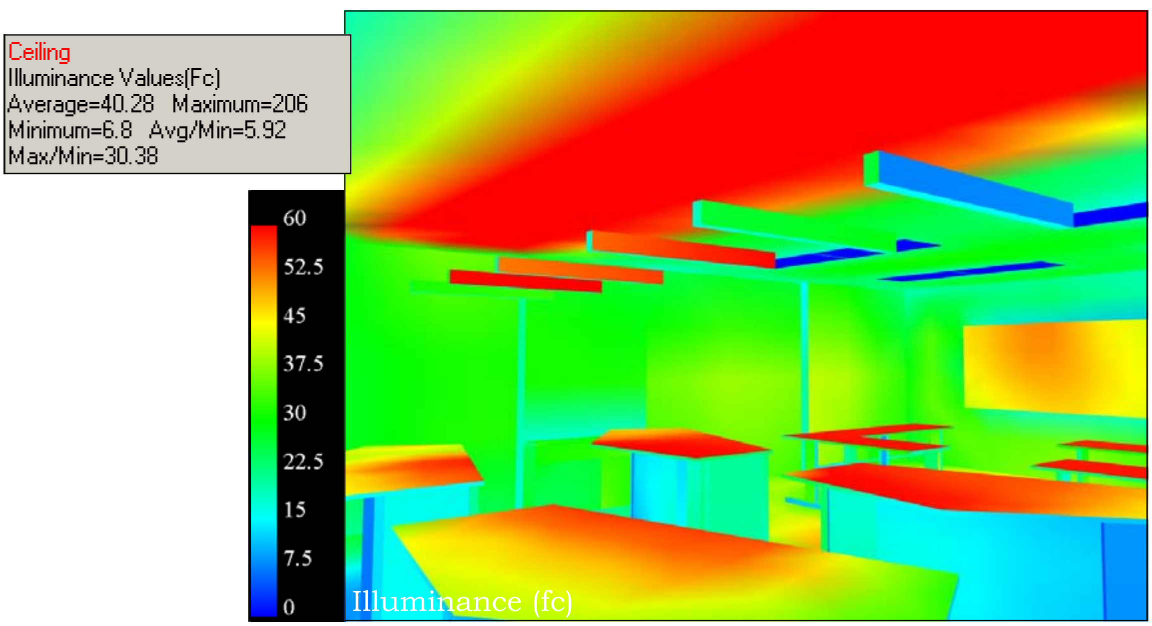


renderings/calcs:

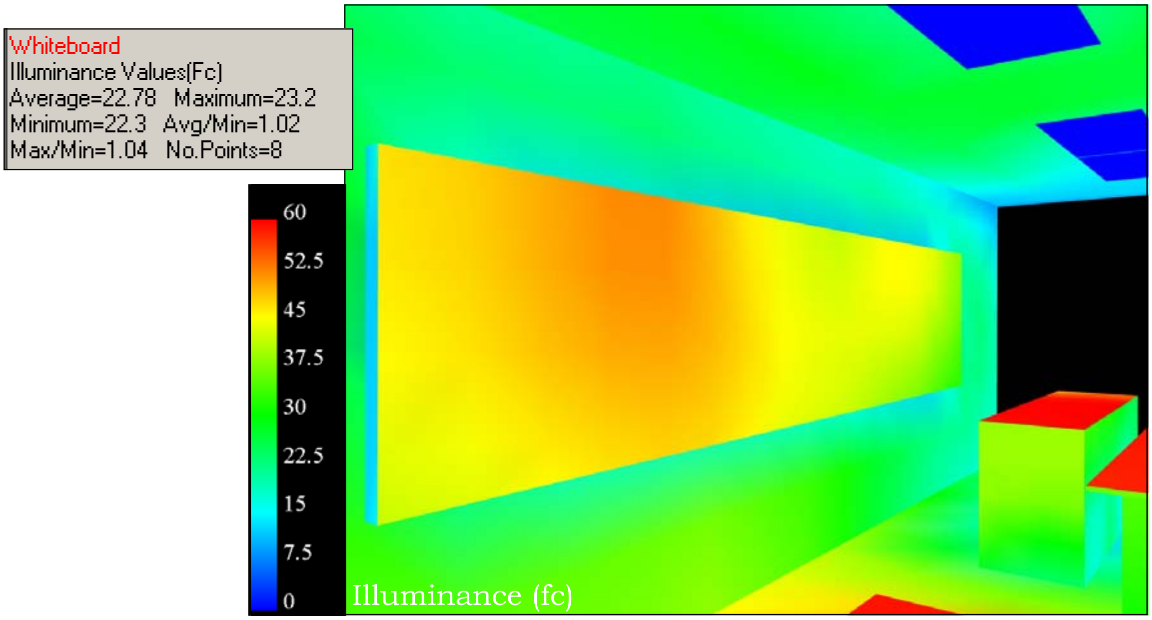
renderings/calcs:

The suspended fixtures create a bright area on the ceiling, this light is refelected back to the surfaces.

The bright ceiling may cause a problem with direct glare..

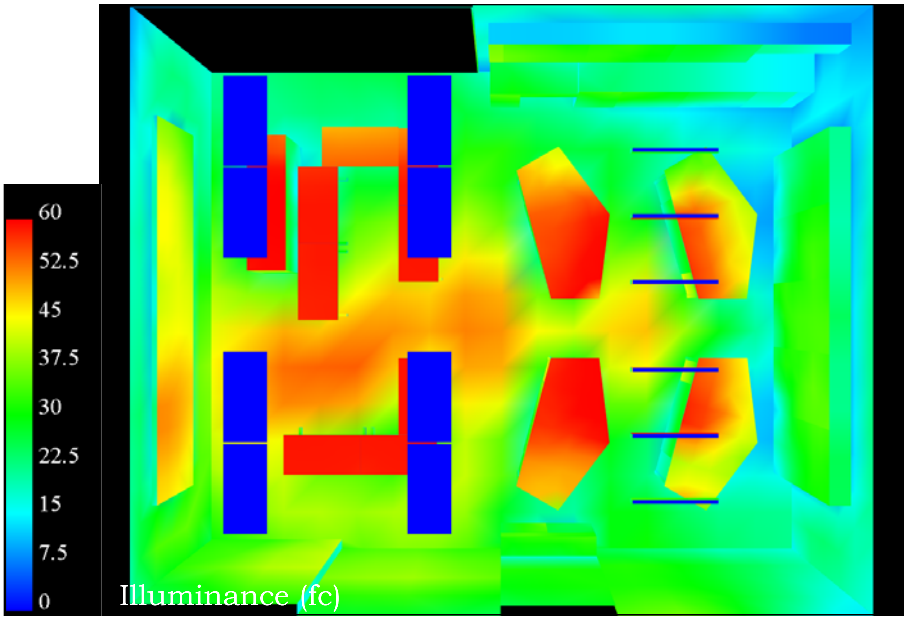


renderings/calcs:



The whiteboard receives higher light levels, and a more uniform distribution.

The overall distribution is not as even as the original design.



power density:

The lighting power density for the space came out to 0.962 W/ft^2. This value is easily within the limits established by ASHRAE/IESNA 90.1. In fact, this is significantly less than the power density for the original design. Overall, there are a total of 544 W able to be used in other spaces.

conclusions:

This design alternative did not perform as well as the original design. Although it did accomplish the goals of 50 fc on the workplane and strong illumination of the whiteboard, the overall feel of the system seemed disorganized. The uneven distribution, even with proper placement of the fixtures, indicates that this may not be the right choice for the space. Also, the max. illuminance on the ceiling of 206 fc would definitely cause problems with direct glare for anyone who looked up during a class.

The recessed fixtures performed well, but perhaps because of the different orientation, or the smaller lamps, the distribution patterns in the front of the room seem skewed. The low power density is the most appealing part of this solution. By using high output l amps in the suspended fixtures, I was able to get more light back in return for the investment in wattage. All in all, this was an interesting design to take on, but not one that sticks out as the best or most practical.

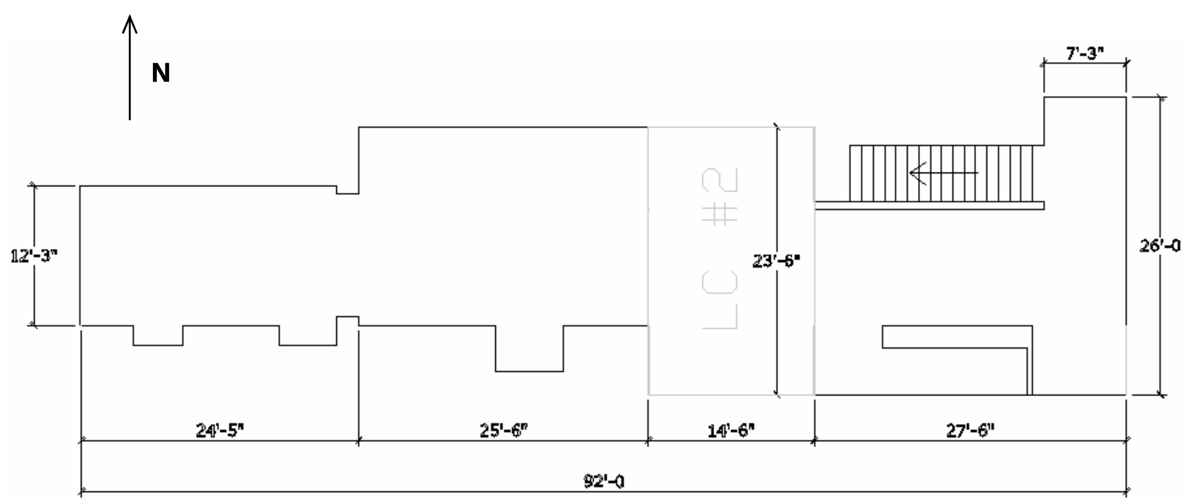
| Space #3: West Corridor

size: approx. 77' x 12' x 9'
height at Light Chamber #2 is 16'
1200 s.f.

description: The west corridor is essentially the main artery of the entire building. The school is set into a hillside, so the Main Entrance is the only thing that a visitor is aware of as they approach the building. Once inside the glass atrium, there is a large staircase that leads one down into the school itself. Once at the bottom of the steps, the visitor is led directly towards the reception desk, and into the West Corridor. The "artery" metaphor holds true, as this space distributes people to the most vital parts of the building.

In reference to the plan below, the Commons Room is located along the north end of the corridor. The administrative area and Headmaster's Office are also adjacent to the hallway. Also, Stair B is located in the northeast corner, and Stair C in the southwest corner. These stairs are the primary methods of accessing the lower level of the school. Light Chamber #2 runs transverse to the corridor near the middle of the room. A corridor on the lower level runs parallel with the light chamber, so at this location, the West Corridor is actually a bridge, allowing light and spaciousness to permeate both levels. The only furniture in the space is the reception desk located near the entrance.

floor plan:



functions:

- → introduction to building
- → circulation
- → viewing artwork on walls
- → communication
- → locating rooms

design criteria:

Light Distribution: A corridor such as this calls for an even distribution of light, to avoid patterning on the walls, and to keep the balanced sense of the space intact.

Vertical Illuminance: The illuminance on the vertical surfaces in the room should not average less than 10 footcandles. Observing this criterion will also serve to give the appearance of a brighter, larger space overall.

Direct Glare: With a relatively low ceiling height, and a large amount of foot traffic, direct glare from fixtures that are too bright or not well shielded could present a problem.

Points of Interest: One of the major functions of the corridor is to allow students to display their projects and artwork on the walls. Narrow-beam fixtures or specular reflectors can be helpful in highlighting these displays.

Modeling of Faces: As with any space where communication is a function, facial modeling cannot be ignored in this case. The best way to achieve realistic modeling is with a fill light in the background, and one or more key lights to provide highlights. The contrast ratio of high to low should be about 3:1.

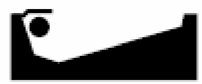
Daylighting Integration: Another light chamber means another issue with daylight integration. Since the light chamber crosses a relatively small portion of the corridor, this criterion is not as critical as in a space like the library, where much of the wallspace is glass.

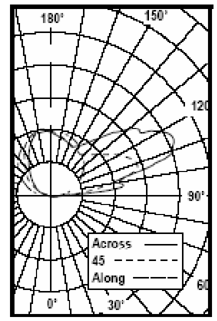
adjectives to describe redesign:

open, informative, luminous, decisive, certain, influential

functional goals of redesign:

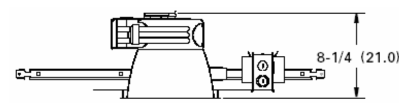
My goal with this space is to differentiate from the other rooms in the building, and also to define as a means to reach any of these other spaces. My first step was to make a change from the recessed linear fluorescent fixtures that have been used consistently throughout the building redesign. Also, keeping in mind the design criteria, I wanted to make sure that the system provided a uniform distribution of light, realistic modeling for faces, and strong illuminance on the vertical surfaces.

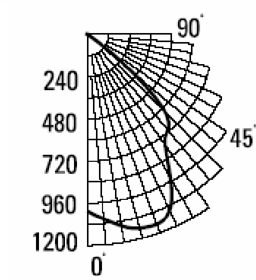




My first idea for the space was to create a architectural cove system. A cove provides uniform light by reflecting light off of the ceiling and back down to the floor. The cove itself can become rather bright, but it plays the role of a large fill light for the rest of the surfaces in the space. There are 2 coves in the space, and 8 fixtures in each of these. Each fixture uses one 32 W T8 lamp, and consists of a high-reflectance white reflector and a luminance control deflector to minimize shadows.

While the cove fixtures will give an even wash of light, the space still requires focus and interest. With this in mind, I chose to balance and accentuate the room surfaces by adding downlights throughout the room. The open downlights are 8" in diameter, with a 32 W triple tube compact fluorescent lamp and a specular reflector. These fixtures provide a relatively wide distribution, but when compared to the large luminous area of the cove, they should resemble focal points for the occupant.





The brightness level of all of the surfaces should blend in nicely with the daylight coming into the space from the transverse light chamber. To compensate for night conditions, I added 5 of the downlights onto the mullions of the glazed chamber. These fixtures provide ample ambient light to the floor, enough to navigate the space and read any signs or communicate with a fellow occupant. The need for inclusion of a daylight dimming system will be analyzed at the conclusion of the design.

materials:

Surface	*Material*	*Reflectance (ρ)*
ceiling	Acoustical Ceiling Tile, White	0.86
floor	Low-height Carpet Tiles, gray	0.20
floor, LC	Laminated Flooring System	0.28
walls	Gypsum Wall Board, White Paint	0.72
wall panels	Wood paneling	0.20
mullions	Glulam Timbers	0.16
glass	double pane 1/4”, gray tint	0.85

luminaire schedule:

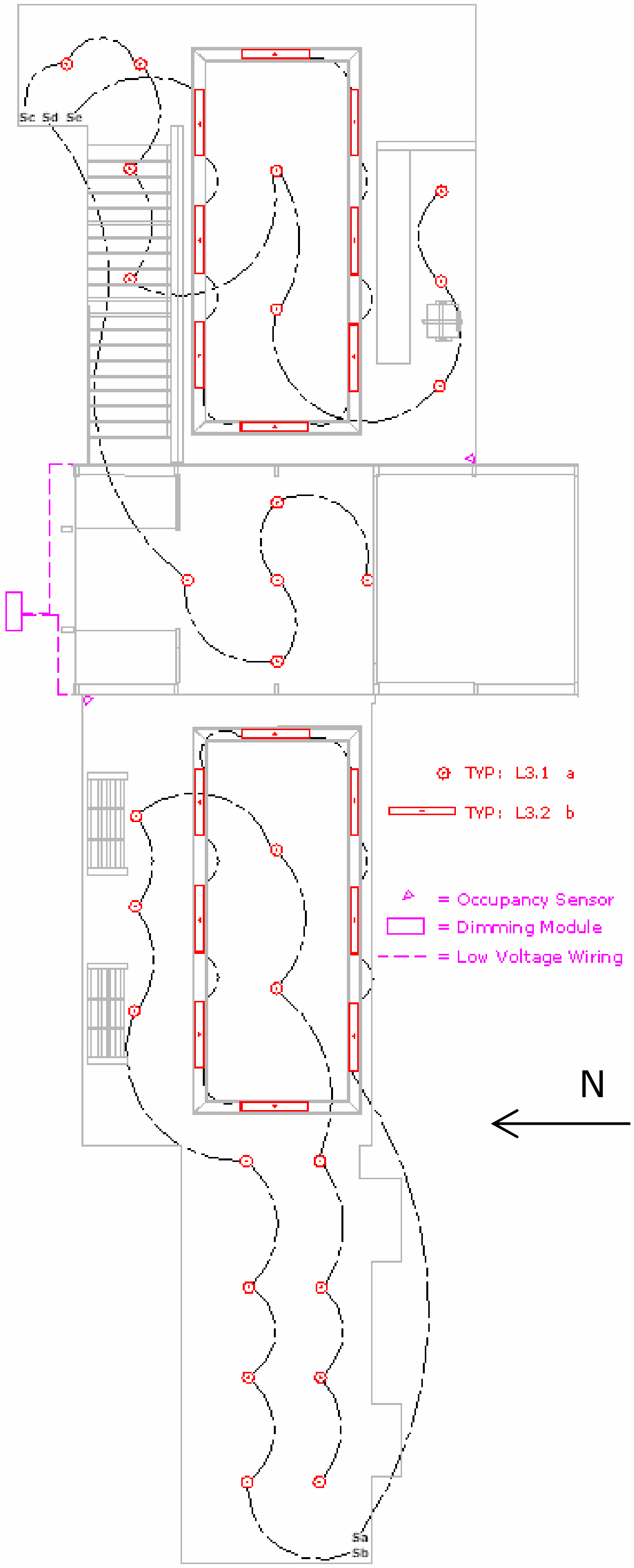
Type	*Name*	*Bulb*	*Watts*	*BF*	*LLD*	*LDD*	*RSDD*	***LLF***
L3.1	8” Baffle Downlight	32W TRT CF	36	1.0	0.86	0.86	0.95	**0.71**
L3.2	2’ Fluorescent Covelight	32W T8	38	0.88	0.90	0.82	0.95	**0.62**

assume: 12 month cleaning cycle
RCR = 4.33
Medium environment

ballast schedule:

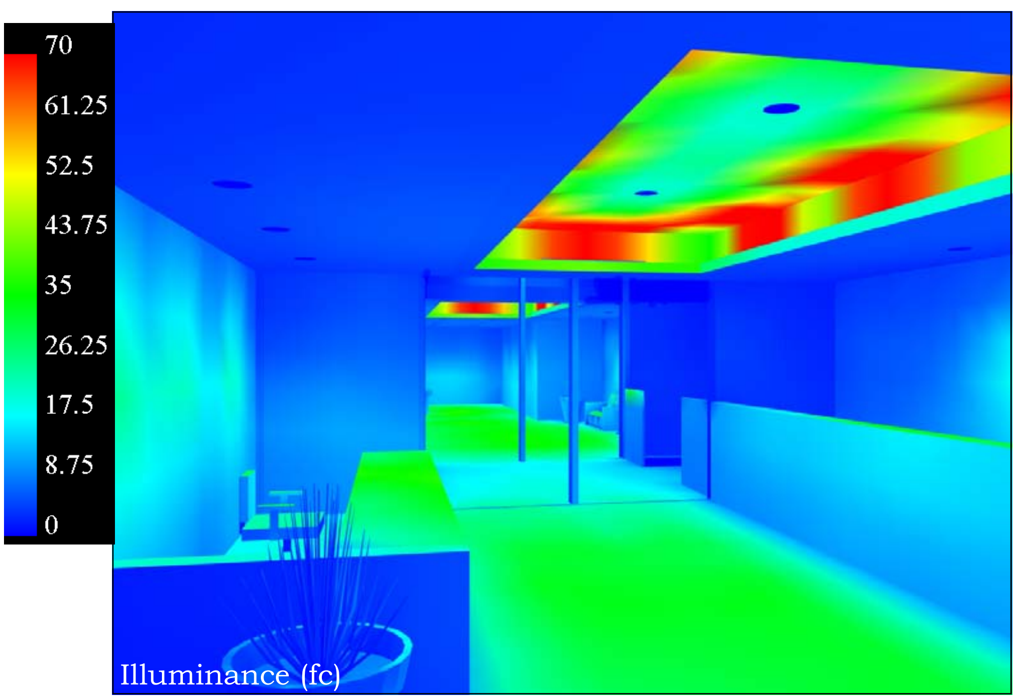
Des.	*Catalog Number.*	*Start Method*	*# of lamps*	*BF*	*Input Power*	*Input Current*	*PF*	*THD %*
a	ICF02S260H10LD@120	PS	1	0.98	36 W	0.31 A	0.98	<10%
b	RCN-132-MC	IS	1	0.98	30 W	0.25 A	0.98	<10%

RCP:

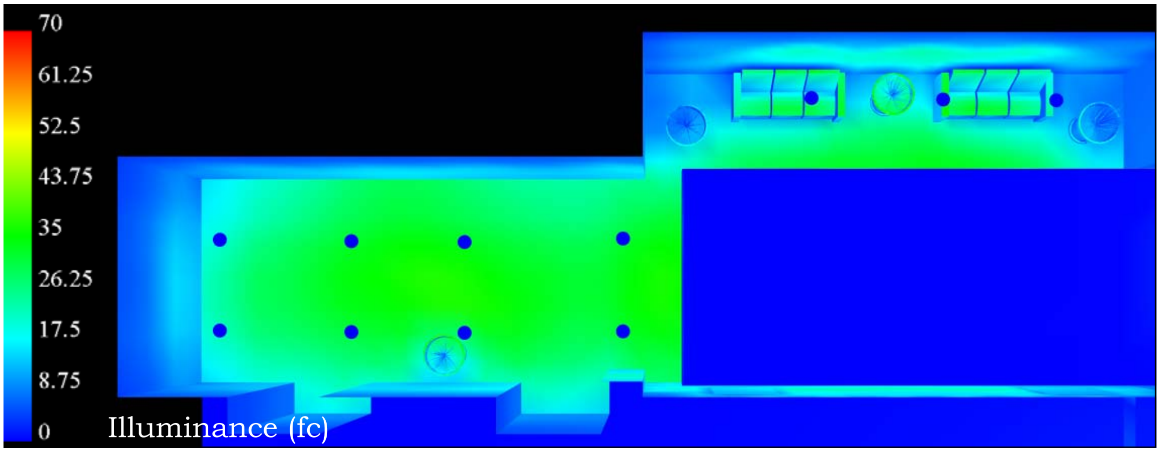

Sc Sd Se
TYP: L3.1 a
TYP: L3.2 b
= Occupancy Sensor
= Dimming Module
= Low Voltage Wiring
N
Sa
Sb

renderings/calcs:

The ceiling coves, while much brighter than the surroundings, create an even distribution onto the corridor floor. The downlights illuminate the walls and workplane, and take focus away from the coves.

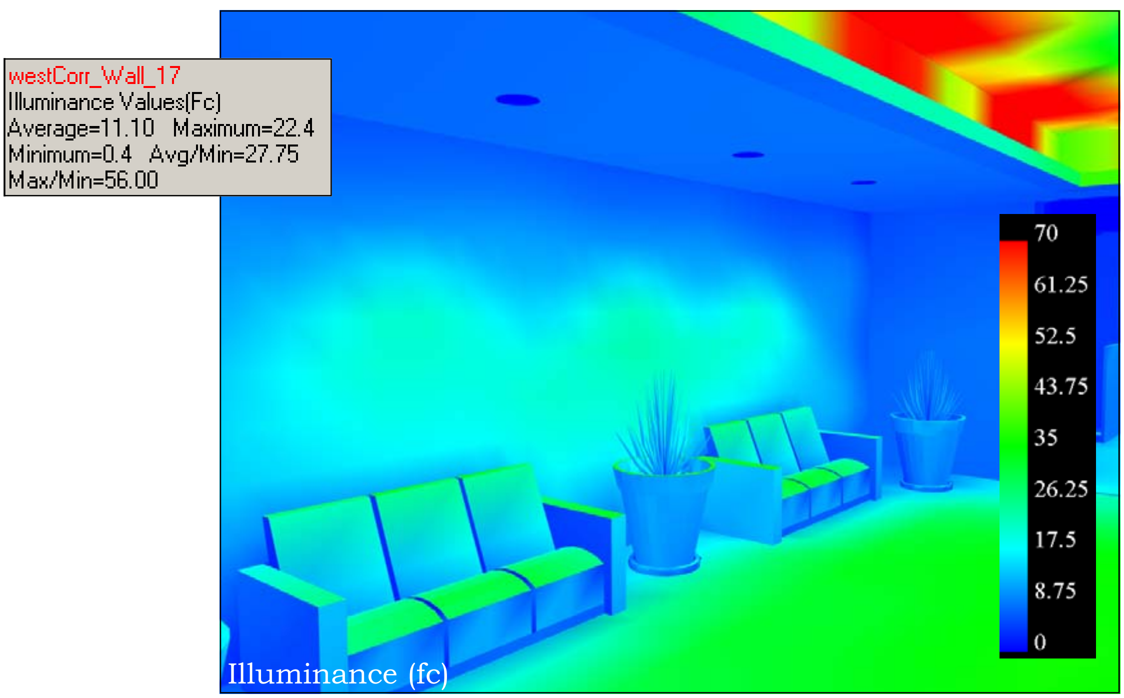


renderings/calcs:



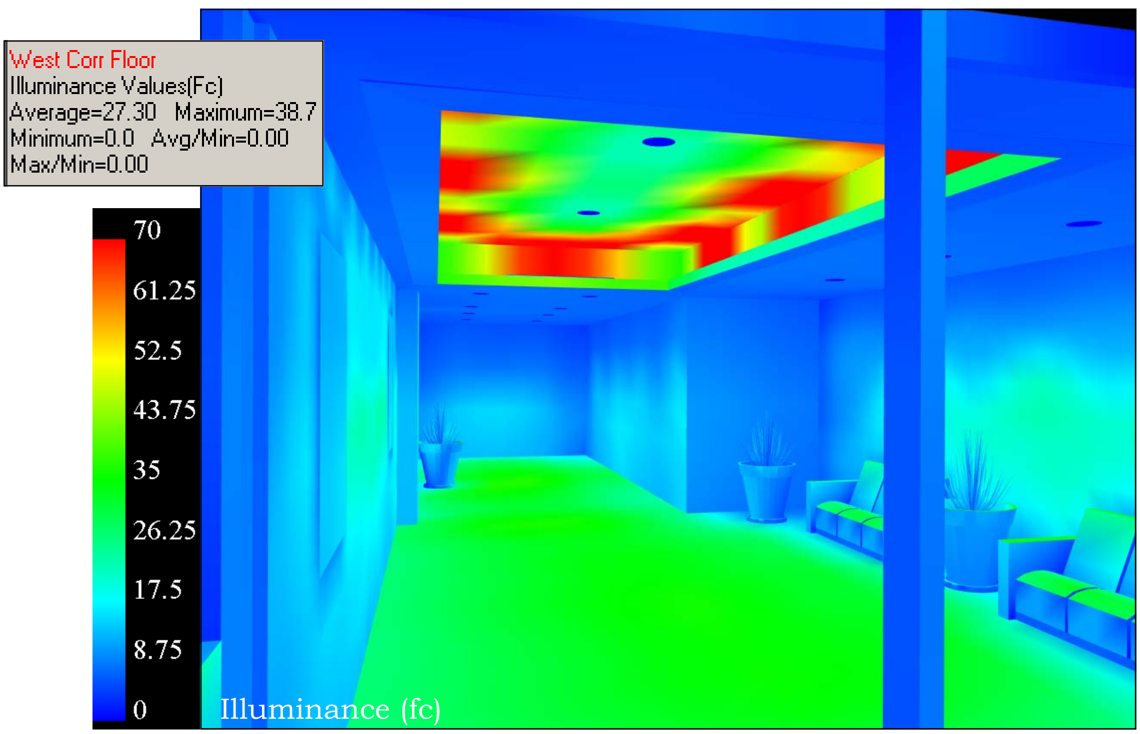
At the west end of the corridor, the use of two coves could have created too much brightness on the ceiling. Instead, I lit the end of the hall with downlights. These create the same even pattern as the cove, but also highlight the walls.

The distribution on the walls is uneven; this is done intentionally to create areas of interest.



renderings/calcs:

As one walks down the corridor, the downlights lead the way, and can help steer the eye towards important destinations or interesting visual displays.



controls:

The controls for this space are designed to minimize power consumption while keeping the switching pattern simple for the occupants of the space. There are 5 circuits in the space. On the east side of the corridor, there is one circuit for each of the two type of fixtures. Each of these are connected to a 1 pole switch located adjacent to the stairs. Both circuits are connected to the central clock located on panel LP-DIM via low voltage wiring. After the clock switches off the lights in the space, the downlight circuit is controlled by the occupancy sensor located next to the receptionist's desk.

The five downlights mounted on the mullions in the light chamber are on a separate, single-pole switched circuit. These lights are wired to the central clock, but will remain on every weeknight of the school year.

Finally, the lights on the west end of the corridor will be circuited almost exactly the same as those on the opposite end. Each fixture type is on its own single-pole switched circuit, and only the downlights will respond the occupancy sensor located near the couches along the north wall.

I did not consider a daylighting dimming system to be necessary in this part of the building. Since it is the primary circulation space in the building, it should be lit to full levels at all times, regardless of the daylight penetration. Of course, there is a significant amount of daylight coming into the space, but I think that the system can stand on its own and blend into this light without dimming any of the fixtures.

power density:

The fixtures in the space utilize 1574 W of power, making the power density of the space about 0.899 W/ft^2. This number is actually above the ASHRAE/IESNA 90.1 allowable for an educational facility corridor of 0.70 W/ft^2. However, since this space function as both the lobby and the main corridor (lobby allowable = 1.8 W/ft^2), I feel that this value is fully justified.

conclusions:

I was very satisfied with the way that this space turned out. The downlights really added another dimension in terms of visual interest. The even distribution on the floor really gave the room a good feeling of unity. If I could change anything, I would have made the space more dependent on light from the downlights instead of the bright cove. Of course, this would have reduced the overall light level, and possibly caused problems with navigating the space. In the end, I think that the two fixtures balanced well together.

| Space #4: Library Courtyard

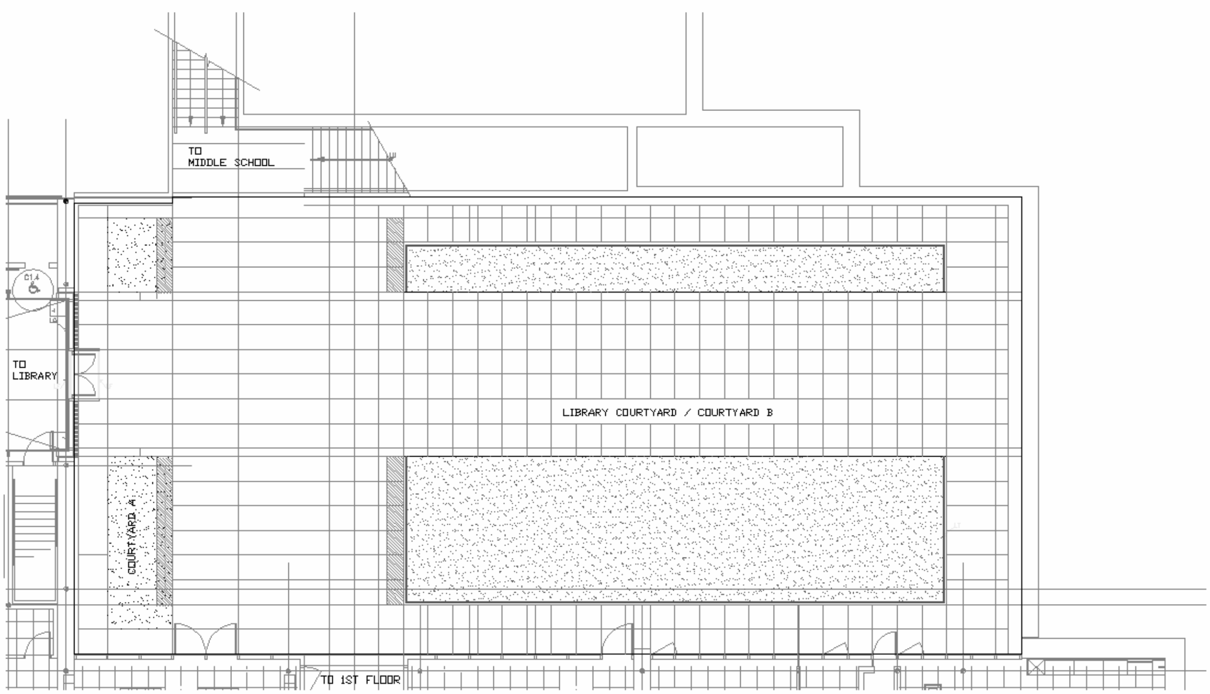
size: 114’ x 56’
6384 s.f.

description:

The library courtyard is located on the north side of the building, and is adjacent to the library entrance. The courtyard is at the same elevation as the first floor, so that from the main entrance, the courtyard looks like it is sunk in about 2 stories. Since the middle school is attached to the upper school, and the library courtyard is adjacent to the courtyard for the middle school, the space serves as the outdoor visual link between the two buildings.

Most of the area is hardscaped for easier pedestrian circulation, but there is a large grassy area in the middle of the space. There are trees lining this area, and several benches placed along the perimeter.

furniture plan:



functions:

- → connection to campus
- → connection to nature
- → pedestrian travel
- → leisure space
- → opens up site

design criteria:

Appearance of Space and Luminaires: The luminaries in an outdoor space, serve both as sources of illumination and as guides through the area. Making the primary path the most brightly lit path will assist people in navigating the courtyard.

Light Pollution: Since this is a courtyard, light pollution into adjacent buildings or outdoor spaces must be considered. However, this particular space is about 2 stories below the grade of the adjacent buildings, so this may be as important as the appearance of the space.

Points of Interest: As much as lighting can be a tool for navigation, it can also lead the eye towards less traveled destinations. The courtyard should serve as a break from the foot traffic of the stairs and sidewalks, and the lighting should be inviting to pedestrians.

Shadows: With a space like this, especially near a girls' school, security is a major issue. Although a subtle lighting tone is suited for the grassy area, the main pathways should be well lit and free of dark corners.

Horizontal Illuminance: Again, strong light levels on the pathways are a must. In this situation, IESNA recommends about 5 fc for orientation and simple visual tasks.

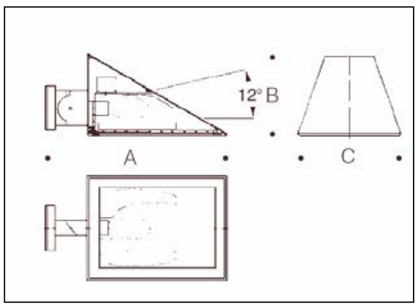
adjectives to describe redesign:

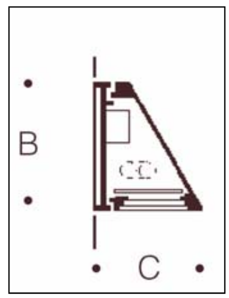
open, discrete, subtle, guiding, clear

functional goals of redesign:

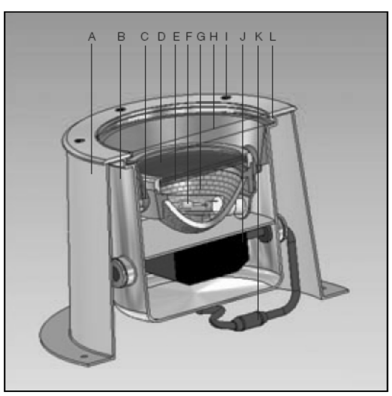
The library courtyard can be broken up into two distinct functions, with each requiring a distinct lighting system. The first is the more practical of the two, and is concerned with leading occupants through the space in a safe and comfortable manner. The entrance to any building has to serve as a sort of ambassador to any visitors that may approach. Since this courtyard is also next to two other buildings, it carries an even larger burden to guide people to their proper destination.

In order to accomplish this goal, I will be employing 2 different type of fixtures. The first is a wall mounted compact fluorescent downlight. The fixture uses 2 26W triple tube lamps, and emits about 3600 lumens. These lights will be mounted directly to the school building, one fixture at the library entrance and one at the first floor entrance. These will be used as both flood lights to illuminate the paved area, but also as navigation keys to make the location of the entrances more obvious.





Next, I will be using a shallow-projection wall light to illuminate the stair cases leading to or from the main entrance and middle school. These surface mounted fixtures each contain a 13 W compact fluorescent lamp, and throw an adequate amount of light onto the horizontal steps. These will be spaced about every 6 steps for maximum efficiency.



Finally, for the more aesthetic function of the space, I will be using special low temperature recessed uplights. These fixtures are built specifically with safety in mind, so even with the 70W metal halide bulb inside, they will not become a fire or burning hazard. The fixtures will be buried at regular interval in the patches of grass and allowed to illuminate the trees or even a wall surface if it becomes a point of interest. Even though there are benches near by, the narrow beam of the luminaire should not cause problems with direct glare. Overall, this system should provide a good balance for the space.

materials:

Surface	*Material*	*Reflectance (ρ)*
walkways	Concrete	0.40
ground	Grass	0.10
walls	Concrete	0.40
glass	double pane 1/4”, gray tint	0.85

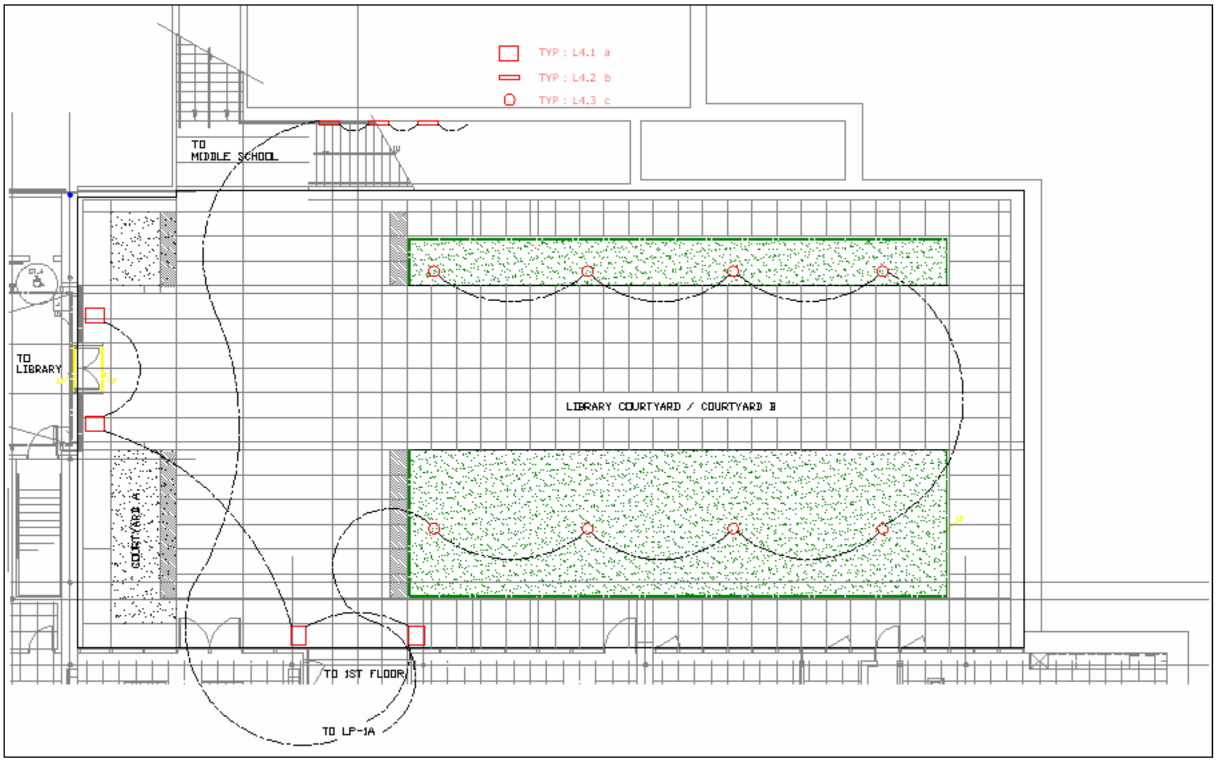
luminaire schedule:

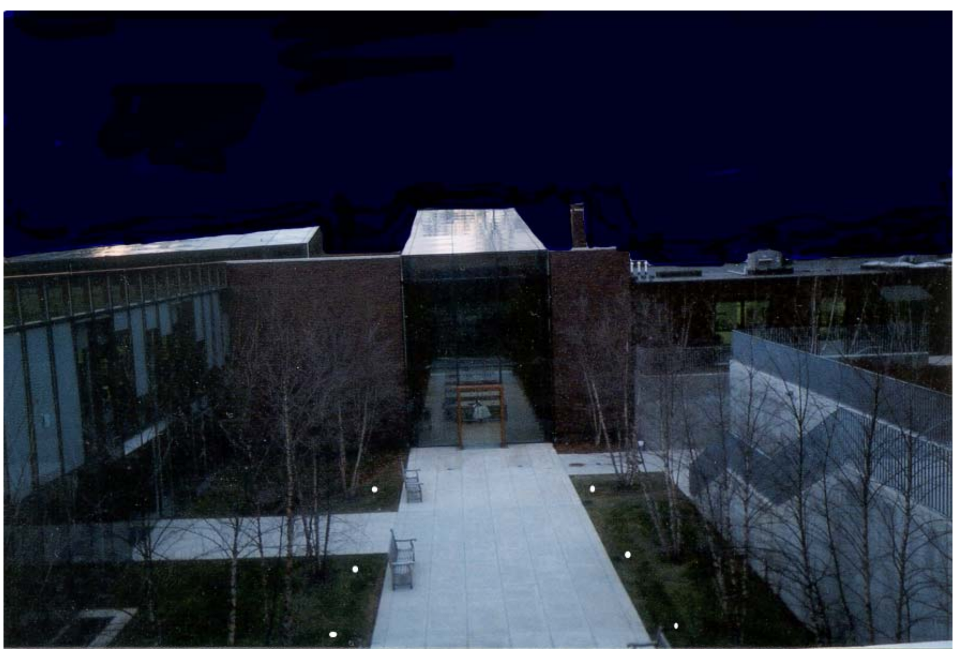
Type	*Name*	*Bulb*	*Watts*	*BF*	*LLD*	*LDD*	*RSDD*	***LLF***
L4.1	Downlight	26W TRT (2)	54	1.0	0.86	0.86	-	**0.740**
L4.2	Stair Light	13W TRT	29	1.0	0.86	0.84	-	**0.722**
L4.3	Recessed Uplight	39W T4 MH	53	1.0	0.80	0.80	-	**0.640**

ballast schedule:

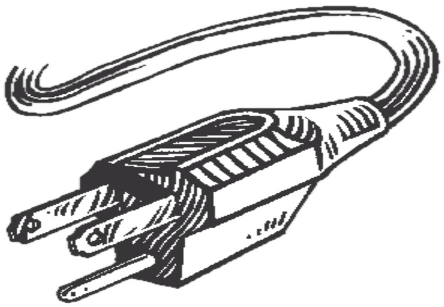
Des.	*Catalog Number.*	*Start Method*	*# of lamps*	*BF*	*Input Power*	*Input Current*	*PF*	*THD %*
a	QTP2X26CFUNVBS	PS	2	1.0	54	0.50	>0.98	<10%
b	QTP12X13CFUNVBS	PS	2	1.0	29	0.25	>0.98	<10%
c	71A50Y1	HX-HPF	1	1.0	53	0.56	>0.90	-

RCP:





This view shows the location of the recessed uplight. The lighting levels will reflect the luminance shown here. Even lighting across most of the pavement, and high contrast points of interest in the grassy areas.



Electrical Redesign
for Greenwich Academy Upper School

general description:

Power is supplied to the Upper School by an existing 13.2 kV connection located on the exterior of the adjacent building, Ruth West Campbell Hall. A new 750 kVA transformer was added during construction to step the voltage down 208Y/120 V. The transformer is located in a vault beneath the exterior stairway closest to the Gym Building. A 4" conduit bank consisting of three (3) #2 (15kV rated) cables feeds the 3000 A Main Distribution Panel (MDP) located in the basement. This switchboard provides 3-phase power to all of the panels in the building.

emergency power:

A 200 kW Generator, located in the same vault as the transformer, provides 3-phase power at 208/120 Volts. The generator is connected by 2 sets of 4 500MCM THHN conductors to an 800 A Automatic Transfer Switch in order to ensure safe shifting of the loads in the event of a power fault. The emergency switchboard supplies the emergency lighting system and emergency receptacles, as well as the hydraulic elevator with 208/120 V power.

overcurrent devices:

The overcurrent protection devices are all located on the Main Distribution Panel (MDP) or the emergency distribution panel (MDP-EM) in the Electrical Room. At this switchboard, all of the panels are protected from overload and ground faults by 3-pole circuit breakers of various capacities. Fused disconnect switches are used to protect from high-level short-circuits. The panels themselves are protected by a 3000 A 3-pole breaker and a 2500A fused disconnect switch.

Additionally, a shunt trip circuit break is provided for the hydraulic elevator motor controller. This 3-pole, 100 A breaker is located in the Elevator Mechanical Room. Disconnect switches are located at each MCC in the basement Mechanical Room.

switchgear, panelboards, MCCs:

The Main Distribution Panel (MDP) is located in the basement level Electrical Room. The building lighting panel (LP-1A), as well as the panels for LED light pipe dimming system (Dimmer Racks 1,2,3) are fed by this panel, and also located on the bottom level. Emergency lighting is provided by panels LP-1EM, LP-2EM, and an emergency dimmer rack. All of these are routed from panel MDP-EM. The MCC's are also fed by this panel and are located in close proximity to their respective equipment, all in the basement. The Fire Alarm control annunciator panel and security system control panel are both located on the top floor, at the Main Entrance.

lighting panelboard sched:

Designation	*Voltage*	*Switch / Fuse*	*Feeder Size*	*Load Type*
LP-1A	208/120V	200A / 200A	4-3/0AWG + #6 GND in 2" C	1st, 2nd, and Bsmt Level Lighting
Dimmer Rack 1	208/120V	200A / 200A	4-3/0AWG + #6 GND in 2" C	DMX Dimming System
Dimmer Rack 2	208/120V	400A / 300A	4-350MCM + #4 GND in 3" C	DMX Dimming System
Dimmer Rack 3	208/120V	400A / 300A	4-350MCM + #4 GND in 3" C	DMX Dimming System
LP-1EM	208/120V	100A / 100A	4-#2AWG + #8 GND in 1-1/4" C	Emergency Lighting
LP-2EM	208/120V	100A / 100A	4-#2AWG + #8 GND in 1-1/4" C	Emergency Lighting
Emer. Dimmer Rack	208/120V	60A / 60A	4-#6AWG + #10 GND in 1" C	Emergency DMX Dimming System

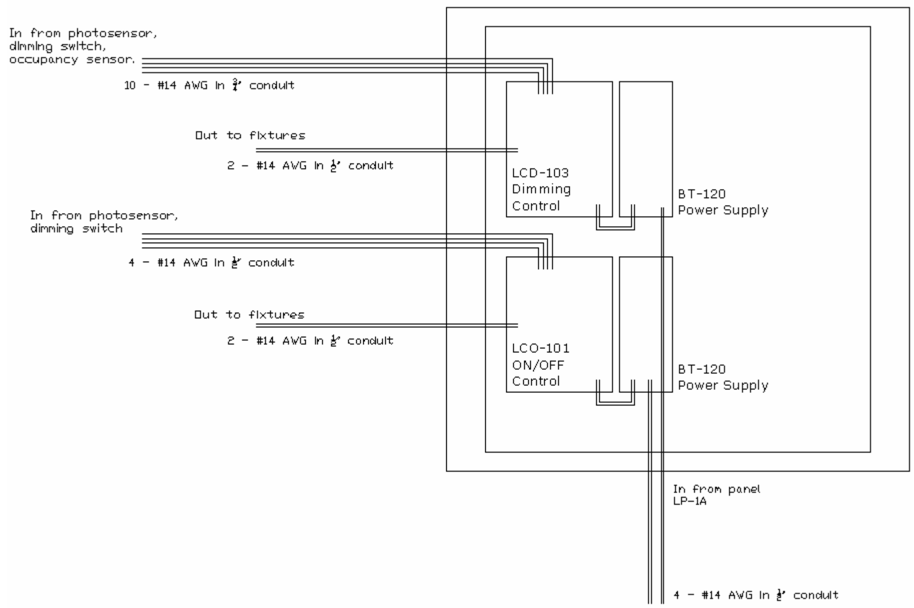
revisions:

After analyzing my design for the building, I determined that the electrical system did not need any major revisions to accommodate the changes in the lighting loads. In all cases, the fixtures that I specified actually added up to less total load than those which were al ready in place. The one major change that will be required is the addition of a photosensor dimmer rack for the library in a separate panel from the other lighting circuits. The technical information for these units is located in the appendices.

The addition of another panel (LP-DIM) will require only a few changes to the system as originally designed. Of course, the first of these is that low-voltage wiring will need to be run to each junction box and sensor. The enclosure will include a dimming module, switching module, and one power supply for each controller.

revisions:

The two controllers and the corresponding power supplies are located in a panel with a pre-mounted double DIN rail. This panel will be adjacent to panel LP-1A in the basement electrical room. The schematic diagram for this panel shows the connections and corresponding wiring:



The wires coming in from panel LP-1A are #14 AWG in 1/2" conduit, and are capable of conducting 16 A each. This is the same wire gauge that is used by the entire daylighting circuit. The daylighting ON/OFF control provides power to the cylindrical downlight fixtures located in the light chamber as long as the signal coming in from the photosensor remains above zero. These lights will stay on up until the point when the controller gets a null signal from the sensor for 20 minutes. This should usually correspond to nighttime or a very over-cast sky, and should alleviate problems with frequent switching.

The dimming module will control the recessed troffers near the windows on the west side of the room. The controller receives light level signals from the photo sensor, and dims the fixtures accordingly. After hours, the zone is controlled by the occupancy sensor, which is also wired into the panel.

The remaining occupancy sensors in other spaces (Science Room and West Corridor) are powered by power pack relays which are connected in the plenum, and therefore do not require any panelboard space.

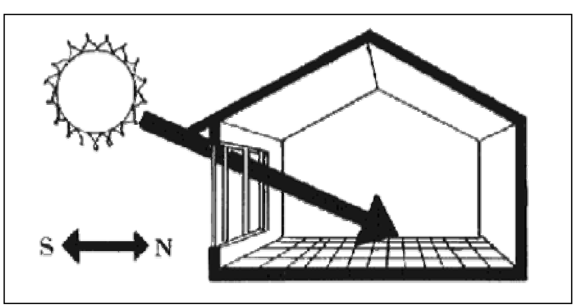
Passive Solar Design
for Greenwich Academy Upper School

overview:

One of the most visually and conceptually striking elements of the entire school building is the uniform glazing which seems to cover the entire building envelope. The concept of applying some of this glazed space into a passive solar heating design intrigued from the moment I started analyzing the building. It seemed that the light chambers could be modified to provide some relief for the heating and cooling loads of the building's HVAC system.

direct-gain passive solar heating:

The concept of direct-gain passive solar heating involves using inexpensive, common-sense tactics to utilize the energy distributed by the sun in building heating and cooling. The most common methods of accomplishing this goal are using double-pane windows of semi-clear glass (usually with a low-emissivity coating on the outer pane), and some kind of thermal mass for storage the collected energy. As the solar rays and diffuse radiation permeate the clear windows, the storage element, usually a stone floor or wall system, absorbs and collects the solar energy.



passive solar heating: (cont'd)

As the sun sets, and heating needs increase, the collected energy will distribute itself back into the space. Once the sun is below the horizon, it is sometimes necessary to adjust the thermal characteristics of the windows, as they will transmit heat out of the building as easily as they allow it inside. This is most simply accomplished by automatic shades or blinds.

system redesign:

For the purposes of this redesign, I will only be investigating changes in the building architecture in one of the four light chambers in the building. I chose the light chamber that is directly above the north end of the library. This space is easily converted to a direct-gain system, as two of the sides, as well as the ceiling are fully glazed. Although the chamber is on the north side of the building, there should still be enough light coming in through the skylight to allow for positive results.

To perform the analysis, I kept the window type the same, two 1/4" panes glass in an aluminum frame and a 1/4" air gap, but changed the coating on the outer lite. Initially, the outer lite was tinted gray to reduce glare, but to increase transmission, I switched to a clear, low-emissivity coated lite. Also, to increase the storage capacity of the floor, I changed it from hardwood to thermally-rated stone. Although this changes the architectural statement of the building, I believe that it serves the "green" focus of the overall design.

Insulating Vision Unit Performance Comparisons[1] 1-Inch (25mm) units with 1/2-inch (13mm) airspace and two 1/4-inch (6mm) lites; interior lite clear

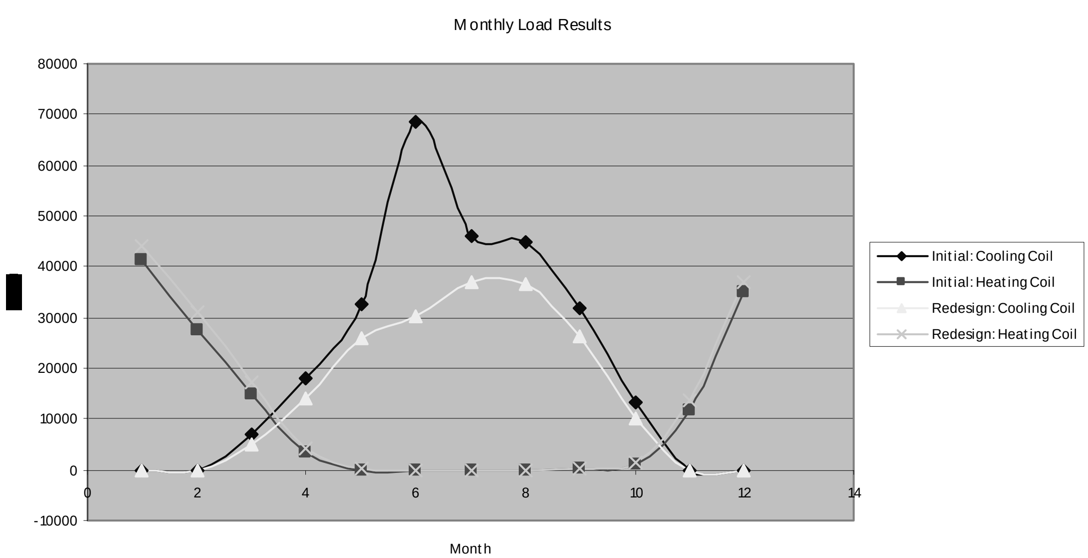
Glass Type	Transmittance[2]			Reflectance[2]		U-Value[3] (Imperial)		K-Value[3] (Metric)		Shading Coefficient[4]	Solar Heat Gain Coefficient[5]	Light to Solar Gain[6] (LSG)
	Ultraviolet %	Visible %	Total Solar Energy %	Visible Light %	Total Solar Energy %	Winter Night Time	Summer Day Time	Winter Night Time	Summer Day Time			
OPTIGRAY® 23 Tinted Glass	6	21	15	6	5	0.47	0.50	2.67	2.84	0.34	0.29	0.72
SOLARCOOL® Glass (Reflective)												
SOLARCOOL (1) SOLEXIA	7	27	18	37	31	0.47	0.50	2.67	2.84	0.32	0.28	0.96

I compared the two arrangements using the Carrier Hourly Analysis Program (HAP) version 4.20. This particular program allows you to input the climate, architecture, and type of air system, and outputs a summary of the building loads and sizes for the required components. The HVAC system in the school is a Variable Air Volume (VAV) arrangement consisting of three chilled water Air Handling Units (AHUs) with a combined minimum outdoor air capacity of 16,400 CFM.

results of analysis:

	initial		redesign	
Month	Central Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Central Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)
January	0	41149	0	43889
February	0	27642	0	31034
March	7047	14692	4869	17205
April	18163	3613	14011	4318
May	32688	58	25813	119
June	38475	0	30385	0
July	46063	0	37138	0
August	44991	0	36398	0
September	32017	157	26410	206
October	13165	996	10144	1350
November	0	11732	0	13592
December	0	35024	0	37130
Total	**232609**	**135064**	**185167**	**148843**

As the data indicates, there is a distinct reduction in the cooling coil load due to the inclusion of the thermal floor. The load was decreased by almost 50,000 kBTU. This change can translate directly into long term savings, as the entire demand on the cooling system has been greatly lowered. On the other end of the spectrum, the heating coil load actually increased because of the changes in the room design. I believe that this is due to the switch to clear glass. This type of glass is much more transmissive, and it seems that the heating load has increased because of additional heat loss through the glass. The solution to this is to install automatic shades which will cover the glazed areas once the sun has moved too low in the sky to be effective. (For additional information, refer to appendix C)



Acoustic Redesign
for Greenwich Academy Upper School

overview:

All libraries, whether inside a small school in Connecticut or a landmark in a major metropolitan area, are always known for one thing. They are quiet. The library is meant to be a place of quiet study and learning. This environment can be easily interrupted by a loud noise, and that noise is only made worse if it is allowed to reverberate throughout the room. It is for this reason that architects and engineers spend so much carefully planning out the spacing and materials for use in a library.

In this study, I will analyze the average reverberation time for the library of the Greenwich Academy Upper School and, if necessary, look into what changes can be made to improve this characteristic of the room.

noise reduction:

The fundamental attribute of a room's acoustic performance is the reverberation time (T_{60}). This is defined as the "time required for sound to decay 60 dB after the source has stopped" (Egan, 63). Reverberation time is calculated by the formula:

$$T60 = 0.05 * V/a,$$

where V is the volume of the room in ft^3 and a is the total square footage of room absorption.

The quantity 'a' is itself calculated by summing the different room surfaces by material, and multiplying each by an empirically determined absorption coefficient (α). A school library such as this one will typically have a reverberation time between 0.6 and 1.4 s (Hendricks, 1). Since this library is fairly large (4400 sq. ft.), the T_{60} will probably end up near the high end of that range.

analysis of existing system:

After tabulating data on the surface areas and absorption coefficients (Egan, 52) I was able to calculate the reverberation time for the entire library, based on frequency of source:

Base Case	*125 Hz*	*250 Hz*	*500 Hz*	*1 kHz*	*2 kHz*	*4 kHz*
a (sabins)	4614.295	4161.58	3820.145	4942.435	5741.045	5824.875
Volume (ft^3)	66012	66012	66012	66012	66012	66012
T_{60} (s)	**0.715299**	**0.793112**	**0.863999**	**0.667808**	**0.574913**	**0.566639**

These values for reverberation time are well within the specified range (0.6-1.4 s), and actually dipping below the lower bound at the 2 kHz and 4 kHz frequencies. I attribute this to both the large volume of the library, and the fact that 85% of the lower ceiling (9') is covered by acoustical ceiling tiles in a suspension grid. These tiles have extremely high absorption coefficients across the spectrum, and especially at higher frequencies. The existing materials in the library appear to adequate to keep reverberation times to a minimum.

analysis of passive solar redesign:

In my study of a passive solar design, I considered changing the laminate flooring in the light chamber portion of the library to polished stone, a better heat storage material. But while it is more efficient thermally, wood has much lower reflective acoustic characteristics. I decided to analyze the room again, but using the stone in place of the wood floor:

Redesign	*125 Hz*	*250 Hz*	*500 Hz*	*1 kHz*	*2 kHz*	*4 kHz*
a (sabins)	4424.175	4025.78	3697.925	4860.955	5686.725	5756.975
Volume (ft^3)	66012	66012	66012	66012	66012	66012
T_{60} (s)	**0.746037**	**0.819866**	**0.892555**	**0.679002**	**0.580404**	**0.573322**

The reverberation times for this case were longer than the original scenario at every frequency, but not by more than 0.03 s. Even the low absorption coefficient of the stone (0.01 for most frequencies) did not have a very large effect on the reverberation time. I would attribute this to the same reasons stated above, the library is a large room with a highly absorptive ceiling. (For additional information, refer to appendix D)

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