Dave Maino	·	**name**
Lighting/Electrical	·	**option**
Dr. Mistrick	·	**advisor**
TCES	·	**building**
Incline Village, NV	·	**location**
3.19.06	·	**date**
Final Thesis Report	·	**title**

Electronic forms of this report and supplemental information can be found on the CD at the back of this booklet. All Appendices are located on the CD as well.

Full report as well as additional reports available for download from the web at "http://www.arche.psu.edu/thesis/eportfolio/current/portfolios/jdm341/"

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Executive Summary:

The Tahoe Center for Environmental Sciences provided many opportunities for developing an integrated, eco-friendly set of building systems. Some of the many design challenges included creating a LEED platinum building, ensuring all the systems fit with the architecture, integrating all building systems to make sense as a whole functioning unit and providing the client with the best possible building. The following report contains design information pertaining to a new lighting system for four rooms, new electrical systems, an in-depth LEED analysis, and a mechanical systems investigation.

The lighting depth covers four spaces: the exterior entryway, the main lobby, the case study classroom, and a chemistry lab. An in-depth analysis of the design criteria for each space lead me to appropriate designs for each room. Each room focuses on integration of fixtures, controls and architecture. Also of top importance is energy consumption. I chose efficient sources to achieve a high degree of energy savings. Additionally, I performed a daylight analysis on the lobby floor to determine light levels in that portion of the lobby.

The electrical depth focuses on the design of a cogeneration system, a photovoltaic system, and an overall electrical system. Prior to the analysis an eQuest energy simulation was performed to determine electrical Loads on the building. I installed two 30kW cogeneration units, along with transformers to step down from 480V to 208V. In addition, 60kW of photovoltaics were installed to attempt to generate power for the building and gain an additional LEED credit. The electrical system in the building was adjusted to accommodate the new systems, including the new lighting loads installed.

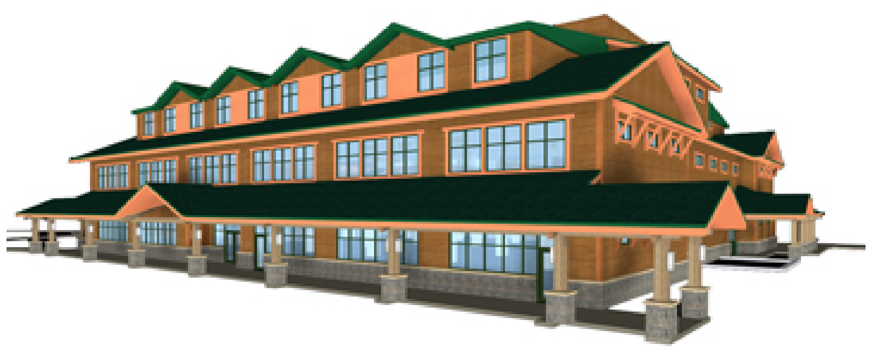
The LEED analysis breadth performed involved a detailed look into the points attained, those not attained, and those that were questionable as to whether they would be attained or not. I attempted to more accurately determine exactly how many points would be gained by finding points that were not obtained and seeing whether they could be achieved or not. Of particular interest was the credit for producing 20% of the building's energy with renewable resources.

The mechanical breadth involves using the output from the eQuest energy model to determine the feasibility of installing six solar hot water heating panels. The heat output from the cogeneration units was also considered when designing the panels.

The new lighting design, electrical system, and the hot water analysis and LEED analysis provide the Tahoe Center for Environmental Sciences with a fully functioning, efficient, and well integrated set of building systems. These systems will not only provide the functions they were designed for, but also will serve as learning tools for the students and faculty using the building.

Background:

The population in the lake Tahoe region has been steadily increasing and with such an increase comes a strain on the local environment. The Tahoe Regional Planing Association (TRPA) has attempted to regulate things such that the impact is minimized, but the impact is still there, nonetheless. For this reason, Sierra Nevada College, U.C. Davis and the Desert Research Institute have teamed up to provide a research facility capable of studying the effects of the local population on Lake Tahoe and the Lake Tahoe Basin. They wished to develop a "green," eco-friendly, LEED platinum building in which to conduct their research and teach classes. The facility in question is the Tahoe Center for Environmental Sciences (TCES).



TCES is both a research facility and an educational facility. Lab, office, classroom, and lecture spaces are combined to provide professionals as well as students a place where research and learning can be accomplished side by side. The mixed use of this building, combined with the unique systems found within make it an extraordinarily interesting structure. Four spaces in particular caught my attention: the entry lobby, the case study classroom, the chemistry lab, and the exterior entryway.

Many "green" systems were also implemented in this building, the most notable of which are photovoltaic (PV) cells, a cogeneration unit, solar hot water heating, a greywater reclamation system, and radiant floor and ceiling panels to heat and cool the space. Every effort was made to achieve a LEED platinum standing, and prior to the building being commissioned it is currently attaining that standing.

Architecture:

Lake Tahoe sits a short distance down the road from TCES, with beautiful water, mountain, and wooded area views in all directions. The exterior of the building complements its surroundings by immersing itself in nature through the use of stone and fibrous-cement siding formed to resemble redwood panels. Careful consideration of the surrounding buildings also played an important role in the design, so that TCES could be instantly recognizable as a part of Sierra Nevada College.

Due to limited land available, the building is organized into the most efficient shape possible, a square. The main entrance, which is located on the North side of the building, is covered by a building-length arcade. The arcade is composed of a truss-laden triangular canopy. Upon entering, the reception area is located to the left, and straight ahead is the main lobby. The lobby contains many walls on which research information, projects, and information about the building are to be located, making the space visually interesting and giving visitors something to look at as they gather in the lobby. Continuing to the center of the lobby you will find the atrium which is a three story daylit space with openings to all above floors, letting natural light into many of the main circulation spaces. Also inside the main lobby is the primary mode of conveyance in the building, the main stair case. In the interest of not only building sustainability but also human sustainability, the architect chose to highlight the stairs and make them prominent in the space to encourage people to walk more and rely less on the elevator. In this way, the lobby serves as one of the main circulation spaces for the building.

Off to the East, immediately after entering the building, is the Case Study classroom. This room is intended for use as a place for visiting researchers work to be reviewed by their peers, as well as for other lectures. The space consists of three rows of seating facing a wall with a projector and space to mount visual aides. A podium stands in the Southeast corner of the room for delivering lectures.

Continuing back into the lobby and up the stairs, you come to the second floor. Along the North wall are a series of chemistry laboratories. These chemistry labs are mainly for teaching classes, but research may also take place here. At the center of each room are a series of work counters and sinks. Lining the walls are cabinets and shelves holding lab equipment that is used. At the front of the room is a teaching wall with blackboards and a projection screen. Chemical storage is located in an adjacent room, with a doorway near the back.

These spaces are all united through a common theme. Much of the spaces are composed of unadorned concrete and simple painted gypsum board. Beauty in simplicity is the predominant theme, which also lends itself very well to the idea of sustainability. Excess of materials is not something found in this building. Throughout every aspect of the architecture in this building, the idea of sustainability is maintained.

Lighting Depth

Introduction

The TCES owners are dedicated to providing the most eco-friendly and efficient building they possibly can. Because of this, they made sure that the lighting design for the building was extremely efficient, not only to gain LEED points but also in an effort to actively conserve energy. They see the building not only as a place where students can come to learn, but want it to also be a teaching point itself. By designing a green building, they can demonstrate how it can be done and hopefully guide other developers to do the same. Due to their extraordinary efforts, lower power densities will be hard to achieve but I will make every attempt to do so.

The four spaces that I will be investigating during this lighting design will be the exterior, the main lobby, the case study classroom, and one of the chemistry laboratories. The exterior is the main point of interaction between the public and the building. A long arcade along the North facade of the building will be the focus for the redesign. The next space the public encounters is the lobby. The lobby serves as the main circulation space as well as the reception area and display gallery. A three-story atrium stands in the center of the lobby, providing light to the hallways up on the 2nd and 3rd floors as well as part of the lobby below. Adjacent to the lobby is the case study classroom, which will be used by visiting professors to have their work reviewed, as well as for lectures and possibly classes. Above all of this on the second floor are the lab spaces. One of the chemistry labs has been chosen in order to reduce the power density in a spaces that is overlit. Spaces chosen for producing finalized renderings are the lobby and the chemistry classroom.

Design Goals

Power densities that are lower than the current power densities are desired. Since the power density in the chemistry lab is above what is allowed, a major goal of mine will be to bring it down to a level below what ASHRAE 90.1 allows. Throughout all the spaces it is important for me to choose fixtures which will integrate with the simple yet beautiful architecture. The fixtures should reflect this simplicity and beauty, and should not be a prominent feature of the architecture but merely a part of the architecture. Of course, neither should they be an eye sore. In addition, I will obtain proper light levels as defined by the IES in all spaces and an appropriate level of control for each space is desired. For individual design goals and criteria for each space, please see below.

Design Solution

To achieve the low power densities that are desired, I have chosen efficient fixtures and sources. In the lobby, I attempted to use daylight from the lightwells during the day when possible. I chose simple fixtures that do not detract from the architecture because they are either too elaborate or too displeasing to look at. In many instances, I have made an effort to find a fixture that can be used in multiple locations, drastically reducing the number of fixtures needed on the project.

General Information

Overall Design Concept

After I visited the site and took in the views of the mountains, the lake, and all the trees surrounding the building, I couldn't help but come away with a sense of what the owners of TCES wanted to help preserve. As such, nature provided me with two main design concepts. The first is the idea of sustainability to ensure that the views that I enjoy are there for future generations. The second is the idea of “Beauty in Simplicity” that comes from observing how simply things in nature seem to interact and respond to one another. As such, I will chose fixtures to blend and compliment the architecture of the building in addition to being efficient and energy-saving. Much like nature, I will attempt to avoid waste and at the same time create a visually pleasing experience. Also, to relate rooms to one another I will choose a minimal amount of fixtures to serve the spaces, meaning that the fixtures chosen must be usable in many settings. This will also promote sustainability in that fewer fixture types means fewer lamp types, fewer manufacturers producing fixtures, and fewer man-hours spent installing fixtures since the contractor will only have to learn to install a limited amount of fixtures.

Fixture Schedule

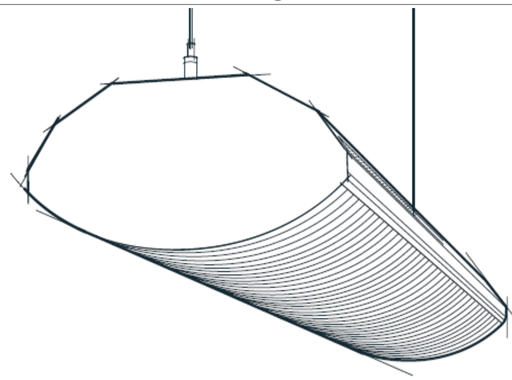
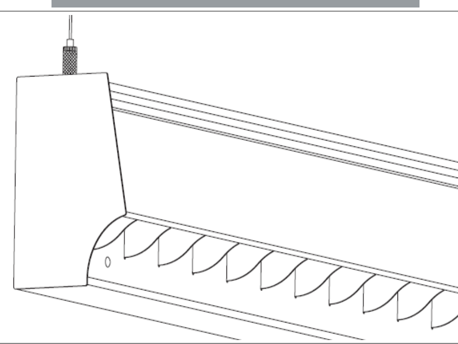
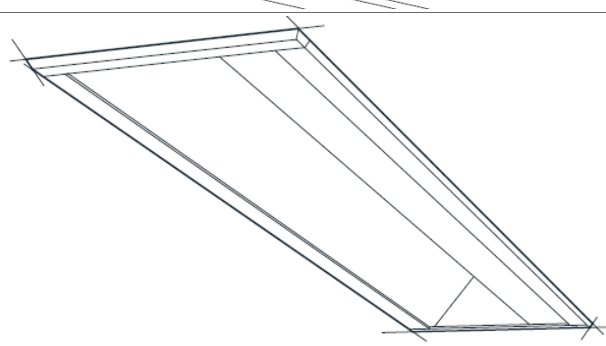
Fixtures are grouped together by letter if the physical housing of the fixture is the same. Variations on the mounting, lamping, ballasts, etc. are denoted by a number following the letter. See figure 1.1 below for fixture types and descriptions. Full fixture cutsheets are available for viewing in Appendix A-CD. Images of each fixture type can be found in figure 1.2.

LIGHT FIXTURE SCHEDULE

TYPE	MOUNTING	MODEL	LAMP	BALLAST	FINISH	DESCRIPTION / NOTES
A1	Surface	Prudential PRU-7 surface mounted 4'-0" linear semi-direct fluorescent fixture.	Philips F32T8 835 ALTO	E	Galvanized	Ceiling Mounted Semi-Direct
A2	Suspended	Prudential PRU-7 suspended 4'-0" linear semi-direct fluorescent fixture.	Philips F32T8 835 ALTO	E	Galvanized	Suspended Semi-Direct
A3	Suspended	Prudential PRU-7 suspended 4'-0" linear semi-direct fluorescent fixture.	Philips F32T8 835 ALTO	ED	Galvanized	Suspended Semi-Direct
B1	Track	Erco JILLY track mounted floodlight.	Philips CDM-T 35W 830 T6	M	Cast Aluminum	Flood Light
C1	Surface	Finelite X2-R surface mounted 4'-0" linear wallwasher.	Philips F32T8 835 ALTO	E	Galvanized	Surface Mount Wallwasher
D1	Recessed	Prudential P-5900 4'-0" recessed linear fluorescent wallwasher.	Philips F32T8 835 ALTO	E	Painted Aluminum	Recessed Wallwasher
E1	N/A	Erco LUCY adjustable arm compact fluorescent task light.	Philips PL-T 18W 835 4P ALTO	E	Anodized Aluminum	CFL Tasklight
F1	Surface	Fail-Safe HDSCR surface mounted metal halide downlight.	Philips CDM 50W 830 ED17	M	Stainless Steel	Wet Location Downlight

Ballast Codes:		
E	=	Electronic
ED	=	Electronic Dimming
M	=	Magnetic

Figure 1.1

Type	***Image***
A1, A2, A3	
B1	
C1	
D1	

Type	***Image***
E1	
F1	
	Figure 1.2

Ballast Schedule

Ballasts and lamps used for each fixture type are listed in figure 1.3. For ballast and lamp cutsheets please see Appendix A-CD.

BALLAST INFO							
TYPE	BALLAST	E/M/D	LAMP	NUM LAMPS	WATTS	AMPS	VOLTAGE
A1	Advance Transformer RCN-3P32-SC	E	32W T8	(2)	65	0.54	120
A2	Advance Transformer RCN-3P32-SC	E	32W T8	(2)	65	0.54	120
A3	Lutron FDB-4827-120-2	ED	32W T8	(2)	69	0.57	120
B1	Advance Transformer 71A5005P	M	35W MH	(1)	55	0.5	120
C1	Advance Transformer RCN-3P32-SC	E	32W T8	(2)	65	0.54	120
D1	Advance Transformer RCN-3P32-SC	E	32W T8	(2)	65	0.54	120
E1	Advance Transformer RCF-2S18-M1-LS-QS	E	18W CFL	(1)	20	0.17	120
F1	Advance Transformer 71A5105P	M	50W MH	(1)	69	1.55	120

Figure 1.3

Light Loss Factors

Light loss factors and the assumptions used to get them are listed in figure 1.4 below. The IESNA Handbook, ninth edition, was used to determine appropriate values.

LIGHT LOSS FACTORS						
TYPE	CAT.	BF	LLD	RSDD**	LDD	TOTAL LLF
A1	II	1.03	1*	0.95	0.95	0.93
A2	II	1.03	1*	0.95	0.95	0.93
A3	II	1	1*	0.95	0.95	0.9
B1	IV	1	1*	0.95	0.89	0.85
C1	II	1.03	1*	0.95	0.95	0.93
D1	IV	1.03	1*	0.95	0.89	0.87
E1	II	1.05	1*	0.95	0.95	0.95
F1	IV	1	1*	0.78	0.82	0.64

Notes:
* Mean lumens used, so LLD is 1
** Based on 12 month cleaning cycle

Figure 1.4

Controls

Unless otherwise noted, switches are to be standard 2-pole throw switches. Exceptions include the use of Lutron dimming switches (Nova 3PS – see Appendix A-CD for cutsheet) in the case study classroom, and the use of a smartwire switching system for several lobby fixtures as well as exterior fixtures, in addition to them being controlled by regular 2-pole throw switches. See figure 1.5 below for smartwire switching system schedule.

SMARTWIRE SWITCHING SYSTEM RELAY SCHEDULE			
RELAY #	BREAKER	LOAD DESCRIPTION	CHANNEL
-01	1L1-13	LOBBY AREA LIGHTS	A
-02	1L1-15	LOBBY WALLWASHERS	A
-03	1L1-17	LOBBY FLOODLIGHTS	A
-04	1L1-18	EXTERIOR LIGHTS	B

SMARTWIRE SWITCHING SYSTEM NETWORK CLOCK SCHEDULE			
CHANNEL	GROUP	AUTOMATION SCENARIO	DATA
A	LOBBY	SCHEDULED ON/OFF	M-F 8AM-10PM SAT-SUN 8AM-6PM
B	EXTERIOR	ASTRO (DARK) ON/OFF	SWITCH OVERRIDE

Figure 1.5

Motion Detector Schedule

Motion detectors are used in all spaces to automatically shut off the lights when the spaces are unoccupied for a certain period of time. Refer to reflected ceiling plans for models used in each room. See figure 1.6 below for details, as well as Appendix A-CD for cutsheets.

MOTION DETECTOR SCHEDULE				
TYPE	MOUNTING	MODEL	VOLTAGE	COVERAGE
U1	Ceiling	The Wattstopper Ultrasonic Model UT-355-2	120V	1000sf
U2	Ceiling	The Wattstopper Ultrasonic Model UT-355-3	120V	2000sf
D	Wall	The Wattstopper Dual-tech Model DT-200	120V	2000sf

Figure 1.6

Exterior Design

Design Concept

The exterior of the building is covered by an arcade the length of the building. The arcade is a triangular shaped roof structure that can easily hide fixtures from passersby and serve to cut down on the amount of light trespass to adjacent properties. I will highlight the front door to indicate to visitors where they should enter, and I will maintain safe illuminance levels (as set forth by the IES) along the arcade walkway to ensure proper illuminance for walking as well as facial feature identification.

Design Criteria

Reflected Glare:

Glare reflected in the windows can be distracting and due to low ambient light levels at night, can have a blinding effect since the eye is not accommodated to higher light levels. For safety reasons, I will avoid glare in glazing whenever possible.

Direct Glare:

Glare coming directly from fixtures is also a problem for the same reason that reflected glare is problematic. The luminaires will be mounted 12-15ft in the air, however, so this may not be a problem.

Light Trespass:

In order to meet LEED standards, no direct light may leave the property. This means that fixtures must be chosen carefully so as not to create light trespass onto neighboring properties.

Dark Sky:

To satisfy LEED criteria full cutoff fixtures must be used to avoid light pollution into the sky. Full cutoff fixtures do not put out light above the horizontal plane, so no light can escape into the sky where it would be useless.

Illuminance Criteria:

Horizontal:
- Walkways: IES .5fc

Vertical:
- Facial Recognition: IES 3fc

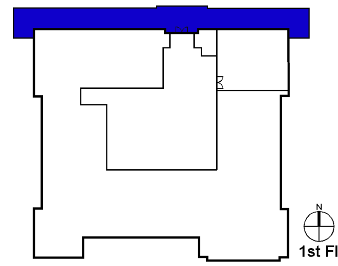
Importance:

Vertical and horizontal illuminances must be increased in order to accomplish the tasks that the space requires. Right now, the space is underlit per IES recommendations and should probably be increased both for ease of accomplishing tasks and for safety reasons.

Power Density:

ASHRAE 90.1 allowance:
30 w/lf main entrance
20 w/lf other doors
1.25 w/sf canopies

Reflected Ceiling Plan



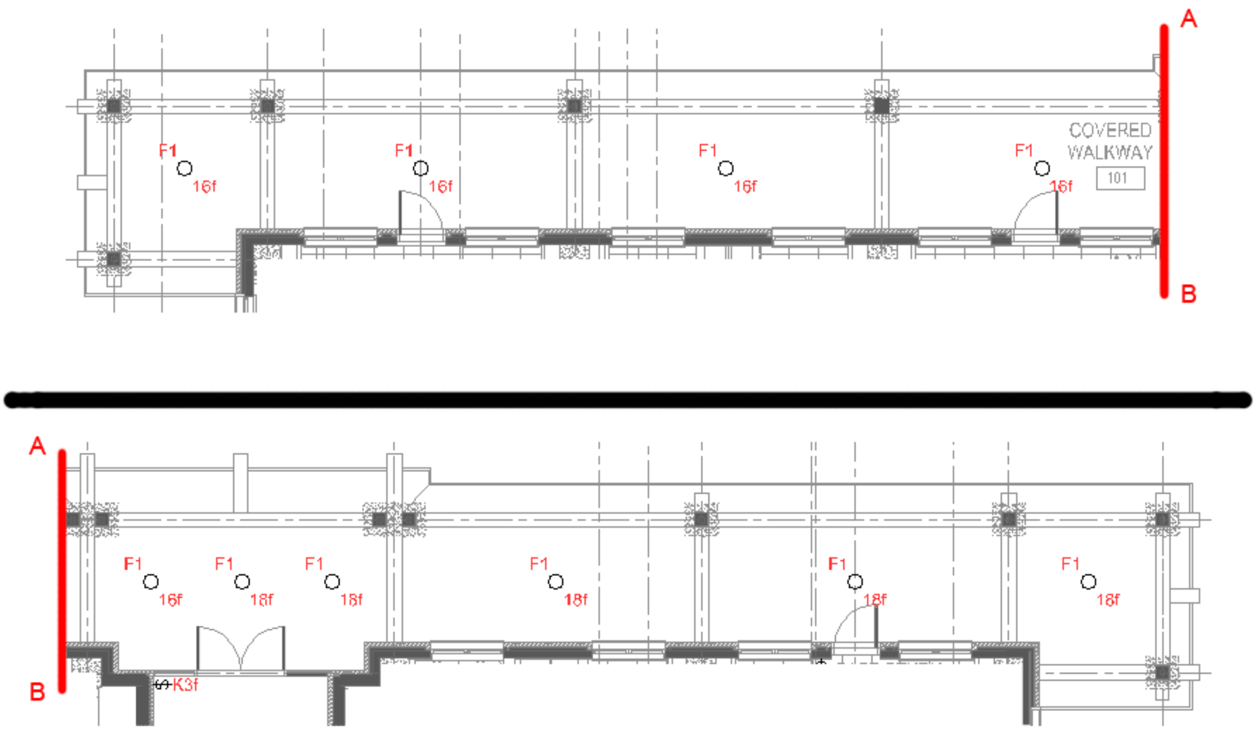


Figure 1.7 – Circuit all fixtures to PNL-1L1 (see figure 1.10)

Power Density Calculations

The exterior power densities came in below ASHRAE 90.1, and while the main door power density is above the existing power density, the others are below. Calculations are shown in figure 1.8 below.

EXTERIOR POWER DENSITY					
TYPE	**BALLASTS**	**WATTS**	**TOT. WATTS**	**AREA**	**CHECK**
F1	2	69	138	Main Door	
F1	2	69	138	Other Door	
F1	6	69	414	Canopy	
Main Door LF			6		
Other Door LF			9		
Canopy SF			1897		
Allowed Main Door W/LF			30		
Allowed Other Door W/LF			20		
Allowed Canopy W/SF			1.25		
Main Door Density			**23**		**OK**
Other Door Density			**15.33**		**OK**
Canopy Density			**0.22**		**OK**

Figure 1.8

Controls

The exterior lights are controlled by the smartwire switching system (see figure 1.5) on an astronomic time clock that turns the lights on at dusk and off at dawn. The users can override the system by using a key-controlled switch just inside the vestibule leading to the lobby. All of the lights in the space will be controlled together.

Electric Light Illuminance Calculations

AGI was used to determine values for the floor and vertical facial illuminance. Figure 1.9 below shows a calculation summary for the lobby area. For complete AGI32 output and files please see Appendix A-CD.

Horizontal Average: 3.26fc
Vertical Average: 1.86fc

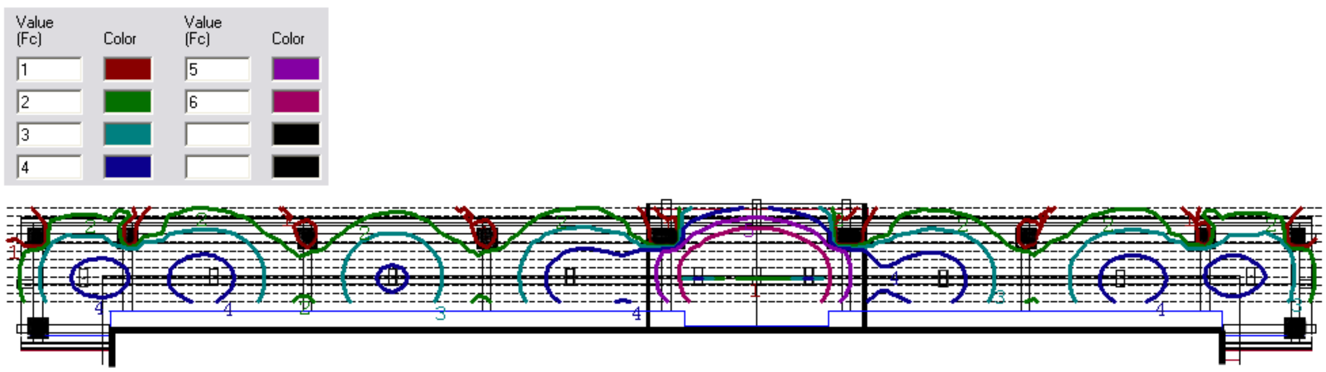


Figure 1.9

Conclusions

I achieved appropriate horizontal light levels along the exterior, and an increased light level was obtained at the entrance to set it apart from the rest of the facade. A full cutoff fixture was used to comply with dark sky ordinances. The power densities I achieved were less than that required by ASHRAE 90.1 while still maintaining acceptable horizontal light levels by IES standards. The space could further save energy by using a lower wattage source since the horizontal illuminance is higher than is needed, however the vertical illuminance, which is already slightly below recommended levels, would be decreased as well.

Lobby Design

Design Concept

As the visitors enter the building, I will draw their attention to three things in a very particular order. First, I will highlight the receptionist desk and emphasize it the most since that is where people will go if they need directions, have a meeting, or wish to contact someone in the building. Second, they will notice the highlighted walls that contain various research materials and information about the building that explain what TCES is all about and what sort of research is conducted there. Third, I will highlight the stairs in an attempt to encourage people to walk and use the stairs. I will deliberately not highlight the elevator in an attempt to draw even more attention to the stairs. Since bare concrete can be found all throughout the lobby, I have chosen industrial, galvanized metal fixtures to complement the architecture.

Design Criteria

Daylight Integration:

Due to the lightwell present in the center of the lobby, daylight integration must be considered. The well provides an opportunity to bring daylight into the space, but it may not be as efficient as it could be. Redesigning the skylight and lightwell to bring more light into the space is required.

Green Design:

Since TCES is designed to be a LEED platinum project, energy efficient design and general “green design” is of utmost importance. The power density is already low, but could be lower with the successful integration of daylight and the possible use of more efficient light sources such as linear fluorescents instead of compact fluorescents.

Fixture Appearance:

With the exposed concrete slab, there is little possibility of using recessed fixtures, so surface or pendant mounted fixtures must be used. Fixtures must be chosen that will compliment the architecture and will not detract from it. Finding a unifying theme for all fixtures chosen (such as shape, finish or style) may help the fixtures to not detract from the space, and to not distract the users.

Glare:

The main source of glare in the lobby would be from the light well. Because the skylights are so high up, it may not be a problem as far as direct glare onto the floor is concerned. Also, direct sunlight that may fall on the walls can be desirable in the lobby as it adds visual interest and a connection to the outdoors. As for electric lighting, because of the polished nature of the concrete floor fixtures will need to be carefully selected to avoid reflected glare off the floor.

Accent Lighting:

As this will be a space to display various research projects, accent lighting is essential. Because the exhibits will be changing fairly frequently, a solution that can cover a wide range of objects and exhibit types is desirable. The lightwell should not interfere too much with accent lighting as the areas to be accented are between 10 and 20 feet away from the lightwell and the ceilings are only about 11 feet high.

Highlighting:

People will need visual cues as to where to go when they enter the building. As such, the receptionist desk will be highlighted, as well as the walls and stairwell. Additional layers of light will be used to lead people to various rooms and displays, but the visual hierarchy will first be composed of the receptionist, then the walls and stairwell.

Illuminance Criteria:

Horizontal:

Reception:	IES 10fc
Gathering:	IES 10fc
Circulation:	IES 5fc

Vertical:

Reception:	IES 5fc
Gathering:	IES 5fc
Illuminated Walls:	IES 30fc

Importance and Hierarchy:

Vertical and horizontal illuminances must be maintained in order to accomplish the tasks that the space requires. Horizontal illuminances must also be met to meet local egress code requirements for light levels. Currently, everything is fairly flat, with the walls being the main accent points. The hierarchy of objects in the space will need to be looked at and the illuminances and luminances varied accordingly so that objects will be noticed in order of importance.

Power Density:

ASHRAE 90.1 allowance (school/university lobby): 1.8 W/sf

An additional 1W/sf can be added for decorative wall sconces and highlighting exhibits, but will most likely not be used.

Reflected Ceiling Plan

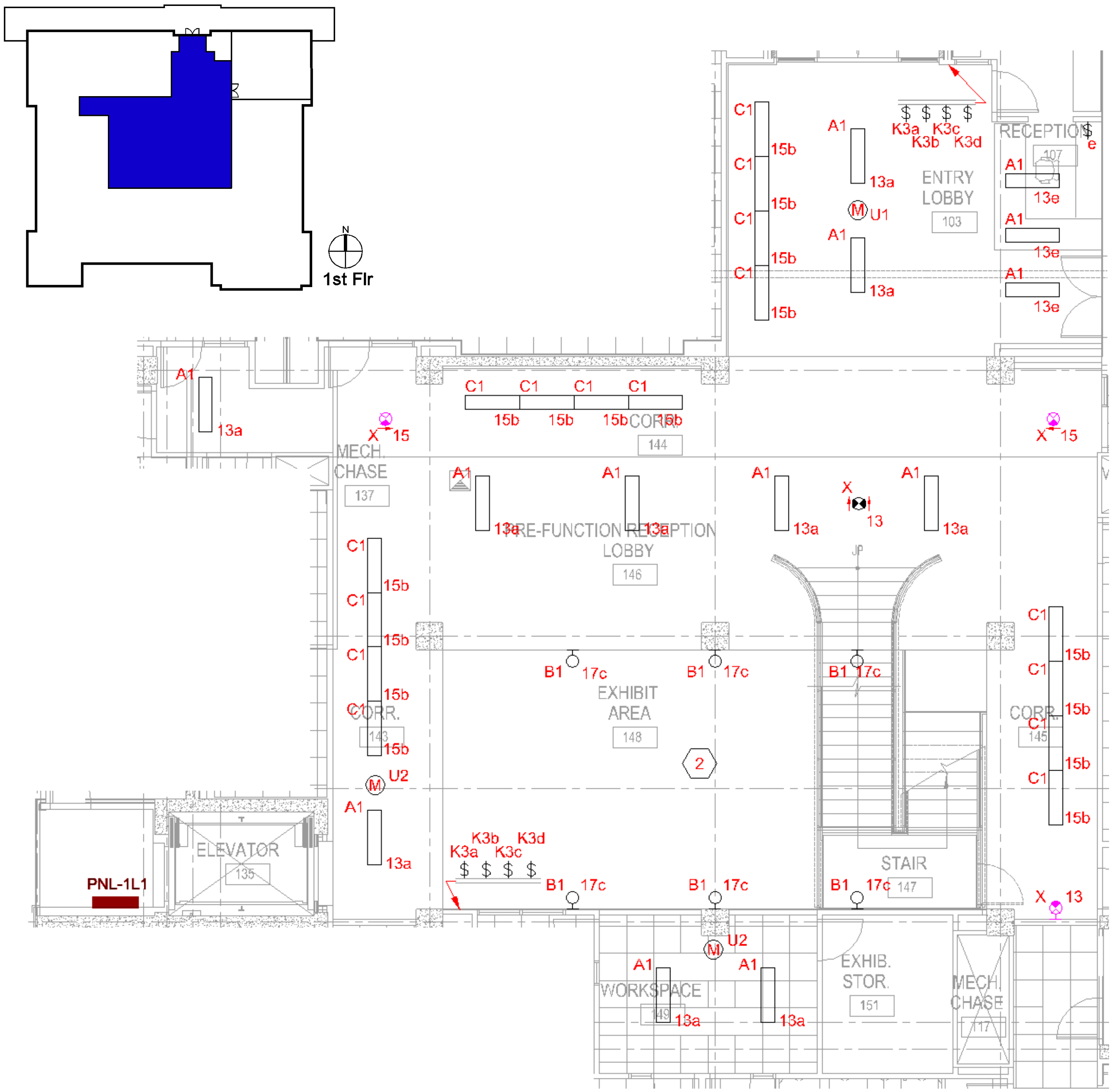


Figure 1.10 - All fixtures circuited to PNL-1L1

Power Density Calculations

The existing power density of .978 W/sf was well below the allowed 1.8W/sf, but after calculating the new power density I was able to reduce that even more while maintaining proper light levels. See figure 1.11 below for calculation details.

LOBBY POWER DENSITY				
TYPE	BALLASTS	WATTS	TOT. WATTS	CHECK
A1	13	65	845	
B1	6	55	330	
C1	8	65	520	
Total:			1695	
Area:			3070	
Allowed:			1.8	
Density:			**0.55**	**OK**

Figure 1.11

Controls

The control scheme that I decided to use for the lobby is a scheduled on/off using a smartwire switching system (see figure 1.5 for details) and a series of relays. Based on known building occupancy schedules, on Monday through Friday the lobby lights will be turned on at 8am and off at 10pm, unless overridden using the manual switching by the user. On Saturday and Sunday the lobby lights will be on from 8am to 6pm, unless overridden. The lobby will also have ultrasonic occupancy detectors which will shut off lights when the space is unoccupied in addition to 3-way switching that will control the fixtures. The area lights, wallwashers and floodlights can all be controlled separately.

Electric Light Illuminance Calculations

AGI was used to determine values for the floor, the receptionist desk, and vertical facial illuminance. Figure 1.12 below shows a calculation summary for the lobby area. For complete AGI32 output and files please see Appendix A-CD.

Floor Average:	18.43fc
Vertical Average:	13.37fc
Wall Average:	24.94fc
Desk Average:	32.5fc

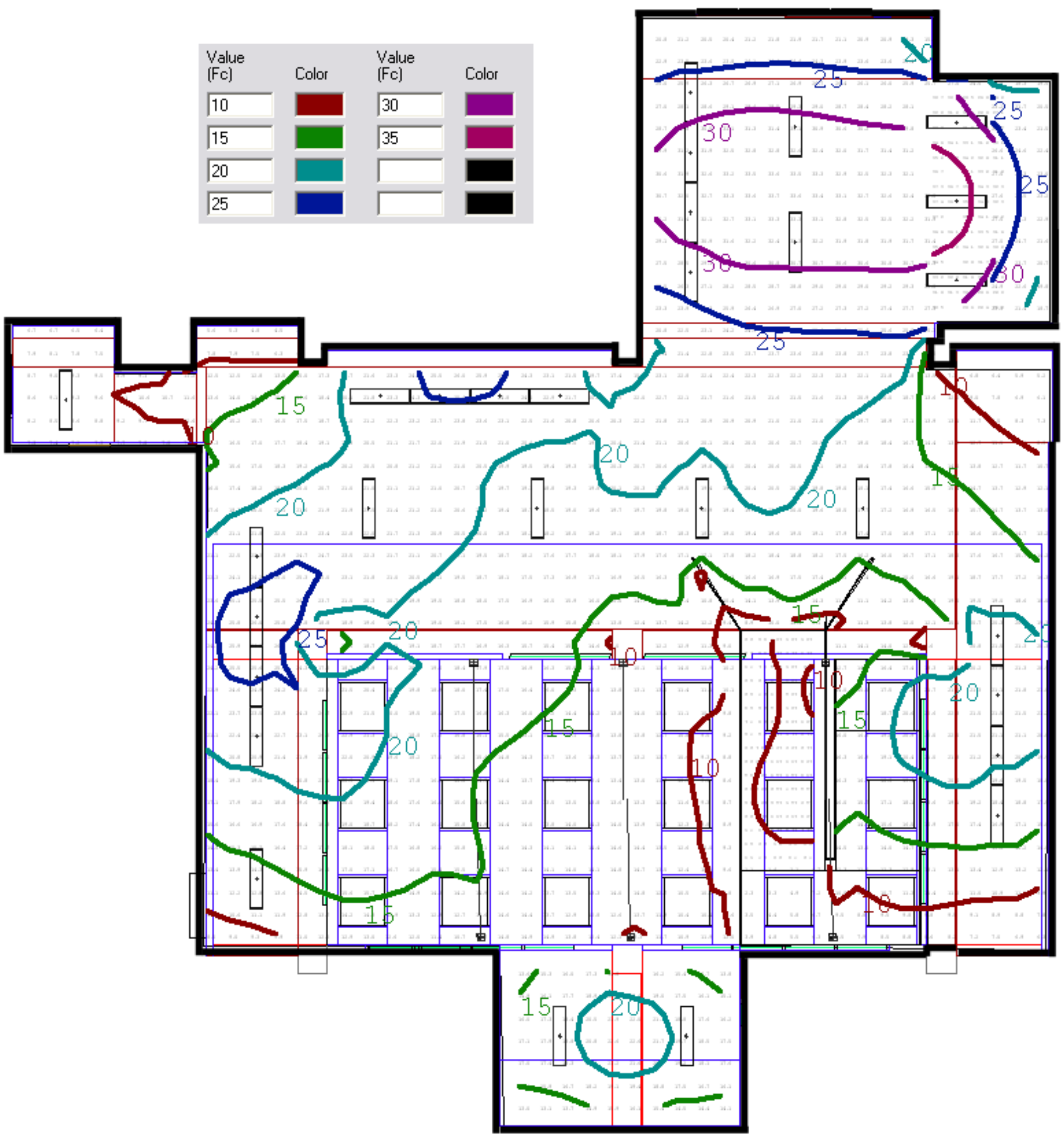


Figure 1.12

Skylight Redesign

Introduction

The atrium in TCES is a 3 story tall structure in the center of the building. At the top of the atrium are 18 skylights (3 rows of 6 skylights) that provide light to the inner circulation spaces on the upper floors and part of the lobby below. I will use TracePro to determine efficiency of the current skylight as well as to explore efficiencies of new designs. Radiance, and in particular the rtcontrib program, will then be used to determine illumination levels at the lobby floor (see “Daylight Analysis” on page 29).

Design Goals

Since the lobby floor is three stories below the skylights, the main goal of this analysis is to improve the efficiency of the skylight lightwells to achieve as much light on the floor as possible. The current solution is analyzed along with my own designs to find the most efficient design that will fit with the current structure and glazing systems.

Design Solution

The lightwells currently consist of completely vertical walls, and the skylights are tilted at a 30 degree angle toward the south. The new designs to be tested involve splayed wells and a different degree of tilt to attempt to get the efficiency up as high as possible. Once the highest efficiency is established, Radiance's rtcontrib program is used to find daylight levels for January 21st, March 21st, and May 21st since those dates can closely approximate the average for the months around the winter solstice, the equinox, and the summer solstice, respectively.

Analysis

After examining the structural system supporting the skylight well (see Appendix A-CD for detailed notes on the structural system) I determined that the skylight could be splayed by an additional 6” on each side at the bottom while maintaining the same size at the top. This width allowed me to keep the same structural supports in place while gaining extra light. Simply splaying the well was the first alternate solution I investigated. The second solution was to splay the well and tilt the skylight to 39 degrees. The optimal angle for light gathering is equal to the latitude at the location of installation, which is how I arrived at 39 degrees. Below are the TracePro irradiance maps of the exit point in the lightwell (figures 1.13 – 1.18) for the conditions and times I chose (December 21st and June 21st since those are the points where the sun is at its most extreme angles). The images shown are the rays leaving the lightwell. For a more detailed view of the rays incident on the glass and larger views of the rays exiting the wells, please see Appendix A-CD.

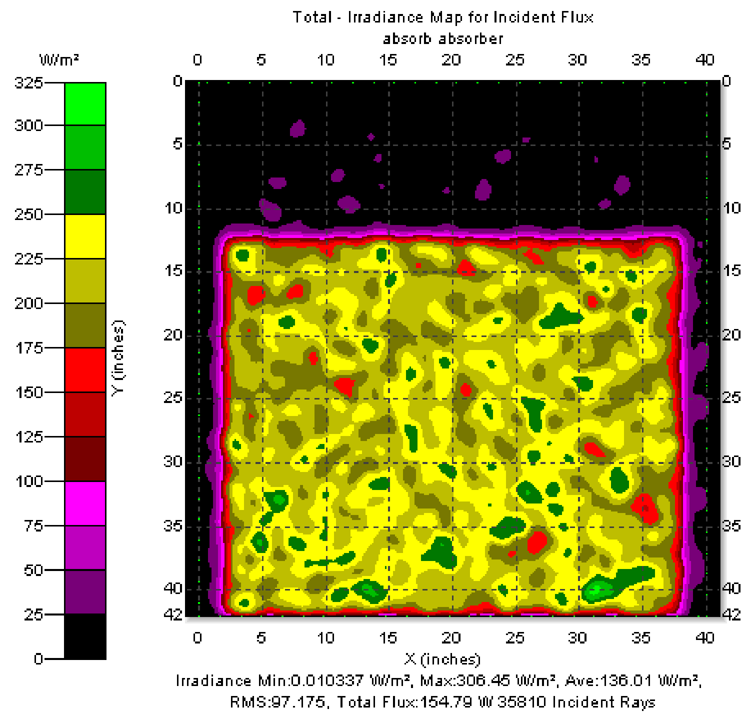


Figure 1.13 - Summer, Original Design

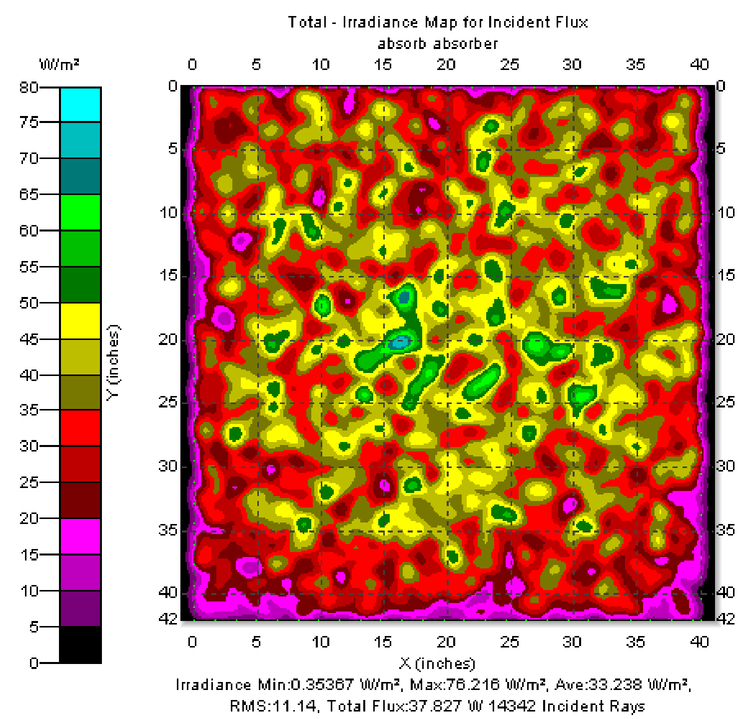


Figure 1.14 - Winter, Original Design

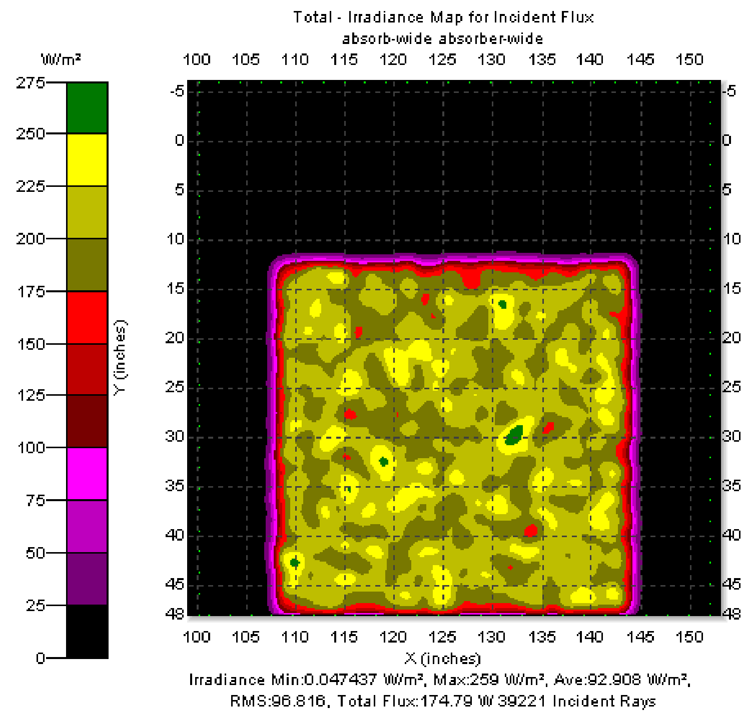


Figure 1.15 - Summer, Splayed

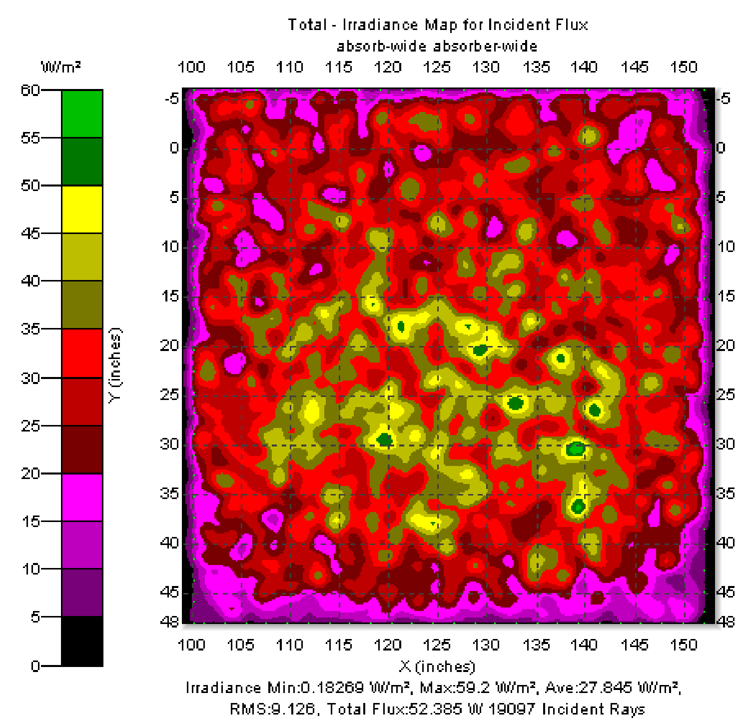


Figure 1.16 - Winter, Splayed

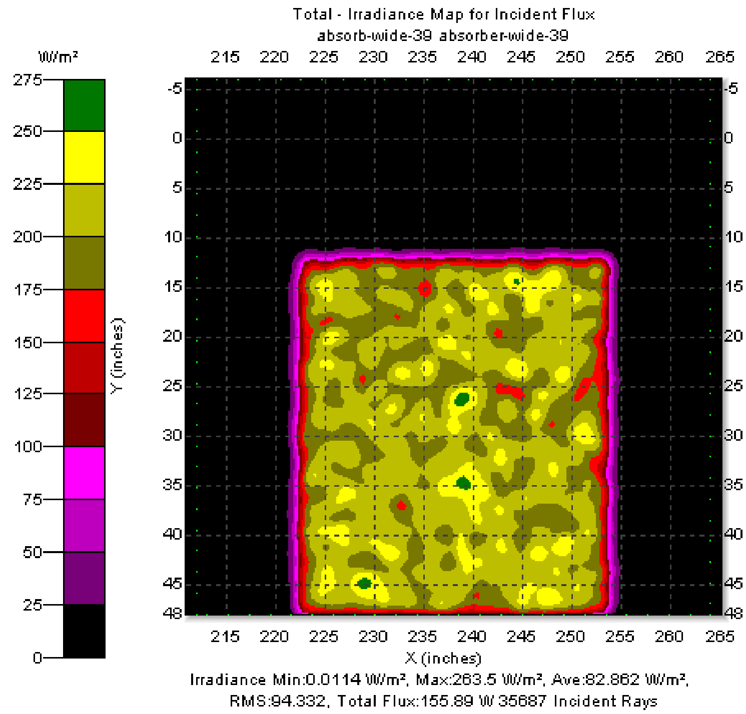


Figure 1.17 - Summer, Splayed & Tilted

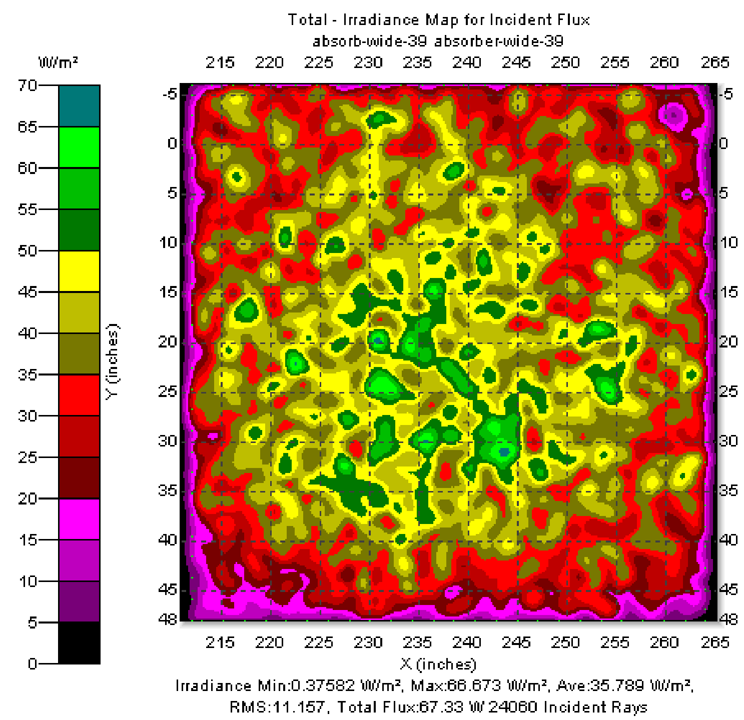


Figure 1.18 - Winter, Splayed & Tilted

Results from the TracePro runs are summarized in table 1.19. The number of rays that were incident on the glass was compared with the number of rays exiting the lightwell. The ratio of rays exiting the well over the rays incident on the glass covering the well is the efficiency. Both of the splayed options performed similarly, and we're better than the original design by quite a bit. The additional tilt placed on the skylight actually decreased the performance, especially in the summer time when the sun is the highest since the more extreme tilt may cause the higher sun angle to effectively be blocked.

Lightwell Efficiency Calculations					
Summer			***Winter***		
Original Design			**Original Design**		
	Glass	= 51,540 rays		Glass	= 68,266 rays
	Absorber	= 35,810 rays		Absorber	= 14,342 rays
	efficiency	= 70.5%		efficiency	= 14.7%
Splayed			**Splayed**		
	Glass	= 44,292 rays		Glass	= 65,648 rays
	Absorber	= 39,221 rays		Absorber	= 19,097 rays
	efficiency	= 84.2%		efficiency	= 24.2%
Splayed & 39 Deg			**Splayed & 39 Deg**		
	Glass	= 46,472 rays		Glass	= 77,376 rays
	Absorber	= 35,687 rays		Absorber	= 24,060 rays
	efficiency	= 76.4%		Efficiency	= 23.9%
					Table 1.19

Daylight Analysis

Introduction

I used Radiance's rtcontrib program to determine daylight levels from 8am to 6pm on January 21st, March 21st and May 21st. The program calculates the amount of light that different skypatches contribute to a set of points that you wish to find the illuminance at. These contributions can then be multiplied by the luminances of the skypatches (determined by the rtrace program) to determine the illuminances at each point. I then analyzed the data to determine if there is a significant amount of light available within the space. For reasons which will become clear during the analysis, I then ran several runs of AGI32 to study the daylight in the space as well.

Design Goals

The main goal of the analysis is to determine if the floodlights placed in the atrium are necessary throughout the day or if they can just be switched on via a timer. Daylight levels comparable to those achieved with just the electric lighting are desirable in order for this to be plausible. Because the fixtures used are metal halide, dimming is not a cost-effective option. Switching the fixtures on and off may be possible, but with the warm-up time and the re-strike time of metal halide the option I will shoot for is to be able to have the lights on during the day and turned off via a timer at night since it will be unoccupied.

Design Solution

Because of the difficulties involved with dimming or switching metal halide, the most likely solution is to keep the floodlights on during the day, however the daylighting study may show that this is unnecessary.

Scripts Used

See Appendix A-CD for the actual scripts listed below.

sensors.cgi – program to output a list of sensor points and an array of values to input into excel to view the final illuminances in a more usable form
gensky.sh – script to create sky definition files for clear, cloudy, and intermediate sky conditions based on criteria entered such as latitude and longitude
skylum.sh – script to calculate the skypatch luminances based on the sky definitions created by gensky.sh
rtcontrib.cgi - program to read in the contributions and multiply them by the appropriate luminance to determine the illuminance at each sensor input point

Analysis

All files mentioned herein are available for viewing in Appendix A-CD. First, the radiance scene of the lobby was set up and sensor points (sensors.inp) were established to determine the illuminance at the (x,y,z) coordinates listed. Sky definitions for each time, day, and condition desired were created using the gensky.sh script. After that, rays were traced to each of the 145 skypatches to help determine the luminance of each patch using the skylum.sh script.

```
rtrace -h -ov -ab 3 -ad 1000 -ar 3000 -as 20 -aa 0.1  sky.oct < skypatch.inp | \
rcalc -e '$1=179*($1*0.265+$2*0.67+$3*0.0648)' > sky.lum
```

I then used the rtcontrib program to calculate the contributions from each skypatch.

```
rtcontrib -I+ -b tbin -ab 6 -ad 26000 -ar 30000 -aa .1 -as 100 -lw 0.00001  \
-o rt.out -m sky_glow -f tregenza.cal overall.oct < sensors.inp
```

The output was then run through the rtcontrib.cgi program to get the illuminance values, which were then put into excel to analyze. An example graph can be seen in figure 1.20.

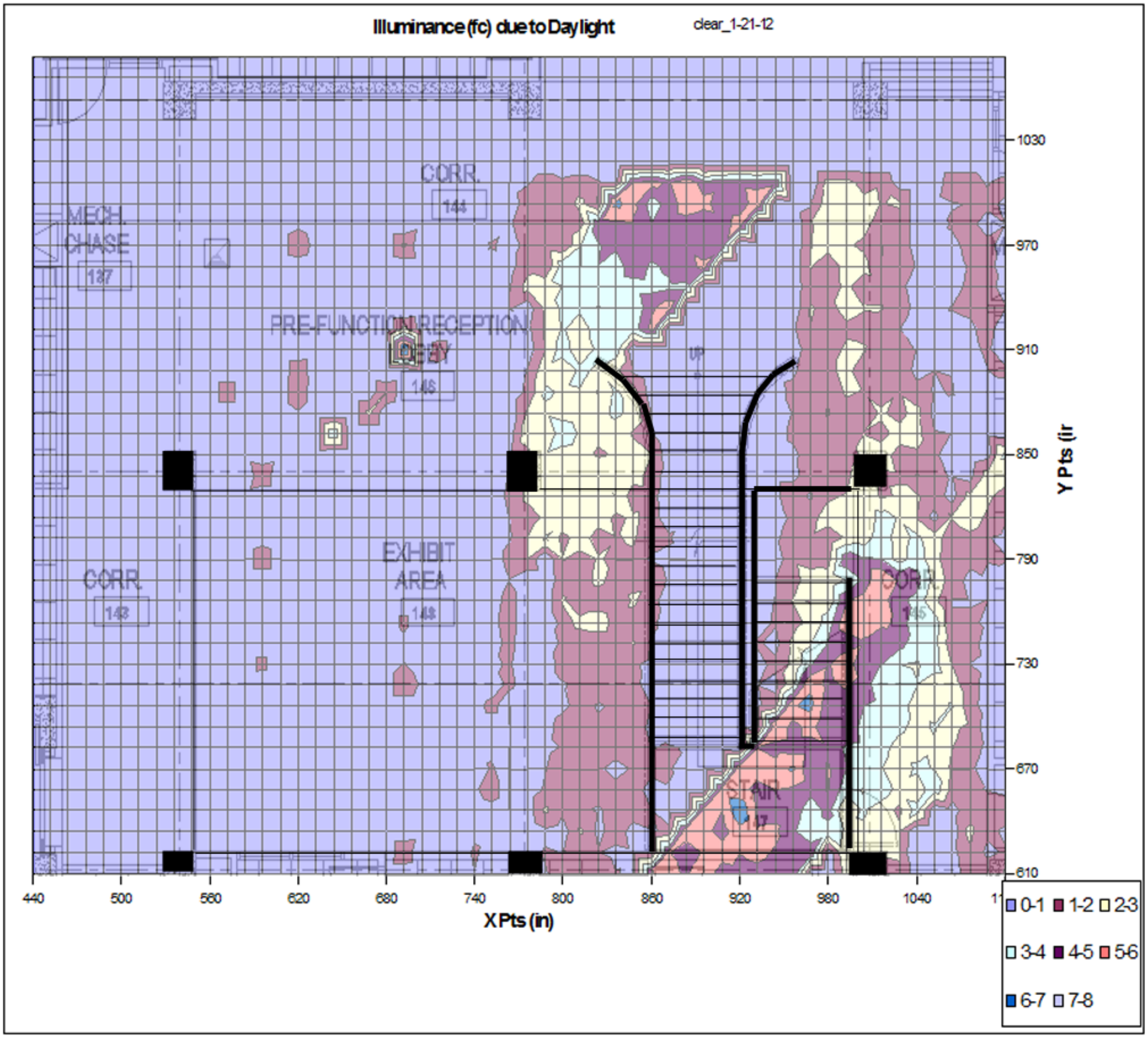


Figure 1.20 – Radiance: Jan 21st, 12pm, Clear Sky

After analyzing the results, I noticed that they did not seem to make much sense. Why is there so much light underneath the stairs on the right? Why is a good amount of light reaching far back into the space, but not is not present in the lightwell itself? After reviewing my scripts and comparing them with several other people's algorithm's used, I determined that the strange results were not due to a fault in the algorithm. Investigations into the rtcontrib output files, however, revealed that many of the skypatches were not contributing anything to quite a few of the illuminance points (the output can be found in rt.out in Appendix A-CD). Perhaps this was due to settings that were too low in the rtcontrib program.

In an effort to determine whether these results were indeed valid or not, I ran a series of clear sky conditions in AGI32 to compare the results. See figure 1.21 below.

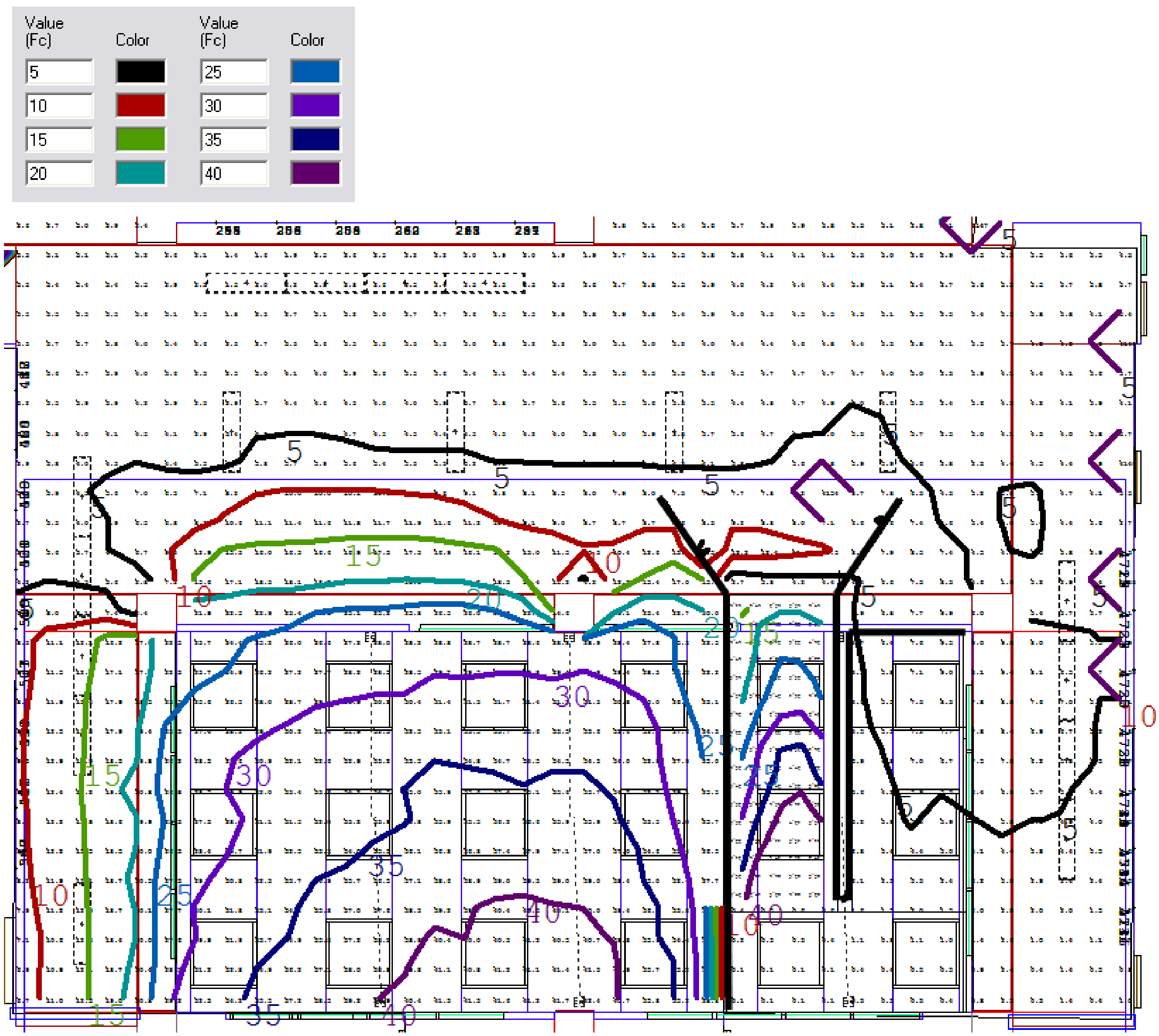


Figure 1.21 - AGI32: Jan 21st, 12pm, Clear Sky

The AGI32 calculations produced much more reasonable results, showing a good amount of light in the lightwell and less as you move into the room. For complete Radiance and AGI32 results please see Appendix A-CD.

Renderings

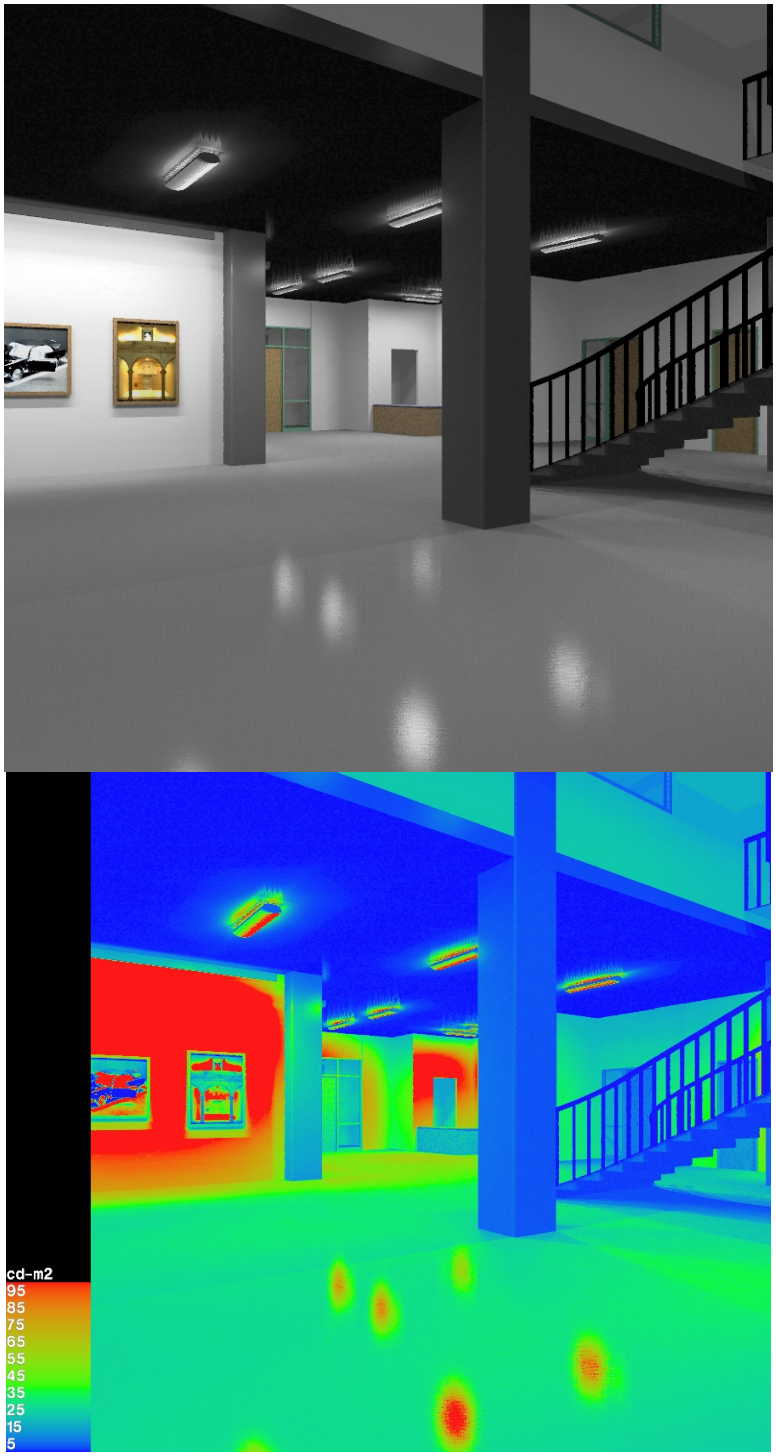


Figure 1.22

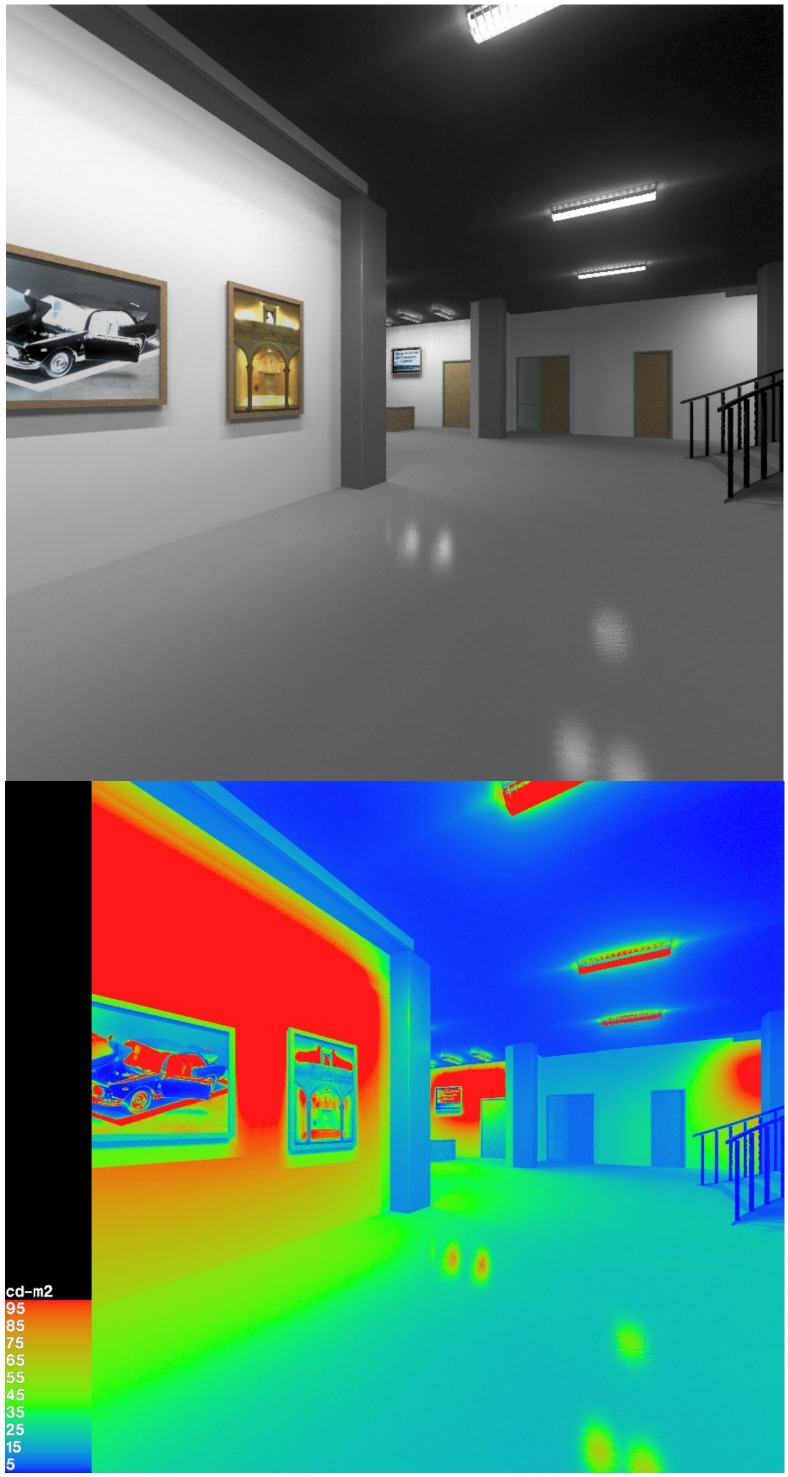


Figure 1.23

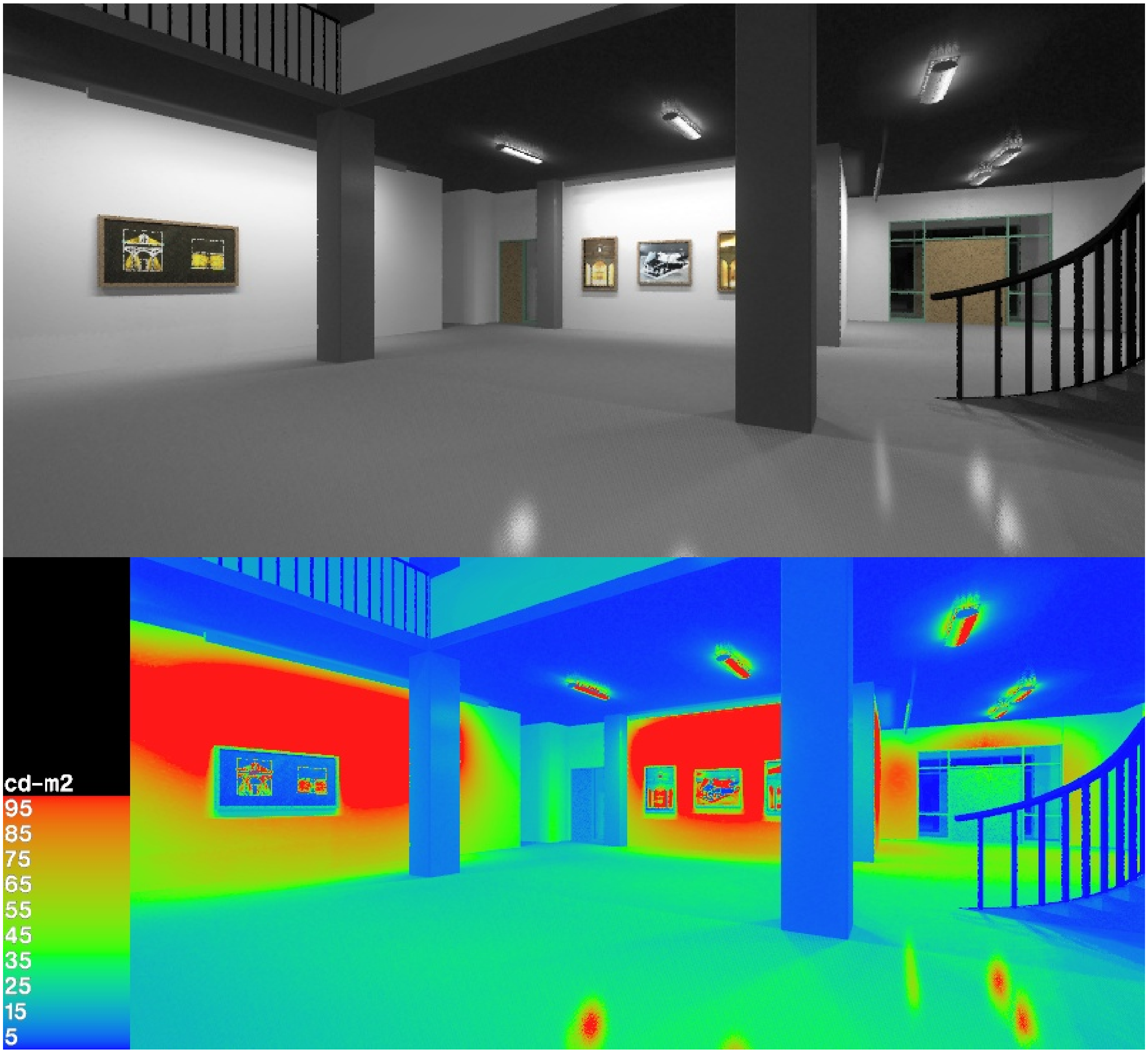


Figure 1.24

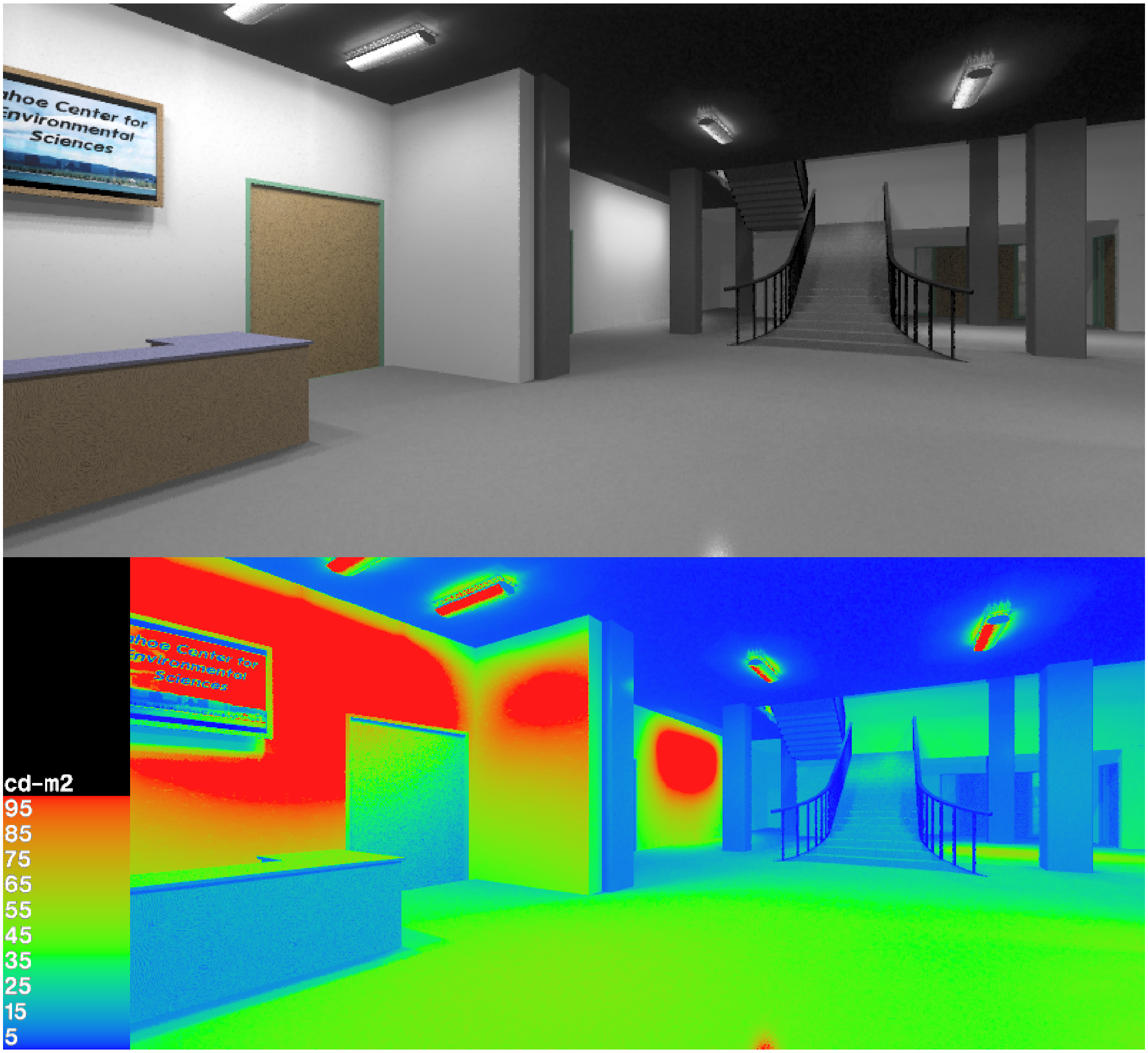


Figure 1.25

Digital copies of each rendering can be found in Appendix A-CD.

Conclusions

The lobby was designed with integration and sustainability in mind. The fixtures chosen were more efficient than those previously chosen, leading to a decreased power density that was well below ASHRAE 90.1 while at the same time maintaining light levels. A clear hierarchy of spaces and features can be seen in the renderings as your eye is drawn to the brighter areas first. Also seen in the renderings are how the fixtures compliment the architecture well. They neither draw unnecessary attention to themselves, nor do they appear out of place. The controls system offers a simple way to control the lights in the space and contains several safe-guards to ensure that the lights are not left on when the space is unoccupied, resulting in a loss of energy. The daylighting analysis led to mixed results when using Radiance and AGI. Based on the Radiance output, the best control scheme for the floodlights would be to have them on during the day, with an optional switch control to turn them off. The AGI calculations, however, show much more light in the space with a much more reasonable distribution of light. I would still recommend having the lights on all day due to the uncertainty of available light and the long warm-up and re-strike times for metal halide.

Case Study Classroom Design

Design Concept

Since the case study classroom will be used for a variety of things, including professional lectures and regular classes, an easy to use but flexible system is desired. To accomplish this, I will use simple controls to interface with the lights. The main overhead lights in the room will be dimmable for adjusting light levels for various presentations and classes. The front of the room will be used for everything from writing on the blackboard to displaying printed material to projecting digital presentations. As such, I will include wallwashers which can be controlled separately from the main lights overhead to provide light for those types of presentations that may require it.

Design Criteria

Reading Tasks:

Since a majority of the time in this room will be devoted to reading one form of material or another, priority should be placed on vertical and horizontal light levels that are appropriate for reading various types of media. Since the types of media can vary between pamphlets, papers, slides (PowerPoint and the like) and posters, the lighting system must be flexible enough to allow for all these types of materials to be easily read.

Fixture Appearance:

Since the main use of the room is to teach people and to help the flow of information from speaker to listener, the fixtures must not be distracting to the occupants. Both the speaker and the listeners must not be distracted by obnoxious looking fixtures or fixtures that may interfere with a listeners line of sight. The fixture must also complement the architecture well.

Accent Lighting:

Some forms of media such as posters may need to be accented, while other forms such as computerized slides, will not benefit from being accented. As such, a versatile and controllable accenting system should be implemented that allows the speaker to easily highlight whatever they wish while at the same time not washing out slides they may be using. The controls should be simple enough for visiting presenters who are unfamiliar with the system to understand.

Illuminance Criteria:

Horizontal:
Reading - Desk: IES 30fc

Demonstration: IES 100fc

Vertical:

Front Wall: IES 30fc

Importance:

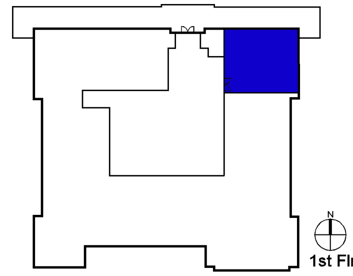
Vertical and horizontal illuminances must be maintained in order to accomplish the tasks that the space requires. While this space may be used for demonstrations that require very fine work, that will not be it's primary use, so the 100fc that the IES recommends may be a bit high for something that isn't required very often.

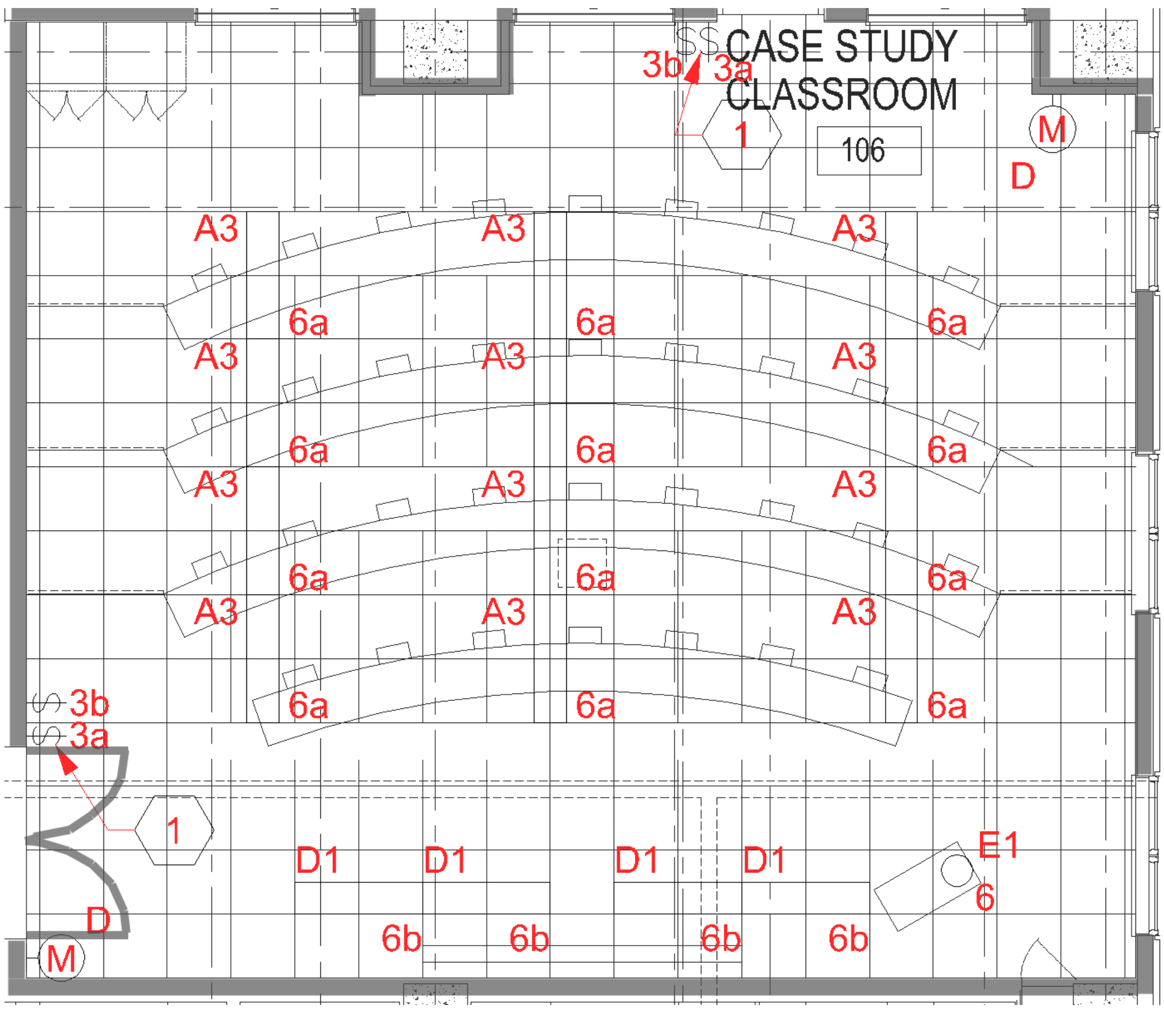
Power Density:

ASHRAE 90.1 allowance (school/university lecture hall): 1.6 W/sf

An additional 1W/sf can be added for decorative wall sconces and highlighting artwork, but will not be used.

Reflected Ceiling Plan





1 – Provide Lutron sliding dimmer switch model NOVA 3PS

Figure 1.26 – All fixtures circuited to PNL-1L1 (see lobby plan, figure 1.10)

Power Density Calculations

The existing power density of 1.3 W/sf was below the allowed 1.6 W/sf, but after designing the new system the power density is even lower, leading to even more energy savings. See figure 1.27 below for details of calculations performed.

CASE STUDY POWER DENSITY				
TYPE	BALLASTS	WATTS	TOT. WATTS	CHECK
A3	12	65	780	
D1	2	65	130	
E1	1	20	20	
Total:			930	
Area:			1015	
Allowed:			1.6	
Density:			**0.92**	**OK**

Figure 1.27

Controls

Dimming was a desired feature of the main lights in the room for when presentations are given, and since the system should be usable by anyone walking into the room, I decided to use a simple sliding dimmer switch (Lutron model Nova 3PS) as the main means of control for the semi-direct light fixtures. The wallwashers are on standard 2-pole throw switches, and the the task lamp is controlled by a switch on the fixture itself. The room also contains dual-tech motion sensors, meaning that they use ultrasonic and infrared to determine if people are in the room, leading to less false-offs.

Electric Light Illuminance Calculations

AGI was used to determine values for the desk, the wall, and podium illuminance. Figure 1.28 below shows a calculation summary for the lobby area. For complete AGI32 output and files please see Appendix A-CD.

Desk Average: 77.75fc
Wall Average: 59.68fc
Podium Average: 59.08fc

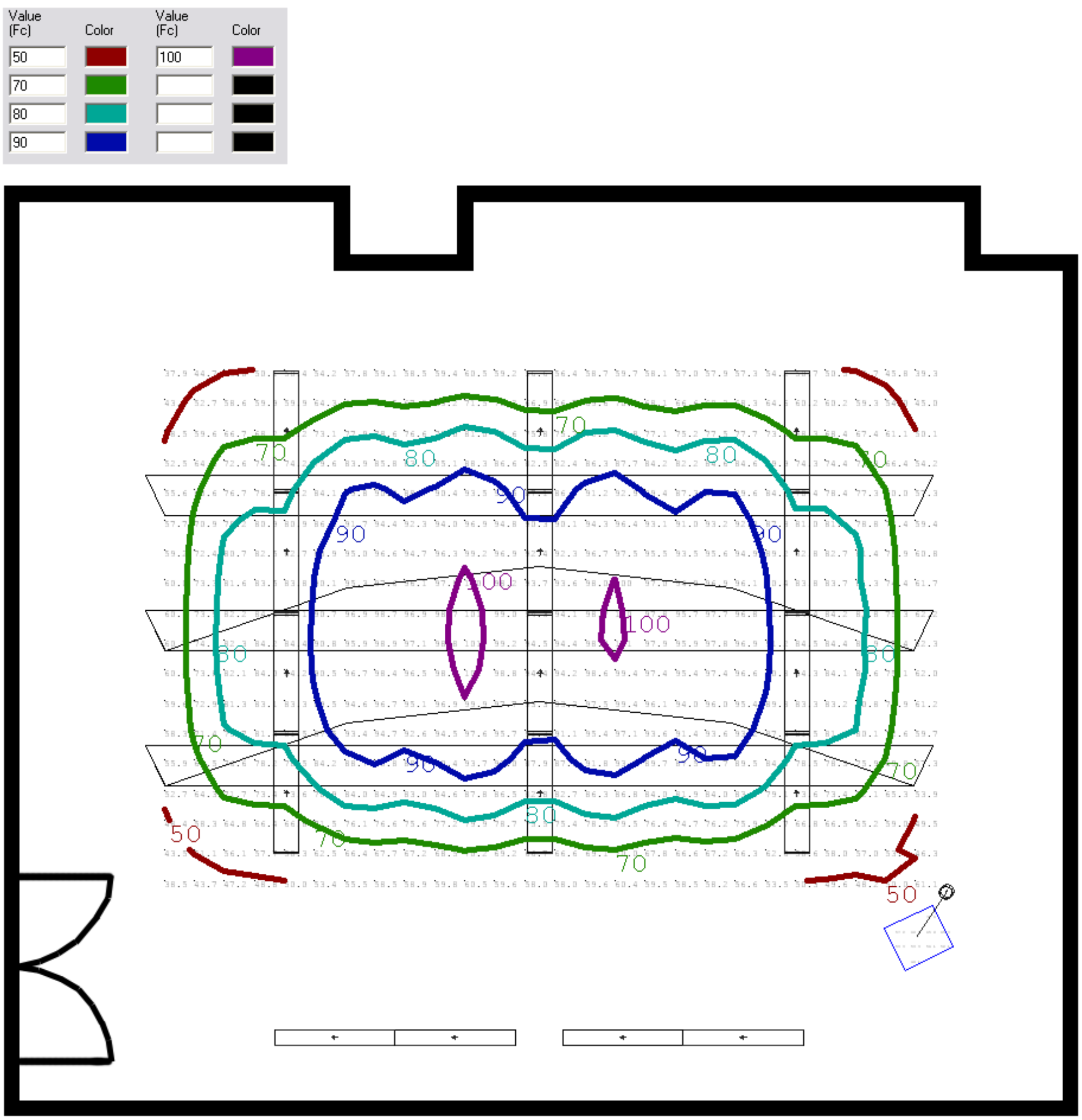


Figure 1.28

Conclusions

The flexibility and ease of use of the system achieved a nice balance, using very simple controls to gain a good amount of flexibility. The wallwashers provide a good amount of light for printed material or for writing on the blackboard, but can be switched separately from the main lights during a presentation. The relatively high amount of light on the desktops normally can be used for finer tasks but can be dimmed while taking notes or during a presentation. The ability of the speaker to control their own podium light is advantageous and easy for the speaker to use and adjust to their liking.

Chemistry Laboratory Design

Design Concept

Because of the dangerous nature of some lab experiments, I will design the space with safety in mind. The fixtures chosen will lead to a minimal amount of glare for the students. The room will not only be used for experiments, however, and will function as a regular classroom as well. As such, I will allow for multiple light levels so that a high light level can be had during fine task work such as experiments, while a lower ambient light level, suitable for taking notes, will be available as well. Simple bi-level switching will provide this control. The blackboard at the front of the class will be used for teaching at times, so wallwashers will be provided to illuminate the board.

Design Criteria

Reflected Glare:

The high level of risk involved in some chemistry experiments necessitates reducing the amount of glare and the number of glare sources in the space. Since there will be large amounts of glass in the space in the form of windows, beakers and jars, elimination of glare sources is essential.

Direct Glare:

As with reflected glare, direct glare from the fixtures cannot be tolerated as it may pose a safety hazard to those in the lab as they work on experiments.

Fixture Appearance:

Since the main use of the room is to teach people and to help the flow of information from speaker to listener, the fixtures must not be distracting to the occupants. Both the speaker and the listeners must not be distracted by obnoxious looking fixtures or fixtures that may interfere with a listeners line of sight. The fixture must also complement the architecture well.

Illuminance Criteria:

Horizontal:
- Workstation: 102fc (IES 50fc)

Vertical:
- Workstation: 47fc (IES 30c)
- South Wall: 46fc (IES 30fc)

Importance:

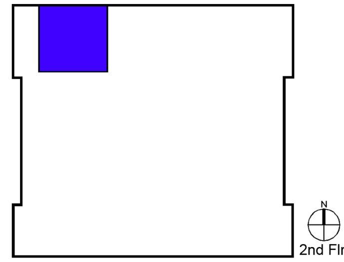
Vertical and horizontal illuminances must be maintained in order to accomplish the tasks that the space requires. Right now, the space is overlit per IES recommendations, and perhaps some over lighting is called for, but in order to bring the power density down the lighting levels may need to be dropped. The importance of the tasks, however may dictate that the power allowance not drop much below that of ASHRAE 90.1. By reducing the horizontal illuminance for ambient lighting the power densities may be reduced, and by adding task lighting for fine tasks, the 100 footcandles currently designed may be reached without greatly increasing the power density.

Power Density:

ASHRAE 90.1 allowance (school/university classroom):1.6 W/sf

An additional 1W/sf can be added for decorative wall sconces and highlighting artwork, but will not be used.

Reflected Ceiling Plan



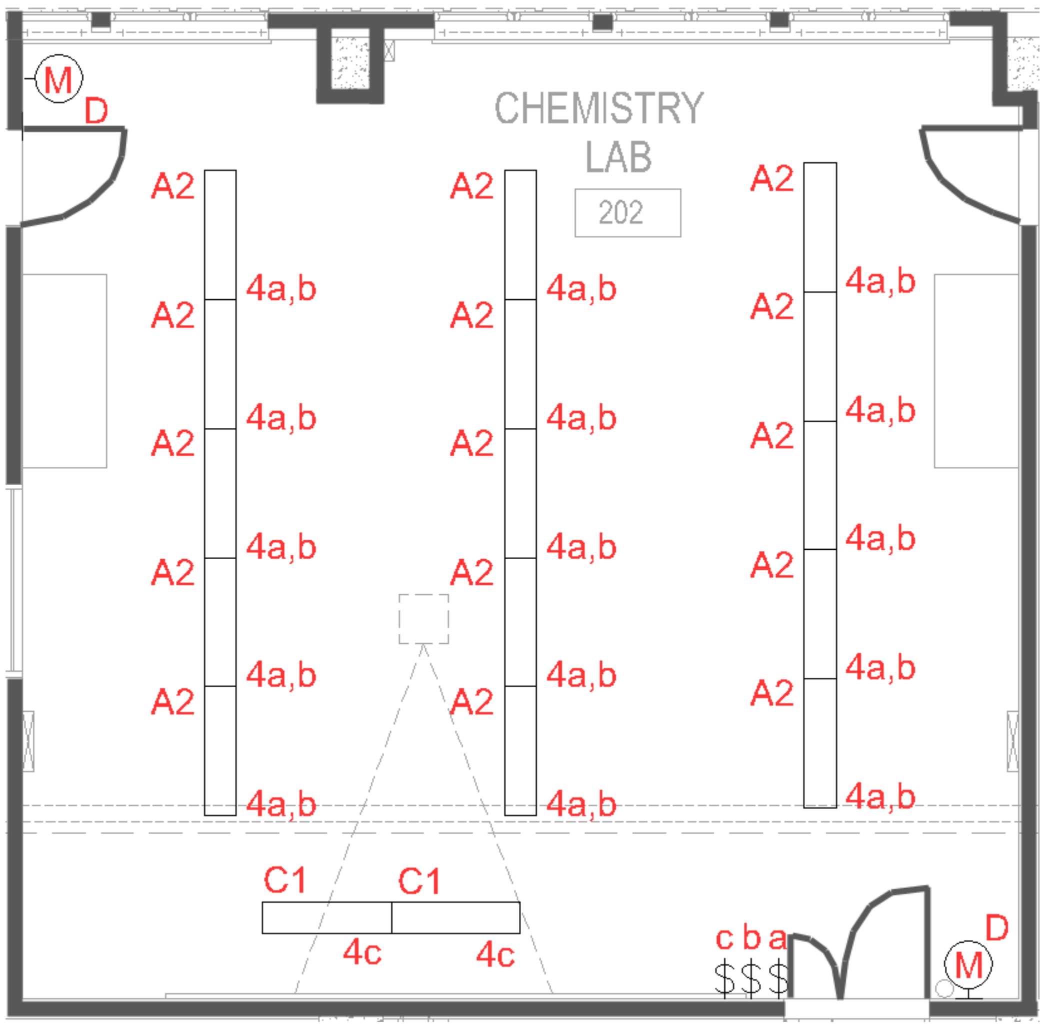


Figure 1.29

Power Density

The current power density in the chemistry lab is 1.7 W/sf, which exceeds the 1.6 W/sf allowed by ASHRAE 90.1. In the new design, the power density is significantly smaller, as is seen in figure 1.30 below.

CHEMISTRY LAB POWER DENSITY				
TYPE	**BALLASTS**	**WATTS**	**TOT. WATTS**	**CHECK**
A2	15	65	975	
C1	1	65	65	
Total:			1040	
Area:			907	
Allowed:			1.6	
Density:			**1.15**	**OK**

Figure 1.30

Controls

Simple bi-level switching will control the main lights in the room, with the wallwashers having their own dedicated switch for when they are needed. In addition, dual-tech occupancy sensors monitor the room for people and switch lights off when no one is there.

Electric Light Illuminance Calculations

AGI was used to determine values for the desk, facial and the wall illuminances. Figure 1.31 below shows a calculation summary for the lobby area. For complete AGI32 output and files please see Appendix A-CD.

Desk Average:	71.38fc
Wall Average:	72.06fc
Vertical Average:	55.69fc

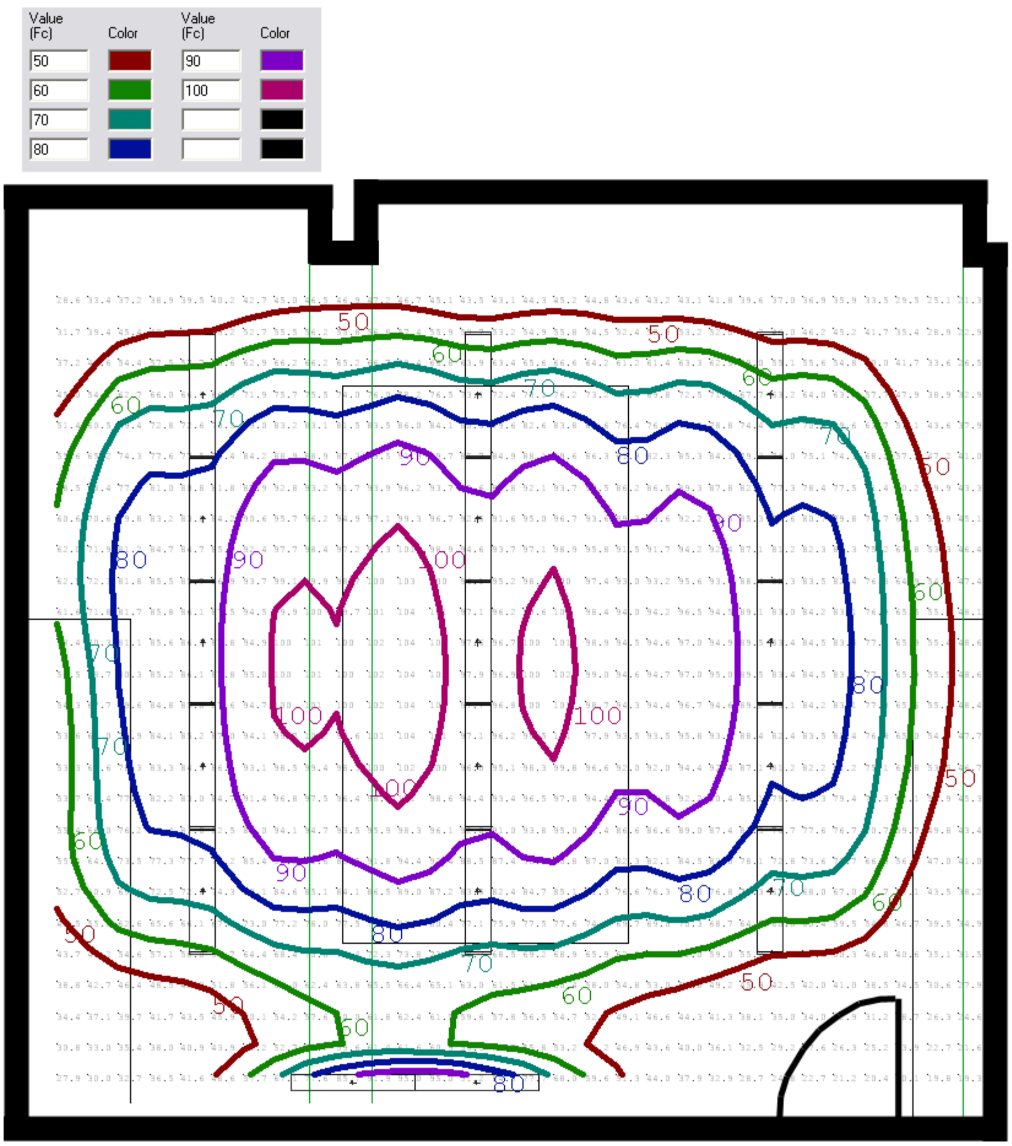


Figure 1.31

Renderings

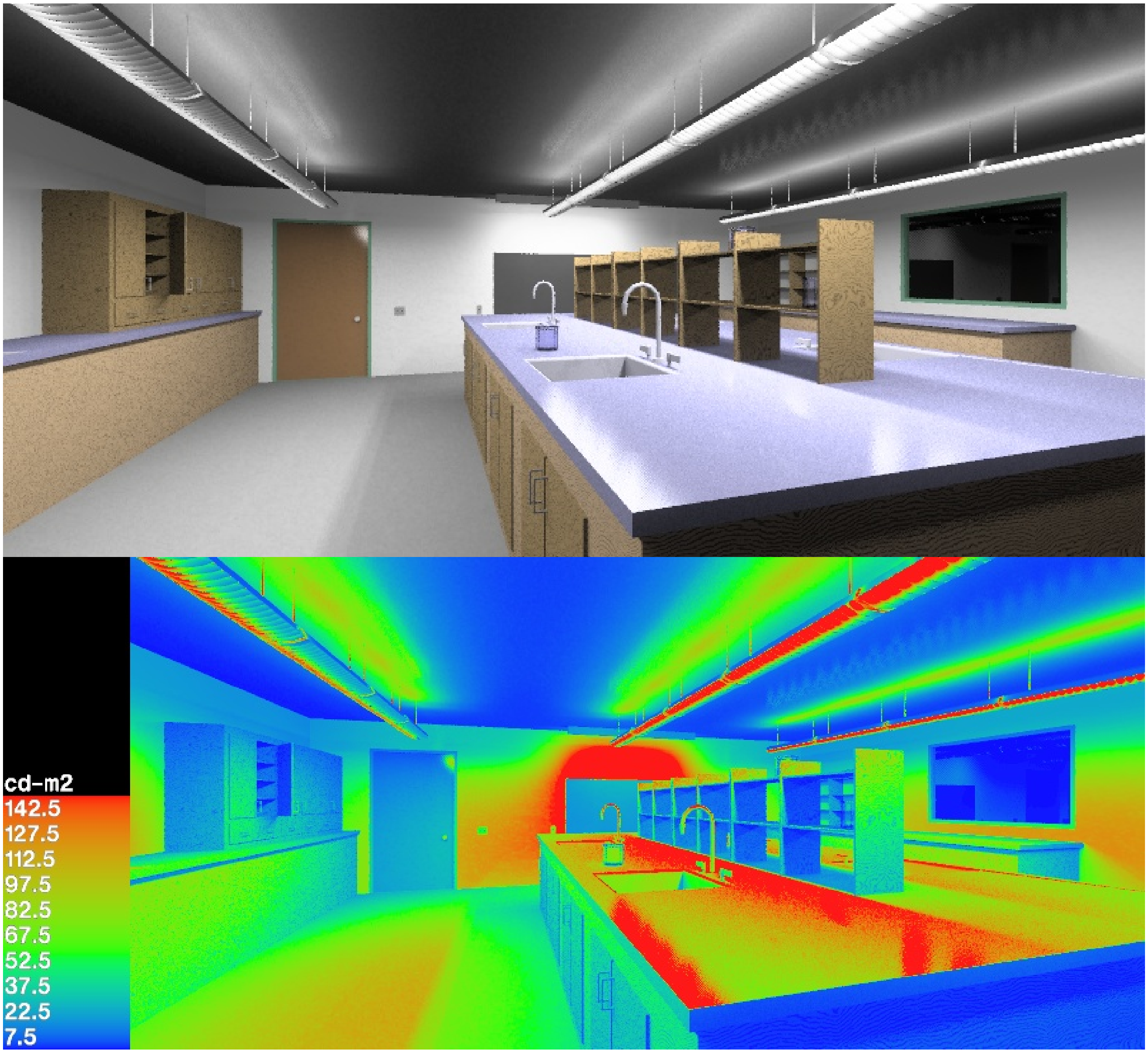


Figure1.32

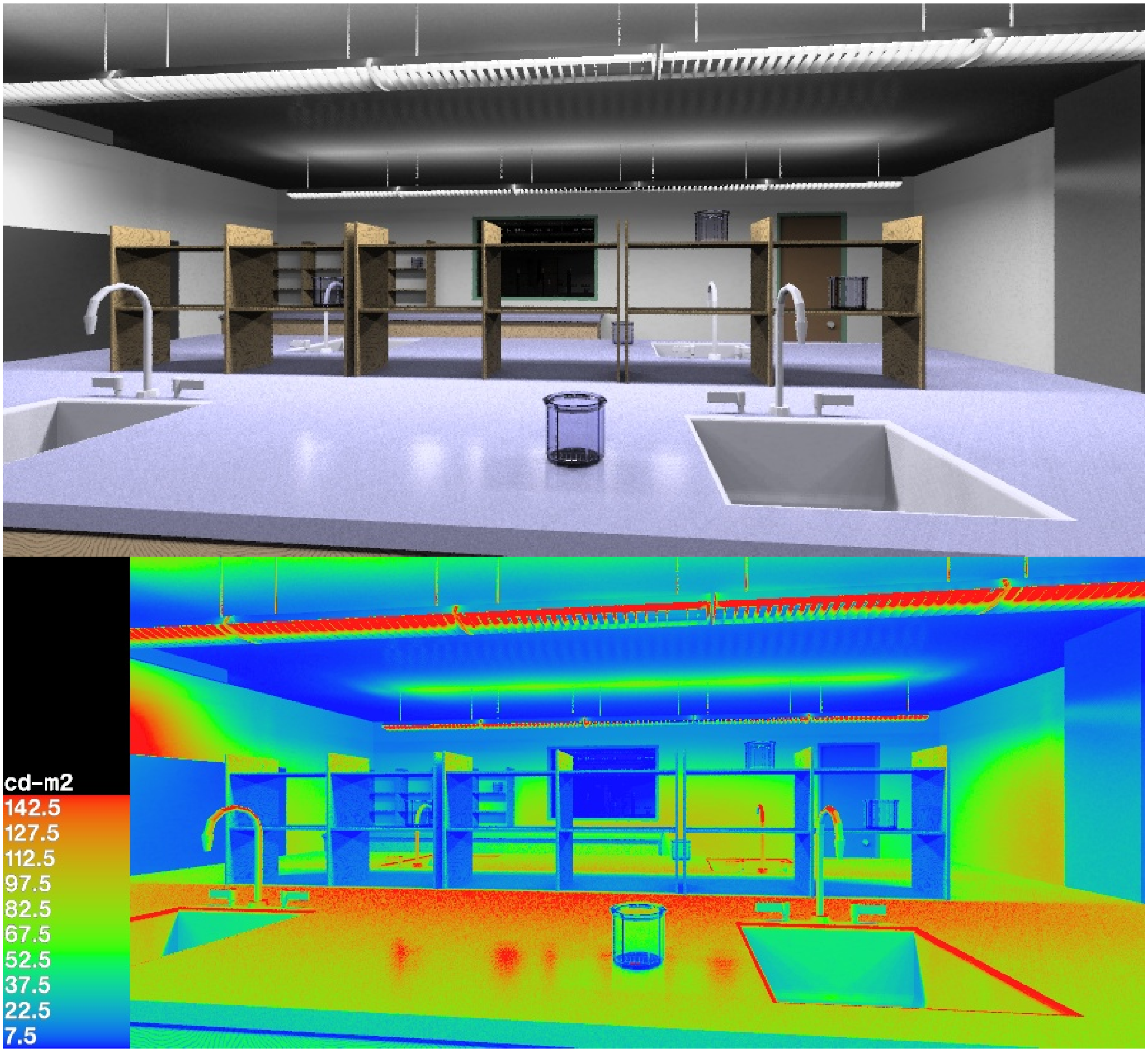


Figure 1.33

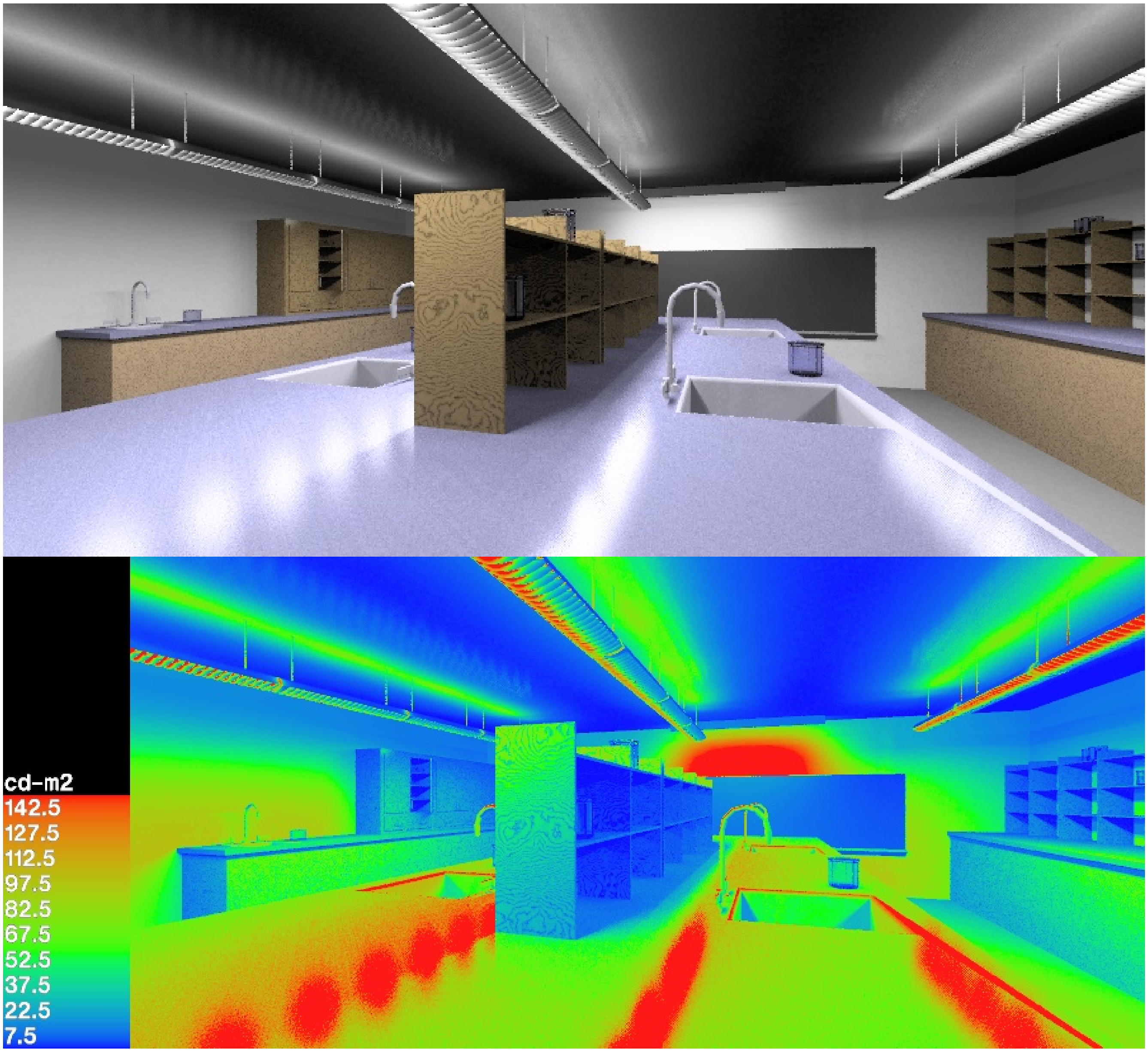


Figure 1.34

Conclusions

The chemistry lab space is a highly specialized space that required a lot of care. Too much glare in the room could be hazardous due to the caustic chemicals sometimes used. For this reason, fixtures that would not produce much glare were chosen. Also of importance is the ability to control the light level for when fine task work is necessary and for when reading and note taking are the tasks, so the bi-level switching effectively solves that problem. The multiple uses for the board at the front of the room led to the use of wallwashers in that area to light the blackboard, which accomplish the task of lighting the wall nicely.

Electrical Depth

Introduction

The nature of TCES and the desire to be as efficient and green as possible led me to investigate several unique aspects of the electrical system. In many buildings, power is generated on site using a cogeneration unit, which can produce usable power as well as waste heat in the form of steam or hot water. This is much more efficient than a traditional grid energy and natural gas boiler combination. In addition, photovoltaics are becoming more common as a means to produce energy and reduce the load drawn from the grid.

The first thing I am investigating in my electrical depth is the new cogeneration system and then I will move to the photovoltaic system. From there I will move to the new lighting loads that were added as a consequence of the new design for the lobby, chemistry lab, case study classroom, and exterior. Finally, any major electrical components that are impacted, such as new panelboards, new feeders, and new equipment will be addressed and added to the riser diagram. Costs for new equipment will be analyzed within each section to which that equipment pertains. To expand the relevance of this depth study to encompass more of the architectural engineering disciplines, I will also be investigating the impact that the cogeneration unit has on the solar hot water heating and service hot water (see “Solar Hot Water Analysis” on page 73).

Design Goals

The overall goal of the electrical study is to design a fully functional system that suits the needs of the building and complies with the 2002 NEC code. Please see individual sections for each part's individualized design goals.

Design Solution

Please see individual sections for each part's individualized design solution.

Cogeneration Design

Introduction

For proper analysis of the Cogeneration system I will use the results obtained from the eQuest energy model which can be found in Appendix B-CD. Natural gas and electricity prices have been obtained from Nevada Power Company as well as rate structure data concerning cogeneration within the grid (See Appendix B-CD for rate structure details). In addition to using eQuest to analyze the system, I will use RETScreen International's Combined Heat and Power tool to determine feasibility, cost effectiveness, and greenhouse gas savings for the new cogeneration system.

Design Goals

The overall goal of this analysis is to determine the feasibility of installing (2) 30kW microturbines. This feasibility analysis attempts to determine whether this is a viable design option based on the criteria of building electrical load, payback analysis, and greenhouse gas analysis. The cogeneration units must make sense in terms of the electrical load profile generated by eQuest, as well as have a reasonable payback of less than 10 years and produce less greenhouse gases than just using the grid alone. After the analysis is completed, conclusions will be drawn as to the viability of adding a second cogeneration unit to the existing building infrastructure.

Design Solution

Due to strict emissions requirements set forth by TRPA in addition to the desire to be as “green” as possible, microturbines are determined to be the best solution. They emit far less greenhouse gases and other pollutants than internal combustion engines or diesel engines, are much less costly than fuel cells, and are much more compact than turbines. Also, they allow for the smaller sizes required by the building electrical load. As such, (2) 30kW Capstone C-30 microturbines (cutsheet located in Appendix B-CD) are used in the design. The use of (2) 30kW turbines versus (1) 60kW will allow for one turbine to be turned off at night or during periods of low electrical load while the other is running at close to peak capacity, leading to higher efficiencies for the turbines. The use of two turbines also allows for redundancy in the event that one should fail. If this happens, you will still have a working source of power even if the grid is also down.

Analysis

Building Electrical Load

The output from eQuest (which can be viewed in it's entirety in Appendix B-CD along with the eQuest input files) indicates that the electrical load on the building throughout the year varies from about 190kW to about 300kW during operating hours. Since this is the case,

(2) 30kW cogeneration units make sense since they will be able to run at full capacity throughout the day (even when considered in conjunction with 60kW of photovoltaics. See “Photovoltaic Design” on page 58 for details). However, at night with computers in stand-by mode and only a limited number of lights and other equipment operating, the load on the building will likely not exceed 30kW. Because of this fact, I decided to go with (2) 30kW units instead of a single 60kW unit so that one can be shut down at night while the other runs at, or near, peak capacity.

Abbreviated eQuest output	
Month	**Load (kW)**
January	193.2
February	204.5
March	220.0
April	268.7
May	254.7
June	255.5
July	268.1
August	244.7
September	302.6
October	236.0
November	234.0
December	196.8

Table 2.1

Payback

Using RETScreen International's CHP analysis program, I performed a cost analysis. A 25 year life was assumed, along with less than average costs for operating and maintenance due to the fact that Capstone microturbines use a proprietary magnetic bearing system that does not require the use of oil, leading to a minimal amount of physical contact between many of the moving parts. This lack of contact mean less maintenance is required, and no oil use means no oil changes and a smaller environmental impact. The additional cost of a transformer was also figured in. Because the spark gap (the difference in price between buying electricity and buying natural gas to produce electricity) is so large, the payback (table 2.2 below) is relatively quick and after 8 years TCES would see a large amount of savings on energy. Please see the spreadsheets in Appendix B-CD for more detailed information concerning the process and figures used.

Yearly Cash Flows		
Year	**Pre-tax**	**Cumulative**
#	**$**	**$**
0	(67,534)	(67,534)

Yearly Cash Flows		
1	7,318	(60,216)
2	8,211	(52,005)
3	9,130	(42,875)
4	10,077	(32,797)
5	4,097	(28,700)
6	12,057	(16,643)
7	13,092	(3,551)
8	14,158	10,607
9	15,256	25,862
10	8,323	34,185
11	39,987	74,172
12	41,186	115,358
13	42,422	157,780
14	43,695	201,474
15	35,658	237,132
16	46,356	283,487
17	47,746	331,234
18	49,179	380,412
19	50,654	431,066
20	41,337	472,403
21	53,739	526,142
22	55,351	581,492
23	57,011	638,504
24	58,722	697,226
25	47,921	745,146

Table 2.2

Greehouse Gases

Using data obtained from Electrical Power Annual concerning the make-up of how energy is produced in the United States (percent produced using coal, percent using nuclear, etc. - see table 2.3 below), the RETScreen program was again used to determine the greenhouse gas savings benefits to using the cogeneration system versus grid energy.

Fuel type	***Fuel Mix***
Natural gas	9.3%
Nuclear	22.8%
Coal	55.7%
Hydro	4.7%
Wind	4.7%
Oil (#6)	2.8%

Fuel type	***Fuel Mix***
Tot Electricity Mix	100.0%
	Table 2.3

Based on the amount of CO_2 produced by each method of producing electricity the amount of tons of CO_2 that were saved each year was calculated to be 245 tons. This calculation does not, however, include any greenhouse gases generated during the production of the cogeneration units themselves since this is a yearly savings. A more in-depth analysis would be needed to determine the greenhouse gas payback period.

RETScreen Output		
Grid GHG emissions (tCO2)	***Cogen GHG emissions (tCO2)***	***Net annual GHG reduction (tCO2)***
1,850	1,605	245
		Table 2.4

Using my own spreadsheet (Appendix B-CD) and additional data taken from Electrical Power Annual I found that you save about 340 lbm of particulate matter, 4,000 lbm of SOx, 2,200 lbm of NOx, and 660,000 lbm of CO_2 (299.35 tons) per year by using a cogeneration unit versus relying on the grid to supply your energy.

Data Obtained Using EPA Data						
	kW	***kWh/year***	***Particulates (lbm)***	***SO2 (lbm)***	***NOx (lbm)***	***CO2 (lbm)***
Grid	60	525,600	337.93	3,964.77	2,333.53	725,487.31
Cogen	60	525,600	0.00	0.66	124.02	65,526.57
	Savings per year:		337.93	3,964.11	2,209.50	659,960.74
						Table x.5

Conclusions

The installation of (2) 30kW microturbines is highly recommended based on the information gathered. Given the 25 year project life, the 5 year payback is acceptable, and falls within the criteria set forth before the analysis began. When combined with the additional savings of 245 to 299 tons of greenhouse gases (depending on the analysis method involved) and the ability to be less reliant on the grid for energy, it is apparent that adding the additional cogeneration unit for a total capacity of 60kW is a practical and beneficial way to obtain energy.

Photovoltaic Design

Introduction

In the following photovoltaic analysis results from the eQuest energy model are used in conjunction with the RETScreen photovoltaic analysis tool to obtain data concerning the viability of increasing the photovoltaics from 30kW to 60kW. Pricing data for the photovoltaic modules as well as the inverters is obtained from the module manufacturer, Connect Energy. The photovoltaics used are thin-film, flexible units that are thermally bonded directly to the roof, so balance of systems is assumed to be minimal from an equipment and cost perspective. Pricing for purchased energy as well as rate structuring concerning photovoltaic systems is obtained from Nevada Power. RETScreen International's photovoltaic tool is used to determine feasibility, cost effectiveness, and greenhouse gas savings for the revised photovoltaic system.

Design Goals

The primary goal in this analysis is to determine the feasibility of installing a photovoltaic array of 60kW versus an array of 30kW. General criteria used in the analysis are payback time, LEED benefits, greenhouse gas benefits, and electrical load of the building. More specifically, a reasonable payback time of 10 years or less (even though preliminary analysis shows this to be nearly impossible) is hoped for. Also, the cost to benefit ratio of an additional LEED point added to the project scorecard (Credit 2.3 – Renewable Energy, 20% Contribution. See “LEED Analysis” on page 70 for more details) is investigated to discover if the additional LEED point is worth the added cost. Throughout all of this, the photovoltaic system must also make sense in terms of the electrical load profile of the building as determined by the eQuest energy model. In addition to these goals the system must be able to support a snow load of 200 lb/sf. After the analysis is performed, conclusions will be drawn as to the viability of the new photovoltaic system.

Design Solution

The decision to investigate whether 60kW of installed photovoltaics is a viable option was driven by the LEED credits concerning renewable energy production. Producing 60kW of power would mean that 20% of the building's load is generated using renewable resources (see table 2.7 below). This would result in an additional LEED point being gained. Another expected benefit of this would be a lower monthly utility bill and a reduction in greenhouse gases and pollutants. The photovoltaic modules used are model SP480 from Solar Roofing Systems, Inc. (a subsidiary of Connect Energy) and were chosen for their high snow-load rating and high efficiency. The modules are flat, flexible, and are thermally bonded directly to the roof, leading to a lower cost for the balance of systems. A problem arises, however, when deciding where to put the modules. There is enough additional roof space on the south facade to add the modules, but the orientation of the roof is not always directly south due to sloping peaks, meaning that the output of the modules would be affected. This has been accounted for in the efficiency of the modules. See illustration 2.6 for proposed location.

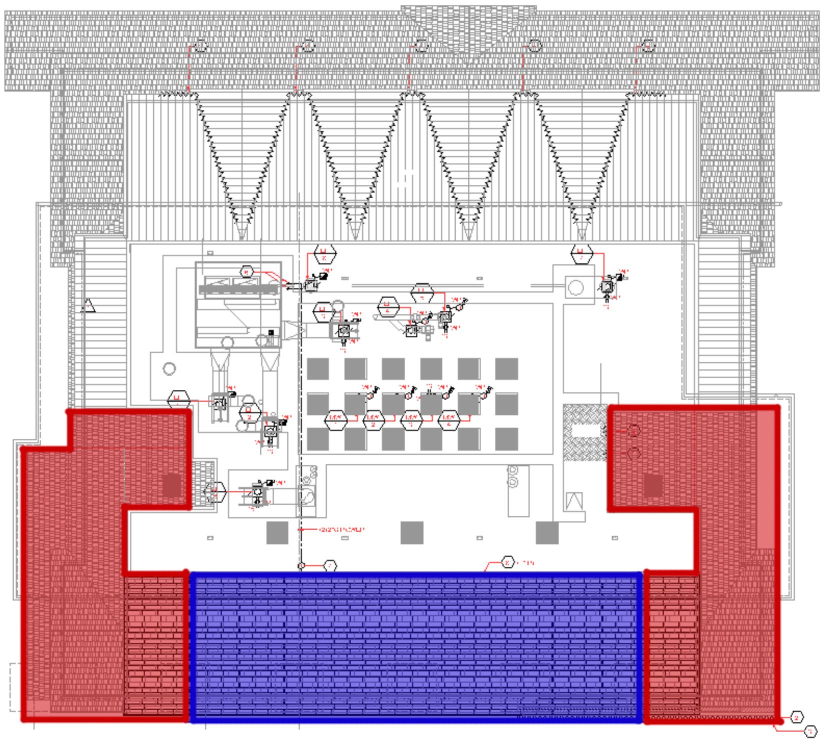


Figure 2.6 - Blue = existing, Red = Proposed addition

Analysis

Building Electrical Load

The output from eQuest (which can be viewed in it's entirety in Appendix B-CD along with the eQuest input files) indicates that the electrical load on the building throughout the year varies from about 190kW to about 300kW during operating hours. This leads to the conclusion that during the day the 60kW of photovoltaics will be used effectively (even when considered with 60kW of cogeneration).

Abbreviated eQuest output	
Month	**Load (kW)**
January	193.2
February	204.5
March	220.0
April	268.7
May	254.7

Abbreviated eQuest output	
June	255.5
July	268.1
August	244.7
September	302.6
October	236.0
November	234.0
December	196.8

Table 2.7

The daytime load is large enough to consume all the power generated by the photovoltaic system and the building electrical load at night can be taken care of by a cogeneration unit, so a battery system is judged to be unnecessary, eliminating a sizable portion of the up front cost of system. The ability to store power during periods of low power consumption during the day was weighed against the price of including such a feature, and the batteries were found to not make sense from a cost-benefit stance. An additional inverter is necessary to handle the added load, which is assumed to be replaced every 15 years, and an additional panelboard must be added to connect the photovoltaics to the building's grid.

Payback

RETScreen's photovoltaic analysis tool was used to conduct a basic cost analysis of the new system. A project life of 25 years was assumed along with a 15 year replacement period for the inverters. A price of $8,000 per installed kilowatt of photovoltaics and $500 per kilowatt for the inverter are used, both of which were confirmed by several industry sources including a representative from Connect Energy. Also considered was the fact that Nevada Power allows a rebate of up to 1/3 of the cost of the modules and installation ($2666.67 per installed kilowatt) and a 5 year accelerated tax depreciation rate. RS Means is used to determine the cost of an additional 100A, 3 phase panel. The payback period is 24 years (see table 2.8 below), which does not meet the goals of having a payback period of under 10 years. Realistically, the photovoltaics were never expected to pay for themselves within the life of the project. For a more detailed view of the calculations please see Appendix B-CD.

Yearly Cash Flows		
Year	**Yearly**	**Cumulative**
#	**$**	**$**
0	(239,936)	(239,936)
1	4,514	(235,422)
2	4,977	(230,445)
3	5,462	(224,983)
4	5,969	(219,014)
5	6,499	(212,515)
6	7,053	(205,462)

Yearly Cash Flows		
7	7,633	(197,828)
8	8,240	(189,589)
9	8,874	(180,715)
10	9,538	(171,177)
11	10,232	(160,945)
12	10,959	(149,985)
13	11,720	(138,266)
14	12,516	(125,750)
15	(30,100)	(155,850)
16	14,221	(141,629)
17	15,134	(126,495)
18	16,090	(110,405)
19	17,091	(93,314)
20	18,139	(75,176)
21	19,236	(55,940)
22	20,385	(35,555)
23	21,589	(13,966)
24	22,849	8,883
25	24,169	33,052

Table 2.8

Greenhouse Gases

Using data obtained from Electrical Power Annual concerning the make-up of how energy is produced in the United States (percent produced using coal, percent using nuclear, etc. - see table 2.9 below), the RETScreen program was again used to determine the greenhouse gas savings benefits to using the cogeneration system versus grid energy.

Fuel type	***Fuel Mix***
Natural gas	9.3%
Nuclear	22.8%
Coal	55.7%
Hydro	4.7%
Wind	4.7%
Oil (#6)	2.8%
Tot Electricity Mix	100.0%

Table 2.9

Based on the amount of CO_2 produced by each method of producing electricity the amount of tons of CO_2 that were saved each year was calculated to be about 71 tons. This calculation does not, however, include any greenhouse gases generated during the production of the modules themselves since this is a yearly savings. A more in-depth analysis would be needed to determine the greenhouse gas payback period.

RETScreen Output		
Grid GHG emissions (tCO2)	***PV GHG emissions (tCO2)***	***Net annual GHG reduction (tCO2)***
71.02	0	71.2
		Table 2.10

LEED Credit

Credit EA2.3 in the LEED 2.1 rating system states that a credit can be gained by providing 20% of the building's energy from renewable sources, of which photovoltaics falls into this category. Based on the eQuest energy model, 60kW of photovoltaics will equate to 20% of the building energy load and cost (which maxes out around 300kW, but for much of the year is below that). This would guarantee the project another LEED point, giving a slightly higher probability of gaining the LEED platinum rating that the owner desires in case some points are lost.

Snow Load

Due to a high snow load in the Lake Tahoe area (around 200lb/sf), many photovoltaic panels cannot be used as they have glass covers that will not hold up under such loads. As such, I sought out a system of completely flat, cover-less photovoltaics that would be able to withstand such loads. Both the CE-tiles and the SP480 tiles manufactured by Connect Energy would work, but in the end I went with the SP480 tiles due to their flat, flexible, and lightweight nature (they weigh only 2.5lbs per square foot). Please see the cutsheet in Appendix B-CD for more information.

Conclusions

The decision of whether or not to install 60kW of photovoltaics is not very cut and dry. The advantages of reducing greenhouse gas production, an additional LEED point and coexisting well with the building's electrical load must be weighed against the large upfront cost and long payback period of the modules. Because of the fact that the owner has put a large emphasis on gaining a LEED platinum rating, and the strong desire to be as sustainable as possible, I recommend installing the 60kW photovoltaics. The benefits, in this case, outweigh the costs.

Electrical System Design

Introduction

The main impacts on the electrical system are from the cogeneration units (see "Cogeneration System" on page 54), the photovoltaics (see "Photovoltaic System" on page 58), and from the fixtures that were chosen for the four rooms studied (see "Lighting Depth" on page 7 for details). Panels are redesigned for the added equipment, and the riser diagram is investigated to provide feeders and space for the photovoltaics and cogeneration.

Design Goals

The main goal of this analysis is to design a functional, logical system that complies with the NEC 2002 code. The addition of a panelboard to accommodate the photovoltaics will require the sizing of a new feeder, which must be large enough to handle the amperage of the system. The cogeneration system feeds directly into the main switchboard, so an appropriately sized breaker and feeder must be designed. In addition, space must be found for the new lighting equipment on the existing panelboards.

Design Solution

The existing switchboard contains space to connect the cogeneration unit in addition to space for the new photovoltaic panel. The cogeneration unit must be connected via a 30kW transformer due to the fact that it produces 480/277V instead of the needed 120/208V. The photovoltaics also require an inverter and combiner boxes to gather all the arrays together. All of the equipment is connected via appropriately sized wire based on the NEC 2002 requirements, and is protected by the necessary overcurrent devices as determined using the NEC 2002 code as well. Lighting loads were all below the original design loads, so no panels needed to be resized, however individual lighting circuits were checked to ensure they were using appropriately sized wires and the correct size breakers.

Analysis

Single Line Diagram

For size and readability reasons, a printed copy of the single line diagram is not included. Please see the electronic version on the CD in Appendix B-CD.

Feeders

Each cogeneration unit produces 30kW, which assuming a 90% power factor yields:

$$30\text{kW}/.9 = 33.33\text{kVA}$$

cogeneration side: 33.33kVA / (277V *3) = 40.11A
switchboard side: 33.33kVA / (120V *3) = 92.58A

Because the cogeneration system is intended to be run constantly, a 1.25 multiplying factor is used.

cogeneration side: 40.11A * 1.25 = 50A
switchboard side: 92.58 * 1.25 = 116A

This means that on the cogeneration side of the transformer, the feeder must be sized for 50A, and on the switchboard side it must be designed for 116A. Wire ampacity ratings and sizes are obtained from table 310.16 of the NEC 2002 code.

50A – cogeneration side: (3) #6 + (1) #8 G.
116A – switchboard side: (4) 1/0 + (1) #6 G.

In addition, a 125A circuit breaker is needed when connecting the feeder to the switchboard.

Each photovoltaic panel will also be connected to 30kW at 208/120V and a 90% power factor is again assumed. This yields:

30kW/.9 = 33.33kVA
33.33kVA / (120V * 3) = 92.58A

Because the photovoltaic system is intended to be run constantly, a 1.25 multiplying factor is used.

92.58A * 1.25 = 116A

Thus, the feeder for the photovoltaic panel must be sized for 116A, as must the circuit breaker for the panelboard itself. Using wire ampacity ratings and sizes obtained from table 310.16 of the NEC 2002 code.

Panels PV1 and PV2: (4) 1/0 + (1) #6 G.

In addition, a 125A circuit breaker is needed to protect the panels.

Branch Circuits

Lighting

It is desirable to put all lighting on #12 AWG wire and protect them with 20A circuit breakers since this is the most common design practice, which will likely lead to cheaper costs.

The gauge of wire chosen must be derated to 16A, and it is hoped that 12A will not be exceeded on each circuit for expansion and addition reasons. The summary of each circuit can be found in table 2.11 below, and the panelboards can be found in figures 2.12 and 2.13. For the physical locations of lighting panelboards, please see the section entitled "Lighting Depth" on page 7.

Panel	***Ckt #***	***Description***	***Amps***	***Wire Size/Breaker***
1L1	13	Lobby – Area Lights	5.94A	(2) #12 – 20A
1L1	15	Lobby - Wallwashers	4.32A	(2) #12 – 20A
1L1	17	Lobby - Floodlights	3A	(2) #12 – 20A
1L1	6	Case Study Classroom	9.17A	(2) #12 – 20A
1L1	16	Exterior	7.75A	(2) #12 – 20A
1L1	18	Exterior	7.75A	(2) #12 – 20A
2L1	4	Chemistry Lab	8.64A	(2) #12 – 20A

Table 2.11

PANELBOARD "1L1"

VOLTAGE:	208/120	MLO	:MAIN C/B
PHASE:	3	100A	:BUSSING
WIRE:	4	RECESSED	:MOUNTING

LOAD 129, 136	A	B	C	BKR	ckt	abc	ckt	BKR	A	B	C	LOAD
LTG RM 124, 125, 132, 131, 129, 136	1.4			20A-1P	1		2	20A-1P	1.5			LGT RM 141
LTG RM 121, 119, 123		0.6		20A-1P	3		4	20A-1P		1.2		LTG RM 139
LTG RM 118, 151, 152			0.8	20A-1P	5		6	20A-1P			1.1	CASE STUDY CLASSROOM
LTG RM 115, 116	0.8			20A-1P	7		8	20A-1P	0.8			LTG RM 108
LTG RM 111, 112		0.8		20A-1P	9		10	20A-1P		1.0		BASEMENT LTG
STAIRWELL LIGHTS			1.8	20A-1P	11		12	20A-1P			0.9	BASEMENT LTG
LOBBY - AREA LIGHTS	0.4			20A-1P	13		14	20A-1P	0.5			BASEMENT LTG
LOBBY - WALL WASHERS		0.7		20A-1P	15		16	20A-1P		0.9		EXTERIOR
LOBBY - FLOOD LIGHTS			0.6	20A-1P	17		18	20A-1P			0.9	EXTERIOR
LOBBY LTG - CORRIDOR	0.2			20A-1P	19		20	20A-1P	1.0			GREEN HOUSE
LOBBY LTG - CORRIDOR		0.3		20A-1P	21		22	20A-1P		0.2		LTG RM 126
			0.0	20A-1P	23		24	20A-1P			0.4	GREEN HOUSE RECEPTACLE
LOBBY LTG - WORK SPACE	0.2			20A-1P	25		26					
VESTIBULE LTG		0.4		20A-1P	27		28					
					29		30					
					31		32					
					33		34					
					35		36					
SPARE	0.0			20A-1P	37		38	20A-1P	0.0			SPARE
SPARE		0.0		20A-1P	39		40	20A-1P		0.0		SPARE
SPARE			0.0	20A-1P	41		42	20A-1P			0.0	SPARE
	3.0	2.8	3.2						3.8	3.3	3.3	

KVA PHASE A:	6.8	1.00	:DEMAND FACTOR
KVA PHASE B:	6.2	19.4	:DEMAND KVA
KVA PHASE C:	6.5	54.0	:TOTAL LOAD AMPERES
TOTAL KVA:	19.4		

Figure 2.12

VOLTAGE:	208/120	PANELBOARD "2L1"	MLO	:MAIN C/B
PHASE:	3		100A	:BUSSING
WIRE:	4		RECESSED	:MOUNTING

LOAD 224, 225	A	B	C	BKR	ckt	abc	ckt	BKR	A	B	C	LOAD
LTG RM 216, 217, 222, 225	0.3			20A-1P	1		2	20A-1P	0.7			LTG RM 201, 239, 237
LTG RM 226, 228		0.8		20A-1P	3		4	20A-1P		1.0		CHEMISTRY LAB
LTG RM 226, 219			0.7	20A-1P	5		6	20A-1P			1.2	LTG RM 203, 246, 244
LTG RM 218, 219	0.8			20A-1P	7		8	20A-1P	1.5			LTG RM 204
LTG RM 215		1.0		20A-1P	9		10	20A-1P		1.5		LTG RM 205
LTG RM 208, 209, 211, 214			0.6	20A-1P	11		12	20A-1P			1.2	LTG RM 206
					13		14					
					15		16					
					17		18					
					19		20					
					21		22					
					23		24					
					25		26					
					27		28					
					29		30					
					31		32					
					33		34					
					35		36					
SPARE	0.0			20A-1P	37		38	20A-1P	0.0			SPARE
SPARE		0.0		20A-1P	39		40	20A-1P		0.0		SPARE
SPARE			0.0	20A-1P	41		42	20A-1P			0.0	SPARE
	1.1	1.8	1.3						2.2	2.5	2.4	

KVA PHASE A:	3.3	1.00	:DEMAND FACTOR
KVA PHASE B:	4.3	11.3	:DEMAND KVA
KVA PHASE C:	3.7	31.4	:TOTAL LOAD AMPERES
TOTAL KVA:	11.3		

Figure 2.13

Photovoltaics

As with the lighting, is would be desirable to put the loads from the photovoltaics on #12 AWG wire and protect them with 20A circuit breakers. Since expansion of the photovoltaic system is not very likely, leaving room on each circuit for expansion is not as high a priority as it was for the lighting. Since all of the circuits on the photovoltaic panels are the same, only one circuit was analyzed (see table 2.14 below). For the complete panelboard layouts, see figures 2.15 and 2.16 below, and for locations of panelboards and inverters see figure 2.17.

Panel	***Ckt #***	***Description***	***Amps***	***Wire Size/Breaker***
PV1	1	PV Modules	14.2A	(2) #12 – 20A

Table 2.14

VOLTAGE:	208/120	PANELBOARD "PV1"		125A/3P	:MAIN C/B
PHASE:	3			125A	:BUSSING
WIRE:	4			SURFACE	:MOUNTING

LOAD	A	B	C	BKR	ckt	abc	ckt	BKR	A	B	C	LOAD
PV TILES	1.7			20A-2P	1		2	20A-2P	1.7			PV TILES
		1.7			3		4			1.7		
PV TILES			1.7	20A-2P	5		6	20A-2P			1.7	PV TILES
	1.7				7		8		1.7			
PV TILES		1.7		20A-2P	9		10	20A-2P		1.7		PV TILES
			1.7		11		12				1.7	
PV TILES	1.7			20A-2P	13		14					
		1.7			15		16					
PV TILES			1.7	20A-2P	17		18					
	1.7				19		20					
PV TILES		1.7		20A-2P	21		22					
			1.7		23		24					
					25		26					
					27		28					
					29		30					
	6.8	6.8	6.8						3.4	3.4	3.4	

KVA PHASE A:	10.2	1.00	:DEMAND FACTOR
KVA PHASE B:	10.2	30.6	:DEMAND KVA
KVA PHASE C:	10.2	85.0	:TOTAL LOAD AMPERES
TOTAL KVA:	30.6		

Figure 2.15

VOLTAGE:	208/120	PANELBOARD "PV2"		125A/3P	:MAIN C/B
PHASE:	3			125A	:BUSSING
WIRE:	4			SURFACE	:MOUNTING

LOAD	A	B	C	BKR	ckt	abc	ckt	BKR	A	B	C	LOAD
PV TILES	1.7			20A-2P	1		2	20A-2P	1.7			PV TILES
		1.7			3		4			1.7		
PV TILES			1.7	20A-2P	5		6	20A-2P			1.7	PV TILES
	1.7				7		8		1.7			
PV TILES		1.7		20A-2P	9		10	20A-2P		1.7		PV TILES
			1.7		11		12				1.7	
PV TILES	1.7			20A-2P	13		14					
		1.7			15		16					
PV TILES			1.7	20A-2P	17		18					
	1.7				19		20					
PV TILES		1.7		20A-2P	21		22					
			1.7		23		24					
					25		26					
					27		28					
					29		30					
	6.8	6.8	6.8						3.4	3.4	3.4	

KVA PHASE A:	10.2	1.00	:DEMAND FACTOR
KVA PHASE B:	10.2	30.6	:DEMAND KVA
KVA PHASE C:	10.2	85.0	:TOTAL LOAD AMPERES
TOTAL KVA:	30.6		

Figure 2.16

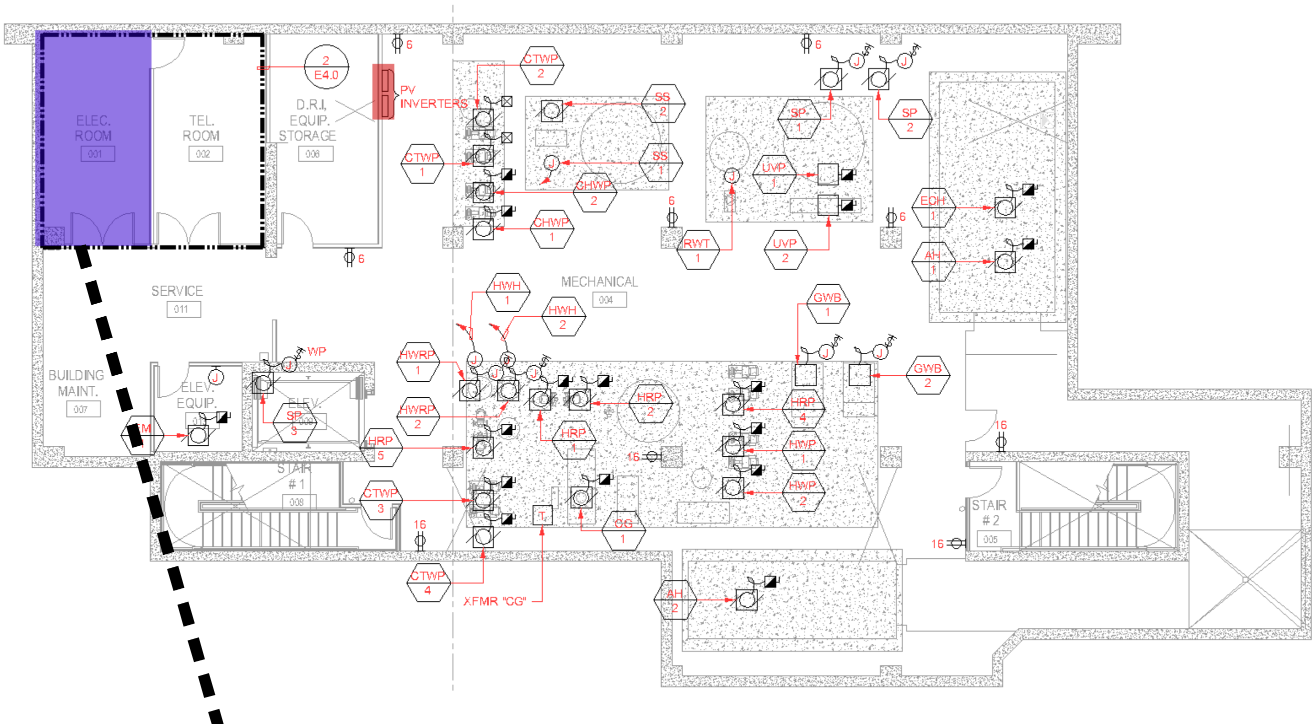
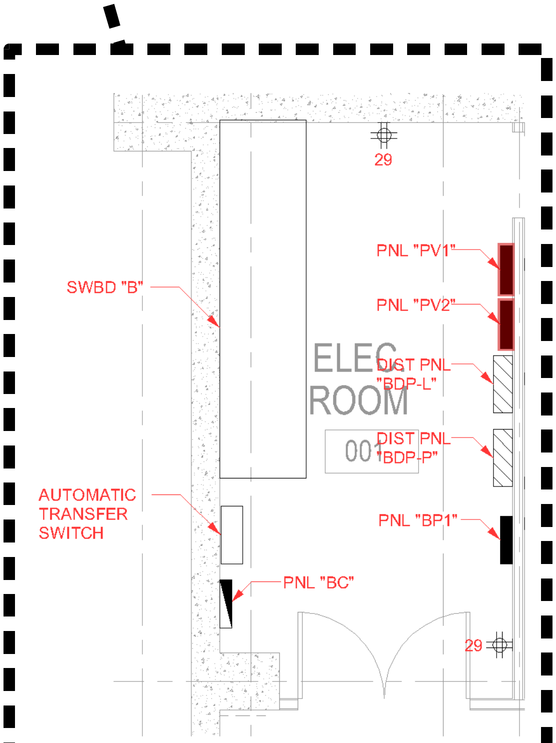


Figure 2.17 – Red = Inverter Locations, Blue = Elec. Room



Red = PV Panelboards

Conclusions

After careful review of the design documents, all the systems are functional and comply with the NEC code requirements. The equipment added is factored into the individual cost analysis performed and every effort was made to ensure that the proper equipment was chosen to complete a fully functioning system. Please refer to the “Cogeneration Analysis” on page 54 and the “Photovoltaic Analysis” on page 58 for more detailed conclusions for those systems, in addition, more in depth information pertaining to the lighting system can be found in the “Lighting Depth” section on page 7.

LEED Analysis

Introduction

At current count, TCES has 52 assured points on it's LEED scorecard (see Appendix C-CD for the complete scorecard), which will just barely give it a LEED platinum rating. As such, I will perform a re-evaluation of the LEED points to ensure that every point that is being counted will really be achieved during commissioning as well as to discover whether it is possible or practical to achieve those points which were not counted. The LEED 2.1 rating system (the current version at the time of writing) was used to determine the previously mentioned criteria.

Analysis Goals

The main goal in the following analysis is to determine if there are points that were not achieved that have a chance of being achieved, to determine why points that weren't achieved cannot be achieved, and to determine if there are any points that might be questionable as to whether they will be counted or not. Hopefully, this will give a better picture of where the building stands with regards to its LEED platinum certification. As it stands, the building has 52 points that the design team is sure about and is right at platinum level, so accuracy in determining whether some will be counted or not is of the utmost importance.

Analysis

Terms

SS – Sustainable Sites
EA – Energy and Atmosphere
MR – Materials and Resources
EQ – Indoor Environmental Quality

Points not achieved

Why they may still not be achieved

Credit SS 2 – Urban Redevelopment
Building is not being built in an urban setting that meets the population density set forth in the LEED criteria of 60,000sf per acre.

Credit SS 3 – Brownfield Redevelopment
Building is not located on a seriously contaminated site. The EPA does not consider the site an officially defined “brownfield” site, which is an “abandoned, idled, or under-used inductrial and commercial facility where expansion is complicated by real or perceived environmental contamination.”

Credit MR 1.1 – Building Reuse, Maintain 75% of existing shell

Building is new construction (no previous building was on site prior to construction), so cannot apply for this credit.

Credit MR 1.2 – Building Reuse, Maintain additional 25% of shell

Building is new construction (no previous building was on site prior to construction), so cannot apply for this credit.

Credit MR 1.3 – Building Reuse, Maintain 100% shell & 50% non-shell

Building is new construction (no previous building was on site prior to construction), so cannot apply for this credit.

Credit MR 6 – Rapidly Renewable Materials

Due to the type of construction of the building it may not be possible to find enough types of rapidly renewable materials that would be applicable. With radical redesign of the architecture it may be possible to obtain the credit, but as-is it is not possible. For example, a certified wood structure rather than concrete could be used, but it might be very impractical from a design standpoint.

Credit EQ 8.1 – Daylight and Views – Diffuse Sunlight to 75% of Space

Without drastic redesign of the building, getting a 2% daylight factor in 75% of the spaces is not feasible. Large Redwood trees (in excess of 100ft tall) stand just outside the building, blocking much of the sunlight coming in through the windows, and the skylights located in the atrium are not able to serve the whole building, only the main circulation areas. As a result, the daylighting levels on the interior are extremely small compared to exterior levels and would likely not meet the 2% daylight factor criteria.

Points not achieved

Possibility of achieving them

Credit SS 7.2 – Landscape and Exterior design to reduce heat island effect

A re-evaluation of materials used for paving and roofing may lead to the possibility of achieving this credit. Some possibilities for materials might include a roof garden, high emmissivity and high reflectance roofing materials that do not absorb much heat and at the same time do not retain heat, pervious paving materials such as loose stone or paving bricks packed in sand rather than cement which would reduce the amount of land covered by good heat-absorbing materials, or including more plants and trees on site.

Credit EA 2.3 – Renewable energy, 20% contribution

By installing a total of 60kW of photovoltaics the 20% contribution can be achieved. See “PV analysis” on page 58 for additional details.

Points achieved

Questionable as to whether they will be counted

Credit SS 6.2 – Stormwater management treatment system

Because it is difficult to accurately determine how much waste the building will produce in terms of Total Suspended Solids (TSS) and annual post-development Total Phosphorous (TP), it is unknown as to whether 80% of TSS and 40% of TP that is required to gain the credit will be filtered out by the stormwater treatment system.

Conclusions

For the most part the points that were not achieved cannot be gained by any reasonable means. 2 credits, however, can be achieved with a reasonable amount of planning and redesign. This gain is offset by one credit that is uncertain, for a total gain of 1 credit. This additional credit, while it is not a huge gain, may make the difference between getting a platinum rating and getting a gold rating, so I recommend making the changes discussed to gain the additional 2 credits as a sort of buffer in case a few other credits are not granted.

Solar Hot Water Design

Introduction

For proper analysis of the solar hot water heating system the results obtained from the eQuest energy model are used to determine service hot water loads. In addition, hot water produced by the 60kW of cogeneration is also considered. Natural gas prices have been obtained from the Nevada Power Company. In addition to the eQuest energy model that was used, RETScreen International's solar hot water design tool was used to determine feasibility, cost effectiveness, and greenhouse gas savings for the solar hot water heating system.

Design Goals

Ultimately, the main goal of this analysis is to determine the feasibility of installing (6) 10'x4' solar hot water collectors. I am attempting to determine whether this is a viable design option based on criteria of building service hot water load, cost analysis, roof area available and a greenhouse gas analysis. It is hoped that the panels will have a payback time of less than 10 years, produce significant savings in greenhouse gases and fit in the space available on the roof. The panels must also make sense in terms of the building's service hot water demand and the hot water produced by the cogeneration system. After the analysis, conclusions will be drawn as to the viability of installing 6 solar hot water collectors.

Design Solution

To add to the building's available hot water I decided to examine the results of installing (6) 10'x4' solar hot water panels. The panels chosen were SunEarth, Inc. model Empire EC-40 (See Appendix D-CD for cutsheet). The motivation for installing the panels was attempting to reduce the greenhouse gases caused by natural gas being combusted in a traditional boiler. The small amount of surface area of the collectors is due to limited space as much of the prime space is taken up by the photovoltaic system.

Analysis

Roof Area

Due to the size of the solar hot water panels and limited roof space available, it was vitally important to find space that met numerous requirements. The first requirement is that the panels must not block the photovoltaics or the skylights. Next, they must have a predominantly south-facing exposure for maximum energy gain. And lastly, and perhaps most importantly, there must be enough room for all six of the panels. After investigating the roof plan, the space directly south of the atrium skylights was judged to be the best location (see figure 4.1). The atrium skylights are up on a curb, raising them above the roof line, so even when angled the solar panels will not shade the atrium skylights. However, there is a skylight to the south of the panels that would shade the panels themselves. It is not very big when compared to the size of the panels though, so it will not effect the panels' output to an extreme degree. One downside to the location is that it is situated in between 2 pieces of mechanical equipment which may may maintenance on the mechanical equipment and the solar panels themselves difficult.

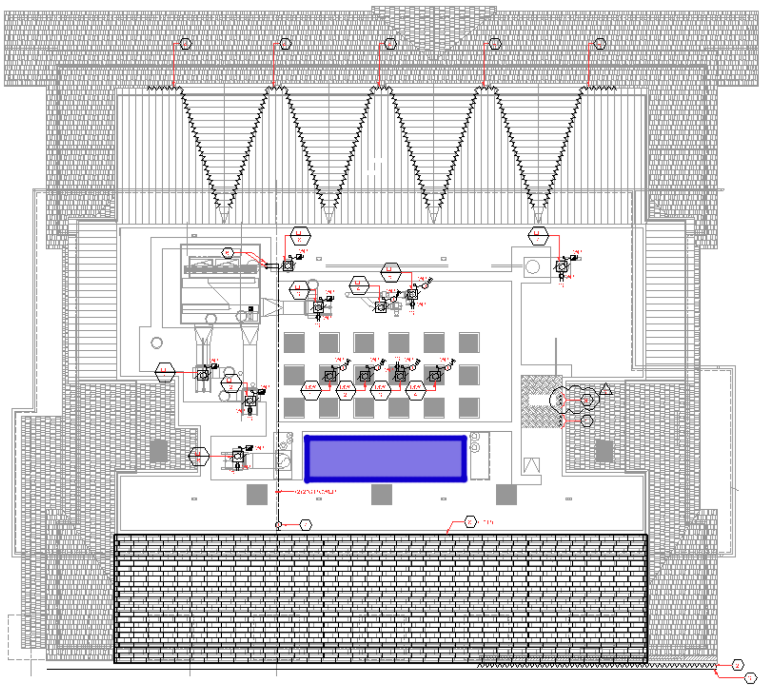


Figure 4.18 - Blue = Proposed location

Greenhouse Gases

The RETScreen solar hot water heating program was used to determine the greenhouse gas savings as compared to a natural gas fired boiler. The net reduction in CO2 using the solar hot water heating panels is 2.51 tons of CO2 as can be seen in table 4.2 below. Compared to the savings from the cogeneration system (page 54) and the photovoltaic system (page 58) this is a negligible amount of greenhouse gas emissions that are saved. For additional details on calculations done and figures used, please see the spreadsheet located in Appendix D-CD.

RETScreen Output		
Grid GHG emissions (tCO2)	***SHW GHG emissions (tCO2)***	***Net annual GHG reduction (tCO2)***
2.51	0	2.51

Table 4.2

Payback

To determine the payback period, the RETScreen tool was used in conjunction with cost information contained in the RETScreen product database and pricing for natural gas was obtained from Nevada Power. A price of $65 per square meter of collector was used along with a $250 cost to repair valves and fittings every 10 years. The payback period is 16 years, which exceeds the 10 years that was hoped for. For more detailed information on the cost information used, please see the spreadsheet in Appendix D-CD.

Yearly Cash Flows		
Year	**Yearly**	**Cumulative**
#	**$**	**$**
0	(2,973)	(2,973)
1	172	(2,800)
2	177	(2,623)
3	183	(2,440)
4	188	(2,252)
5	194	(2,058)
6	200	(1,858)
7	206	(1,653)
8	212	(1,441)
9	218	(1,223)
10	(111)	(1,334)
11	232	(1,102)
12	238	(864)
13	246	(618)
14	253	(365)
15	261	(105)
16	268	164
17	276	440
18	285	725
19	293	1,018
20	(149)	868
21	311	1,180
22	320	1,500
23	330	1,830
24	340	2,170
25	350	2,520

Table x.20

Service Hot Water

From the eQuest simulation performed, I determined that an hourly load of 2.2 million

BTUs was sufficient to heat the building (for complete eQuest output as well as input files, please see Appendix B-CD). The cogeneration units together produce 0.3 million BTUs per hour, leaving an additional 1.9 million BTUs per hour that need to be addressed by either the solar hot water system or the natural gas fired boiler. The panels, however, only produce 0.049 million BTUs per hour. This is insignificant compared to the additional load that the building requires during the day.

Conclusions

Due to the long payback period, the insignificant amount of hot water given, the tight squeeze into the available space, and the small amount of savings on CO_2 emissions, I recommend not installing the solar hot water hearing system. The 16 year payback period does not make it economically feasible, and since it has no other visible benefits other than a very small amount of greenhouse gas savings, it would be hard to justify the extra cost to the owner.

References

Lighting

Larson, Greg W., et al. *Rendering with Radiance.*
San Fransisco, CA: Morgan Kaufmann Publishers, 1998.

Rea, Mark S., ed. *The IESNA Lighting Handbook*: Reference & Application.
New York: Illuminating Engineering Society of North America, 2000.

Sillon, Francois X., et al. *Radiosity & Global Illumination.*
San Fransisco, CA: Morgan Kaufmann Publishers, 1994.

Structural

Manual of Steel Construction. Load and Resistance Factor Design, Third Edition.
Chicago, IL: American Institute of Steel Construction, Inc., 2001.

Mechanical

Duffie, John A., et al. *Solar Engineering of Thermal Processes.*
Indianapolis, IN: John Wiley & Sons, 1991.

Horlock, J. H. *Cogeneration: Combined Heat and Power.*
Malabar, FL: Krieger Publishing Company, 1997.

Construction Management

Chiang, John H., ed. *Means Electrical Cost Data 21st Annual Edition 2002.*
Kingston: R.S. Means Company, Inc., 2001.

LEED

LEED Reference Guide Version 2.1.
Washington, DC: United States Green Building Council, 2002

Scripting

Burtch, Ken O. *Linux Shell Scripting with Bash.*
Indianapolis, IN: Sams Publishing, 2004.

Christenberry, Johnnie R., et al. *CGI: Fast and Easy Web Development.*
Roseville, CA: Prima Publishing, 2000.

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