Architectural Breadth | Library Skylight / Roof Garden Walkway

Increasing the amount of daylight can connect the indoors with the outdoors, make students and faculty more productive and proud of their setting, save energy, and increase the quality of architecture. To accomplish all of these things, I made several adjustments to the fenestrations of the Library.

When I noticed excessive light levels from my original model (see Figures 23 through 25) I reduced the transmittances of the windows (by approximately 30%).

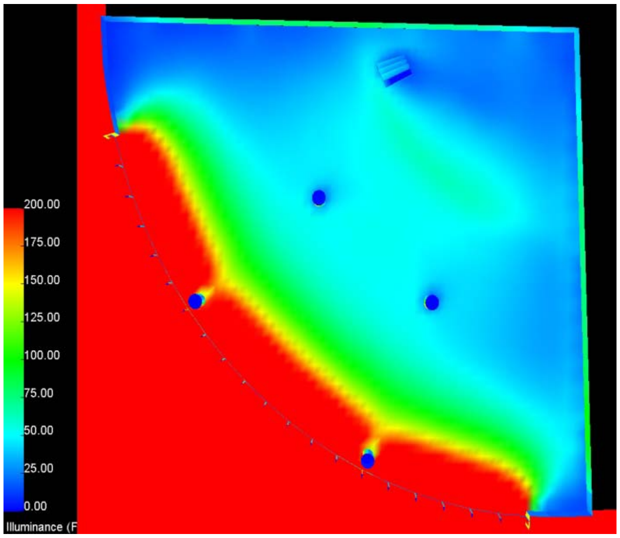


Figure 34 Pseudo Color of first floor during March 21st noon

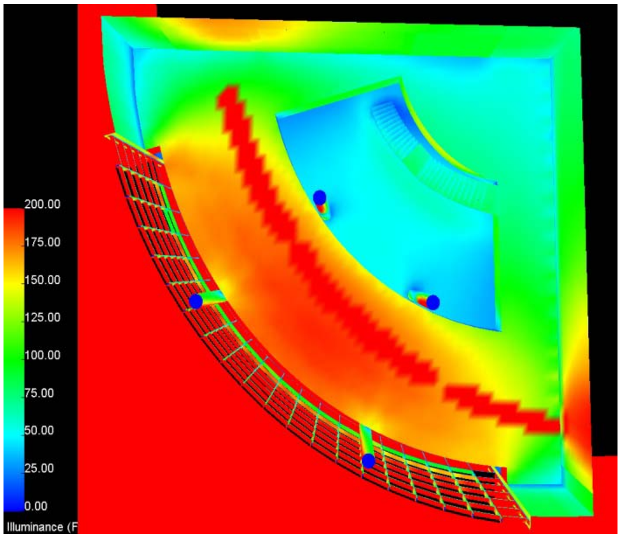
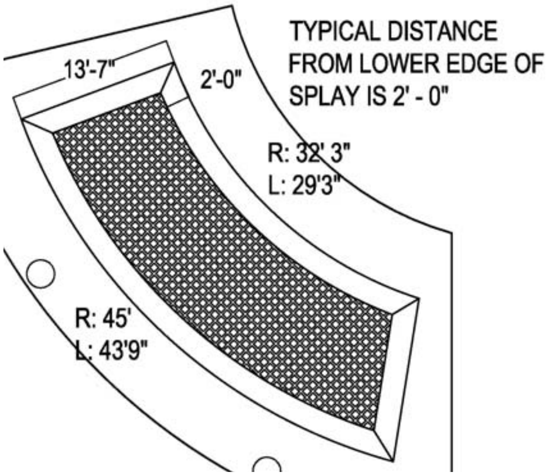


Figure 35 Psuedo Color of second floor during March 21st noon

After studying the effects of this reduction, I felt it was necessary to add a skylight to provide light down to the first floor. Although the space seems to pass the LEED criteria for March on a clear day, the Library (especially on the first floor) would be quite dim (or use mostly electric light) on an overcast day. Additionally, without the skylight, the fenestration area is too minimal to pass for the Daylight Factor criteria set by the USGBC and LEED.

The skylight added was not an ordinary 2'x4' rectangle, but a radial pattern of 8" glass blocks (See Figures 15 and 16 for renderings). The skylight also serves as the walkway for the roof garden above. During the day, the skylight will maximize the amount of light reaching the tables in the designated reading space on the first floor; at night, the walkway on the roof will be illuminated due to the ambient light from the space below. The skylight is located in an original bulkhead in the 3rd floor ceiling. Please see the details below and Appendix C for more information.



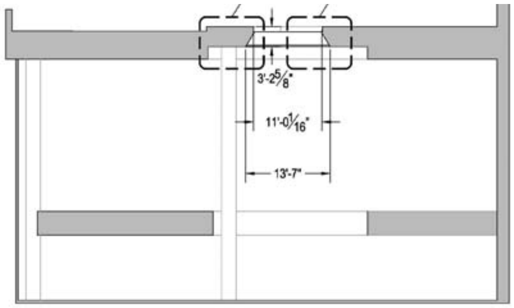


Figure 37 Section Through Skylight

Figure 36 Skylight Plan

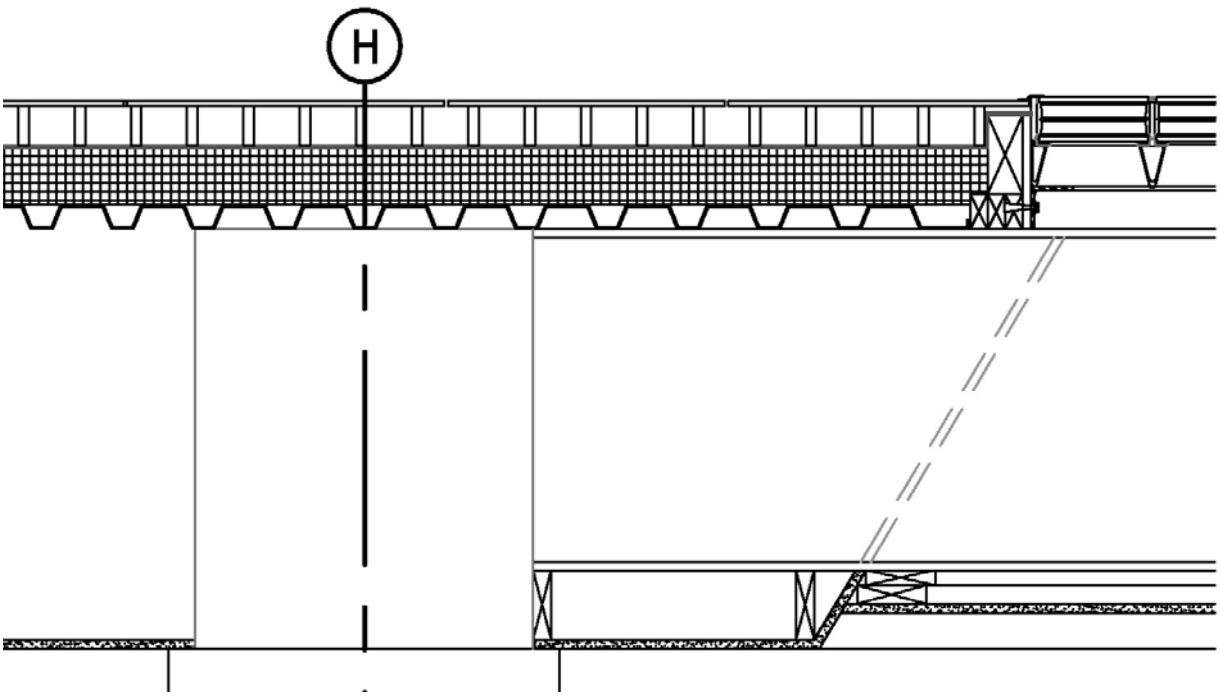


Figure 38 Detail Section Through Skylight splay and connection

To best analyze how the reduction of window transmittance and the addition of skylights affect these systems I conducted the following studies:

- Hand calculation to size steel members that support roofing system (Structural Breadth Section)
- Thermal load analysis (Mechanical Breadth Section)

Structural Breadth | Library

The addition of the masonry-glass-block skylight will affect the structural layout and sizing for the library space. The existing design (seen below) uses an asymmetrical steel frame and an array of various size wide-flange beams, girders, and columns to support the Roof Garden above.

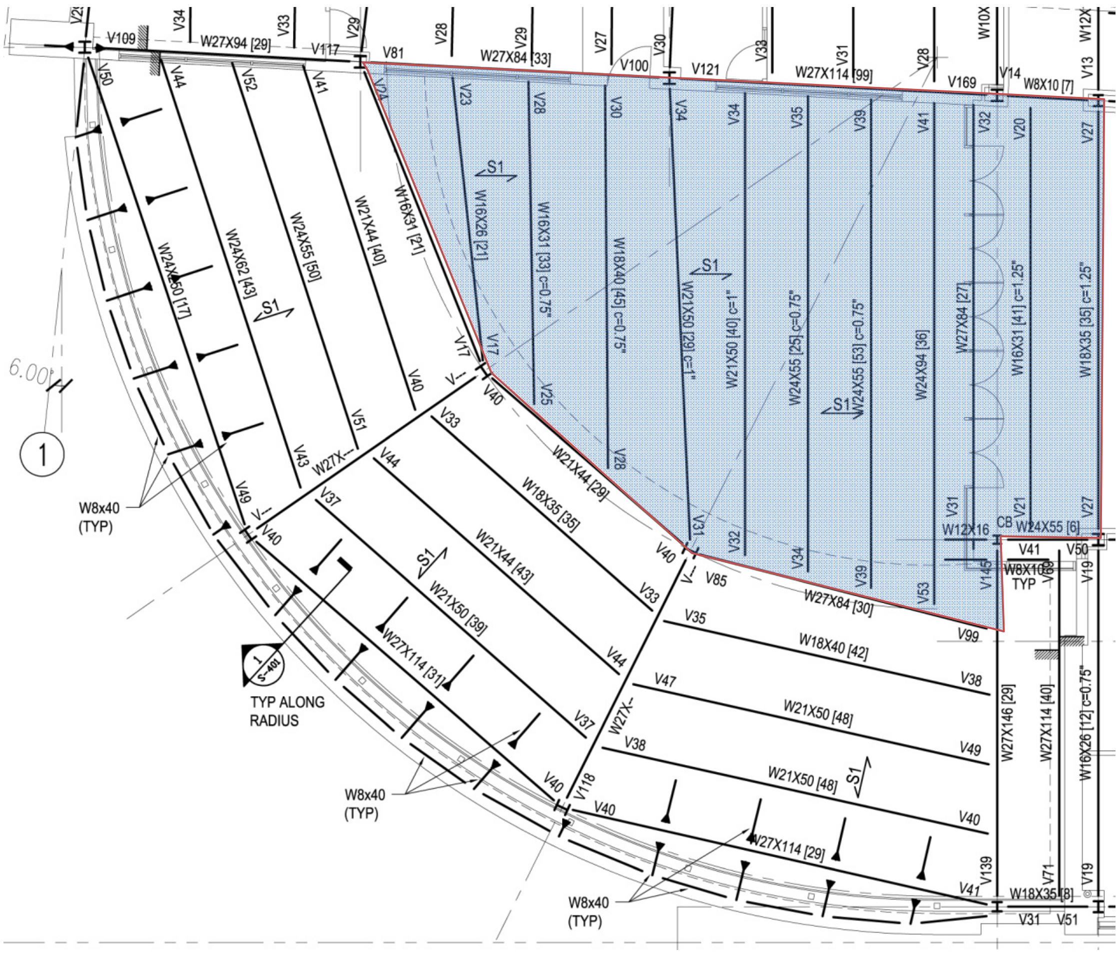


Figure 39 Existing Structural Framing in Library (3rd Floor)

I knew from the orientation of the existing structure that I would need to re-arrange the support beams to better coincide with the proposed skylight/walkway. It was a goal to minimize the amount of structure below the skylight so that a maximum amount of light could pass through (in reference to both daylight and ambient light from below). Additionally, I would not only need to meet roof loading criteria, but that of occupants who would commonly walk on this surface. The following diagram illustrates how I would layout the new structural plan.

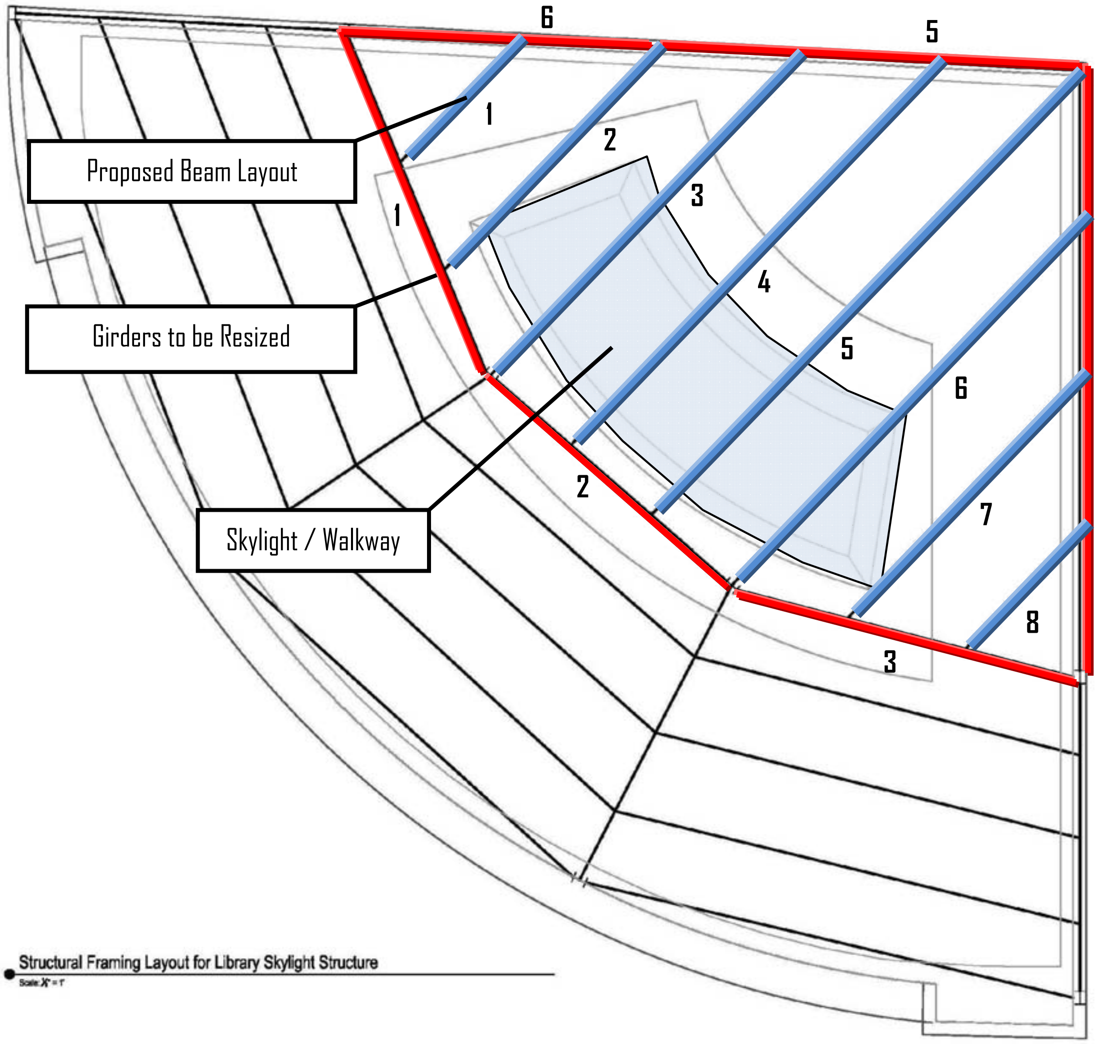


Figure 40 Conceptual Framing Layout; redesigned beams in red,

I oriented the beams so their lengths would be perpendicular to that of the skylight. This would allow less obstructions to get in the way of daylight. To calculate the size of the beams, I used equations from AE 404 Building Structural Systems taken in the Fall of 2007 and I made the following spreadsheet: (more information can be found in Appendix B under the Structural Section).

PSF	Dead Load		Live Load
1.2	20[i]	1.6	100[ii] =[1.2(DL)+1.6(LL)]*Span(ft)
Span	ft	in	
	8.24306	98.91672	← Standard spacing O.C.
L	14		← Varies
Mu	moment	simple	
	24.77314299	37.15971	← Moment Con.= (lb/ft)*(L^2)/(12*1000[iii]) Simple Con.= (lb/ft)*(L^2)/(8x1000)
Vu	10.61706128		← Vu.= (lb/ft)*(L)/(2x1000)
Δ	**moment**	**simple**	**Pass?**
live	0.011080118	0.033641	PASS[iv]
total	0.013296142	0.040369	PASS
Δ live	=LL*(L^4)*12^3*/(384*29000*I)	=5*LL*(L^4)*12^3*/(384*29000*I)	*I is given in table below*
Δ total	=(DL+LL)*(L^4)*2^3*/(384*29000*I)	=(DL+LL)*(L^4)*2^3*/(384*29000*I)	*I is given in table below*
	MAX allowable live	**MAX total**	
	L/360	L/240	
	0.466667	0.7	

Table 5 Structural member sizing (beam)

Beam Type	Length (ft)	Given I (per steel Handbook)
W12x14	14	88.6
W14x30	24.5	291
W18x35	35	510
W21x62	42	1330
W24x68	48	1830
W18x40	38.5	612
W16x31	25	375
W12x22	12	53.8

Table 6 Beam Dimensions and Properties

[i] Assumed self weight of glass block and roof combination

[ii] Assumed live load for pedestrians on roof

[iii] Divide by 100 to arrive at *kip* load

[iv] Reads "PASS" if calculated deflection is less than *L/240* or *L/360*

PSF	Dead Load		Live Load
1.2	39.2[5]	1.6	100[6] =[1.2(DL)+1.6(LL)]*Span(ft)
L	27		← Varies
Mu	moment	simple	
	239.5	359.2	← Moment Con.= (lb/ft)*(L^2)/(12*1000) Simple Con.= (lb/ft)*(L^2)/(8x1000)
Vu	53.2		← Vu.= (lb/ft)*(L)/(2x1000)
Δ	**moment**	**simple**	**Pass?**
live	.00532	.026602	PASS
total	.007408	0.03704	PASS
Δ live	=LL*(L^4)*12^3*/(384*29000*I)	=5*LL*(L^4)*12^3*/(384*29000*I)	*I is given in table below*
Δ total	=(DL+LL)*(L^4)*2^3*/(384*29000*I)	=(DL+LL)*(L^4)*2^3*/(384*29000*I)	*I is given in table below*
	Δ MAX allowable (live)	**Δ MAX allowable (total)**	
	L/360	L/240	

Figure 41 Girder Sizing

Girder	Beams In	Self Weight	Length of Beam	Weight Of Beam	Roof Area	Self Weight	Live Load	Total Load (lbs)
1	W12x14	14	7	98	574	11945.5	57400	106174.6
	W14x30	30	12.25	367.5				
2	W21x62	62	21	1302	817	19274	81700	153848.8
	W24x68	68	24	1632				
3	W16x31	31	12.5	387.5	575	12019.5	57500	106423.4
	W12x22	22	6	132				
4	W18x40	40	19.25	770	169	20592.5	16900	51751
	W16x31	31	12.5	387.5				
5	W18x35	35	17.5	612.5	1030.5	110117	103050	297020.4
	W21x62	62	21	1302				
6	W12x14	14	7	98	630	66615.5	63000	180738.6
	W14x30	30	12.25	367.5				

Table 7 Load Calculation for Girder

[5] Assumed self weight of roof and bordering space combination

[6] Assumed live load for pedestrians on roof and bordering space

To analyze the cost effectiveness of my redesigned system, I calculated the total weights of every member that I changed and compared the two. I did not compare pricing, however I am comparing the property of the members that would directly correlate with the cost of the system; *weight*.

In the end, the redesigned beams were much lighter than the original design. This is due to the orientation change. Because I shifted the beams by 45º, I also changed each member's length. The average length of my design is 29.875', while for the actual design is higher at 37.75'. having shorter lengths of beams allowed to reduce sizes for most of the members. Only in some cases, where the length of the actual design was longer, was the weight less. For the Girders, the length stayed the same, but the members being supported by the girders moved considerably. For example, girders 1, 2, 5, and 6 serve more beams than they did in the original design. Therefore the sizes of the girders increased. For girder 3, the number of members running into it decreased, as did their self weight. In turn, I was able to decrease this member's size. Overall the girder self weight increased by 331 lbs, and because so much weight was reduced from the beams, the overall weight of the structural members was decreased by 5,366 lbs.

Original				Redesign			
Girder/Beam Type	Length (ft)	Beam lbs/ft	Weight	Beam Type	Length (ft)	Beam lbs/ft	Weight
W16x31	28	31	868	W24x62	28	62	1736
W21x44	24	44	1056	W24x76	24	76	1824
W24*84	27	84	2268	W24x62	27	62	1674
W27x84	39	84	3276	W21x48	39	48	1872
W27x114	33	114	3762	W36x135	33	135	4455
W27x84	24	84	2016	W24x84	24	84	2016
W16x26	26.66	26	693.16	W12x14	14	14	196
W16x31	29.42	31	912.02	W14x30	24.5	30	735
W18x40	34.89	40	1395.6	W18x35	35	35	1225
W21x50	41.16	50	2058	W21x62	42	62	2604
W21x50	42.17	50	2108.5	W24x68	48	68	3264
W24x55	43.36	55	2384.8	W18x40	38.5	40	1540
W24x55	44.55	55	2450.25	W16x31	25	31	775
W24x94	45.72	94	4297.68	W12x22	12	22	264
		Total	29546.01			Total	24180

Table 8 Original vs. Redesigned Weights

Below, you can see the final layout of my redesigned structural system.

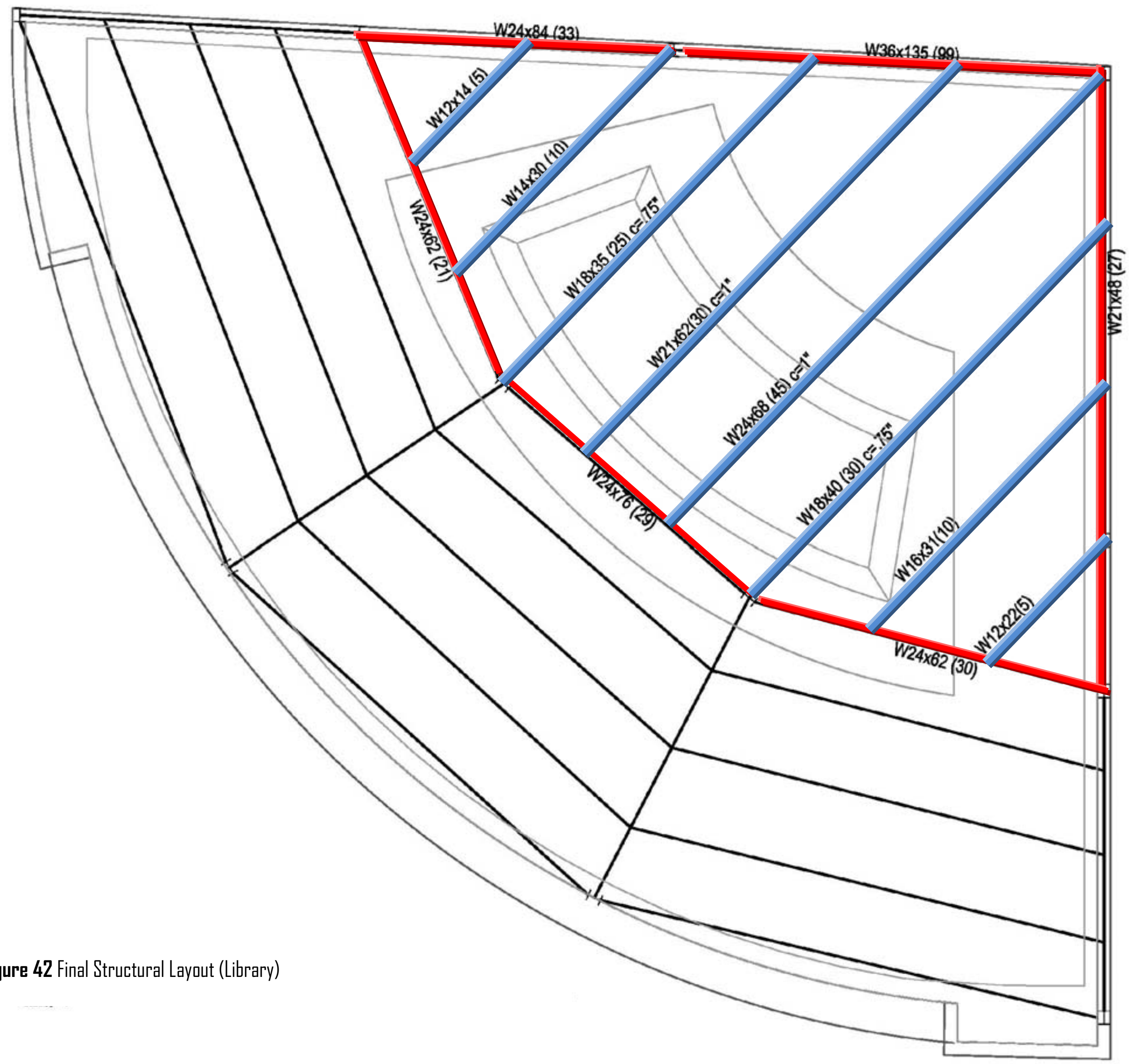


Figure 42 Final Structural Layout (Library)

Mechanical Breadth | Library Fenestration

By changing the fenestration properties and areas in the course of the Library's redesign, it was necessary to confirm that the change in entrance of thermal load did not necessitate a change in HVAC equipment. As an added challenge of this design (as well as my design in the Student Gathering space) to reduce the thermal load entering the space while increasing the daylight (or quality of daylight).

Two methods were followed to summarize the effect of thermal gain through fenestration; first, I followed equations given by the 1997 ASHRAE Fundamentals Handbook to calculate cooling load through fenestration, and second I used thermal load information found online at the National Renewable Energy Laboratory (http://rredc.nrel.gov/solar/old_data/nsrdb/bluebook/data/04725.SBF).

In the first method, I followed processes given by chapter 28 of the ASHRAE Fundamentals Handbook (section 28.41). This chapter references the following equations which were used together:

qcond=UA CLTD for conduction through solid exterior surfaces or windows where q is the associated cooling load (W), U is the U value of the fenestration, A is the area in square meters (fenestration), and CLTD is the cooling load temperature difference (given in a table in ASHRAE handbook).

qrad = A SC SCL for cooling load caused by solar radiation q (W), A is the fenestration area in square meters, SC is the shading coefficient (given by PPG glass specification), and SCL is the solar cooling load (W/m2) from Table 36 in the ASHRAE Handbook.

After finding these equations, I located the U values, Solar Heat Gain Coefficients (SHGC), and Shading Coefficients (SC) for the original glazing and what I was replacing with.

Library Roof Area (Replaced)					
Total Area (ft2)	U				
311	0.283723	W/m2 °C			
	ASHRAE PG 23 (25)				
Library Glazing Area As Designed					
Glazing Type	Façade Direction	Total Area (ft2)	SHGC	U	SC
GL-1A+B	3	1362	0.38	1.55	0.44
GL-2A+B	3	3010	0.3078	1.55	0.35397
Library Glazing Area Re Designed					
Glazing Type	Façade Direction	Total Area (ft2)	SHGC	U	SC
GL-1A+B	3	1362	0.31	1.187380755	0.3565
GL-2A+B	3	3010	0.2349	1.187380755	0.270135
Masonry Glass Skylight	Horz.	311.00	0.56	2.7237408	0.45

Table 9 As-Designed and Re-Designed Fenestration Properties

After obtaining this information, I found the tables that I would use to calculate the end cooling loads. Table 30 pg 28.42, Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs at 40º North Latitude provided me with the CLTD values for a typical roof (I used No. 1 Roof, from Table 31 pg 28.42,Roof Numbers Used in Table 30). This information helped me calculate the cooling load from conduction through the original roof area that was replaced with skylight and the skylight itself. To find what roof type my building was considered, I assumed that the mass was placed evenly around the insulation of the roof, that the R-Value was 0-.9, and that the roof had A3, Steel Deck. These assumptions led me to choose a No. 1 roof.

Table 34 pg 28.49 Cooling Load Temperature Differences (CLTD) for Conduction through Glass supplied information that allowed me to calculate the cooling load from the conduction through the windows I was replacing and replacing with.

Finally, Table 36 pg 28.5, July Solar Cooling Load For Sunlit Glass 40ºNorth Latitude (Zone type A) was used to calculate cooling load due to radiation from the original and replaced glazing. I assumed that my wall no. was 1, the floor covering was carpet, the partition type was gypsum, and that the inside shade was type b. My zone type would then be A. (Please see Appendix B for calculation sheet B27)

Each coefficient of value was given for a specific hour on the 21st day of July. For Table 36, it was necessary correct the CLTD values to correspond with my site. To do so, ASHRAE has given the following equation:

Design temperatures	**Corr. CLTD = CLTD + (25.5 - tr) + (tm - 29.4)**
where	
tr = inside temperature and	tm = maximum outdoor temperature - (daily range)/2

Figure 43 CLTD Correction (per ASHRAE)

For my site, I used the temperature information given by the NREL. I used the maximum outside temp of 73.7ºF, and a daily range of 73.7ºF to 65.7ºF or (8ºF). For my example the Corrected CLTD was:

Corrected CLTD = CLTD+25.5 – 22.22 + (23.1667 – (23.1667- 18.722)/2 – 29.4) = **CLTD - 5.17787**

I used the maximum outside temp of 73.7ºF, and a daily range of 73.7ºF to 65.7ºF or (8ºF).

Also, it was necessary to correspond the correct façade direction with the given direction on the table (ranging from N, NE … W, and Horizontal). After totaling each glazing (or roof) contribution to the cooling load per hour, I graphed the as designed vs. re designed cooling loads (watts) over a 24hr period in July. This graph can be seen below.

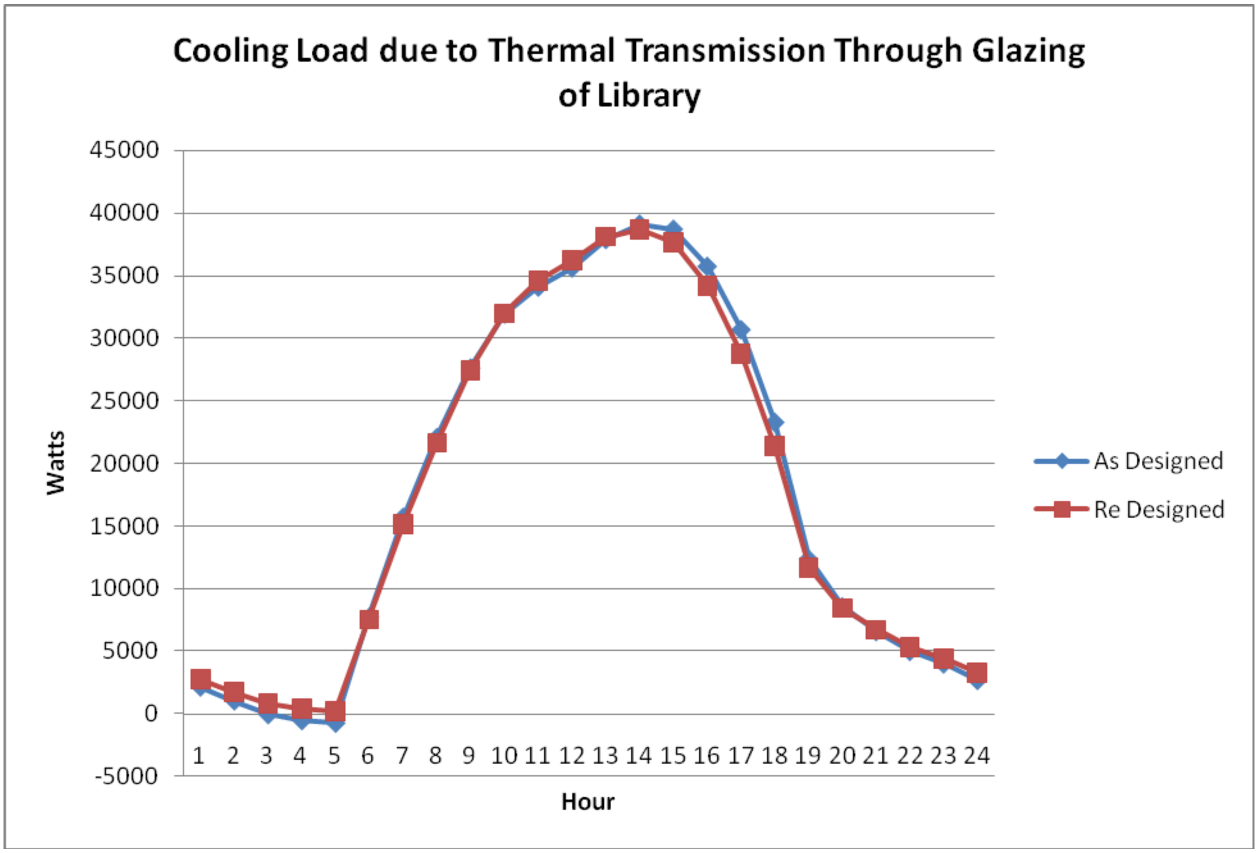


Figure 44 Graph for Cooling Load using ASHRAE Method (Library)

Using the resources from the National Renewable Energy Laboratory (http://rredc.nrel.gov/solar/olddata/nsrdb/bluebook/data/04725.SBF) I created a similar graph that summarized the total Btu/day coming through the window and skylight on a monthly basis throughout a standard year. This resource provided values of Btu/day*ft2 for each month and North, East, West, South and horizontal facades. For the Btu/day*ft2, three types of sky are also given; diffuse (overcast), clear, and global—which I am assuming to be a yearly "average" of sky type. For my analysis I am using the global sky type to analyze the cooling load. The graph of this calculation is below (Please see Appendix B for calculation sheet pg B28

).

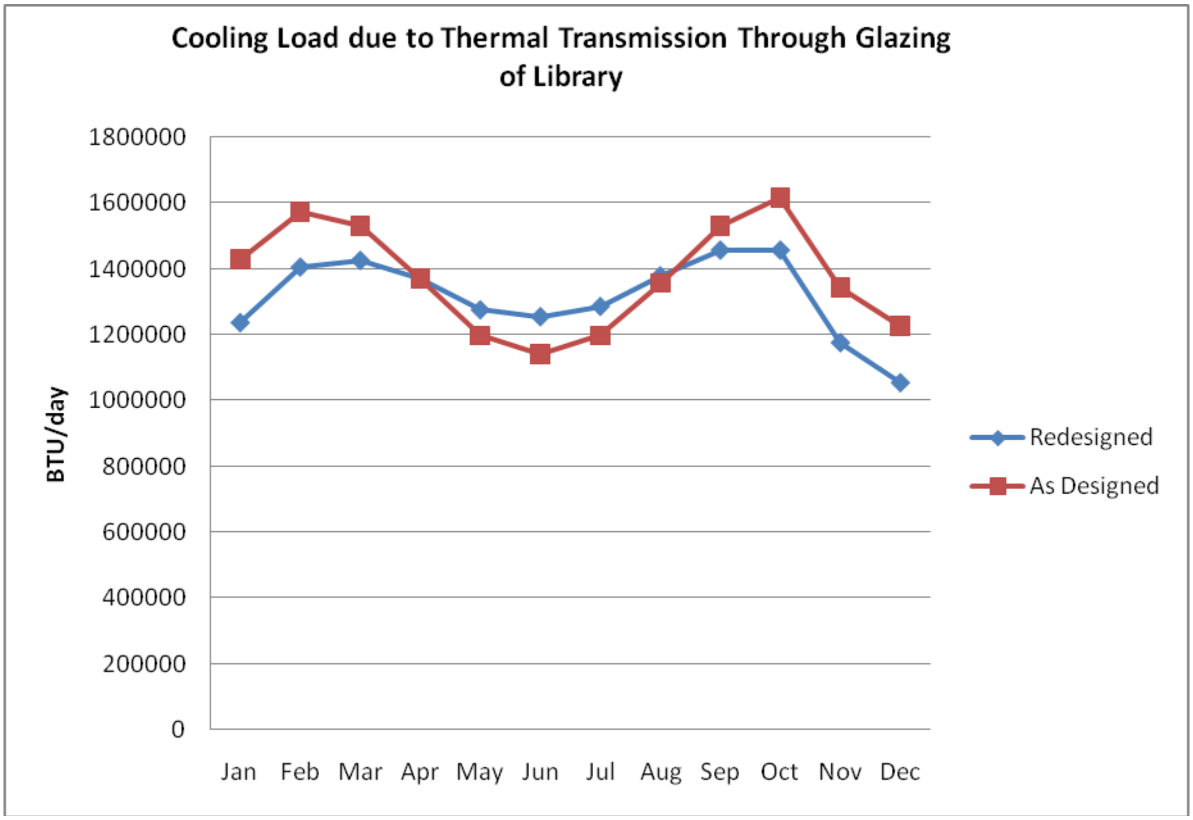


Figure 45 Graph for Yearly Cooling Load using NREL Method (Library)

The two analyses I have conducted are somewhat split. By the ASHRAE analysis I have slightly reduced the cooling load for the 21st day of July. This is only significant to prove that I have not increased the cooling load from fenestration. However, the NREL method proves the opposite; in July my design have surpassed the original in cooling load. I could attribute this to the addition of the skylight. The majority of area that I am considering with this calculation is the vertical window area; because July has a high profile angle (the sun is higher in the sky) less direct penetration will come through the windows in summer months. July is the second lowest value in Btu/day*ft2 for south facing glass. This is the reason for the dip in the graph during summer months. Horizontal glazing has the second highest value of Btu/day*ft2 in July; and because of this increase in thermal load entering through the horizontal glazing, the skylight contributes 27% of the cooling load during July. The difference between the as-designed and redesigned scenarios during June (the valley of the graph above) is 113585.3 Btu/day, which is approximately 9% of the total cooling load of my redesign. It is very likely that, due to solar shades, that 10% of the window is covered in all summer months and the actual amount of direct sun penetration is minimal causing the Btu value to decrease substantially. Also, trees on the roof will contribute some shade to the skylight blocking more direct light and more cooling load (though this value is likely to be minimal). Therefore, I can estimate that in the summer months, the cooling load is again lower than that of the original design. Using these two methods, I can say that the HVAC system in the Library will need no resizing or new equipment to counteract the effect of the fenestration change or addition.