Solar Shading Analysis

Problem

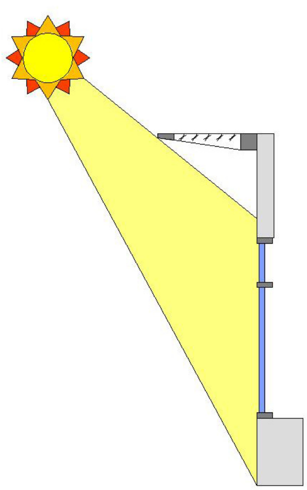
An existing sunshade runs along the perimeter of the fifth floor of the Health and Human Services Building. The current sunshade's primary function is to serve as a capitol to complete the aesthetic look that the architect is trying to achieve. The actual efficiency of the sunshade is debatable. The overhang of the sunshade is 4'-0" and it is located 4'-1 ¾" above the head of the window.

Solution

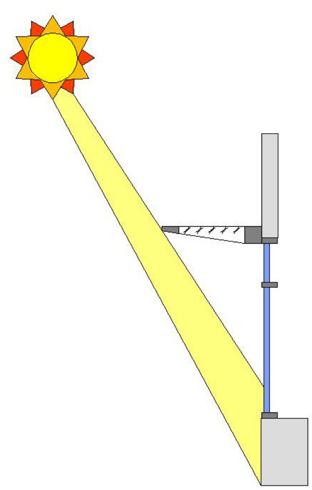
The goal of this analysis is to find the optimal length of the sunshade that will minimize the solar heat gain while minimizing the installation cost and the operating cost of the chiller. A Microsoft Excel program will be written to calculate the yearly solar gain for a building located in Baltimore, Maryland. The program will allow the user to change the height (distance above head of window) and length of the sunshade. The extended length of the overhang will create extra loading on the connection. The connection of the sunshade to the building will be analyzed to see if the additional length has an effect.

Methodology

The first step will be to lower the sunshade to the head of the window. This will allow the window to receive the most amount of shade with the same length overhang. As shown the picture below. The increased amount of shade will decrease



Sunshade at 4'-1 ¾" above Head of Window



Sunshade lowered to Head of Window

the load on the chiller. This load will be calculated in Microsoft Excel in Btu/h. Lowering the sunshade will cause the connection of the sunshade to the building to change. The sunshade will be mounted to a structural steel plate instead of the girder.

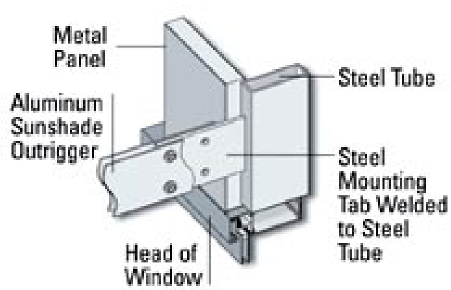
The next step will be to determine the change of solar heat gain as the length of the shade increases. A Microsoft Excel program will be written to calculate the monthly heat gain in Btu/h. The change in Btu/h of the original sunshade design will then be compared to the changed design. The change will be converted to the dollar savings for the cost of electricity. The cost savings in electricity will be compared to the cost of increasing the length of the sunshade to find the optimal length.

Resources & Tools

Dr. Moses Ling
Microsoft Excel
Sunshade Manufacturer – Construction Specialties, Inc
Sunshade Installer – AC Dellovade, Inc
Stein Reynolds – Mechanical and Electrical Equipment for Buildings *Ninth Edition*

Existing Conditions

The current sunshade is designed and produced by Construction Specialties, Inc. A steel tab is welded onto the structural steel which is provided by the steel contractor (S.A. Halac Iron Works, Inc.). A different contractor (A.C. Dellovade, Inc) installs the sunshade and the metal panels. In the connection detail provided the head of the window is located inches below the mounting of the sunshade and steel mounting tab is welded to a steel tube. The existing Health and Human Services Building's design requires the head of the window to be 4'-1 ¾" below the mounting and the steel mounting tab to be welded to a girder.



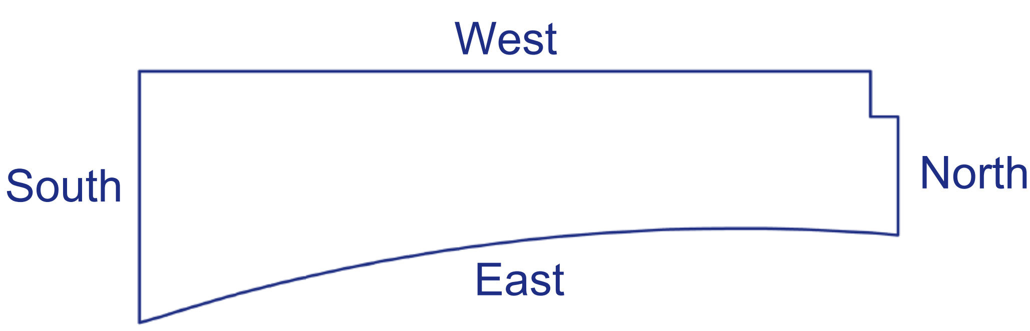
Original Design Connection Conditions

The only thing that will be changed on the sunshade with the redesign will be the length of the tapered outrigger. The current distance between outriggers is five feet. A tapered outrigger with a 4" air foil blade is used in the current design and the redesign.

Specified Outrigger and Airfoil

Installed Steel Mounting Tabs at Coppin State University Health and Human Services Building

The Health and Human Services Building's exposure is in line with the north/ south axis. This means that the north side of the building faces due north. The north side of the building is always shaded. Therefore, only the east, west and south sides of the building will be considered in the re-calculation of solar gain.



Health and Human Services Building's Fifth Floor Exposure

Mechanical Impacts

Lowering the Sunshade

The only affect of moving the sunshade down 4'-1 ¾" is that it increases the amount of shade on the window. This in turn reduces the load that the chiller is required to cool. Table 1 shows the existing load in monthly increments and a yearly total. Table 2 shows the monthly and yearly total when the sun shade is lowered. Table 3 is a calculation of the difference in Btu per year. The month by month calculations can be found in Appendix B.

Table1: Existing Monthly Load

Month	Btu per Month
January	9,171,824
February	11,290,921
March	14,263,934
April	16,668,644
May	19,361,664
June	20,657,017
July	22,163,105
August	19,301,728
September	18,547,310
October	15,776,857
November	9,466,098
December	7,491,578
Total:	**184,160,679**

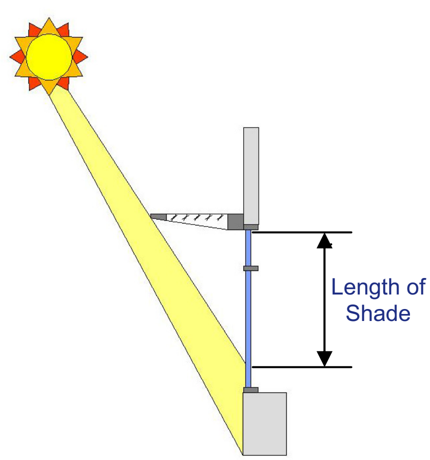
Table 2: Lowered Sunshade Monthly Load

Month	Btu per Month
January	7,068,294
February	8,293,033
March	10,217,519
April	12,269,298
May	14,496,006
June	15,572,578
July	16,679,511
August	13,533,949
September	13,680,595
October	11,807,527
November	7,278,966
December	5,849,392
Total:	**136,746,668**

Table 3: Difference in Yearly Btu from Table 1 and Table 2

Current Btu	Re-design Btu	Change in Btu
184,160,679	136,746,668	47,414,011

The azimuth, altitude, and solar heat gain factor for each solar hour during every month were taken from Reynolds' "Mechanical and Electrical Equipment for Buildings" on pages 1638 and 1648. Baltimore is located at latitude 39.18˚N so the 40˚N information was utilized. The length of shade is the vertical distance from the head of the window to the bottom of the shade projected on the window as seen below.



The length of the shade was calculated on the west and east sides of the building using the following equation:

$$\text{Length of Shade} = \tan(\text{Altitude}) \times \frac{\text{Length of Overhang}}{\cos(\text{Azimuth})}$$

The length of the shade was calculated on the south side of the building using the following equation:

$$\text{Length of Shade} = \tan(\text{Altitude}) \times \frac{\text{Length of Overhang}}{\sin(\text{Azimuth})}$$

Once the length of the shade projected onto the window was calculated the percent of glass shaded for each side was then calculated. The total horizontal linear feet for each side was calculated (Table 4) and then multiplied by the length of shade to calculate the area shaded. The shaded area was then divided by the total area to find the percentage of glass shaded.

	North	South	East	West
Height (ft)	7.33	6.83	7.33	7.33
Length (ft)	86.17	25.33	188.58	229.83
Area(ft^2)	631.89	173.11	1382.94	1685.44

Table 4: Height, Total Linear Feet and Area of Glass on 5^{th} Floor

Solar heat gain was then calculated. All shaded areas were considered to have a heat gain of a north surface. The corresponding heat gain factor was utilized for each side. The total solar heat gain for each month was calculated for every hour using the following equation:

$$\text{Solar Heat Gain}_X \text{ (Btu)} = (1-A_{SX})A_{TX}F_X + A_{SX} A_{TX}F_N$$

Where the "X" is referring the side of the building (north, south, east and west) being calculated, A_{SX} is the percentage of shaded area for whatever side is being calculated, A_{TX} is the total area of glass for the side being calculated, F_N is the north solar heat gain factor and F_X is the solar heat gain factor for the side being calculated.

The solar heat gain calculated above was then multiplied by the solar heat gain coefficient given by the glass and the number of sunny days per month to calculate the monthly solar heat gain given in Table 1 and Table 3.

Extending the Sunshade

Extending the shade will create a longer shadow length over the window. The current length of the sunshade is four feet. The yearly Btu for each length is displayed in Table 5. The solar heat gain calculations for the increased overhang length were performed in the same way as the lowered overhang. All of the calculations in Table 5 are based on the sunshade being installed at the head of the window (a zero height above the head of the window).

Table 5: Difference in Btu/year for Different Sunshade Lengths

Length of Sunshade	Yearly Btu	Difference Between 4' and New Length (Btu)	Difference per Length Increase (Btu)
4'	136,746,668	0	0
5'	126,315,695	10,430,973	10,430,973
6'	117,007,831	19,738,837	9,307,864
7'	109,139,949	27,606,719	7,867,882
8'	102,663,315	34,083,353	6,476,634
9'	97,006,771	39,739,897	5,656,544
10'	92,129,427	44,617,241	4,877,344

Structural Impacts

Lowering the Sunshade

Currently the sunshade mounting tabs are welded to the girder. Lowering the sunshade will require a plate to be welded to the girder and the mounting tabs to be

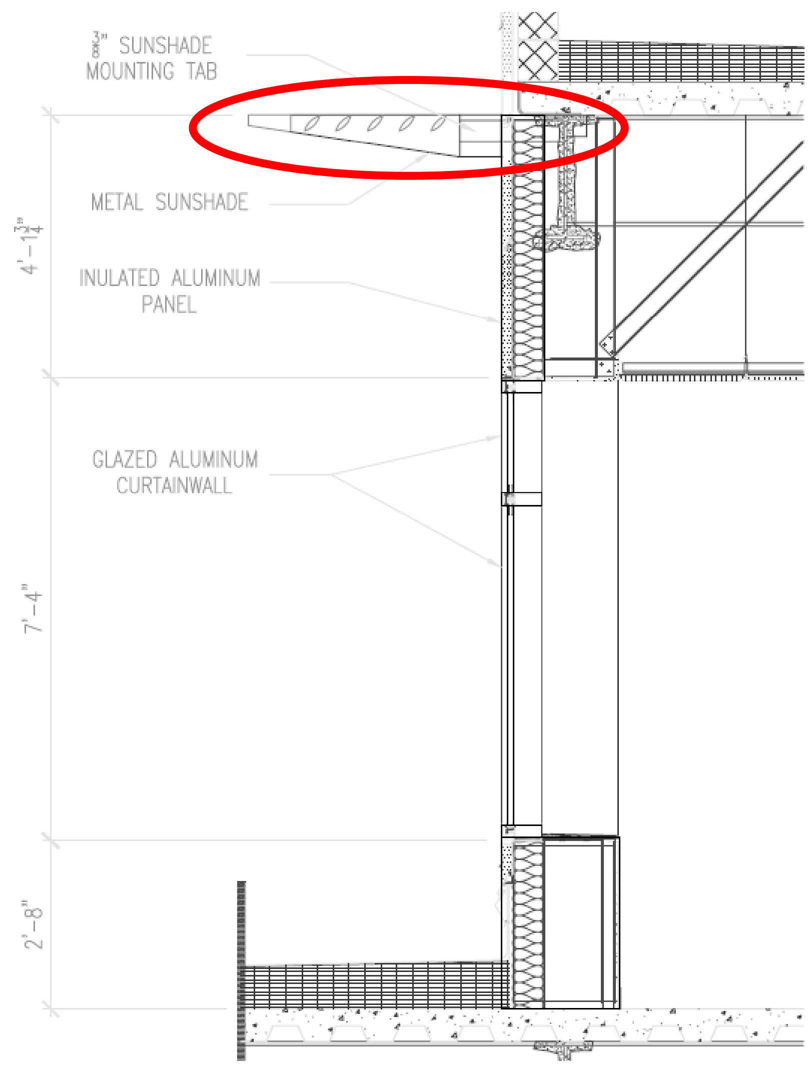


Figure1: Existing Wall Section of 5th Floor

welded to the plate. Figure 1 depicts the existing connection conditions. Figure 2 shows the redesign conditions necessary to lower the sunshade four feet. This detail will be typical around the perimeter or the 5th floor. An A36 24"x 7"x 3/8" steel plate will be welded to the girder beam directly below the original location of the mounted tab. The tabs will remain 5' on center.

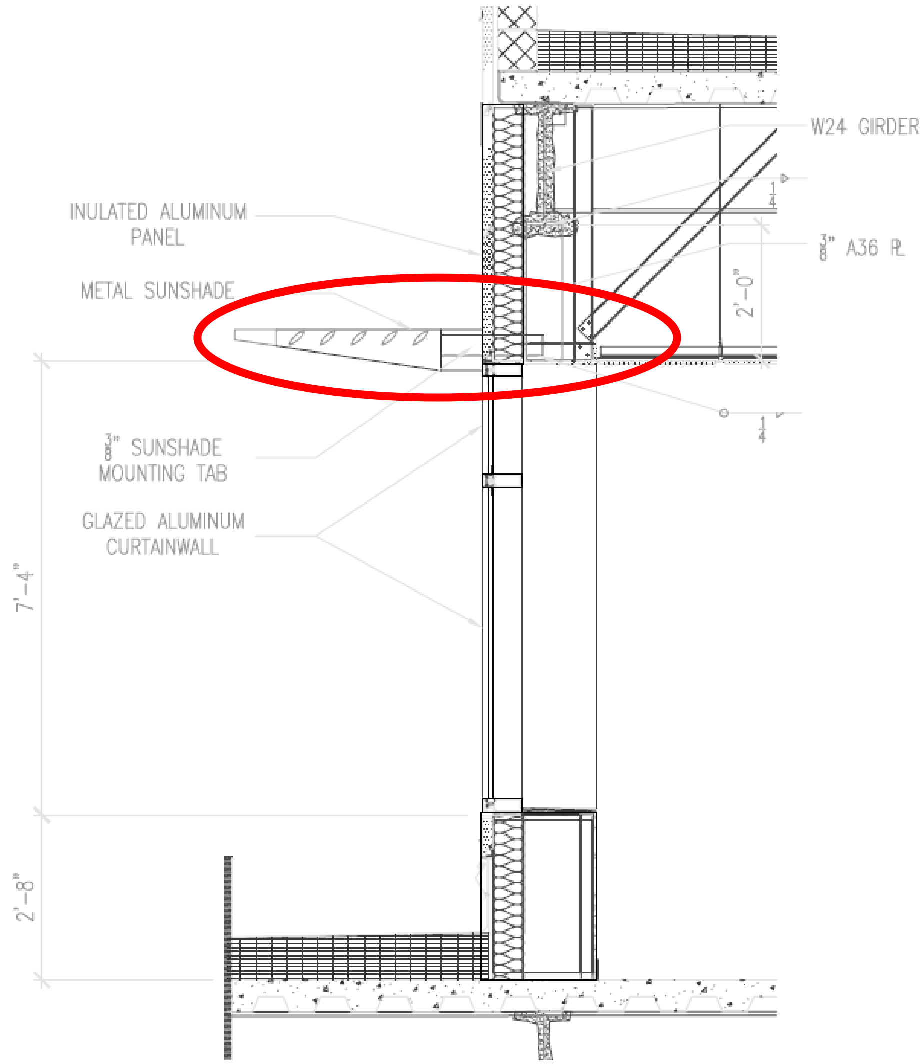


Figure 2: Redesigned Wall Section of 5th Floor

Figure 3 depicts the additional welding of the steel plate. The location of the mounting tab weld is illustrated as well.

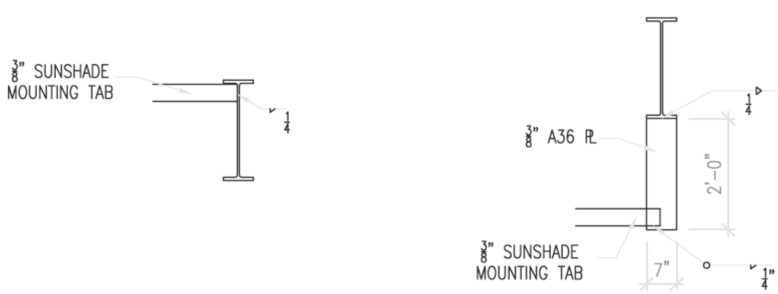


Figure 3: The left detail is the existing conditions and the right detail is the redesign conditions

Cost Analysis

The mechanical savings occur in three different ways. The cost for the amount of electricity that is saved per year, the savings from lowering the demand charge yearly and the savings for the tonnage reduction of the maximum chiller load. There are no structural savings because steel was added to the design.

Lowering the Sunshade

The electricity cost savings are depicted in Table 6 and Table 7. Table 6 calculates the change in Btu from lowering the sunshade 4'-1 ¾". The change in Btu was then divided by the chiller's coefficient of performance to change the thermal load to an electrical load. This number was then divided by 3412 Btu/kwh in order to convert from Btu to kwh. The cost was then found by multiplying by the cost of electricity which is $.0608/kwh. The savings is found to be **$141 per year**.

Table 6: Electricity Savings

Current Btu	Re-design Btu	Change in Btu	Savings
184,160,679	136,746,668	47,414,011	$141

The reduction of Btu allows the demand supply peak to be reduced as well. The difference between the lowest draw of Btu for the original and redesigned conditions was found to be 143 Btu. The decrease in Btu is converted to the number of tons consumed per year. The demand supply is lowered every month for a total of **$3,079** per year.

Table 7: Demand Savings

Current Lowest Hourly Btu	Re-design Lowest Hourly	Difference in Hourly Btu	Change in Tons Required	Demand Charge Saved
7191	7048	143	4.29	$3,079

CostWorks was used to estimate the cost per square foot for a chiller for the 5th floor space the cost was found to be $8.95 per square foot. The total amount of load saved in tons is 4.29. This was then converted to square feet using a multiplier of 450SF/ton. Then the total savings was calculated by multiplying the cost ($/SF) by the number of square feet. The calculation of this savings is depicted in Table 8.

Table 8: Tonnage Reduction Savings

Amount Saved (Tons)	Number of Square Feet per Ton	Cost ($/SF)	Total Initial Savings ($)
4.29	450	$8.95	$17,277.98

Lowering the sunshade required 156 A36 24"x 7"x 3/8" steel plates to be welded to the 5th floor girder. The volume of steel per plate was calculated in cubic feet by multiplying its dimensions. The steel fabricator, S.A. Halac, estimated an increase of 15% in the cubic footage to account for labor. The total cubic footage was then multiplied by 460 pounds per cubic foot to obtain the weight per plate of steel. The number of plates was then multiplied by the weight per plate to calculate the total weight. The total weight was then multiplied by a cost factor, provided by S.A. Halac, of $2.00/lb to find the total cost. The total cost of the additional steel including the labor to install all 156 steel plates is $6,017. Table 9 illustrates the quantities found during this calculation process.

Table 9: Structural Cost for Addition of Steel Plates

Weight of Steel (lb/ft^3)	Volume of Steel per Plate (ft^3)	15% for Labor (ft^3)	Weight per Plate (lb)	Number of Plates	Cost ($/lb)	Cost ($)
460	0.036458333	0.00546875	19.28645833	156	$2.00	$6,017.38

Table 10 provides a summary of the savings and costs from lowering the sunshade. The yearly savings is the electricity saved per year ($141) and the demand supply charge saved per year ($3,079) which totals **$3,220**. The initial cost of adding the structural steel ($6,017) and the savings in chiller tonnage ($17,278) totals for an initial savings of **$11,261**. The initial cost savings is **$14,480** and the yearly savings after that is **$3,220**.

Table 10: Total Savings from Lowered Overhang

Item	Savings
Initial One Time Tonnage Savings	$17,278
Initial One Time Steel Plate Cost	-$6,017
Electricity Savings per Year	$141
Demand Charge Savings per Year	$3,079
Total Savings ($):	**$14,480**

Extending the Sunshade

The mechanical savings per additional foot of sunshade extension are illustrated in Table 9. The electricity, demand supply savings and tonnage savings were calculated in the same way as they were for lowering the sunshade. Savings for each length were calculated using the change in Btu for each additional length.

Table 9: Mechanical Savings for each Additional Foot of Sunshade Extension

Length of Sunshade	Yearly Btu	Difference Between 4' and New Length (Btu)	Difference per Length Increase (Btu)	Electric Cost Savings	Demand Charge	Tonnage Savings per Length Increase($)
4'	136,746,668	0	0	$141	$3,079	$17,278
5'	126,315,695	10,430,973	10,430,973	$172	$3,854	$21,628
6'	117,007,831	19,738,837	9,307,864	$200	$4,629	$25,977
7'	109,139,949	27,606,719	7,867,882	$224	$5,382	$30,206
8'	102,663,315	34,083,353	6,476,634	$243	$6,157	$34,556
9'	97,006,771	39,739,897	5,656,544	$260	$6,932	$38,906
10'	92,129,427	44,617,241	4,877,344	$274	$7,707	$43,255

The one time material and labor cost per additional foot of sunshade extension is depicted in Table 10. A cost per square foot ($41.56) for labor and materials was provided by the contractor, A.C. Dellovade.

Table 10: Cost of Material and Labor for each Additional Foot of Sunshade Extension

Sunshade Length (ft)	Area of Sunshade (SF)	Cost ($)
4'	3,188	$0
5'	4,006	$33,998
6'	4,833	$68,370
7'	5,669	$103,116
8'	6,512	$138,152
9'	7,364	$173,563
10'	8,225	$209,348

The savings per additional foot of sunshade is illustrated in Table 11. The cost of the sunshade labor and materials for the extension of the sunshade is significantly larger than the amount of savings per year. The payback period was calculated by subtracting the cost from the total savings (electric, demand charge, and total tonnage) then dividing the sum (which was negative for most lengths) by the yearly savings (electric cost plus demand charge).

Table 11: Savings per Additional Foot of Sunshade Extension

Sunshade Length (ft)	Cost ($)	Electric Cost Savings	Demand Charge	Total Initial Tonnage Savings ($)	Total Savings	Payback Period
4'	$0	$141	$3,079	$17,278	$20,497	0
5'	-$33,998	$172	$3,854	$21,628	-$8,345	2
6'	-$68,370	$200	$4,629	$25,977	-$37,564	8
7'	-$103,116	$224	$5,382	$30,206	-$67,303	12
8'	-$138,152	$243	$6,157	$34,556	-$97,196	15
9'	-$173,563	$260	$6,932	$38,906	-$127,466	18
10'	-$209,348	$274	$7,707	$43,255	-$158,112	20

Conclusion & Recommendation

Lowering the sunshade provides an initial savings and a yearly savings. However, extending the sunshade has an initial cost and a payback period. Therefore the calculations conclude that lowering the sunshade is feasible but extending the sunshade beyond five feet is unfeasible.