Milestone 4:

Mechanical and Architectural Breadths

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University of Maryland: Prince Frederick Hall

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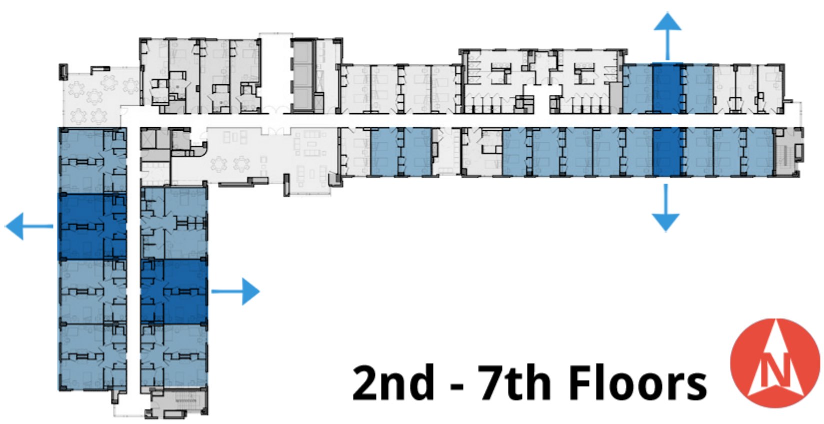
Introduction

> **"Shading windows from solar heat gain is a key design strategy for passive cooling and to reduce cooling loads on active HVAC systems."**
>
> -Mechanical and Electrical Equipment for Buildings[2], page 164

The existing design for Prince Frederick Hall features numerous daylight openings. While this is great for achieving high illuminance values, these unshaded openings also apply a heating load within the building. With proper shading, optimized for each facade, this solar heating load can be minimized in the hot, summer months and maximized in the cold, winter months. This study is comprised of two parts: mechanical and architectural. These studies are linked by the desire to increase solar utility. This means that passive architectural features are used to provide mechanical systems savings.

Scope

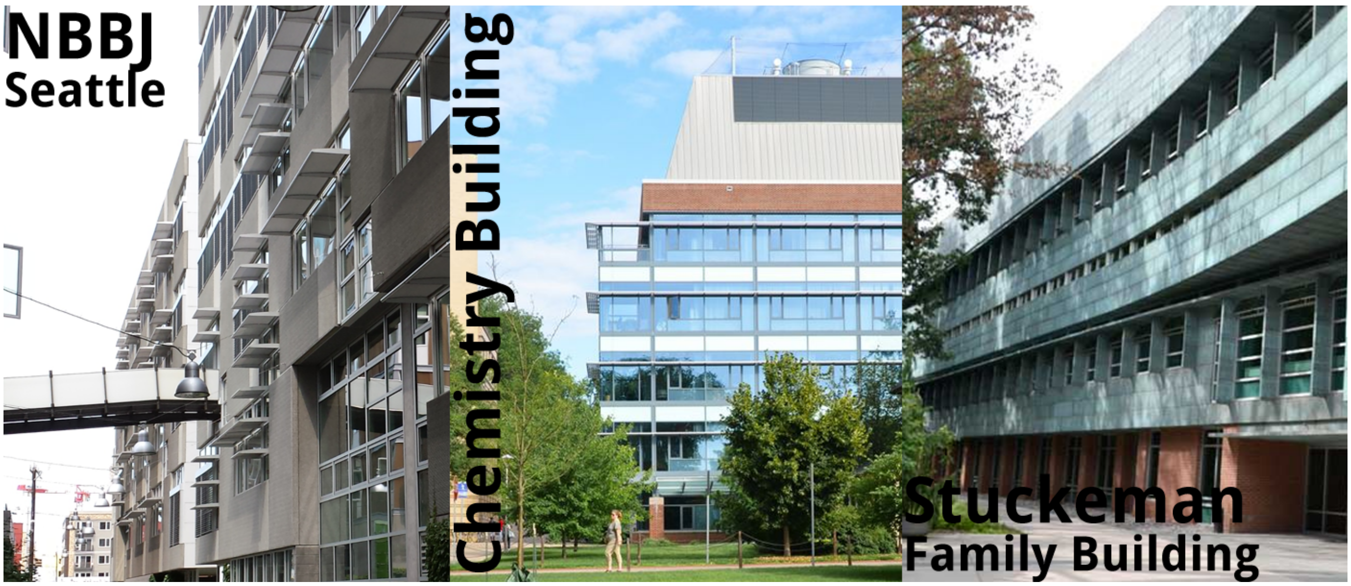
In order to create the largest impact on the total building load, dormitory spaces have been selected as the target for this study. Floors 2 - 7 consist mainly of dormitory rooms, so by selecting typical spaces, the savings calculated for one room can be multiplied throughout all other iterations of that room. The room selection process involved a quick study of the orientation of Prince Frederick Hall and its different typical dormitory rooms. This building is interesting for solar study because it is oriented along the four cardinal directions. To study different shading techniques for different orientations, rooms facing each direction have been selected. At each of these directions, the most common typical space was selected for study. The resulting scope for the mechanical breadth is that solar shading is optimized for the following spaces:



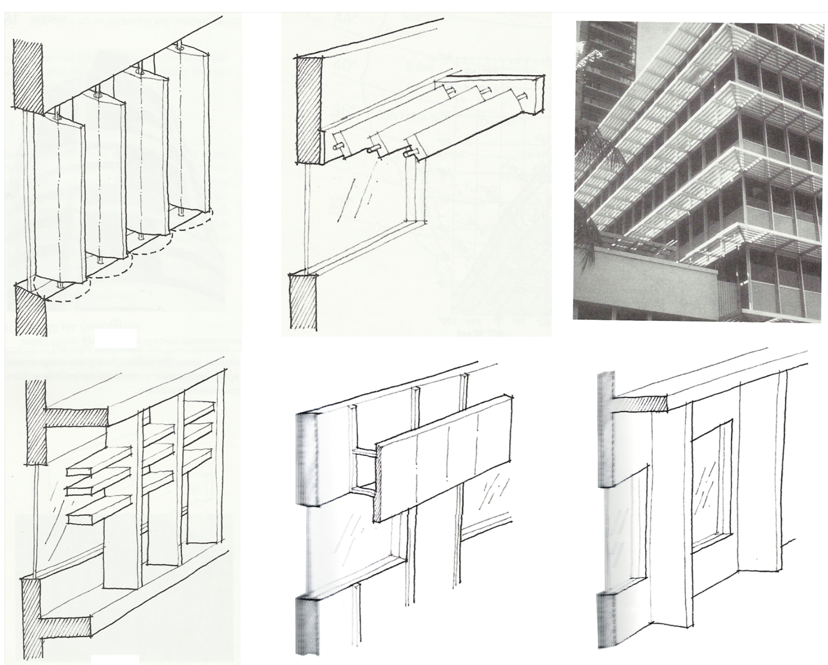
By adjusting the facade to optimize daylight within these spaces, the look of the building will also change. To protect its architectural form, this second breadth will be used to study the changes made during the mechanical study. Daylighting control systems are integrated within the building's architecture, where the scope for this study includes all exterior surfaces of the building. This scope includes the entire facade, not just what was optimized for solar loads, to ensure a consistent architectural expression. This is communicated with a series of renderings to illustrate difference between existing conditions and final design.

Solar Shading Options

The pivotal point of these two breadth studies (mechanical and architectural) is the performance and aesthetics of the passive solar shading. In terms of performance, this is the only variable between the existing design and the redesigned building facade. The glazing type and daylight openings are purposefully left as a constant factor for both situations. The shading devices themselves then are the sole elements responsible for energy savings. Using architecture to provide heating and cooling benefits is not a new idea, as is discussed in the second breadth of this report, so precedent architectural examples were gathered to indicate realistic design techniques. With that in mind, the following are some examples of passive shading elements.

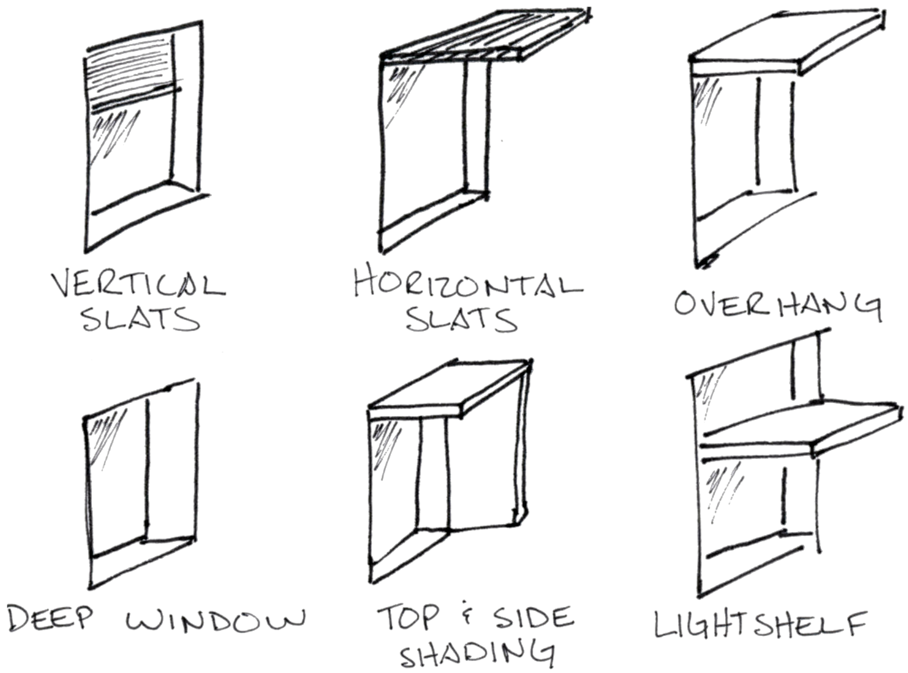


solar shading examples from the life of a PSU student (Photos by: Sarah Miller)



solar shading examples from Mechanical and Electrical Equipment for Buildings [2]

Of the previous examples, the following were determined to be viable options for use on Prince Frederick Hall:

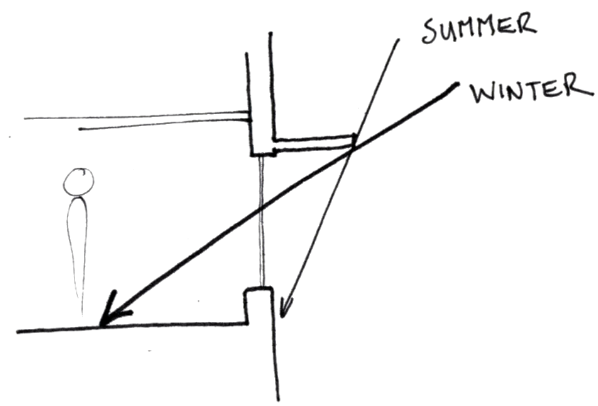


Solar Data

To determine which shading techniques would be the most successful, solar data for the location had to be obtained.

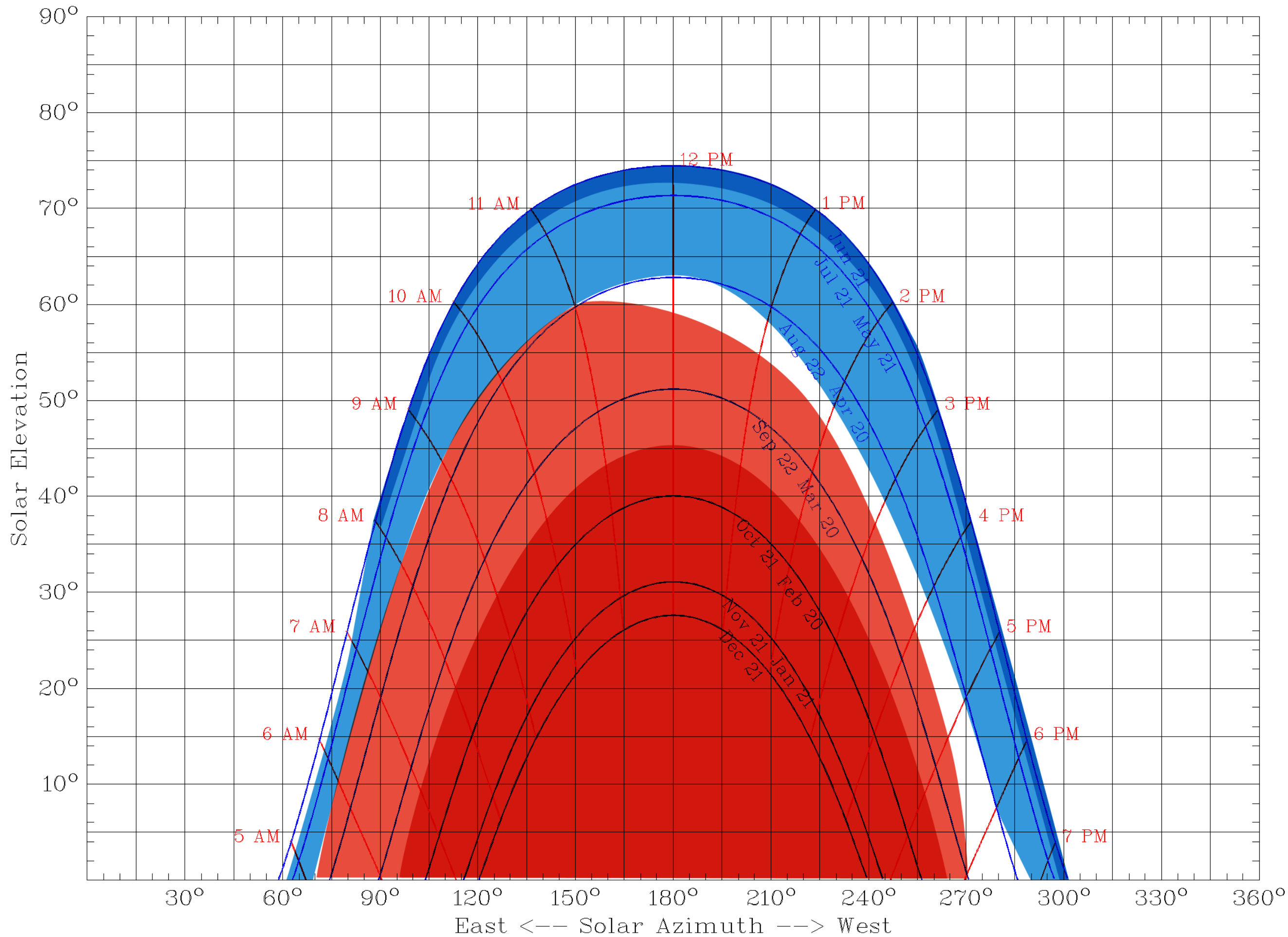
Location: College Park, Maryland
Latitude: 38.9967° N
Longitude: 76.9275° W
TMY Weather Station: 724060, Baltimore Blt-Washngtn Int'l, Class I

The chart on the following page shows the solar altitude and azimuth throughout the year for this specific location. The concept of solar shading is to block the sun when you want to cool a space and allow the sun to enter when you want to heat a space, thus taking full advantage of solar heat gain. In its most simplified form, we see something like this:



Goal

Solar shading added to Prince Frederick Hall must be optimized according to the location. This means, taking into account both the solar angles and the heating and cooling cycles throughout the year. On this solar path diagram, specifically for the latitude of Prince Frederick Hall, the blue and red shading indicate cooling and heating seasons, respectively:



solar path diagram from: University Oregon Solar Radiation Monitoring Laboratory

The goal of the solar shading, then, is to reduce solar penetration between June - August, while still allowing maximum sunlight to enter spaces between October - March.

Mechanical Study

This study focuses primarily on cooling loads. The very nature of adding shading to the windows means that only a decrease in solar heat gain can be achieved. Furthermore, it is important to focus on cooling loads because cooling systems are sized to handle daytime solar gain. Where "heating load calculations are generally done for a single hour and are assumed to occur during the nighttime."[5] Nighttime is when there is no solar irradiation to aid in heating the space. This means that optimizing winter solar penetration into the space will not have a direct effect on the size of heating equipment needed because, regardless of daytime optimization, the heating system will still be sized to meet nighttime heating requirements. However, optimizing solar penetration does mean blocking light during the summer, while still allowing daylight in during the winter. This does not affect the size of the heating system, but it does affect the energy used for heating during the day.

Calculation Method

To compare the heat gain with and without shading, the methods described by Spitler's *Load Calculation Applications Manual*[5] are used. These steps are outlined fully in section 7.5, Computation of Fenestration Heat Gains, and are summarized here:

- Compute relevant solar angles (altitude, azimuth, angle of incidence)
- Use to solar angles to find the unshaded area of windows
- Calculate direct beam solar heat gain
- Calculate diffuse solar heat gain

Equations to Find Total Solar Heat Gain

First, find direct **beam** solar heat gain:

$$q_{SHG,D} = E_D A_{sunlit} \mathrm{SHGC}(\theta)$$

E_D calculate (see below)
A_{sunlit} is the unshaded area of the window
$\mathrm{SHGC}(\theta)$ is the manufacturer's SHGC with an angle correction factor applied

where the method to find E_D is:

$$E_D = E_{DN} \cdot \cos\theta$$

$$E_{DN} = \frac{A}{\exp(B/\sin\beta)} \times CN$$

A and B are both coefficients
CN is the clearness number, a regional coefficient
β is the solar altitude

Next, find **diffuse** solar heat gain:

$$q_{SHG,d} = (E_d + E_r)A \cdot \text{SHGC}_{diffuse}$$

E_d calculate (see below)
E_r calculate (see below)
A is the total area of the window
$\text{SHGC}_{\text{diffuse}}$ is the manufacturer's SHGC with a diffuse correction factor applied

where E_d (for a vertical surface) is:

$$E_{dV} = Y \cdot E_{DN} \cdot C$$

$$Y = 0.45 \qquad for\ \cos\theta \geq -0.20$$

E_{DN} is known from above
C is a listed coefficient

E_r is the ground-reflected diffuse irradiation:

$$E_r = E_{DN}(C + \sin\beta)\rho_g \frac{1 - \cos\Sigma}{2},$$

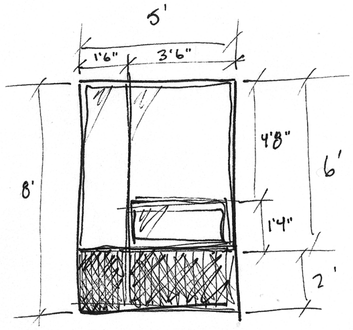
E_{DN} is known from above
C is a listed coefficient
β is the solar altitude
ρ_g is the albedo (ground reflectance)
Σ is the surface tilt angle (90° for vertical surfaces)

Last, combine diffuse and direct solar heat gain to find **total** solar heat gain:

$$q_{SHG} = q_{SHG,D} + q_{SHG,d}$$

This method of calculation relies on finding the area of the window that is left unshaded. Where the greater the unshaded area is, the greater the solar heat gain will be. Methods exist to calculate this unshaded area at different solar angles, but using Trimble SketchUp, this area was easily estimated.

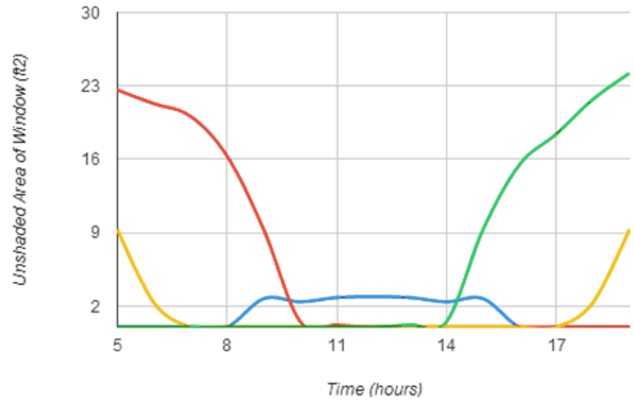
Optimized Shading



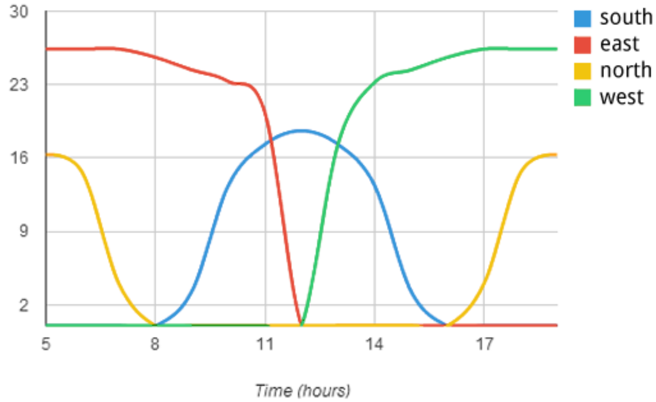
SketchUp was used to iterate the different solar shading options seen earlier in this report. For the four rooms selected for study, all used the same window type, diagramed on the left. Keeping in mind that the unshaded area of the window was the key to controlling solar heat gain, SketchUp's solar angles feature helped to reveal what shading techniques would perform best for each orientation. A summary of the performance of the final shading is shown on the next page. The exact geometry of the shading is discussed afterwards.

Summer: June 21

With Shading

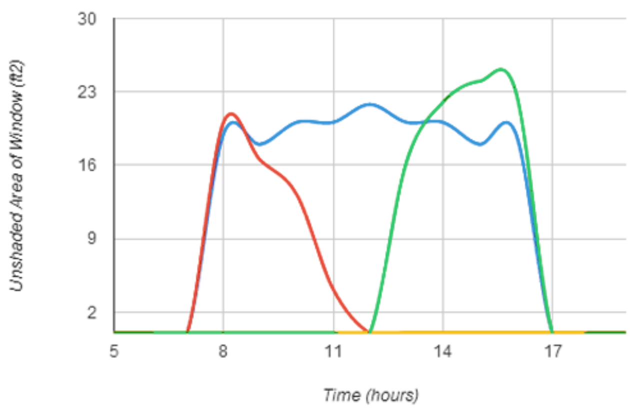


Without Shading

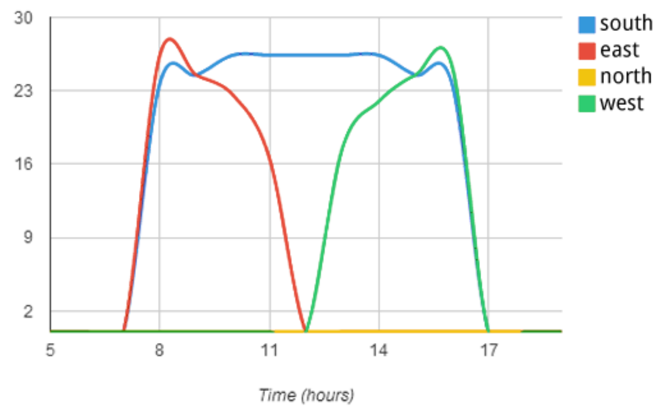


Winter: December 21

With Shading

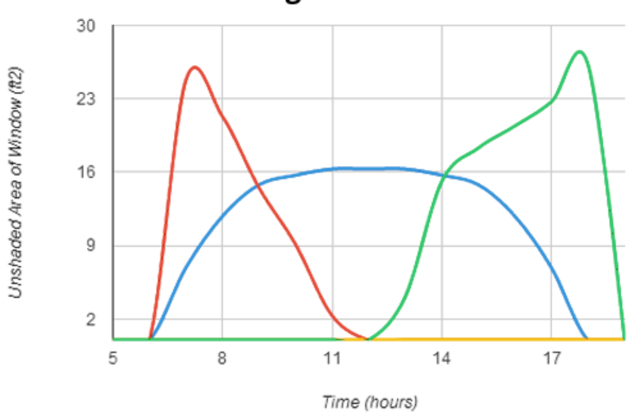


Without Shading

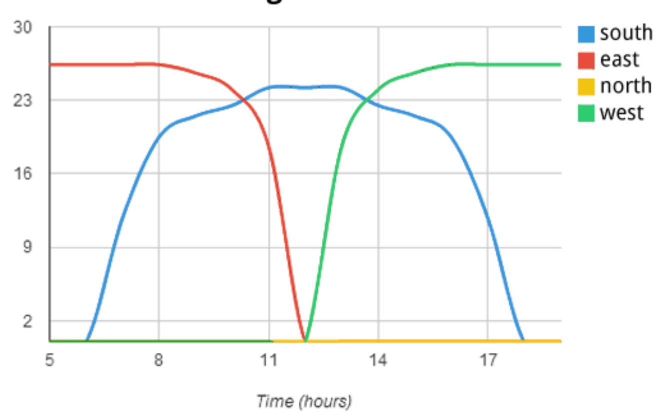


Equinoxes: September & March 21

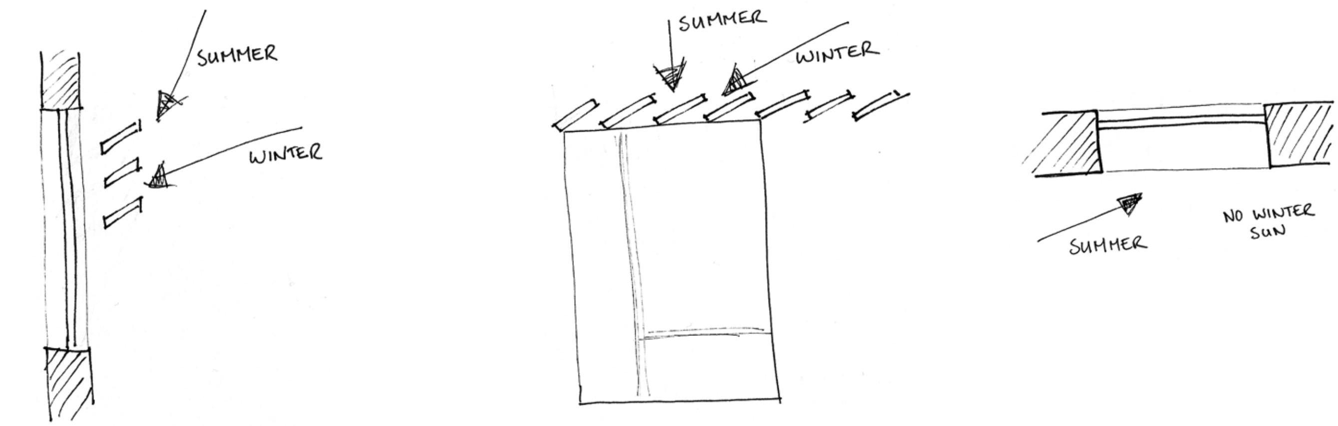
With Shading



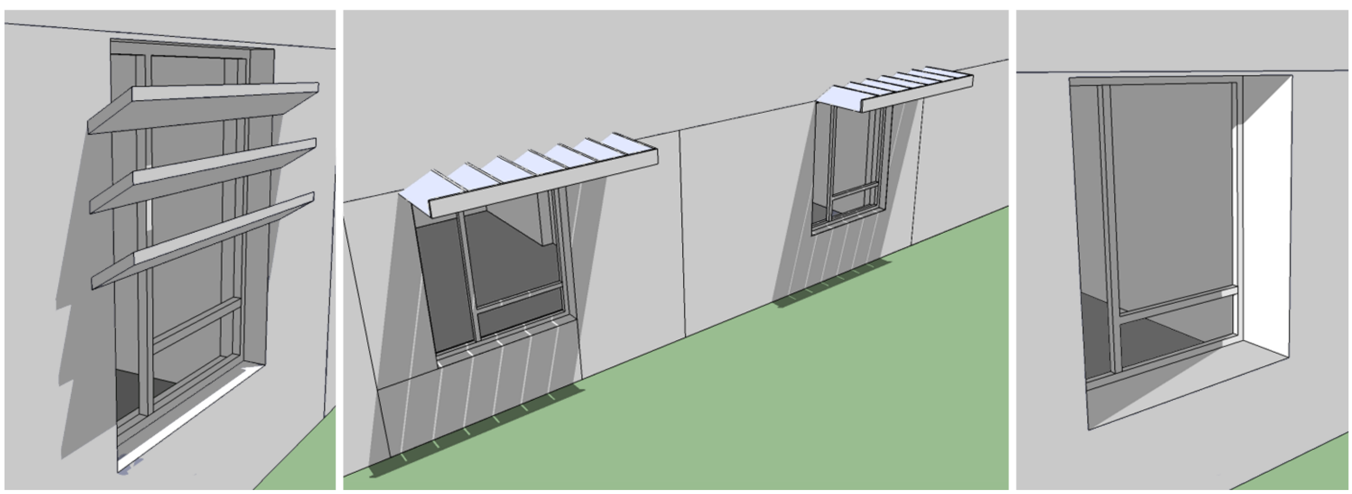
Without Shading



Below are the different shading techniques that were used to achieve the shaded areas graphed on the previous page. For South, East, and West orientations, angled slats were used to allow most winter angle sunlight to pass through and block the majority of summer angle sunlight. For North-oriented windows, winter sunlight doesn't reach these windows, so setting them a few inches deeper into the facade blocks very early morning and very late evening summer sunlight.



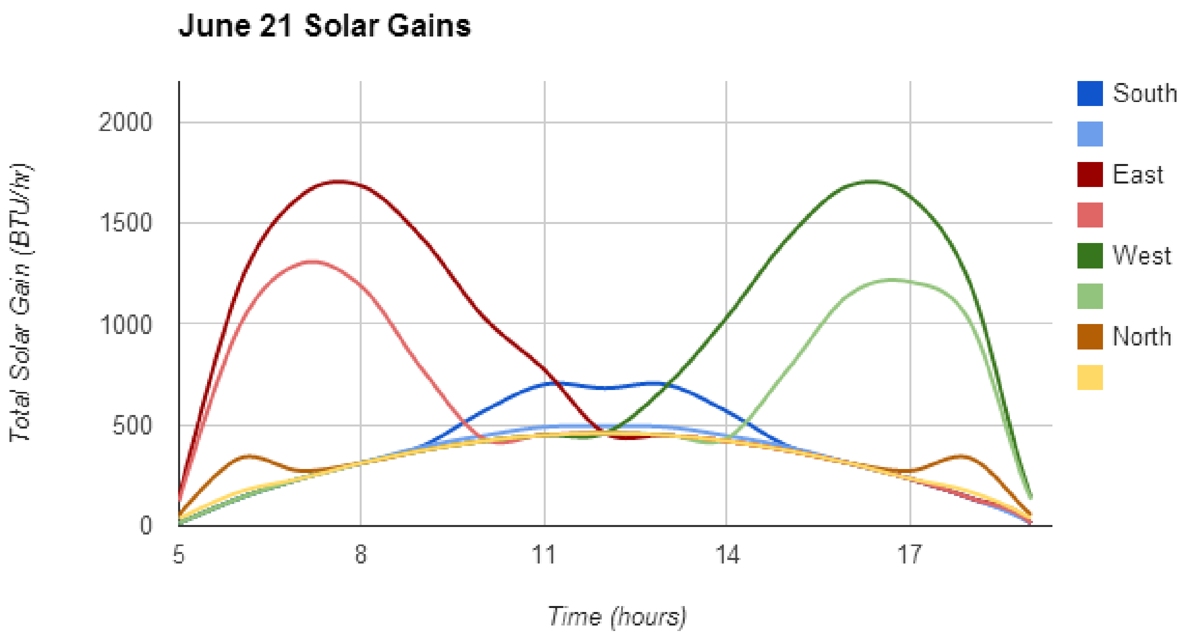
South **East & West** **North**

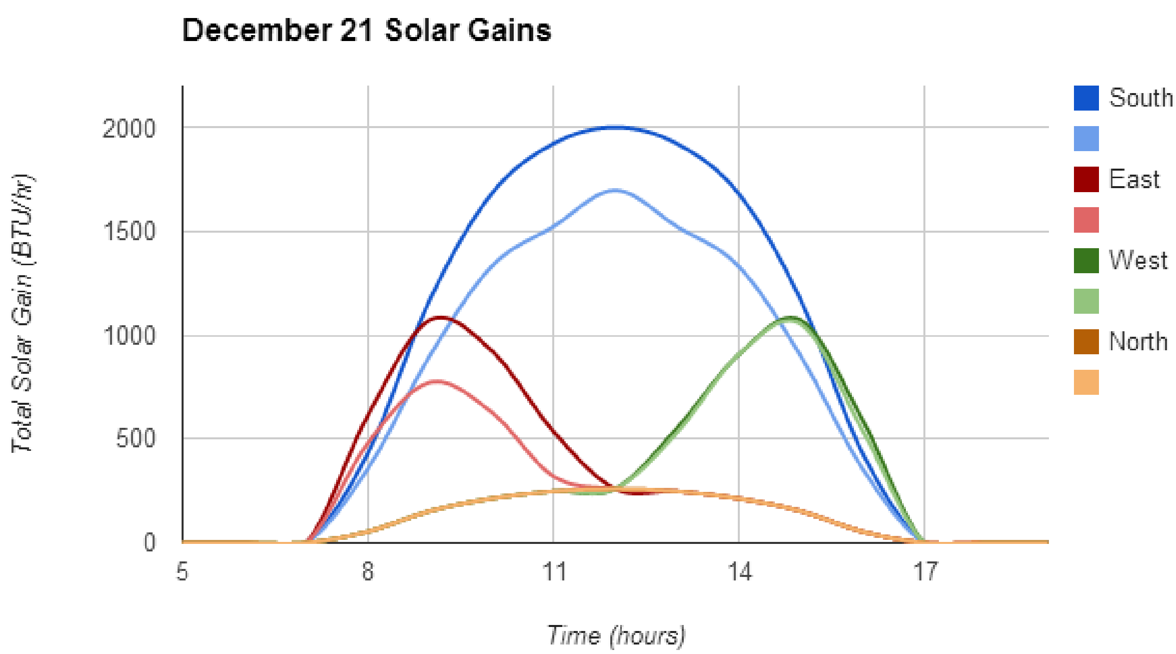


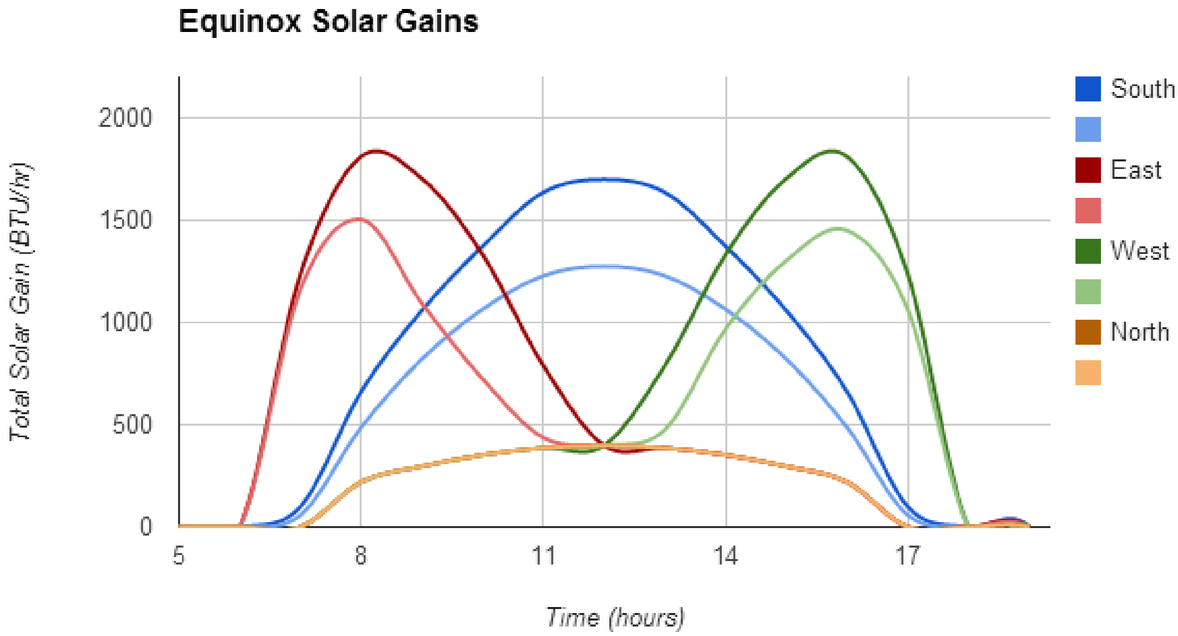
Results

Using the calculation method described above and the area of unshaded window for different days and orientations, the shading techniques applied to Prince Frederick Hall have be quantified in terms of q_{SHG} (BTU/h), the total solar heat gain through a daylight opening.

The following graphs show the different solar gains seen per window at each orientation, on four key days: the summer solstice, the winter solstice, and the equinoxes. The difference is graphed for solar heat gain with and without shading on windows, where the gains without shading are shown in dark colors and the solar gains with shading are shown in light colors.


June 21 Solar Gains
Total Solar Gain (BTU/hr)
2000
1500
1000
500
0
5
8
11
14
17
Time (hours)
South
East
West
North


December 21 Solar Gains
Total Solar Gain (BTU/hr)
2000
1500
1000
500
0
5
8
11
14
17
Time (hours)
South
East
West
North



The four days selected for study are the two solstices (when the sun is at its lowest and highest) and the equinoxes (which both have the same sun angles). During the summer, the goal was to reduce the shaded area as much as possible, but during the winter, the goal was to leave as much area unshaded as possible. However, due to the nature of shading, a reduction of thermal gain still does occur in the winter. To determine if the proposed shading is an effective addition to the building, the beneficially reduced summer solar gain has been compared to the detrimentally reduced winter solar gain. In this case it is assumed that it is beneficial to reduce the solar gain during cooling season: June 21 and September 21. And it is detrimental to reduce the solar gain during the heating season: December 21 and March 21.

Reduction in Solar Heat Gain				
BTU/window/day				
	South	**East**	**West**	**North**
June 21	-858.88	-2,630.91	-2,652.41	-444.66
December 21	-2,494.79	-947.23	-91.49	0.00
September 21	-2,765.25	-1,953.55	-1,613.39	0.00
March 21	-2,765.25	-1,953.55	-1,613.39	0.00

The above values are the calculated difference between the BTUs of solar thermal gain without shading and the BTUs of solar thermal gain with shading. These were first calculated per window at each orientation. Since there is not an equal number of windows per facade, these values were then multiplied based on the number of windows per facade. The total energy savings represents the net solar thermal BTUs saved during the summer less the solar thermal BTUs blocked in the winter.

Energy Savings				
	South	East	West	North
Number of Windows	66	36	48	18
Cooling Season Net BTUs	-239192	-165040	-204758	-8004
Heating Season Net BTUs	-347163	-104428	-81834	0
Net BTUs	-107970	60612	122924	8004
Total			83570	BTUs

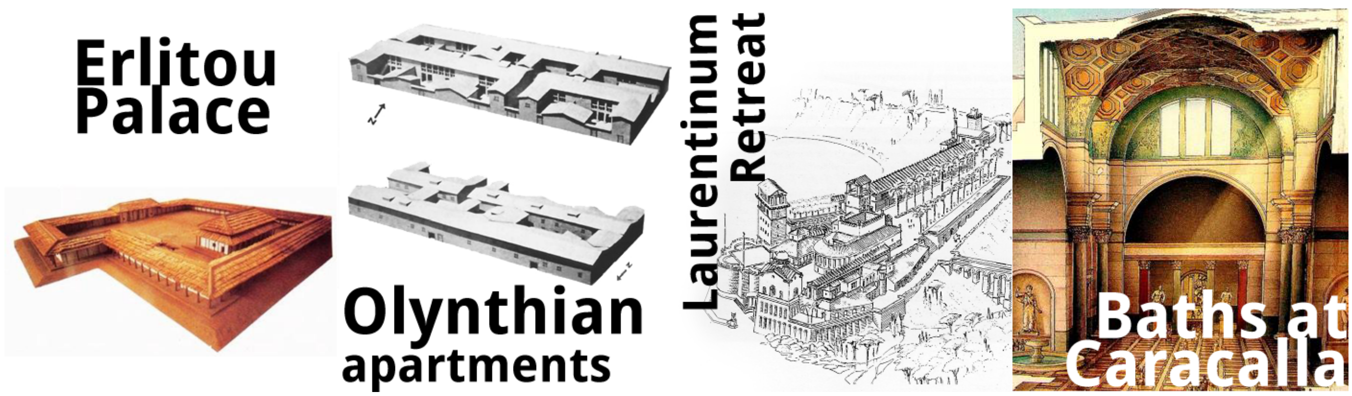
By adding the proposed shading to Prince Frederick Hall, the HVAC system will be required to produce approximately **83,500 less BTUs** of energy per year.

Architectural Study

> **"The house in which the owner can find a pleasant retreat in all seasons… is at once the most useful and the most beautiful."**
>
> -Socrates

Historical Passive Solar Architecture

With the growing popularity of photovoltaics and large-scale solar concentrating systems, it might be easy to think of solar technology as symbolic of our modern society. However, humans have been looking to the sun's energy since the dawn of civilization. As early as the 12th century BCE[4] the Chinese began orienting their buildings to maximize solar utility. Historically, there is evidence of many other cultures that used solar design in their architecture.



The Chinese were only the first "to perfect the art of designing homes and whole cities so that all people could warm their houses with the sun's heat in winter and, during summer, keep the sun out of their houses so they could stay cool and comfortable."[4] The Erlitou Palace was one of their first solar buildings that we have archaeological evidence of today, but the Chinese refined solar architecture over the centuries, establishing cities that were oriented to the sun, making solar accessible to all social classes.

To the Greek's, the solar design of buildings was important as well. Around 432 BCE, a group of Greeks from Athens pioneered a new city. Olynthus was a city designed around solar angles, where streets were spaced so every house could receive sunlight without shadowing those around it.[4] Olynthus proved to the Greeks how effective solar heating was. The growing wealth of Greece began to constrict available fuel sources. And as wood became more and more expensive, the government implemented legislation to protect citizens from ever increasing prices. Incidentally, this "coincided with the popularization of solar architecture there, no doubt also a response to the scarcity of wood."[4] This isn't the last time we will see a nation with rising fuel prices turn to the sun for energy.

In Roman times, Vitruvius addresses solar design in his *The Ten Books of Architecture*. Later Palladius takes up his mantle and recommends sun-heating techniques to his rich clients. Like in Greece, solar design only saw widespread popularity after the rising cost of wood drove the population to seek new innovations to heat their homes.

Modern Architecture

In the Greeks and Romans we see two separate cultures driven to solar power when other energy sources became constrained. So if less available fuel drives a culture to maximize utilization of solar design, is it possible that an abundance of fuel could drive a culture to neglect solar design? In *Solar Energy Conversion Systems* [1], Jeffrey Brownson writes that an "examination of economics and social behavior leads one to hypothesize that the perception of solar energy as diffuse is as much a result of the available geofuels in the USA as it is the perceived necessity of those fuels and the non-substitutability of geofuels for the modern public." The lack of passive solar design in the last 50 years of architecture is, in part, reflective of the public's perception of solar energy as insufficient.

Shown above are buildings characterizing International Style architecture. Skyscrapers all throughout the 20th century exhibit characteristics of this style. And while this style certainly has its merits and many aesthetic and practical reasons for such popularity, it shows a lack of interest in solar utilization. In *Let It Shine : The 6,000-year Story of Solar Energy* [4], John Perlin writes that, "a growing affluence that allowed people to indulge their appetite for new electric appliances, combined with the postwar baby boom, helped increase electricity generation by over 500 percent between 1945 and 1968...U.S. fuel consumption as a whole more than doubled between 1945 and 1970." It seems no mere coincidence that this perception of energy abundance coincides with the popularity of characteristics of the International Style.

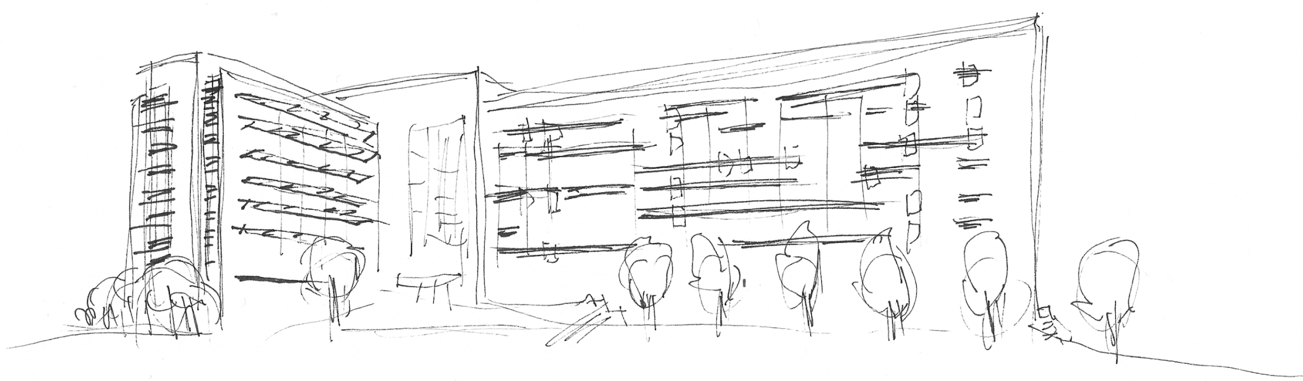
The dawn of nuclear energy turned people further away from solar energy. Until, in the 1970's, when other energy forms hit a crisis. It wasn't until then that reformist groups began to embrace solar energy as having "sufficient potential for changing the institutional structures of the country so that some of the powers find it threatening."[4] This idea has since grown into a potential way for us to combat global warming and increase self-sufficiency. And not unlike the Greeks and Romans, we see a new awareness of solar power as a viable energy source for the 21st century.

Passive Solar at Prince Frederick Hall

> **"The aesthetic goal in any composition is to achieve synergy, where all the elements are so well composed that the whole exceeds the sum of its parts, giving the composition a transcendent quality… passive solar architecture using the theme of comfort, health and sustainability is becoming the architecture of the twenty-first century."**
>
> -Passive Solar Architecture Pocket Reference[3], page 79

The most important goal of the architectural changes applied to Prince Frederick Hall was to create a more comfortable and more energy efficient space. Therefore, the form of the solar shading devices was determined solely by their functionality. In the previous mechanical breadth section, shading devices are defined for use on this building. In this architectural breadth these functionally defined shades are added to the existing building, where other changes have also been made to the facade for a unified composition.

Conceptual Design



Existing Facade

Passive Solar Facade

References

[1] Brownson, Jeffrey R. S. *Solar Energy Conversion Systems*. 1st ed. Oxford, UK: Elsevier, 2014. Print.

[2] Grondzik, Walter T., Alison G. Kwok, Benjamin Stein, and John S. Reynolds. *Mechanical and Electrical Equipment for Buildings*. 11th ed. Hoboken: J. Wiley & Sons, 2010. Print.

[3] Haggard, Kenneth L., David A. Bainbridge, and Rachel Aljilani. *Passive Solar Architecture Pocket Reference*. Ed. D. Yogi Goswami. London: Earthscan, 2009. Print.

[4] Perlin, John. *Let It Shine : The 6,000-year Story of Solar Energy*. Novato, CA: New World Library, 2013. Print.

[5] Spitler, Jeffrey D. *Load Calculation Applications Manual*. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2009. Print.