Lighting Design - Weekly Blog

Week 4

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Tracing the Sun

Tracking and Designing With Daylight

The workshop for week 4 focused on the relationship between the sun's behaviour and the lighting conditions of both the interior and exterior of a building. The first part explored the use of two-dimensional sun paths. The first exercise used a gnomon to track how the shadow a building casts changes through the year and day. The second exercise used a sun path diagram of Edinburgh to determine the azimuth and altitude angle.

The importance and application is demonstrated through the images on the right. This was from an assignment completed in my undergrad. The objective was to model a space (see Figure 2 for dimensions and scale), design windows based on floor area and window-to-wall ratio, and explore the effects of horizontal and vertical shading devices. Figure 2 shows the specifications and calculations to determine the proper sizing.

Figure 3 shows how the sun path diagram was used to predict the sunlight entering the space. The over and under heated periods of the year were determined for the location (Boston, MA, USA), and the orange shading on the left diagram shows the time of year where shading is needed to prevent unwanted heat gains. The purple and blue shading represent the effectiveness of the shading devices. Figure 1 shows how light enters the space based on a physical model. The window's orientation is south-west, so none of the harsh eastern sun during the morning hours enter the space. The shading devices effectively block unwanted sun during the overheated seasons.

This assignment demonstrates one way designers can use simple diagrams to inform decisions that have a major impact on the lighting conditions in a room.

The second part of the workshop focused on using a model of rectangular space to study the same phenomenon with a larger focus on the openings themselves. Starting with simple, square openings, then exploring how patterns and unique designs impact the space.

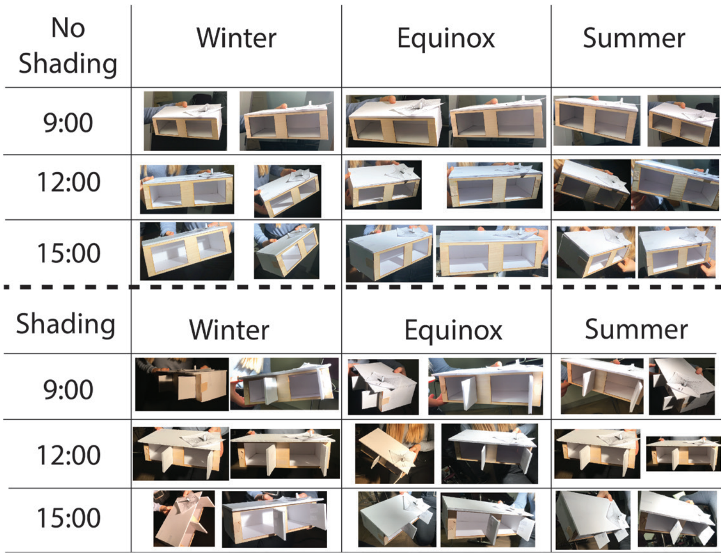


Figure 1: Photos of Sample Room at Different Times of Day and Year

Dimensions	Feet	Inches	Area (in²)
Long Wall			
Length	40	10	30
Height	12	3	
Short Wall			
Length	20	5	15
Height	12	3	
Base			
Length	48	12	72
Width	24	6	

Floor Area (in²)	Required Glazing (in²)
50	17.5

Window Dimensions	
Width (in)	3.5
Height (in)	2.5
Area (in²)	8.75
Amount	2
Total Area (in²)	17.5

Distance from middle of window to edge of overhang: 3.25 in

Conversio	1/4" = 1'- 0"

South-Glazing Area as Percentage of Floor Area:	35%

Full Shade Angle
65°

Overhang Altitude Angle
25°

Overhang Azimuth Angle
40.2°

Vertical Fin Azimuth Angle
27°

Shading and Dimensions	Length (in)	Height (in)	Width (in)
Horizontal Overhang:	10	–	2.75
Vertial Fins:	–	2.5	2.3

Example Altitude Calculation : 90° - 65° = 25°

Example Overhang Azimuth Angle Calculation: $\tan^{-1}(2.75/3.25) = 40.2°$

Figure 2: Calculations for Optimal Horizontal & Vertical Shading Devices

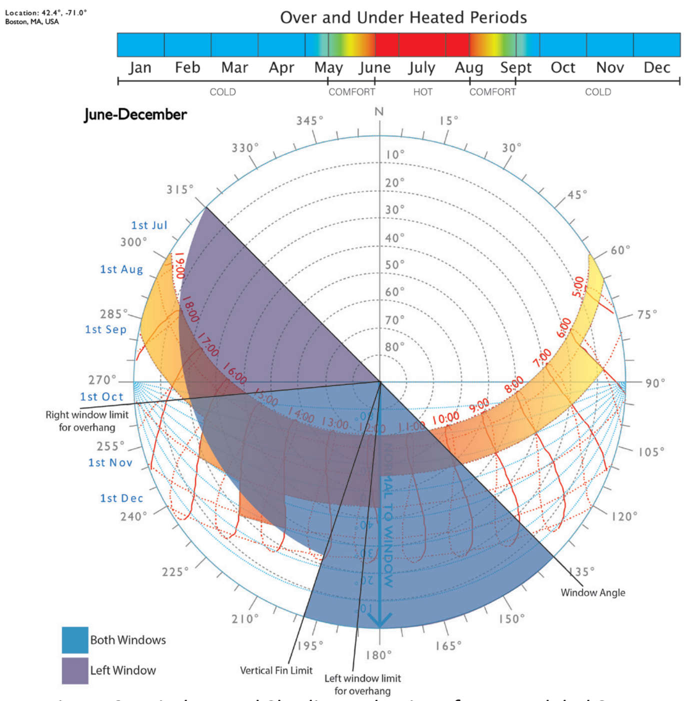
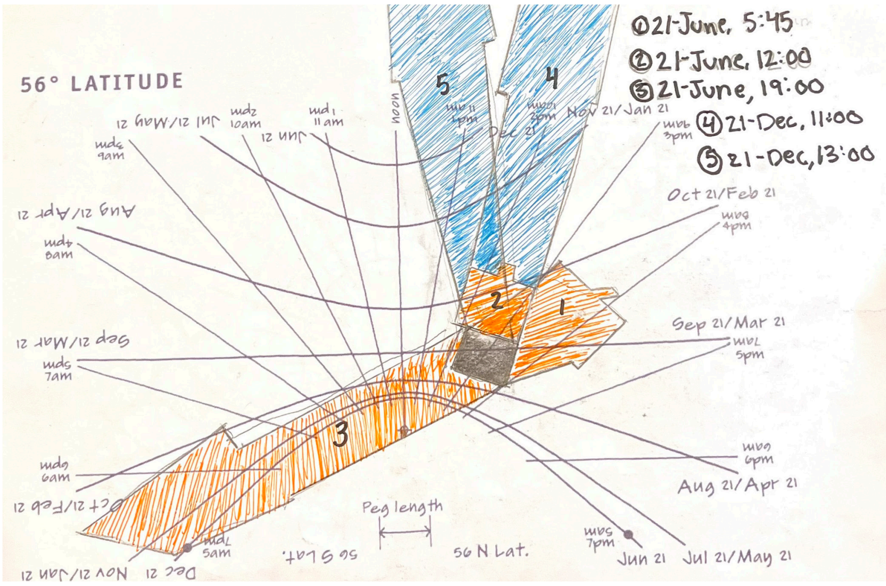


Figure 3: Window and Shading Behaviour from Modeled Space

Task 1: Using a Gnomon

Tracking the Building's Shadow

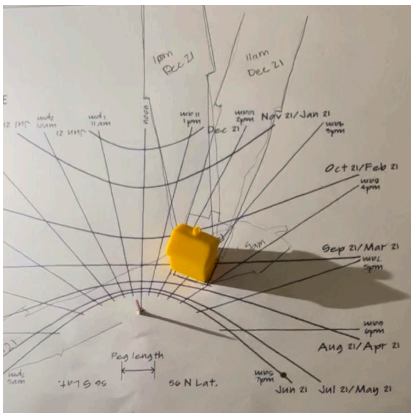
Task 1 involved using a model house (in the form of a Monopoly hotel piece) and a pin to study its annual shadow behaviour. The pin and house were placed in their respected locations, and a flashlight was used to cast a shadow of the pin to follow the typical sun-path for a given day (summer (orange) and winter (blue) solicits in this exercise). The resulting shadow from the building simulates real-life conditions. The image on the right shows a sketch of the shadow when sunlight is available on these dates for in Edinburgh.



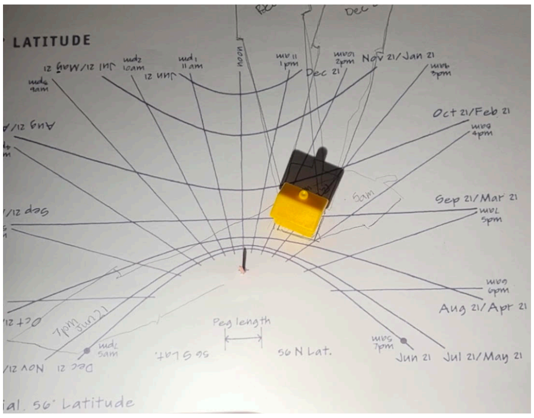
This information can be used when designing a building's form and studying its relation to the site and adjacent buildings. For example, if a large new development were to insist on a structure significantly taller than the surroundings buildings, the architect could use this technique to negate concerns by showing the building will not cast unwanted shadows, or the concerned neighbours could show that they are poorly affected by it and argue against the new development.

21-June

The images on the right show the shadow at sunrise (left) and midday (right) on 21-June. The building faces southeast. In the morning, the sun is low and the shadow is long, pointing to the west. At midday, the sun is high and, the shadow is much closer to the building. The 19:00 shadow show on the sketch above is the longest.



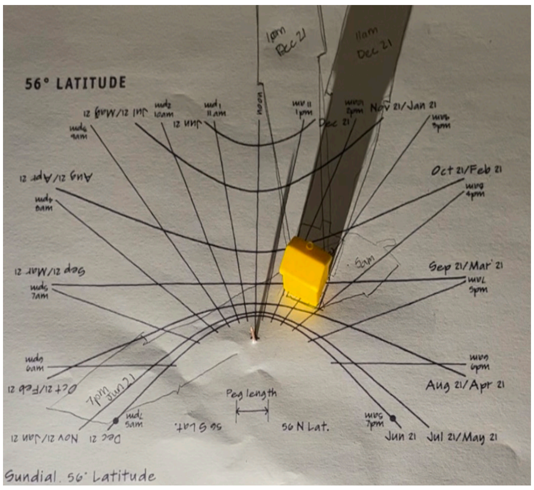
21-June, 5:45



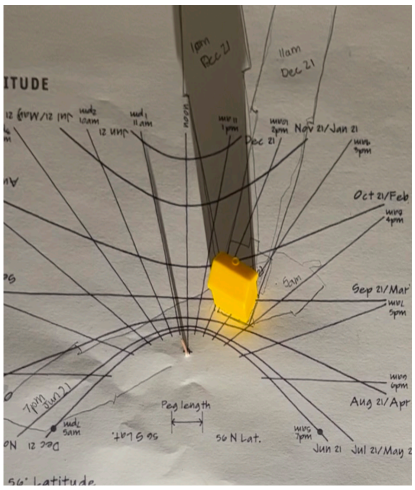
21-June, 12:00

21-December

The images on the right show the shadow in the late morning (left) and early afternoon (right) on 21-December. Compared to summer conditions above, the shadows are longer due to the smaller altitude angle and shorter days. In addition, its path has a much smaller radius than the summer conditions; lacking sharp east and west shadows.



21-Dec, 11:00



21-Dec, 13:00

This exercise demonstrated how a building's shadow changes throughout the year and day. It is an important tool when studying how a building interacts with its surroundings. While this can be simulated on computers, manually sketching it allows for a better understanding and interpretation.

Task 2: 2D Sun path Diagram

Azimuth and Altitude Angles

Task 2 was about using a 2D sunpath diagram to determine the azimuth and altitude. While the diagram in task 1 pertained to studying how to the building's shadow reacts to the site, this diagram demonstrates how the sun interacts with the building.

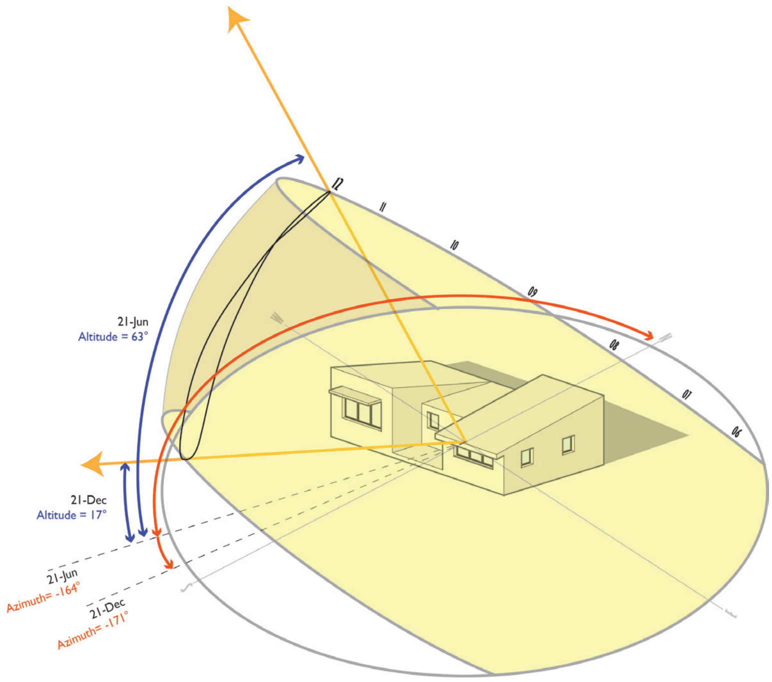
This is important in designing for daylighting because it informs the designer how light will enter the space. If the location is at a much lower latitude, the sun will be higher in the sky, and the spaces will receive more overhead, direct lighting. At higher latitudes, they will receive lower-level, often diffused beams. The exercise mentioned previously demonstrates how it can be used to design shading devices and allow sunlight to enter at desired times.

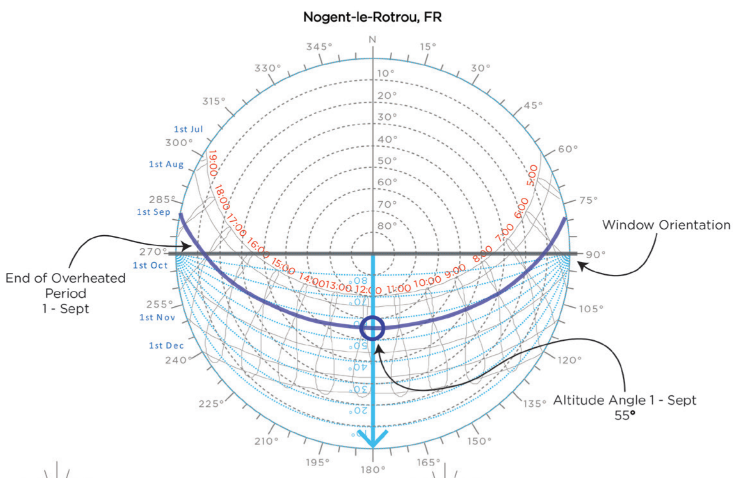
The 2D chart can be transformed into 3D skydome to give a clear understanding of annual sun patterns.

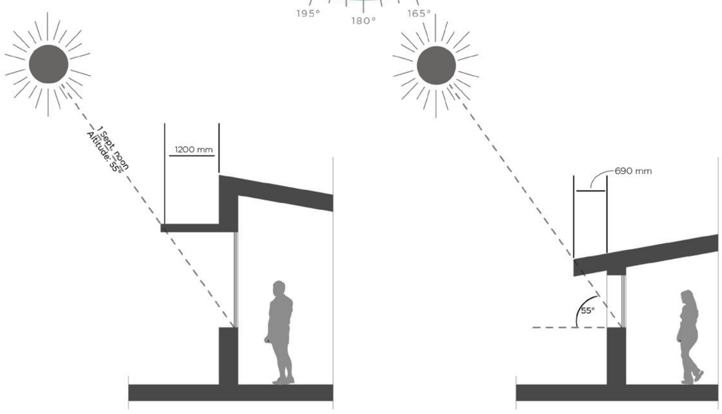
The image on the right shows a sky dome placed over the building for a project in Sustainable Theories and Context. The sun path is marked for winter and summer solstice in the curved black line.

In the winter, the solar radiation is weak in the morning and evening because the altitude angle is quite low. However, during the hours of 9-15:00, the building can gain an adequate amount of solar radiation. This suggests that southern glazing and thermal masses can absorb energy for passive heating.

In the summer, there is a plethora of solar access throughout the previous noted hours. Therefore, it is vital to protect again these rays and prevent excessive solar gains.







To design overhangs to block summer solar gain and allow for winter sun, the over and under heated periods were studied using a 2D sun path diagram.

1-September was determined to be the last day of the overheated period in the summer. The solar path of this day is noted in a thick purple line on the sun path graph on the left.

The orientation of the window is facing directly south, as noted in the gray line. A light-blue arrow points normal to the orientation of the window. The intersection of the two is circled.

This angle is the highest altitude angle on 1-September, approximately 55-degrees. From here, desired overhangs were drawn to ensure this light would not penetrate.

On 31-August, when the sun is higher, the rays will be blocked. On 2-September, when the sun is lower, it will be allowed to enter the space.

Task 3: Testing

Sunlight Entering a Space

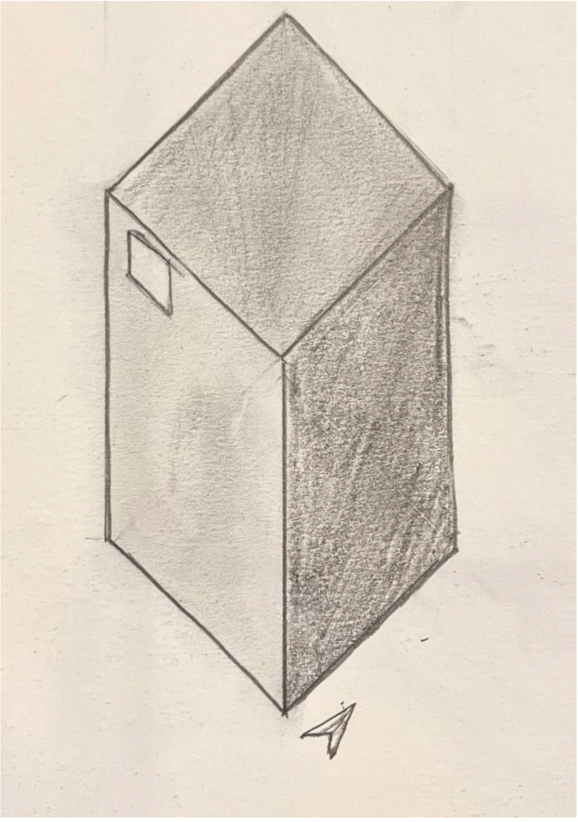
Task 3 involved creating a model of a square room 150mm x 150mm and 200mm in height with a 40mm x 40mm opening. The location of the window was chosen to be in the upper-left corner of the southern facade.

The pictures below capture the conditions at midday for 21-June (left) and 21-December (right). The sun in the summer months is much higher in the sky; the light entering the space reaches a lower level, and the area of glare is longer than winter conditions. Because it reaches the floor, it could cause more glare to the occupants since it is closer to eye level.

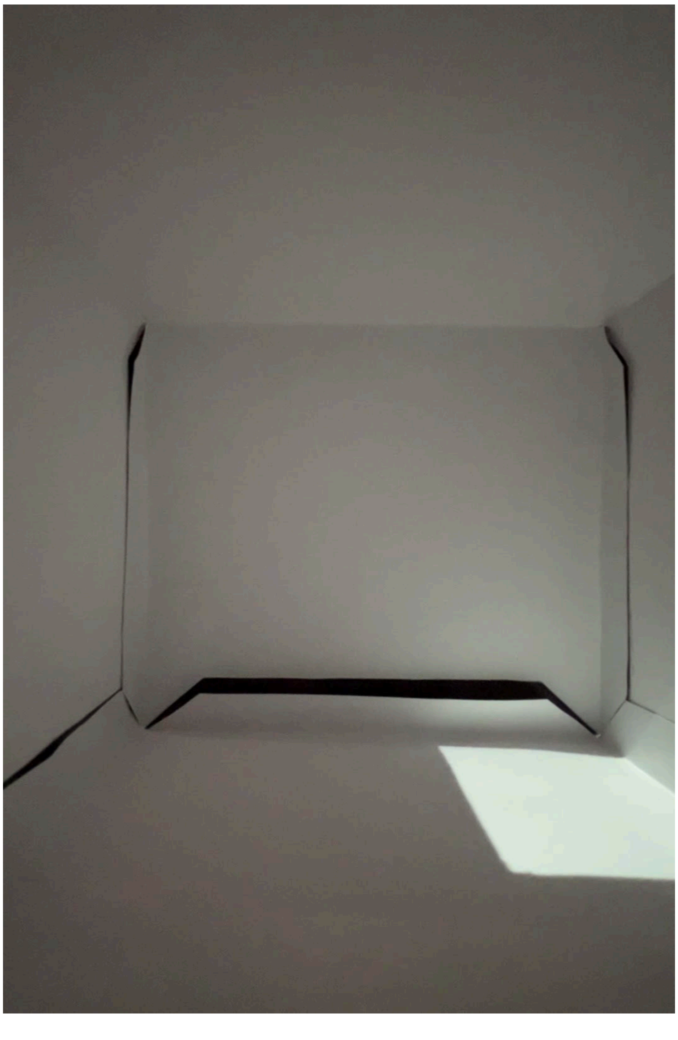
The winter sun is much lower in the sky, so less sunlight enters the space. Because the glazing is high on the wall, there is little potential for discomfort at the occupant's eye level.

During the Spring and Autumn months (April and August/ September), the sun is nearly level to the window, resulting in a nearly perfect square spotlight on the back wall. There is less diffused light than the summer and winter months, so these seasons have the most potential for harsh glare.

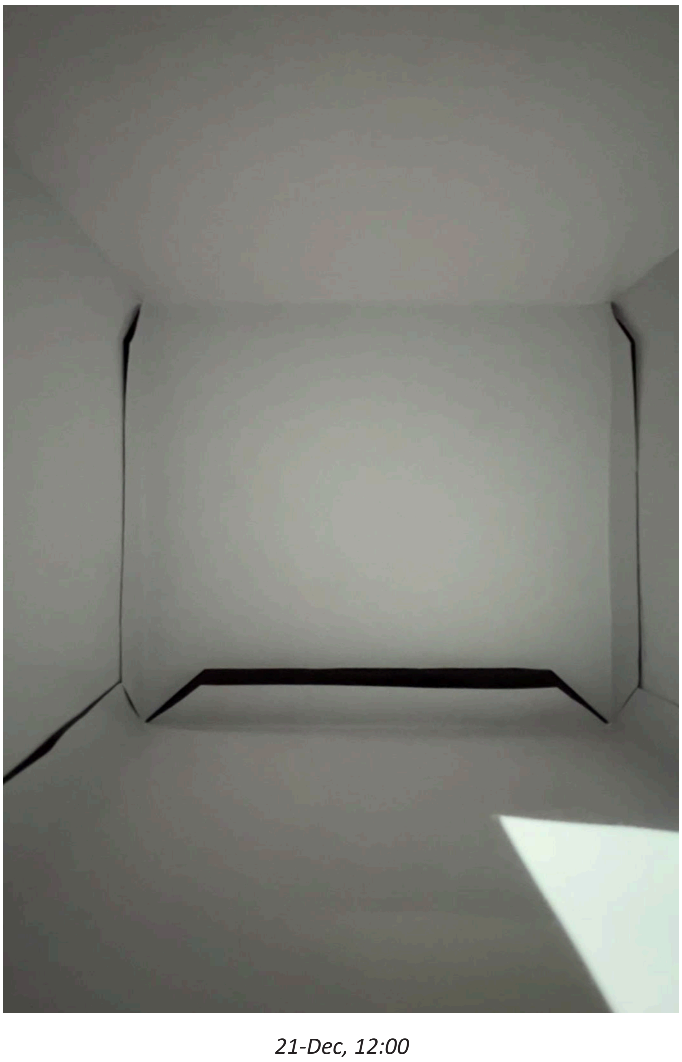
While there was no scale given in the exercise to simulate an actual space, this exercise suggests that having glazing only at high levels on the southern facade is not ideal for Edinburgh that can benefit from natural daylight and passive solar gains.



Sketch of Space and Window Placement



21-June, 12:00



21-Dec, 12:00

Task 3: Testing

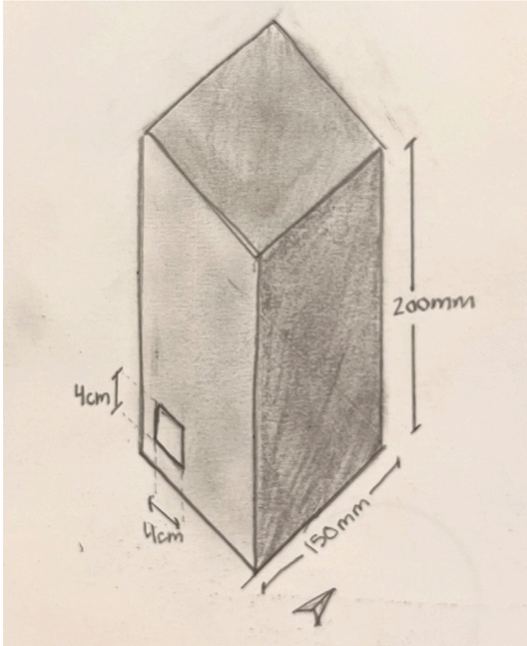
Sunlight Entering a Space

A second study was done with the model flipped upside down to study the conditions of glazing at a lower height. The results are nearly opposite.

In the summer, there is a concentrated and relatively small spotlight on the floor. This would cause the most glare for occupants due to the lack of diffused light. Moreover, the rest of the room receives relatively darker conditions than in the winter.

The light in December is spread across the floor and reaches the back wall. Overall, the space is brighter, and the light is more diffused.

The conditions in the Spring and Autumn months fall in between these two conditions. As the months get closer to the summer solicits, the spotlight gets smaller and more direct, and the space feels darker and filled with shadows.



21-June, 12:00

21-Dec, 12:00

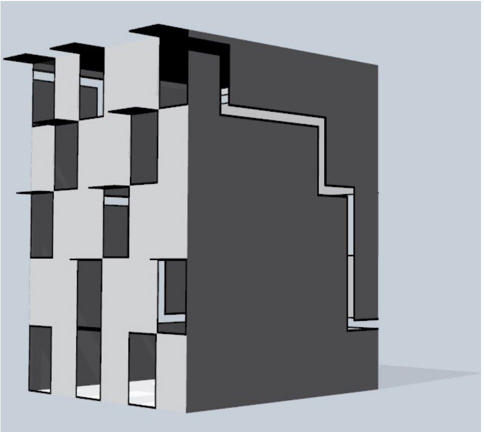
Overall, the design with the windows at a lower height is more conducive to Edinburgh. Buildings in Scotland can have tremendous benefit from natural light and passive heating. Designers can be wary of glare while optimising these conditions. The second iteration allows for the most light to enter in the winter when it is needed. Without the addition of shading devices, less light enters in the summer to minimise unwanted heat gain. This exercise demonstrates the importance of window placement on a building for both lighting conditions and passive heating control.

Task 4: Designing Facades

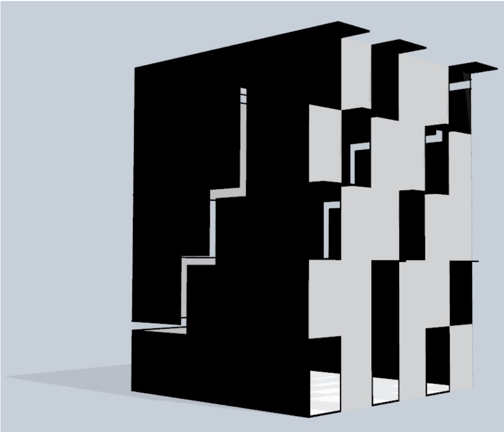
Lighting a Path

In Task 4, the a box of the same dimensions was used to create a unique space and studying how the space changes throughout the year. This includes the addition of windows, overhangs, and light paths around the shape. After designing the openings in each of the facades, the same study as task 4 was performed.

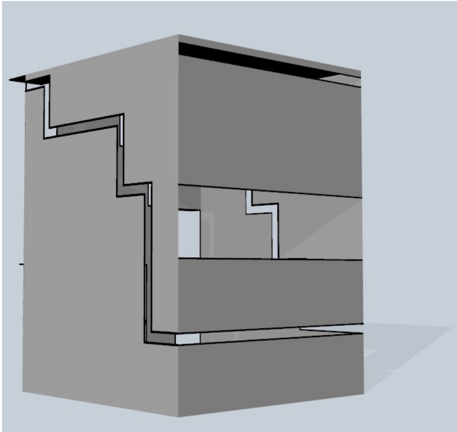
Designers have the opportunity to optimise lighting for internal comfort conditions and lighting levels, as well as energy use. Moreover, creating unique spaces can enhance the occupant's experiences that harnesses the power of dynamic daylighting to create a standalone art piece. These conditions can change throughout the time of day and year based on the designer's intent and use of the space.



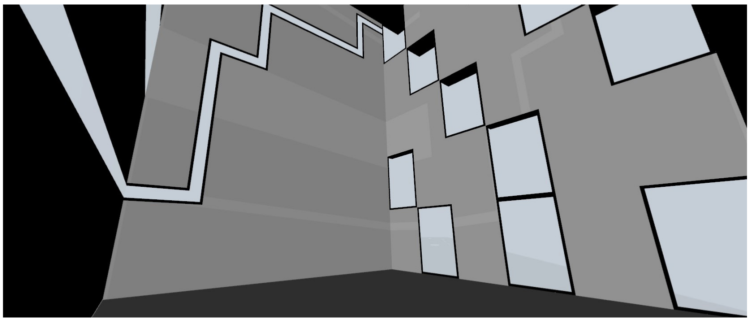
South and West Facade



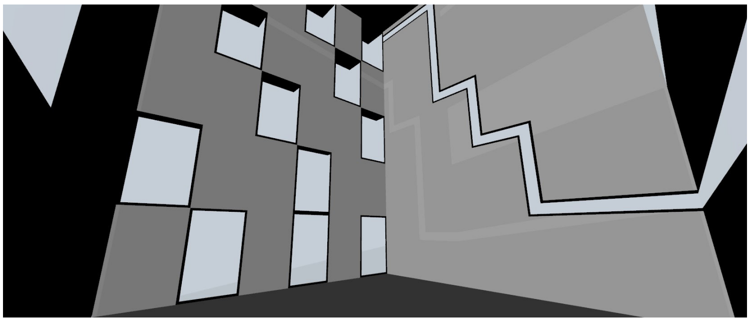
West and South Facade



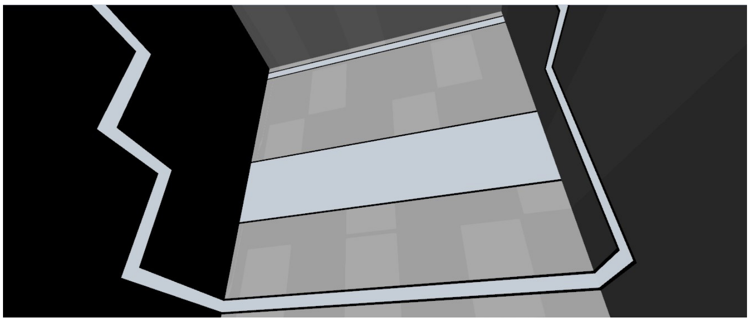
East and North Facade



South and East Interior



South and West Interior



Northern Interior

A digital model of this task was first created and is depicted in the photos above and to the left.

The southern facade includes irregular rectangular openings with overhangs. Vertically, they are spaced between five even rows. The openings on the higher row have larger overhangs and decrease in size moving to the bottom. This was done because the results of task 3 yielded more appropriate conditions that fit the space and climate. The larger overhangs near the top will reduce the lighting they allow enter the space.

The eastern and western facade has a thin opening that steps from the bottom of the box near the southern facade and steps to the top as it nears the northern facade. This was done to roughly mimic the path of the sunrise and sunset.

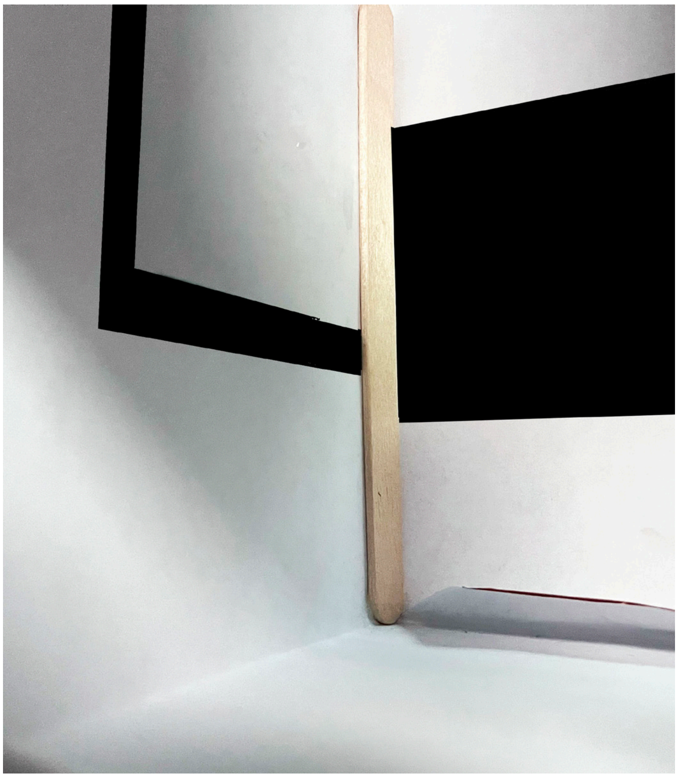
The northern facade connects these openings to create a continuous wrap around the space. In addition, there is a rectangular opening in the middle of the facade to capture the defused lighting the northern facade receives.

Overall, the aim of the lighting design was to create a unique space that celebrates the sun's pattern throughout the time of day and year.

Task 4: Designing Facades

Lighting a Path

The image above shows the lighting conditions in the winter at midday. Compared to the previous tests with only one opening, the space is much brighter, and direct light is able to reach the floor. There may be glare in certain spots, but it does not seem to be as problematic as summer months. This being said, the pattern from the light path does not reflect on the wall.

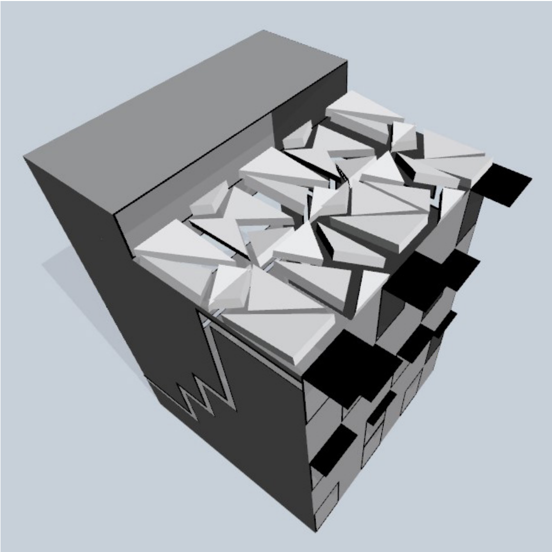


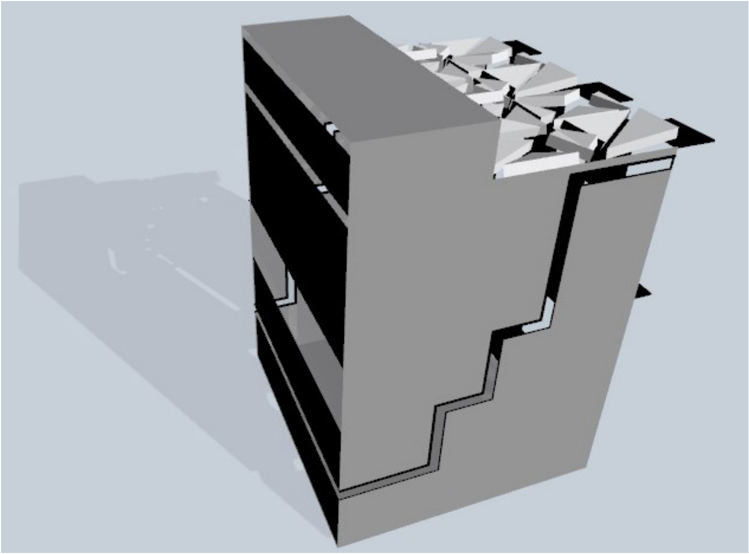
The image above shows the lighting conditions in the summer at midday. Compared to the winter conditions, the glare is higher in the space, and the lighting path is more clearly reflected on the wall. Whether the glare is improved depends on the scale of the space and where eye level is located.

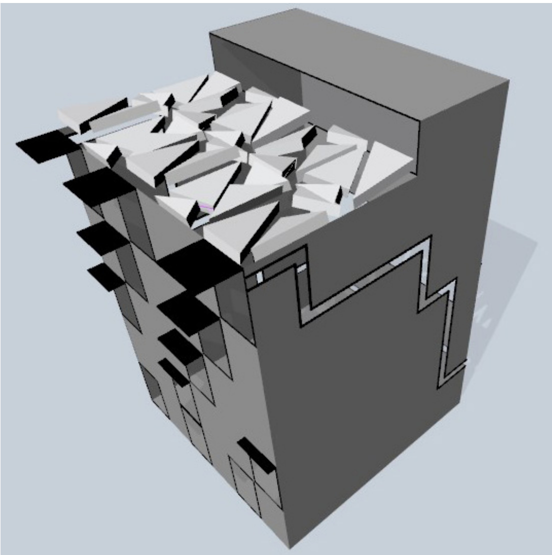
The image to the left shows the lighting conditions at April and August at midday. Compared to December and June, the results are the most successful. The lighting path pattern is clearly reflected and celebrated onto the wall. In addition, there is more defused lighting than the previous tests, which makes for a more evenly lit and comfortable space.

Task 5: Designing Skylights

Lighting From Above



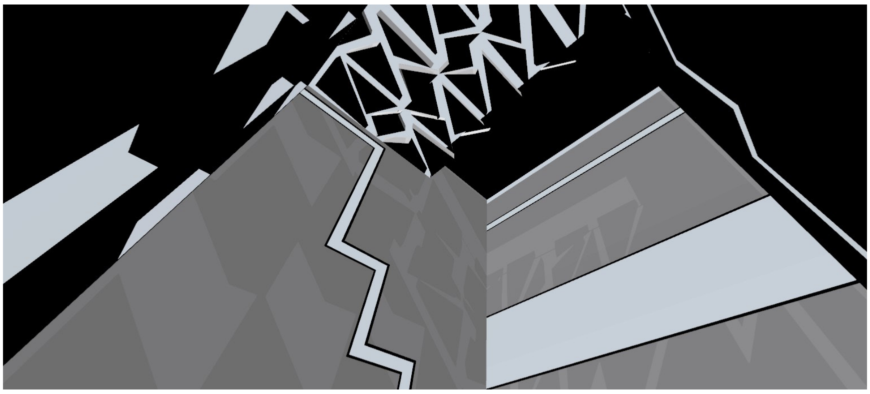


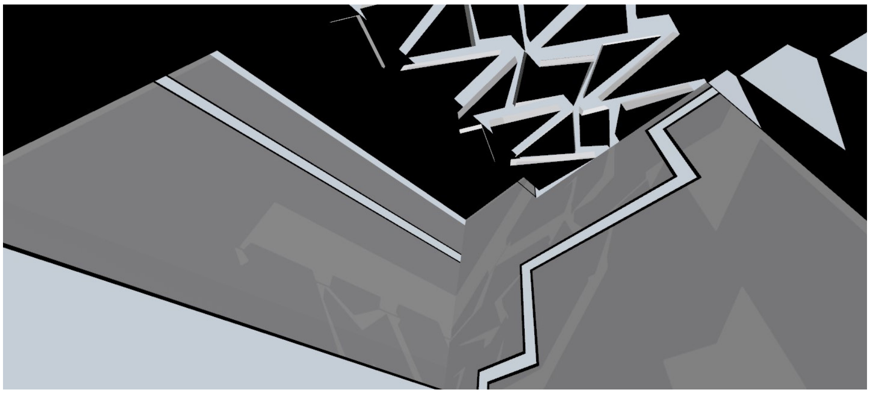


Task 5 took the design from Task 4 and added a skylight component. The same sun path study was conducted.

The light entering the space from a skylight are made up of two components: the defused light from the blue sky and direct sunlight. The latter can cause uncomfortable glare and excessive lighting levels in some skylight designs.

In addition, skylights can be a source of unwanted heat loss and gain; this is especially pertinent to heating dominated climates since heat can escape through glazing as it rises. In the summer, a horizontal glazed surface will receive much more radiation than a vertical opening and lead to more unwanted heat gain.





This being said, a carefully designed skylighting scheme can yield a successful, unique, and energy efficient space.

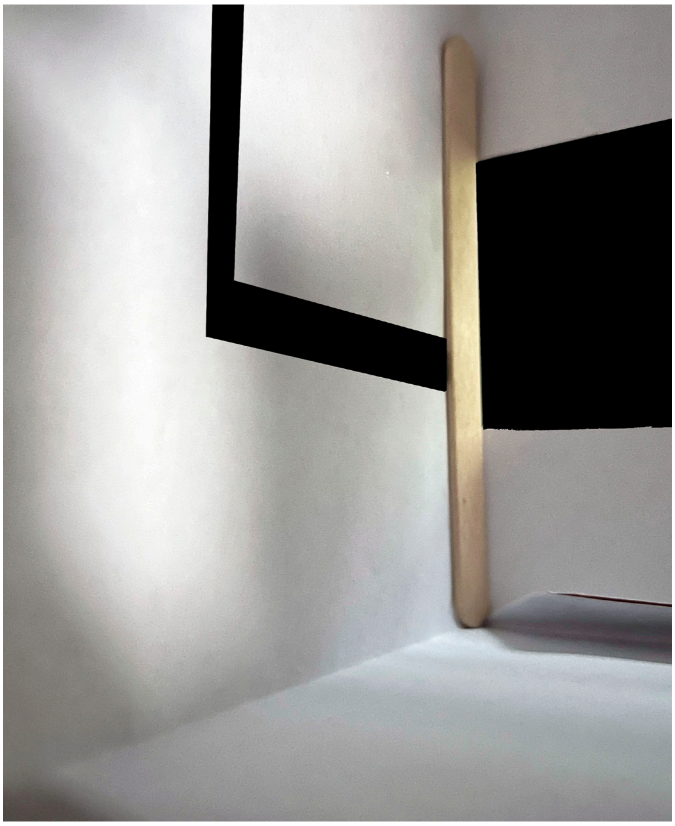
A digital model of this design can be seen in the photos above and to the left. The front portion of the surface has several triangular surfaces tilted at various angles. The aim was to create an irregular pattern and direct the sun in a variety of directions. The other surfaces of the space, while irregularly spaced, follow 90-degree angles. This patterns adds chaos and excitement.

The back portion is a clerestory. The aim was to shine direct lighting to the upper portion of the back wall to light it vertically and provide even, diffused light to the space.

Task 5: Designing Skylights

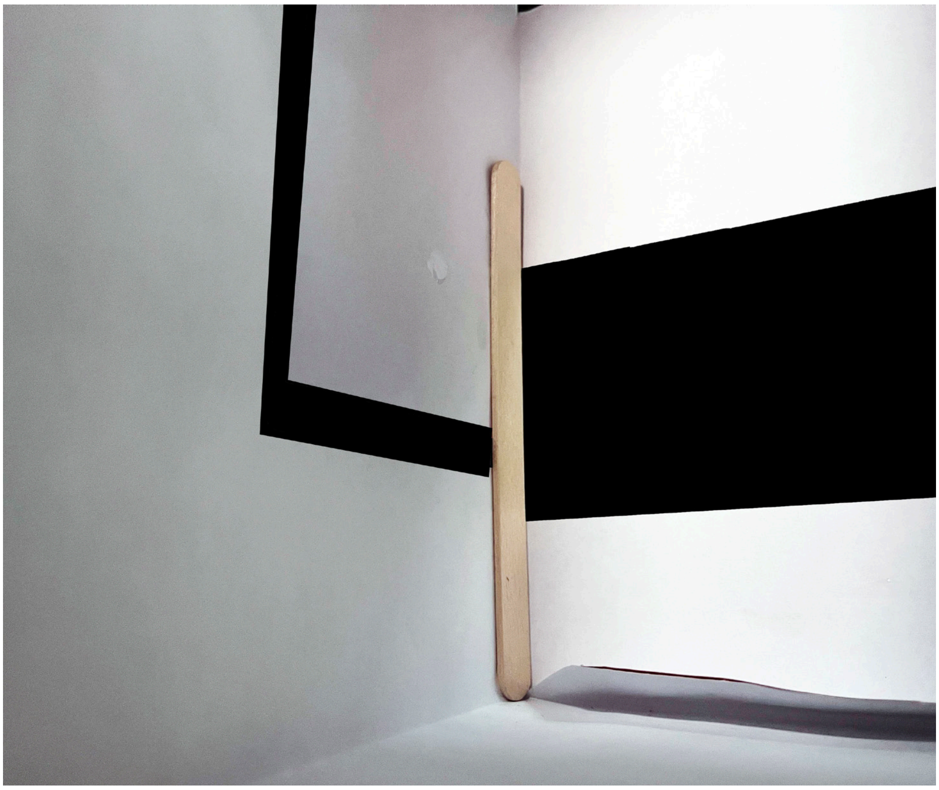
Lighting From Above

Using a physical model, a 4 cm x 4 cm square opening was made on the roof. Using a flashlight, the midday position of the sun was studied. Edinburgh has a wide variation of sun conditions throughout the year, so it is important to study the lighting patterns on a monthly and seasonal basis.



The month that allowed the least light into the space was December at 9:00. The sun is very low in the sky, and the lighting path orientation and pattern did not allow much direct light to enter the space.

The month that allowed the most light to hit the floor was June at 12:00. The sun is the highest in the sky, so it can fully infiltrate all of the south-facing openings, as well as the skylight. Direct light is allowed to hit the floor.



The months that allowed the most light to hit the back wall was June a 3pm. This is also the time that caused the most glare. The sun is coming off of its peak, but is still very high and powerful in the sky. This also casts rays closer to the floor. Assuming this is more at eye level, uncomfortable glare may occur during this time of day. The physical model was not constructed with overhangs, which may prevent the problem.

To maximise the natural light received on the underside of the ceiling, measures like light shelves and three-dimensional reflectors could be used.