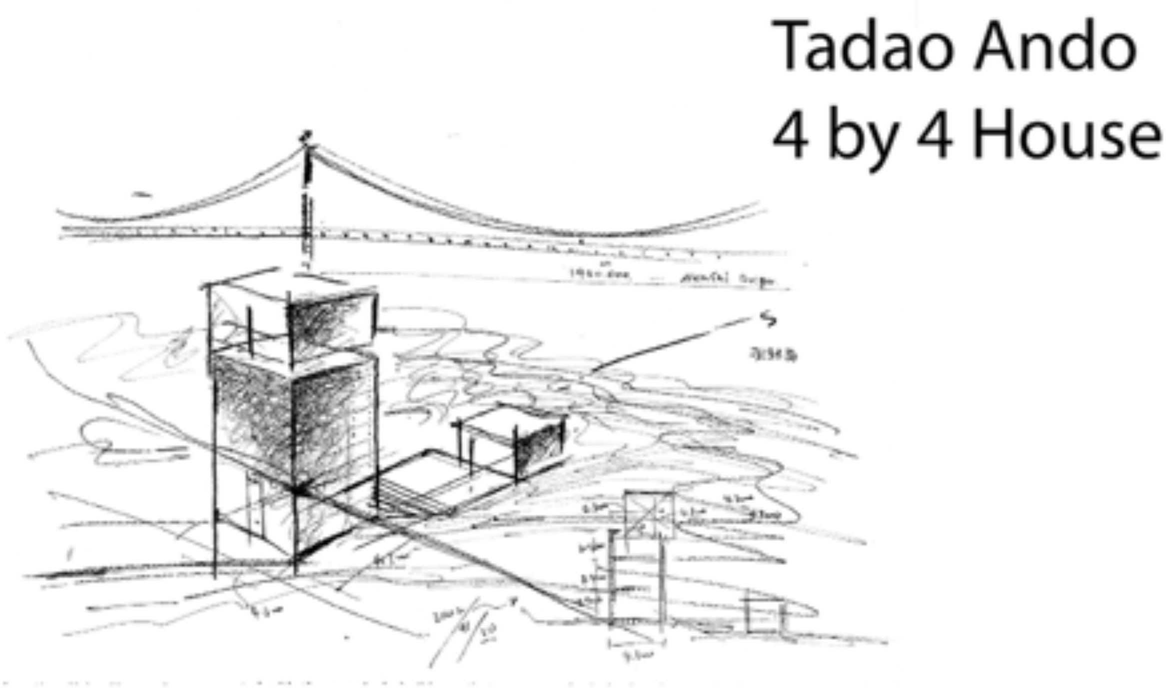


Building Physics: Lighting Report

Lighting Analysis of 4x4 House

Kobe, Japan.

Jingyi Zhu, Isadora Martins, Yushan Liu

Table of Contents

Building Overview

Site and Location

The 4x4 House is located in Hyogo, Kobe, Japan, across from Awaji Island, the epicenter of the Kobe Earthquake. The house is made of two boxes on top of each other on a 22.56 m^2 site, given the small site of the project, the building itself measures 4.75 m on both sides, leaving just enough space for a parking space next to the building. A small site is common in urban Japan.

Layout

The house has four floors each programmed for a different function. The basement is used for storage, service and access on the ground floor, bedroom on the first floor, study on the second and kitchen and dining room on the top floor. All spaces are connected by the stairs which are located on the left side of the building and almost all of them are completely enclosed on three sides but the fourth floor which is opened to face towards the sea. The big windows on the south side of the building allow sunlight to come in during the day in the kitchen and dining room and the study room. While the enclosed spaces on the basement and first floor creates a private space for the bedroom and bathroom kitchen and dining room and the study room. While the enclosed spaces on the basement and first floor creates a private space for the bedroom and bathroom.

Functional Intent

The first two floors of the building are enclosed with slit windows for adequate lighting inside the house, while the third and fourth floor have bigger windows on the southern side that faces the sea to create a sense of openness to the house. The slit windows near the staircases ensure lighting in the day in conservation of energy, the bigger windows on the top floor create a flow of light in the house and serve as picture frames to the scenery on Awaji Island.

Material Properties

The 4x4 House has exterior walls made exclusively of exposed concrete panels. Exposed concrete is the signature material of Tadao Ando, representing the natural state on concrete and it's connection to nature. Reinforced concrete is used for the structural system of the house. The interior materials include exposed concrete, wood and glass. Again stressing the idea of nature, wood was used for floors and cupboards; the transparent attribute of glass allowed light penetration into the spaces. In this case, glass gave the main character for the 4x4 house by creating a sense of nature through the south window. The morning sun floods into the floors from one side, illuminating the top floor. The noon sun is, however, blocked by the roof which creates a shaded relaxing atmosphere. The evening sun streams through the window on the western side of the building creating a red glow in the interior of the building.

Building Environment

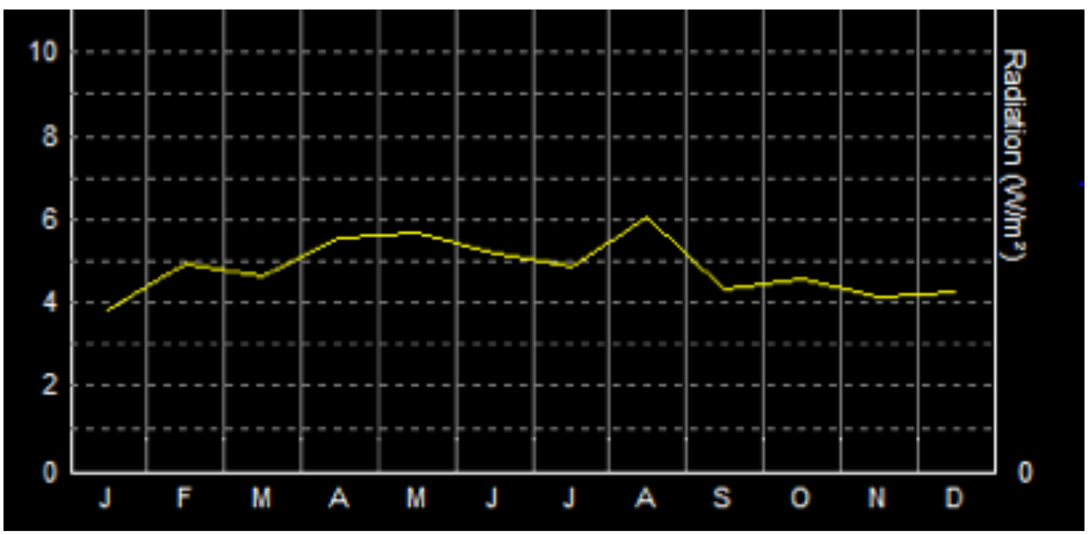


Figure #1: Monthly Radiation

The building is in Kobe, Japan; the nearest city with a usable weather file is Nagoya, Japan. Located in 34.8 N, 135.4 W, Kobe has plenty of sunlight. The radiation chart shows the annual solar radiation, with the maximum of 6043 Wh/m2 in August and minimum of 4126 Wh/m2 in November. Solar radiation is relatively even all year round.Kobe is of a humid subtropical climate, with hot summers and cool to cold winters. Summer is comparatively more humid with higher level of precipitation. Winter is comparatively warm, therefore there's no significant snowfall.

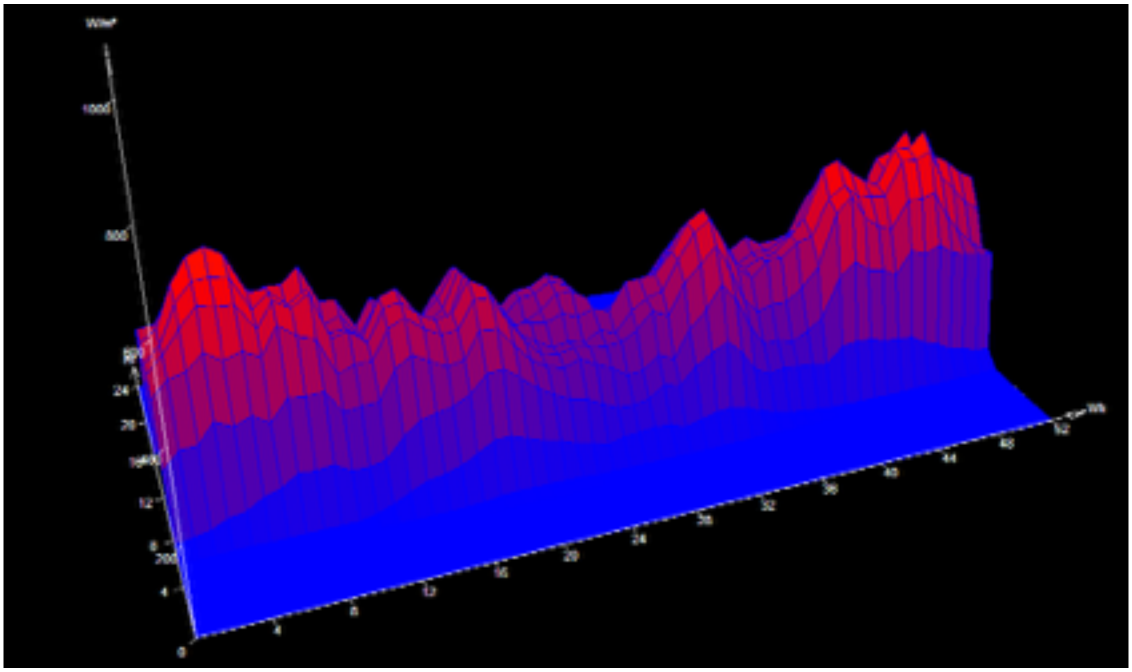


Figure #2: Weekly Direct Solar Radiation

The diagram shows that the site, on average, gets 11 hours of daylight every day.

Figure #3: Cloud Cover Condition

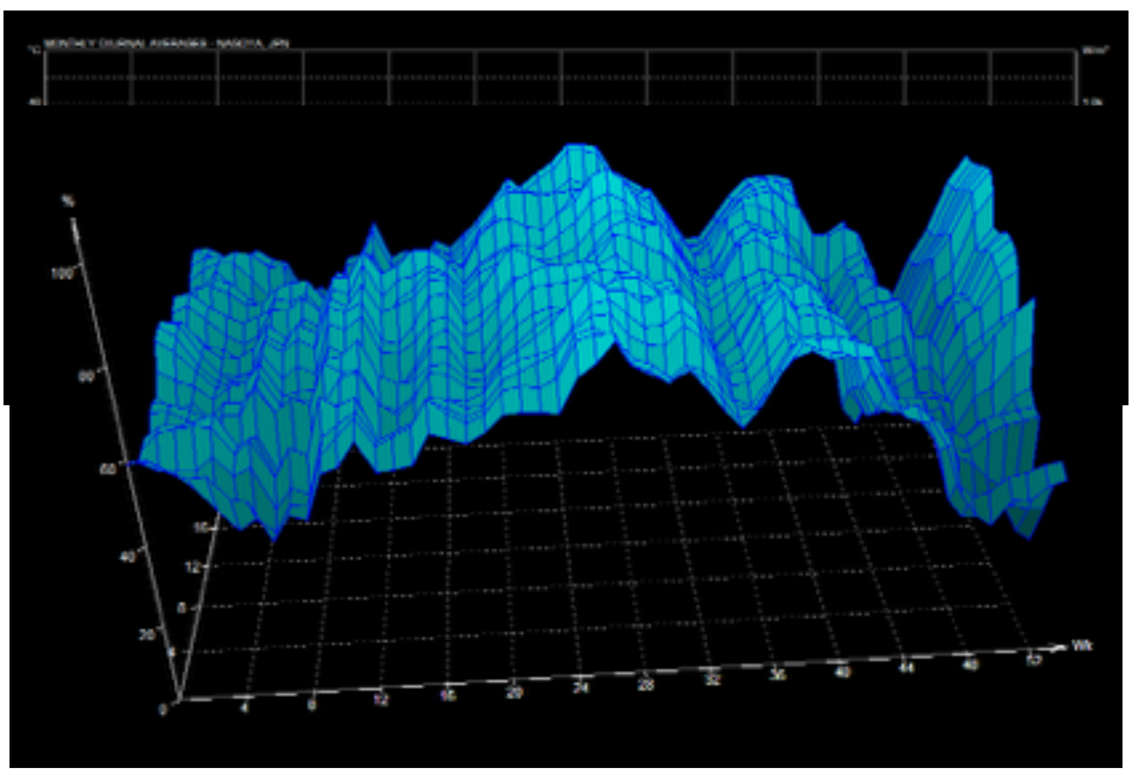


Figure #4: Daily Average

Model Description

The model was built according to elevations, plans, and a detailed section of the building. The height of the building is 13.15 m, with three floors being 2.7 m and the fourth floor being 4.4 m and offset by 1 m to both the south and east. All four floors and the basement are in different zones because of different programs, the stairs are in a separate zone to all other elements in the building. The cube on the top of the building is in a separate zone for convenience in analysis the space.

The exterior walls in the model is set to concrete block render with 110mm concrete block and 10mm plaster inside to represent the exposed concrete, other partitions are set to concrete block plaster or plywood partitions.

Simulation Results Analysis

Solar Analysis

The 4x4 House is situated in Hyogo, Japan, which is generally warm throughout the year. The length of the day varies significantly over the course of the year ranging from 9:51 hours of daylight (shortest day) to 14:29 hours of daylight (longest day).

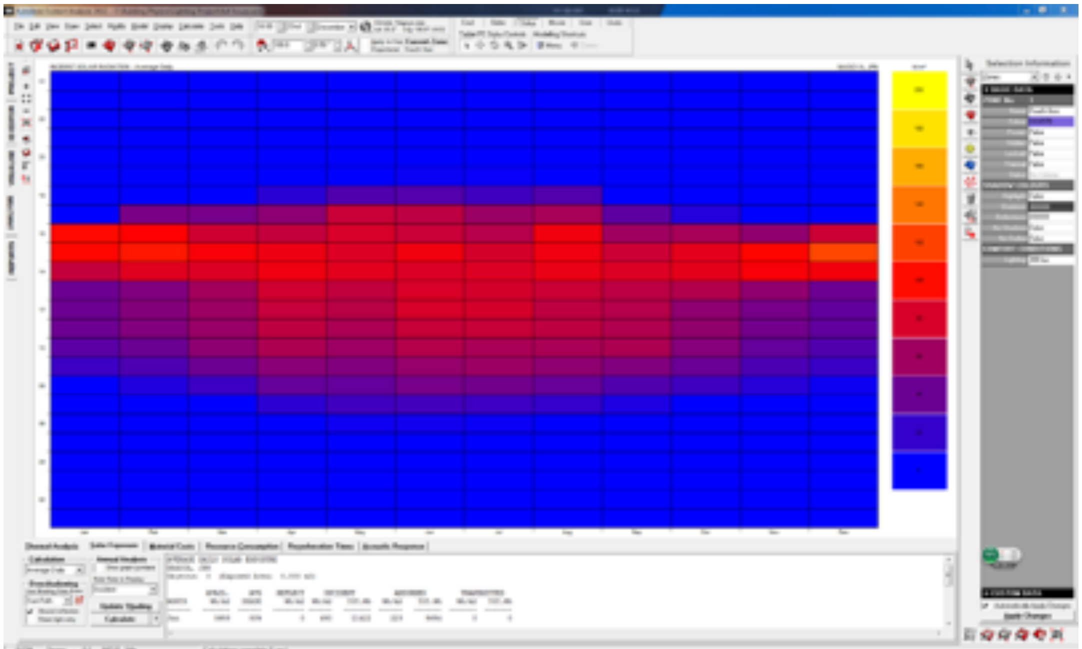


Figure #5: Total Monthly Incident Solar Radiation East Wall

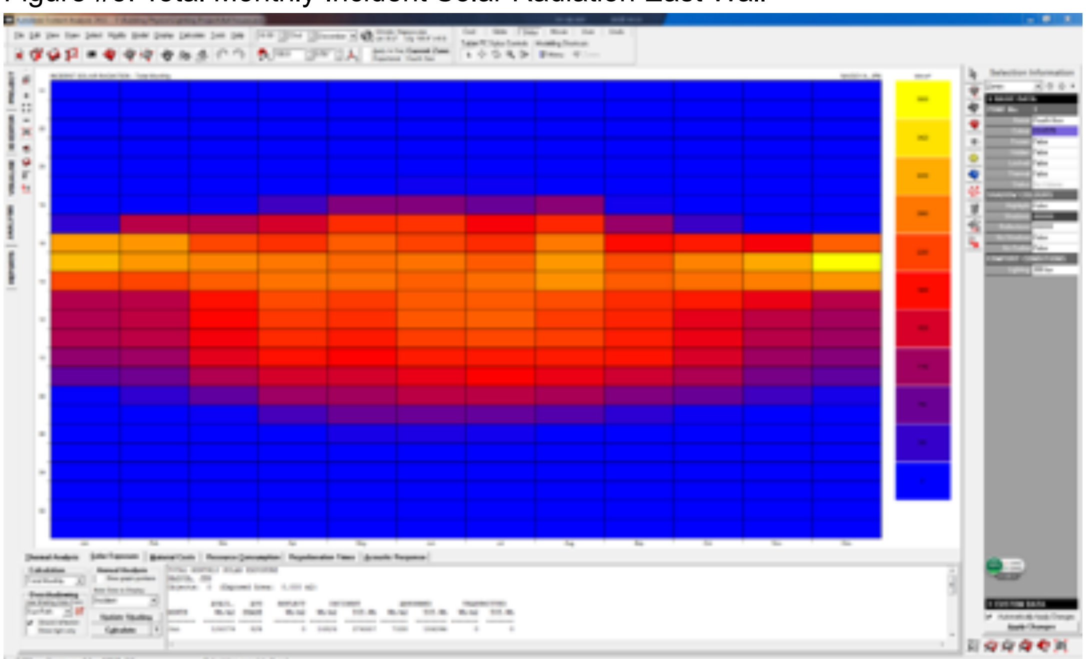
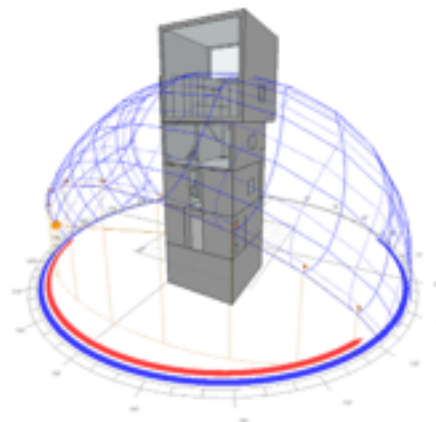


Figure #6: Average Daily Incident Solar Radiation East Wall



The solar radiation of the building is quite low from november to february (shown in the figure above) and it increases as winter ends with an average of 80 W/m2 from 8:00 am to 3:00 pm.

The total monthly incident solar radiation figure was used to analyse the amount of sunlight that hits the east wall of the building throughout the months of the year. The east wall is not the one that receives most sunlight according to the sun path figure (seen below) but we also chose to analyse it considering that that's where the main function of the room is. The figure above shows how the solar radiation on the east wall decreases during winter (Nov - February) and increases through summer.

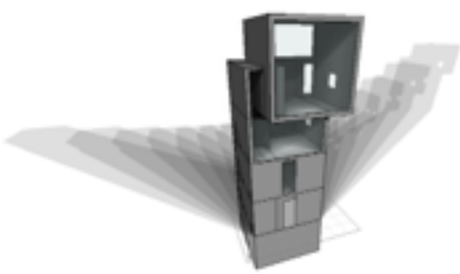


Figure #7: Annual Sun Path

Figure #8: Shadow Range

The figure above shows the shadow range of the building showing how the side of the building that is facing the beach is the side that has most sun exposure

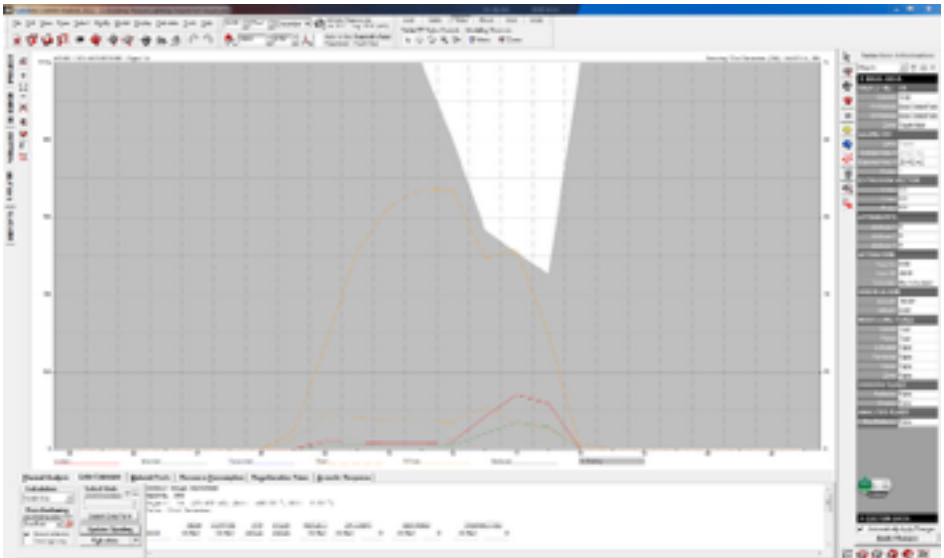


Figure #9: December 22 East Wall Solar Exposure (Winter Solstice)

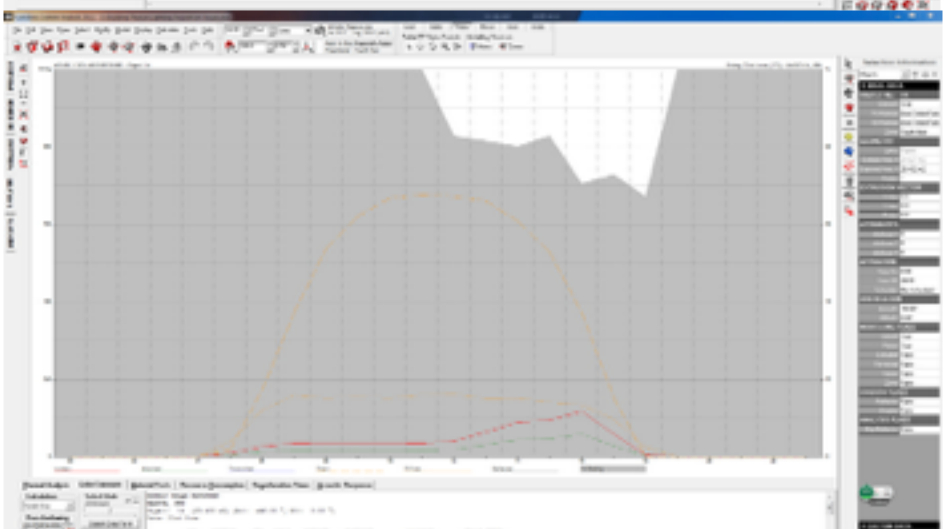


Figure #10: June 22 East Wall Solar Exposure (Summer Solstice)

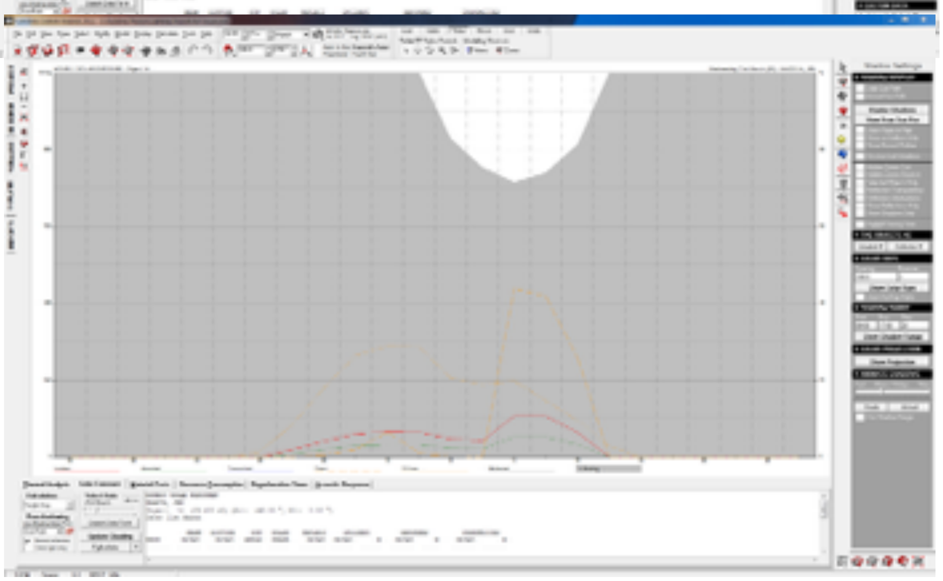


Figure #11: March 21 East Wall Solar Exposure (Vernal Equinox)

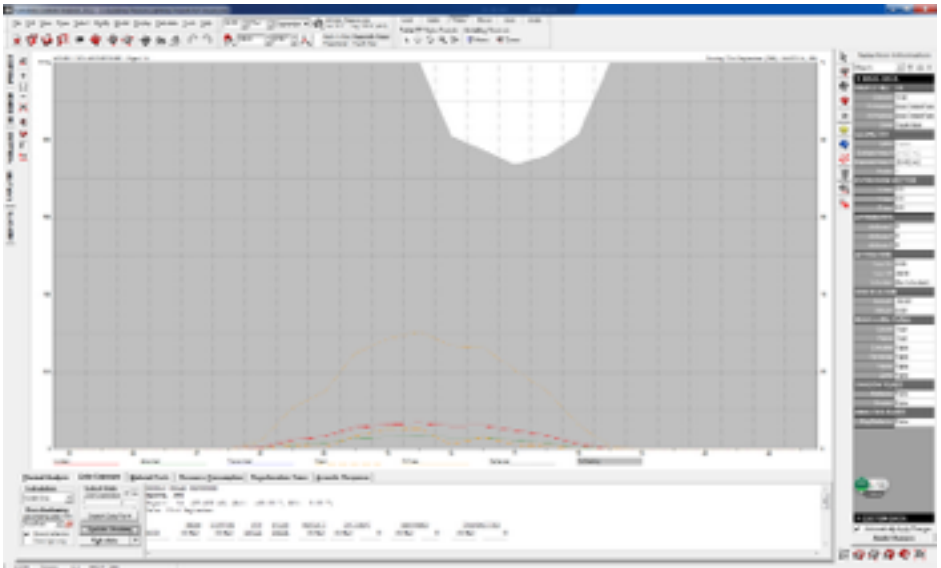


Figure #12: September 23 East Wall Solar Exposure (Autumnal Equinox)

The figures above shows the hourly solar exposure during different days throughout the year. We simulated the solar exposure for summer and winter solstice and found out that during the summer solstice more direct light is available. This is shown by the yellow dashed curve in the June 22 figure which is above 600 W/m2 from 8:00 am to 4:00 pm while the December 22 figure is above it from 9:00 am to 1:00 pm. The Autumnal Equinox shows a very low solar exposure, which doesn't reach 100 W/m2 while the Vernal Equinox figure shows a rapid increase going above 480 from 1:00 pm to 5:00 pm. The Shading percentage is, however, the same between the Autumnal Equinox and the Vernal Equinox while the solstice's shading percentage vary from the Winter Solstice which goes down to 48 % while the Summer solstice only goes down to 68%.

Daylight Factor Analysis

We used the daylight factor analysis to analyse how much sunlight shines on the interior of the building. Two range of percentage of daylight factor were used to show how there might be a more different levels of sunlight shone into the interior of the building depending on the day. The ranges chosen were 20% and 40%. The sky model used in Grid Analysis was an overcast sky model with the illuminance of 8000 lux.

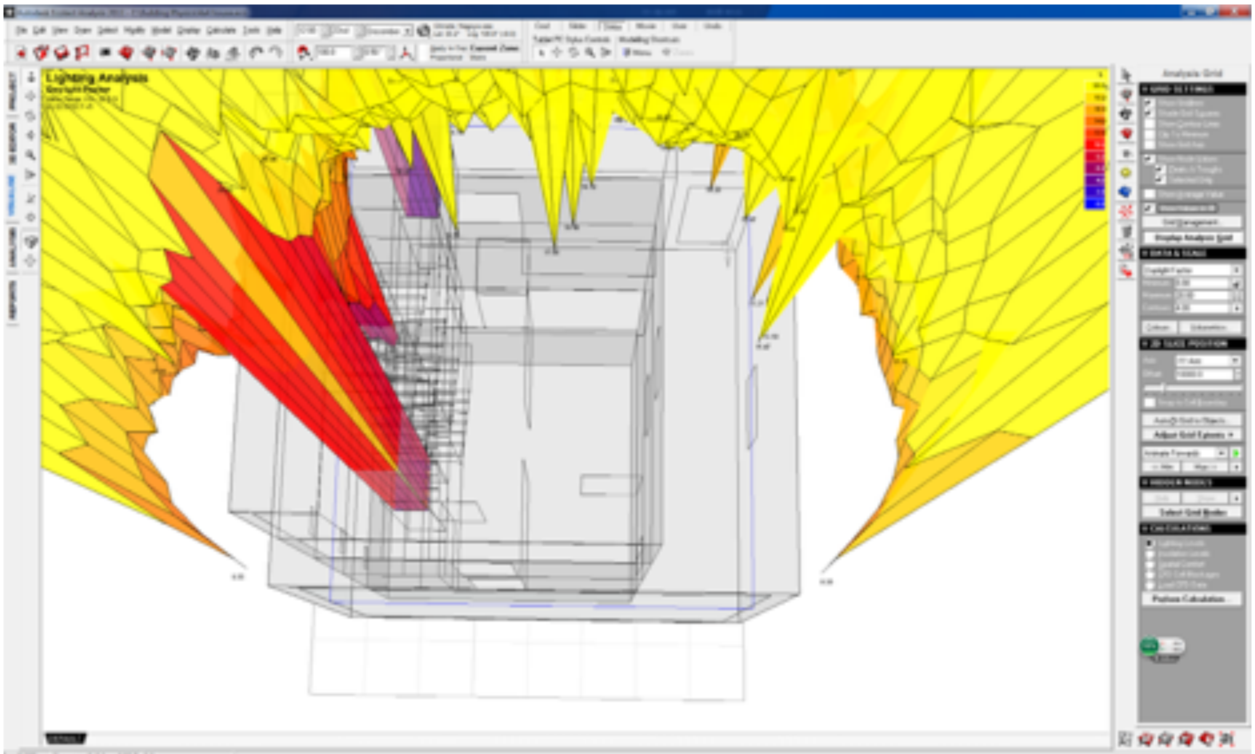


Figure #13: Grid Analysis 3D value- 20%

The figure above shows how much daylight shines on the building and which areas have the most concentration of light. The yellow parts represent the areas that receives most sunlight during the day; so according to the figure above the area surrounding the staircase does not receive a lot of daylight. This makes sense since the staircases are mostly enclosed by concrete walls and have small windows which do not allow a lot of daylight to come through. The areas surrounded by the big glass windows receive most sunlight so most of the area is represented with the yellow marks.

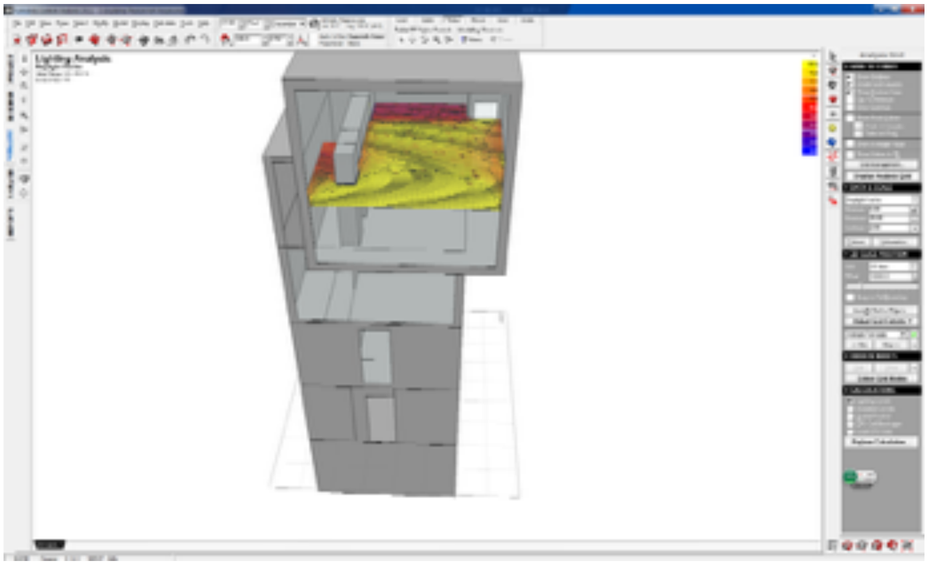


Figure #14: Grid Analysis Contour- 20%

The figure above shows the contour analysis of the daylight on the building and showed us the area that the sunlight hits with contour lines so it accurately shows which area of the floor receives daylight and which do not. This figure again shows how the staircase does not receive a lot of light and how the big window on the top box allows sunlight to shine throughout the floor.

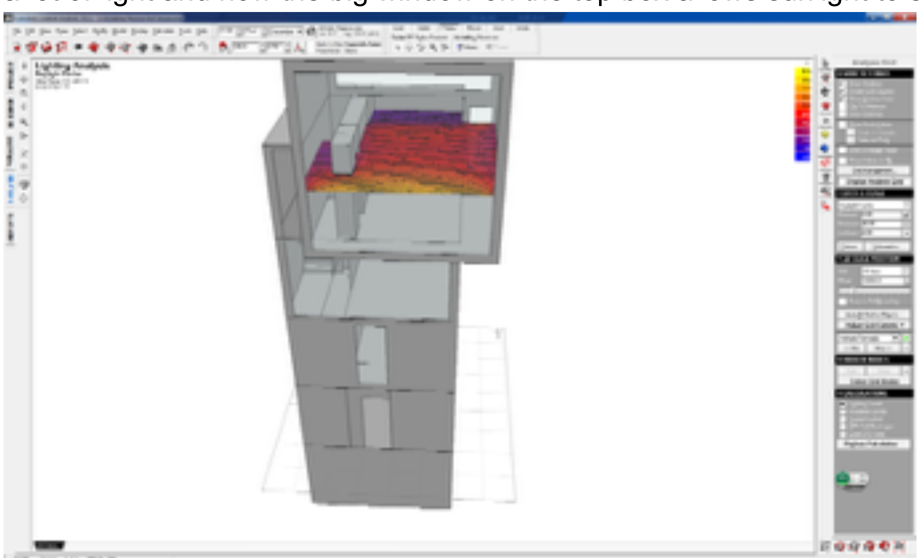


Figure #15: Grid Analysis Contour- 40%

This figure shows the amount of sunlight that hits the floor with the 40% daylight factor. It shows how the sunlight does not reach the area where the staircase is and how the sunlight mostly hits the area surrounded by the big window, that is, the kitchen and dining room area on the 4th floor.

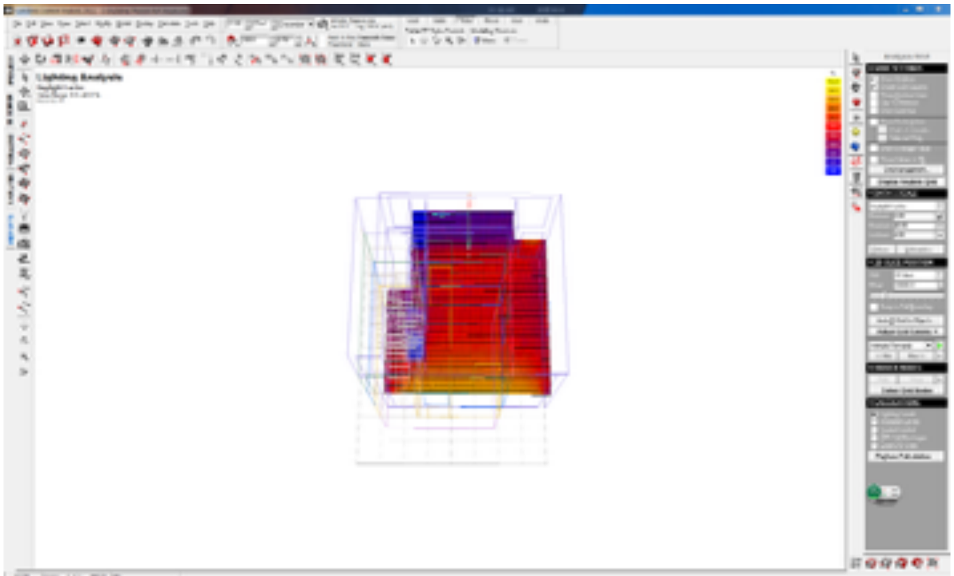


Figure #16: Grid Analysis Plan View-40%

The plan view above showed more clearly how the sunlight does not hit the staircase area and the back area of the building which is further away.

Illuminance Analysis

Illuminance describes the area density of light falling on a certain surface. As shown above, in general, the most illuminated area are near the big panoramic window in the front, where the illuminance reaches up to 2800 lux. Considering the human experience inside the room, the analysis was performed from the perspective of looking out the south window and at the cupboard on the west side of the room, at 9am, 12pm and 4pm on March 21st, Jun 22nd, Sep. 23rd and Dec 22nd respectively.

The sky model used for these simulations is the CIE overcast sky model, in order to remain consistent with the daylight factor analysis performed. From the results, it is clear that the room is well lit. The red lines being far from the south window, showing that the whole area is relatively bright. In these simulations, we used a maximum of 2000 lux when scaling the contour lines to better show the various levels of illuminance in even darker areas.

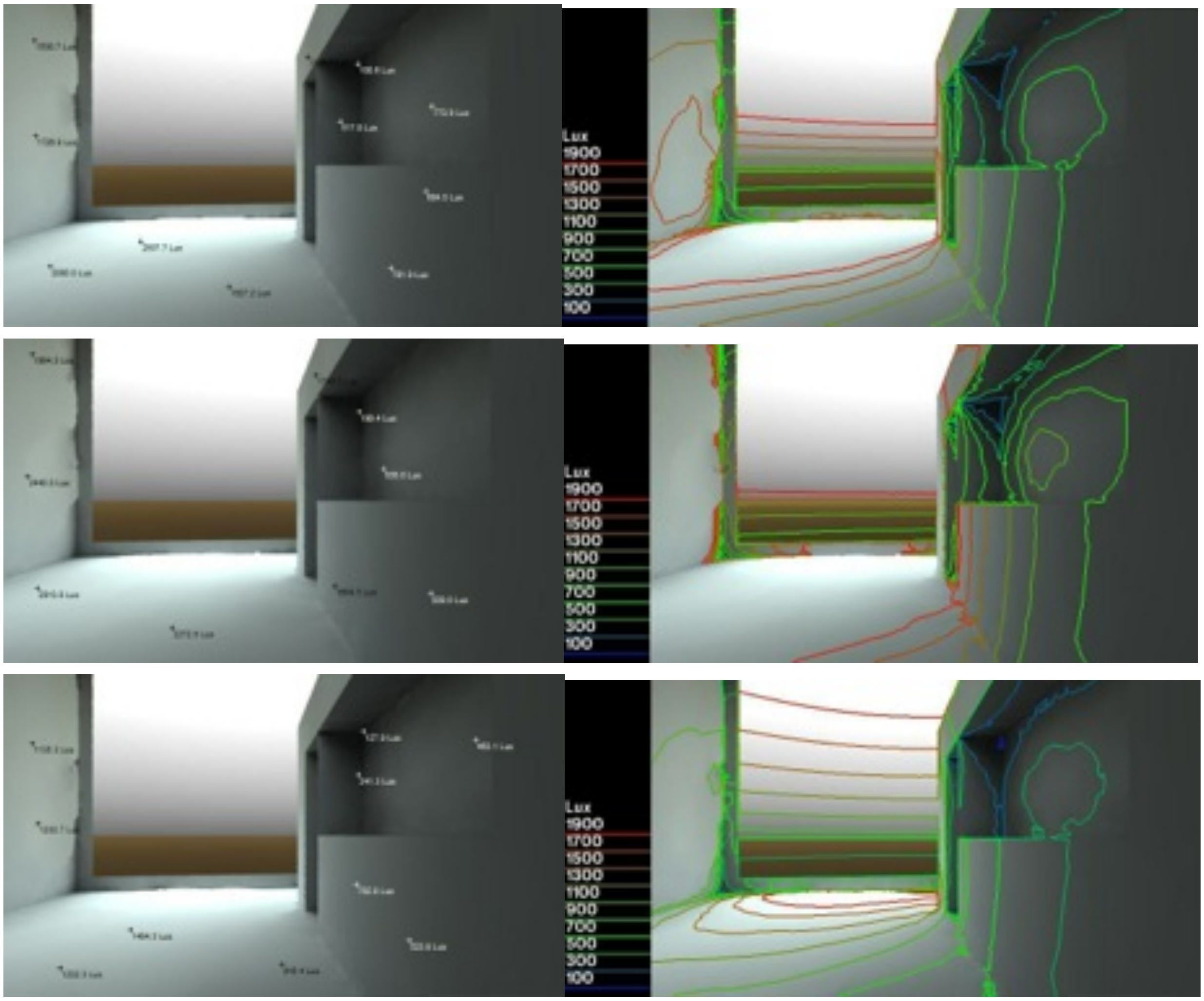


Figure #17: Illuminance on 9:00, 12:00 and 16:00 on March 21st

In spring, 9:00 usually has a higher illuminance level compared to 16:00, due to the sun position of this season. From Figure #17, we can see that most part of the room is well lit by natural light coming in from the south window. Despite the kitchen area being relatively less well-lit, the illuminance level still reached over 100 lux, and we assumed that there is artificial lighting in this part of the room.

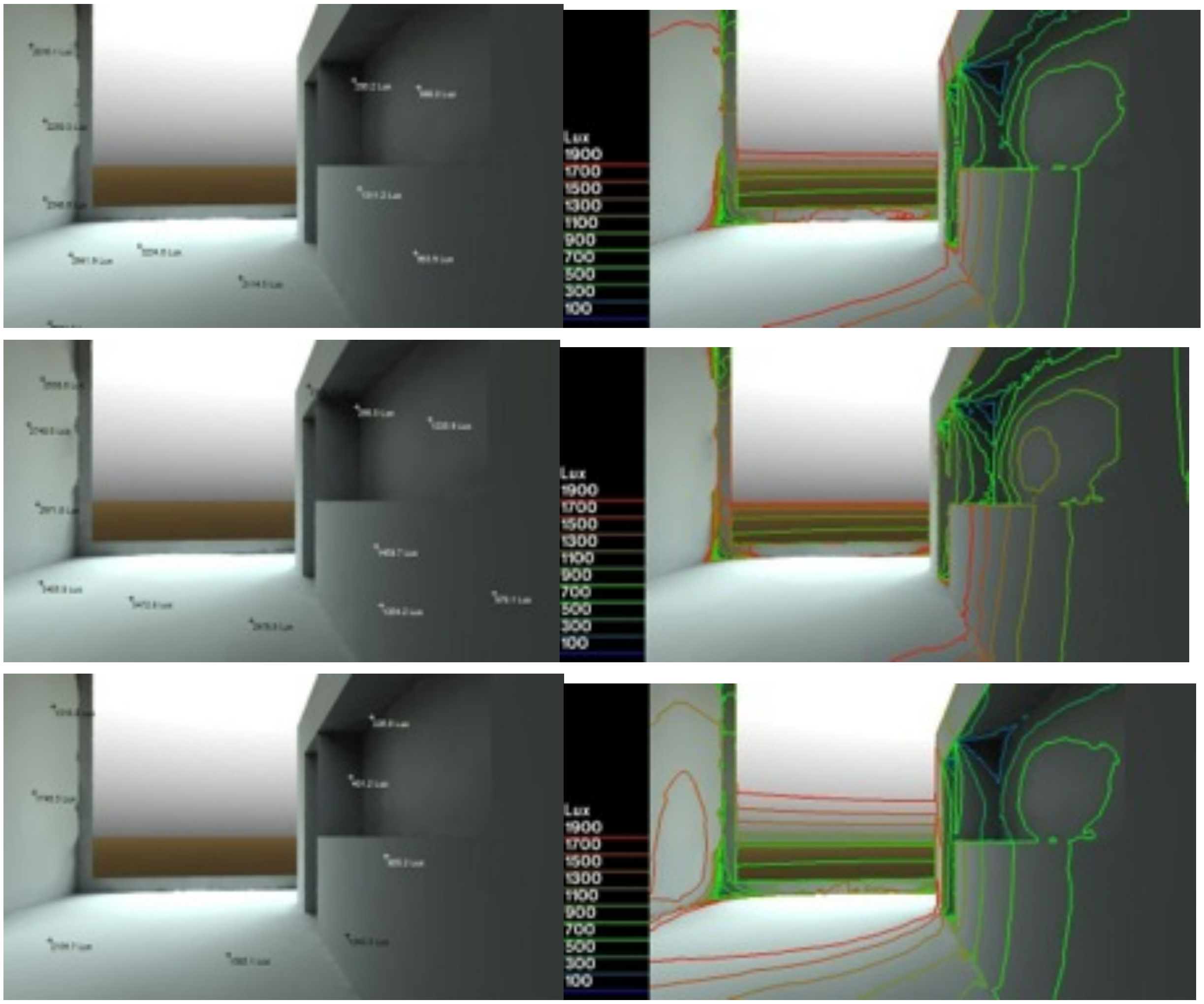


Figure #18: Illuminance level on 9:00, 12:00 and 16:00 on Jun 22nd (Summer Solstice)

As the sun approaches the equator in summer, the difference of illuminance between 9:00 and 16:00 decreased.

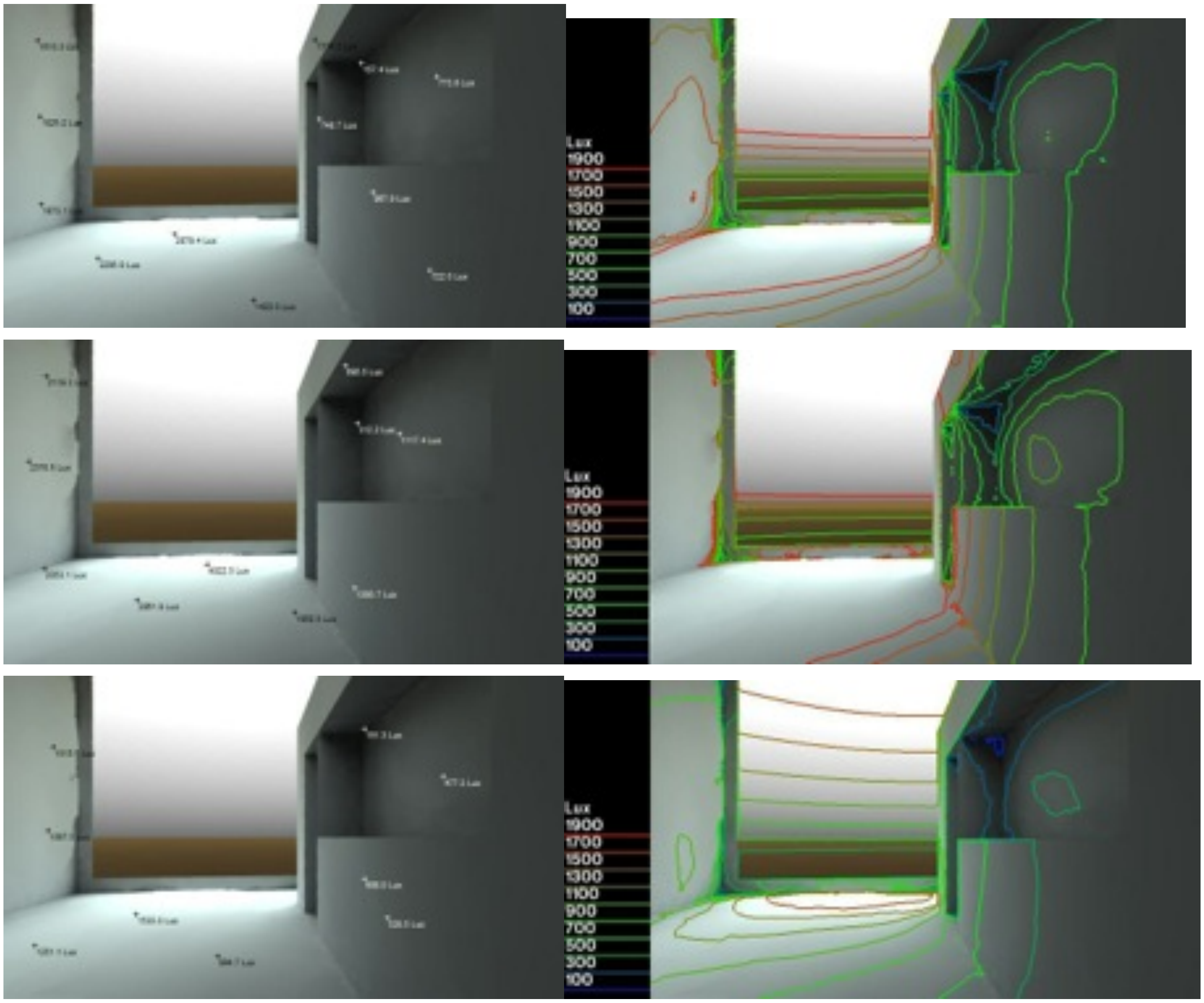


Figure #19: Illuminance level on 9:00, 12:00 and 16:00 of Sep. 23rd

As fall comes, hours of daylight decreases, and sunset becomes earlier and earlier, leaving the dining room less well lit after 16:00, again relying on artificial lighting.

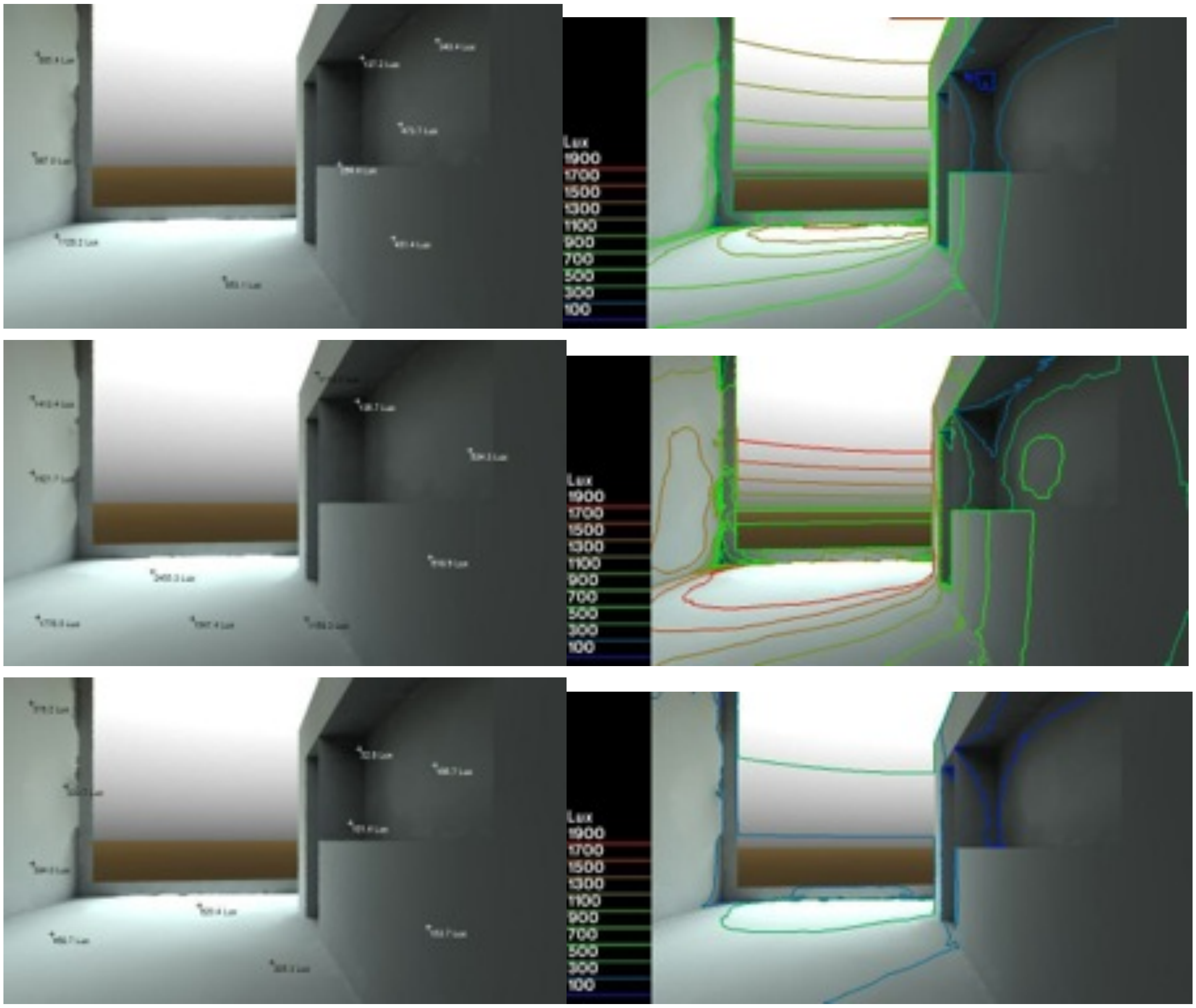


Figure #20: Illuminance levels on 9:00, 12:00 and 16:00 on Dec. 22 (Winter Solstice)

We noticed the wider range of illuminance levels on Dec. 22nd, and decided to take cloud coverage into consideration in our comparison for this particular day. After comparing the daily data, we find that the dense cloud coverage and shorter daylight hours might be the main reason. Cloud coverage is especially dense at 9am and 4pm, which are near sunrise and sunset on Dec 22nd.

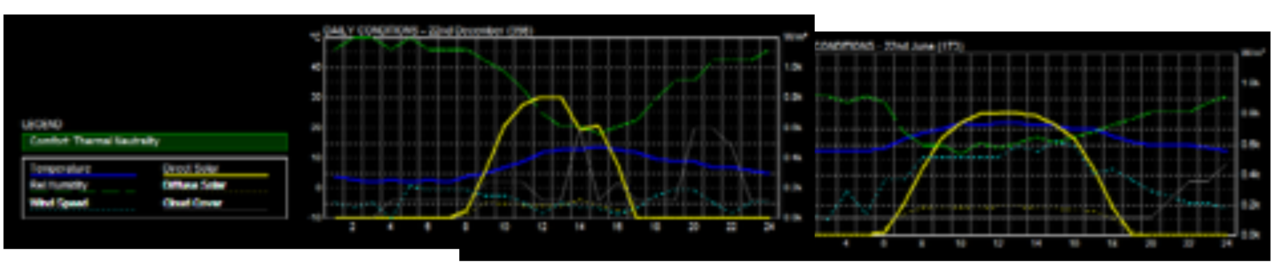


Figure #21: Cloud Coverage

Luminance Analysis

Luminance is another significant aspect of lighting design, which measures the brightness of a surface. However, the luminance level is closely related to the illuminance level. Therefore, the pattern behind the results actually shares a lot of similarity with the illuminance analysis.We ran the luminance simulation using Radiance with the CIE Overcast sky model. The contour lines were on the scale of 500 cd/m^2, trying to show more different levels of luminance.

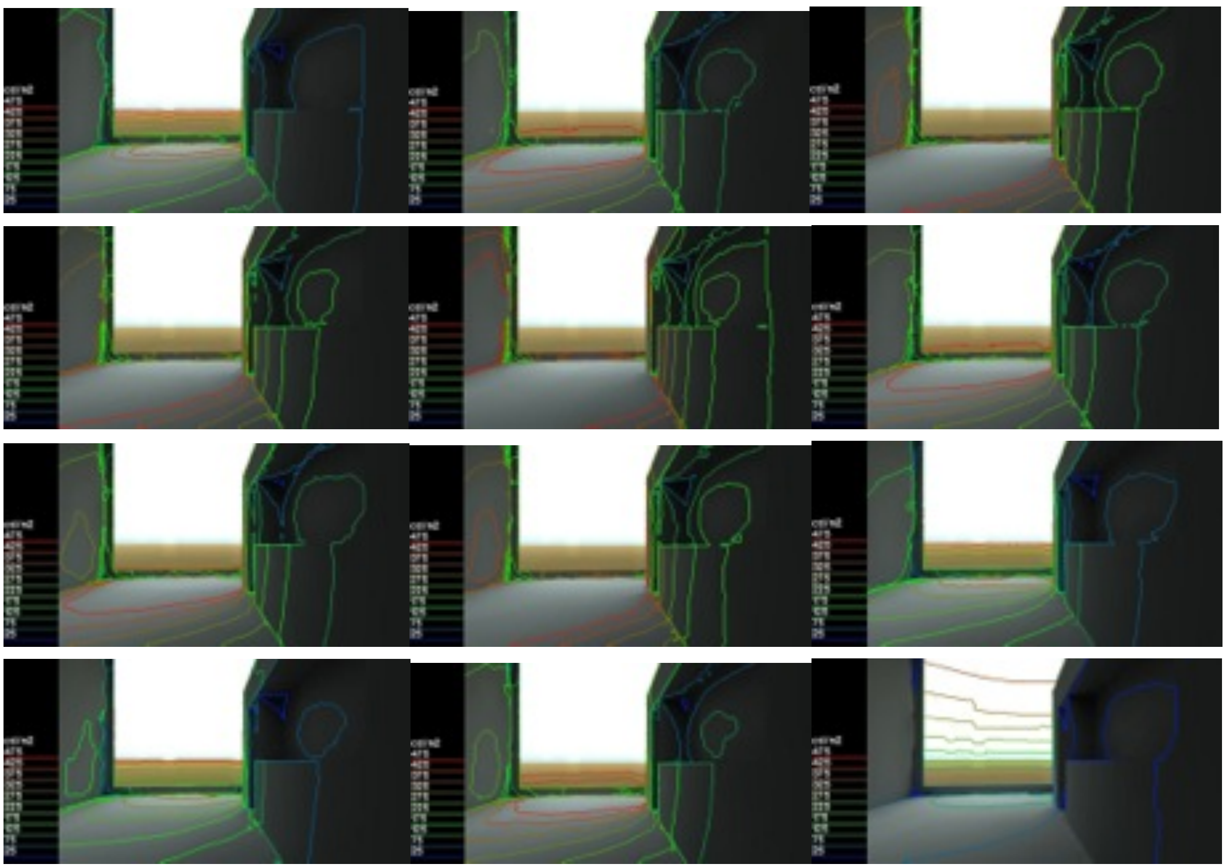


Figure #22: Luminance levels across four season at three different times.

The graphs above demonstrates the luminance conditions of the dining room on the 4th floor, at 9am, 12pm and 4pm on Mar 21st, Jun 22nd, Sep 23rd and Dec 22nd. The brightest area is still near the big window in the front. The luminance reached 772 cd/m2 on 12pm, June 22. The back wall is the darkest area, which reaches its lowest value, only 11cd/m2 at the corner at Dec 22.

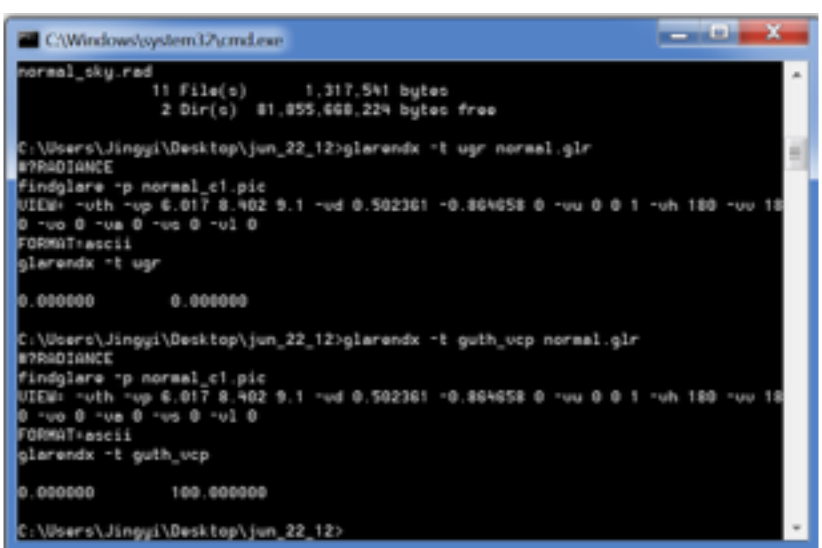
Glare Analysis

Glare is a visual disturbance caused by an uncomfortably bright light source or reflection. By its intensity, there is discomfort glare and blinding glare. VCP and UGR are the 2 indexes used to predict if a certain design will have potential glare problems. VCP (Visual Comfort Probability) predicts if a lighting system would have direct glare problems by estimating the percentage of people that would accept a lighting arrangement as visually comfortable. UGR (CIE Unified Glare Rating) The UGR scale is an interval scale where the differences between numbers represent the perceptible differences in psychological value. The bigger the UGR is, the bigger difference humans feel, the more possible that there is a glare problem.

Figure #23: Luminance rendering

Figure #24: UGR Results

In our calculation, we kept getting results of UGR 0, VCP 100. We tried adjusting camera angles, adjusting different parameters, but the problem still remained. Further exploration showed that the algorithm of the glarendx simulation automatically sets a threshold of 7 times the average luminance level. Anything above 7 times the average will be considered glare. (Refer to http://radsite.lbl.gov/radiance/refer/Notes/glare.html) Changing the threshold when calculating, we found that threshold value from 1000 to 12000 resulted in plausible values, while which ones are accurate is debatable.



Conclusion

Overall, the lighting condition on the 4th floor is good, with slightly darker corners near the kitchen area. Once again, it was assumed that there is artificial lighting for that particular visual task. Luminance and illuminance analysis yielded results that are reasonable; although the glare analysis results were unsure, we found that the relative threshold has an influence on the calculation results. Given that glare is a human perception, we considered this an acceptable result.

The limit of this study remains. There were no consideration about the surrounding areas and landscape in this study, which in this case might be an important component in analysing the lighting condition of the fourth floor. Pictures has shown that the sea has a relatively high reflectance, and therefore might create reflected glare or over-lit conditions within the house. This shortcoming becomes an advantage during winter when the angle of the sun is low.

Further explanation about the glare conditions in the 4x4 house needs calculation as support, but in general the lighting condition of the top floor of 4x4 house successfully creates the sense of openness desired by the architect.