Report 2 – Solar Radiation and Daylight

Numerical Simulations Methods for Sustainable Planning

Seminar report
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1. Introduction

This paper deals with numerical simulations of solar radiation and daylight. Therefore, a six-story office building in Lagos, Nigeria, serves as a case study. All calculations are performed with Rhino Grasshopper.

2. Solar Radiation Analysis

2.1. PV Panels: Orientation and Tilt

Lagos, being positioned near the equator at a latitude of 6°35'N and a longitude of 3°20'E experiences a nearly uniform annual sun path with almost perpendicular sun angles. So, the assumption can be made, that these lead to rather flat angles of the photovoltaics mounted on the flat roof. To find the highest annual insolation, “Opossum”, an advanced evolutionary solver developed by ITKE Stuttgart is used. Moreover, the minimum row distance is calculated with two formulas and implemented in the script [1]:

Module Row Spacing = Height Difference / Tan (17)

Minimum Module Row Spacing = Module Row Spacing x Cos (Azimuth Correction Angle)

As a first result, a tilt angle of 14 degrees as well as a south-eastern orientation have reached average incident radiation up to 1,670.2 kWh/(m²a). This proves the assumption that small angles lead to the highest results. The shift towards the east can be explained when looking at the urban context, which was considered in the calculations, where a slightly higher building in the west blocks the evening sun (See Figure 1). But with a scarce area on the roof, optimization towards maximum total radiation can be seen as the better option. Therefore, a second analysis was conducted, while only the objective was changed from relative to absolute radiation values. Through the flat alignment, an additional 84.6 m² of PV modules can be placed on top of the roof (See Figure 2). While the relative incident radiation slightly decreases by 10 kWh/(m²a), the absolute total radiation increases by almost 50 percent (from 296,834.5 kWh/a to 435,599.8 kWh/a).

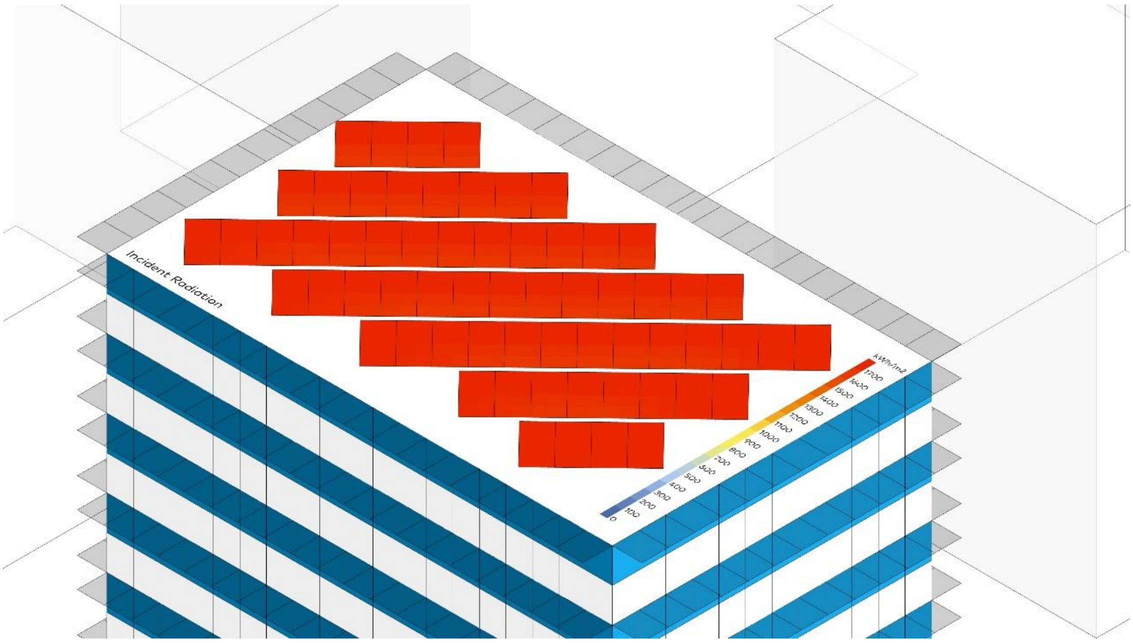

Figure 1: PV-alignment with maximum relative Radiation (296,000 kWh/a)

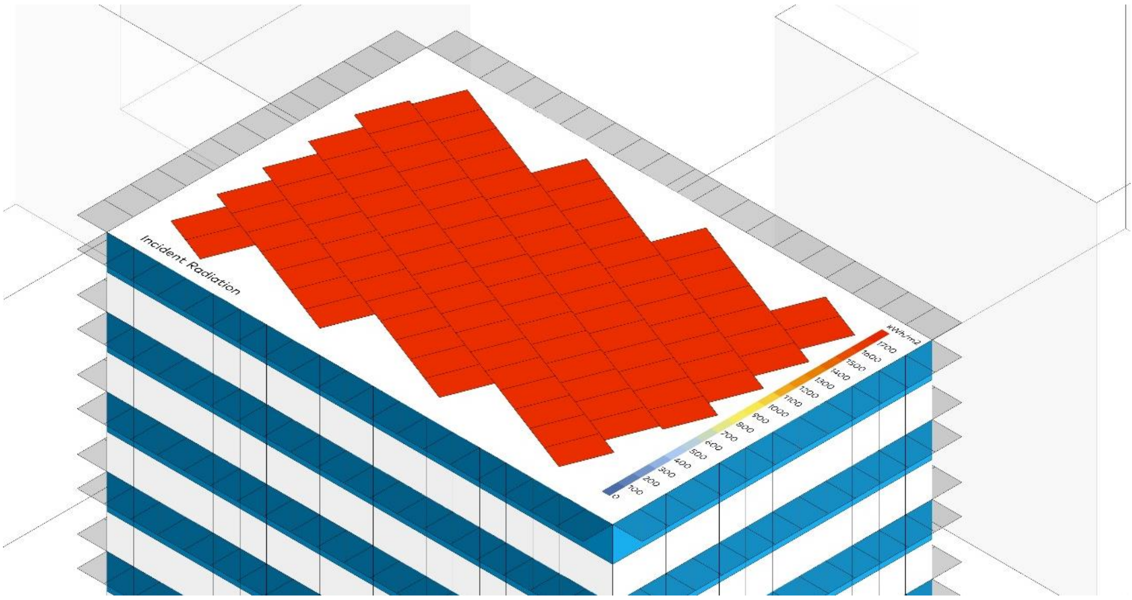

Figure 2: PV-alignment with maximum total Radiation (435,000 kWh/a)

2.2. Electricity Generation

The huge differences in total radiation of the two preceding PV optimization strategies have a direct influence on the maximum possible electricity yields. These can be calculated with the given formula [2]:

$E = A * r * H * P$

• E = Energy (kWh)

• A = PV panel area [m²]

• r [%] = kWp / PV panel area [m²] – solar panel efficiency

• H = Average radiation [kWh/m2] on panels

• PR = System performance ratio [%]

Here, the specific product is a 600W Half-Cell PERC Monocrystalline Solar Panel (b=1.3 m, h=2.17 m, max. power=0.605 kWp, system performance=90%). So, the efficiency of the solar panels is 21.4 %. The respective energy outcomes are 57,294.0 kWh for the slightly elevated photovoltaics and 84,078.0 kWh for the flat version with more modules.

3. Daylight Analysis

3.1. Solar Radiation Study

With Lagos' proximity to the equator, seasonal fluctuations are very minimal. To protect the office building from overheating, the upper boundary for seasonal total radiation on a story's façade glazing is set to 20,000 kWh. This value can be approached by taking both the window-to-wall ratio and the shading overhang as variables. Through generative design, an aperture of approximately 60% combined with a shade of 1.30 m extruded length is within the defined boundary. At a closer look, the differences between the façade orientations can be seen (See Figures 3-4).

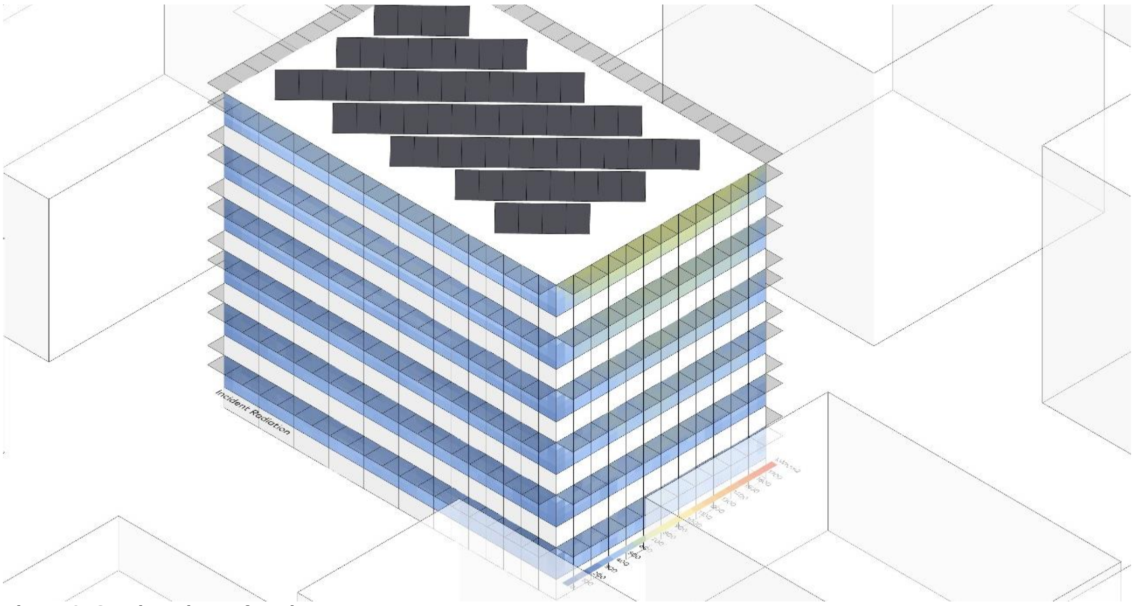

Figure 3: South and east façade

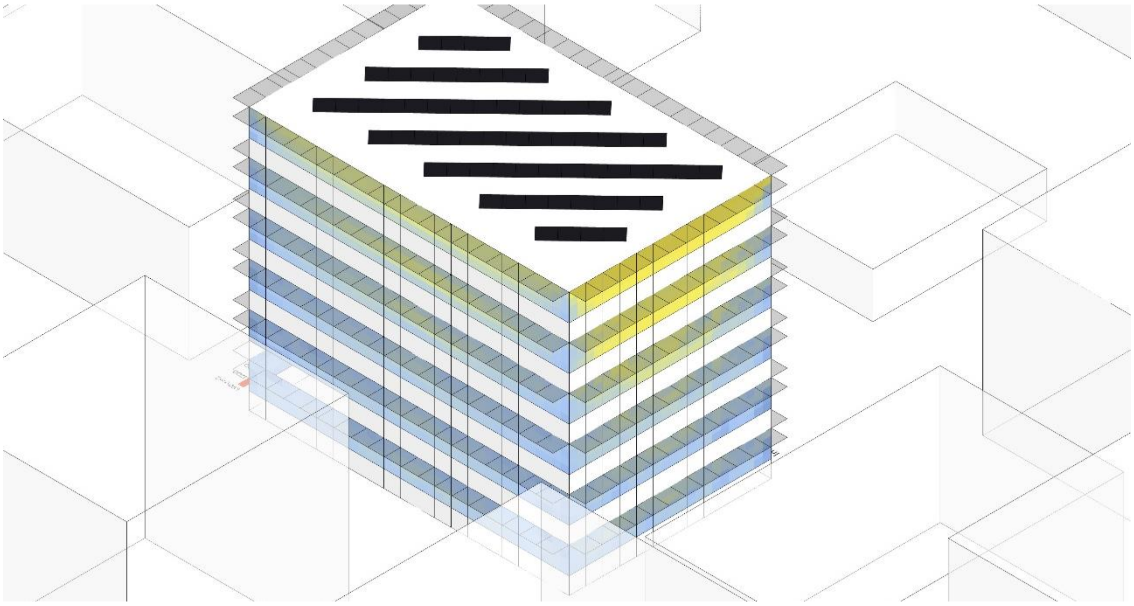

Figure 4: North and west façade

While the south façade has the lowest incident radiation values, the one in the west has the highest. One reason is that the shade overhang does not protect the west façade from the flat evening sun very well. Also, there is direct sunlight on the north façade, causing higher radiation values than on the south, which can be seen in the sun path graphic (See Figure 5). Generally, the upper stories experience less shading through urban context.

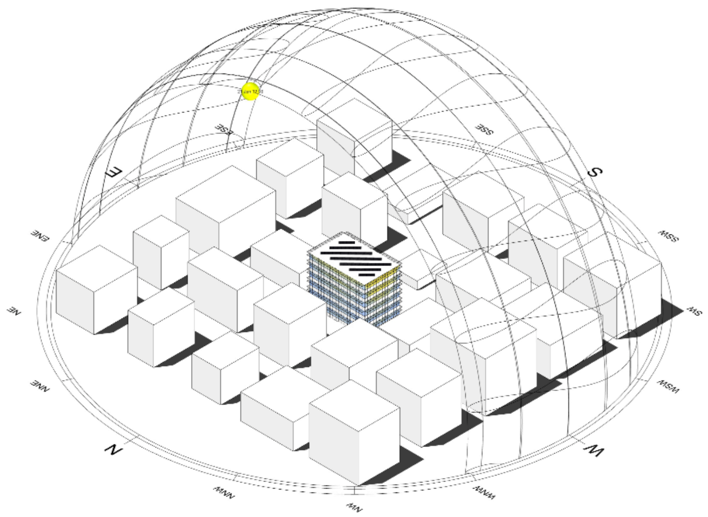

Figure 5: Sun on June 21st

3.2. Illuminance Study

Next, the determined aperture and shade will be the starting point for further indoor daylight studies. More precisely, the Daylight Factor (DF) and the Useful Daylight Illuminance (UDI) are calculated based on the annual radiation. Therefore, a high-resolution grid is generated 0.85 m above ground and with 0.5 m offset to the walls.

3.2.1. Daylight Factor

"The daylight factor is defined as the ratio of horizontal indoor to outdoor illumination by daylight under continuously overcast sky conditions, expressed as a percentage." [3] According to DGNB, for visual comfort, a minimum of 50% of the usable area should have a minimum of 1% or above DF, and for BREEAM an average of 2% DF is required [4]. For the office building in Lagos at least 47% of the indoor area already has a sufficient Daylight Factor of 2% or more (See Figure 6). Additional light guiding systems can bring daylight deep into the room to overcome the 50 percent threshold.

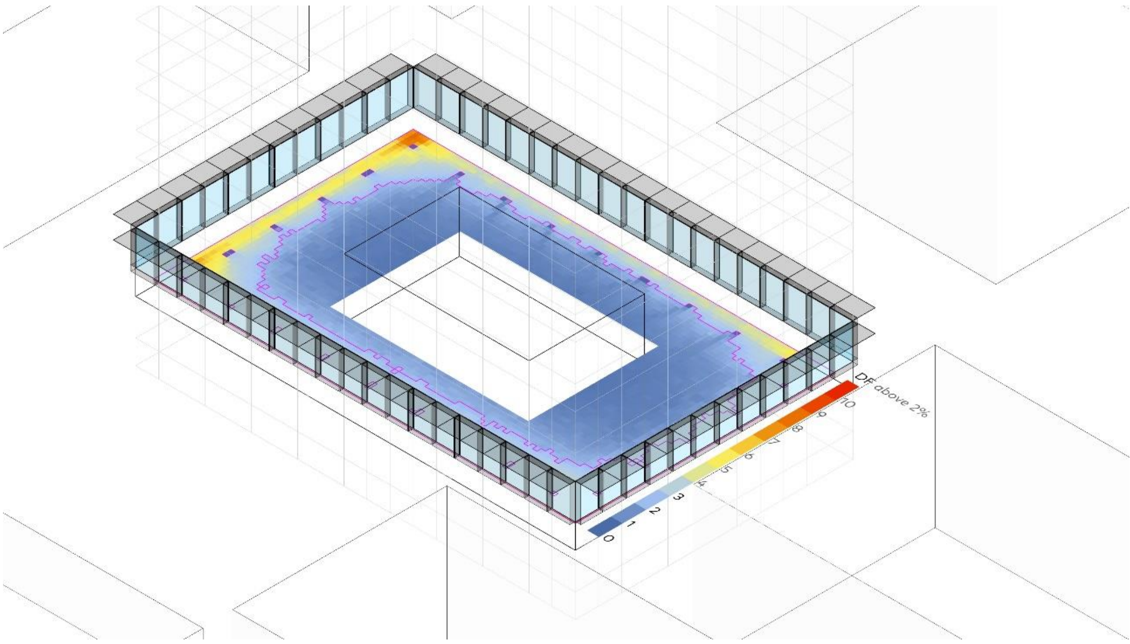

Figure 6: Daylight Factor Results (Pink Outline 2% Minimum)

3.2.2. Useful Daylight Illuminance (UDI)

The Useful Daylight Illuminance is the percentage of time–hours during occupancy (usually 8 am – 6 pm) that the illuminance range is not undercut or exceeded [4]. Hence, the range is defined between 500 to 3000 lux to ensure well-lit desks for working and avoid overheating or too much glare (See Figure 7). The outcome is more than 67% of the quality area that meets the criteria.

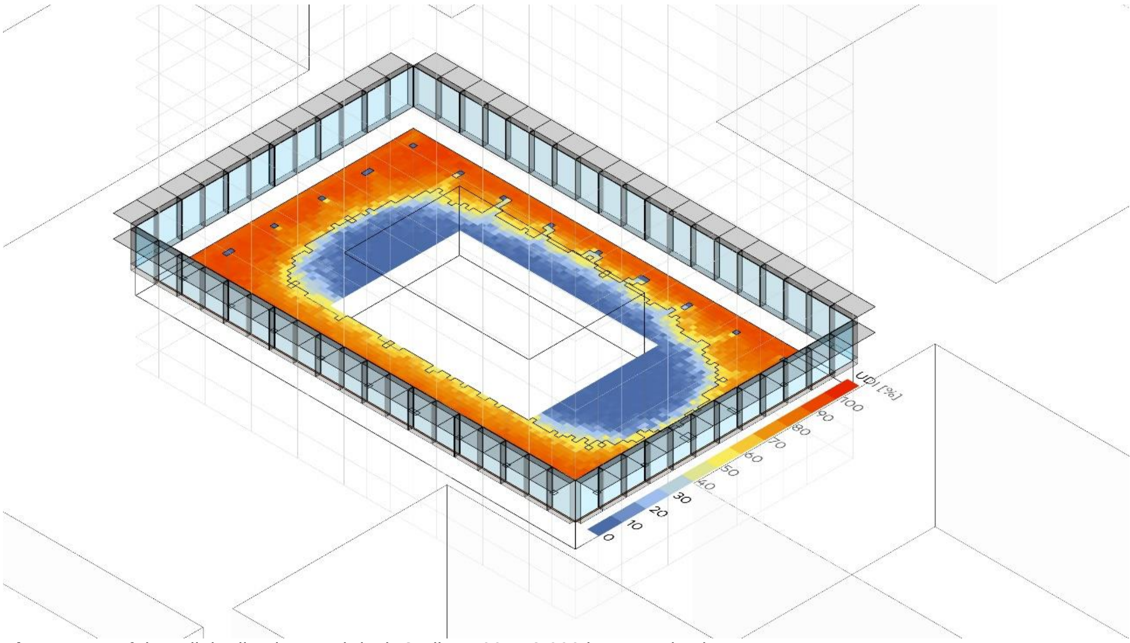

Figure 7: Useful Daylight Illuminance (Black Outline 500 to 3,000 lux Boundary)

Since the two daylight calculations shown here are conducted on the first floor with much additional urban context shading, the chosen aperture turned out to be sufficient in providing enough qualitative daylight.

3.3. Design Measures

Ultimately, here are some thoughts on how to cope with the high radiation on the façade, especially of the upper stories. In general, three of the most important properties of the building envelope include:

1. Thermal conductance (U-value)

U-factors measure thermal conductivity, the rate of heat transfer per unit area, per unit the temperature difference from the hotter side to the colder side.

2. Solar Heat Gain Coefficient (SHGC)

The solar heat gain coefficient (SHGC) is a ratio that defines the amount of solar energy that reaches a glazing assembly (including both the glass and frame) with the amount that gets through to the inside. It represents the ability of a glazing assembly to resist heat gain from direct solar radiation. A low SHGC indicates good resistance. Meaning, only a small percentage of the sun's rays make it through the window or skylight.

3. Visible Light Transmittance (VLT)

The main purpose of windows is to let light pass through. The percentage of visible light that passes through a window or other glazing unit is called the Visible Light Transmittance [5].

As a consequence, using glazing materials with high VLT value low U-value and low SHGC value is the most effective and efficient way to improve the light transmittance with reduced indoor space heating issues. Additionally, low-E coatings can be applied to the glass surface to reduce heat transfer effectively (See Figure 8). While minimizing the amount of non-visible, yet high-energy ultraviolet and infrared light, the full visible spectrum of light can pass through the glass [6].

One Inch Insulating Glass Unit Comparisons with PPG Architectural Glass

	Transmittance			Reflectance		U-Value				
Glass Type	Ultra Violet %	Visable %	Total Solar Energy %	Visable Light %	Total Solar Energy %	Winter Night time	Summer Day-Time	Shading Coeffi-cient	Solar Heat Gain Coeffi-cient	Light to Solar Gain (LSG)
Sungate ® 500 Low-E Glass										
Sungate 500 (2) + Clear	42	74	52	17	14	0.35	0.35	0.71	0.62	1.19
Solexia + Sungate 500 (3) Clear	21	64	33	14	9	0.35	0.35	0.51	0.44	1.45
Atlantica + Sungate 500 (3) Clear	11	56	25	12	7	0.35	0.35	0.41	0.35	1.60
Caribia + Sungate 500 (3) Clear	17	56	24	12	7	0.35	0.35	0.40	0.34	1.65
Azuria + Sungate 500 (3) Clear	29	57	24	12	7	0.35	0.35	0.40	0.34	1.66
Pacifica + Sungate 500 (3) Clear	10	35	19	7	6	0.35	0.35	0.35	0.30	1.16
Solarblue + Sungate 500 (3) Clear	21	46	32	10	9	0.35	0.35	0.51	0.44	1.06
Solarbronze + Sungate 500 (3) Clear	18	44	33	9	9	0.35	0.35	0.53	0.46	0.96
Solargray + Sungate 500 (3) Clear	17	37	28	8	8	0.35	0.35	0.47	0.40	0.92
Optigray23 + Sungate 500 (3) Clear	6	19	13	6	6	0.35	0.35	0.28	0.24	0.80
Graylite + Sungate 500 (3) Clear	5	11	16	5	6	0.35	0.35	0.33	0.28	0.41
Solarban ® 60 Solar Control Low-E Glass										
Solarban 60 (2) Starfire + Starfire	25	74	38	11	43	0.29	0.27	0.46	0.40	1.85
Solarban 60 (2) Clear + Clear	19	70	33	11	29	0.29	0.27	0.44	0.38	1.85

Figure 8: A list of insulated glasses available in the industry [6].

On the other hand, installing blinds, shutters, and curtains is a flexible solution to reduce temporary undesired solar heat gains and glare. Ideally, subtly different solutions can be found for the upper and lower stories without compromising aesthetics.

4. Conclusion

Simulations have shown that often many parameters must be considered to achieve proper results. The evolutionary solver performed fast and reliably. The first optimum result in optimizing the pv alignment was dealt with critically and thereby another solution could be shown. When optimizing towards absolute radiation values, much higher electrical energy yields can be expected over decades, provided that the client can finance the higher investment costs. The daylight simulations were able to certify a high percentage of indoor areas with costless quality daylight. Nonetheless, further energy simulations are needed to compare the daylight results with energy demands - in the case of Lagos – especially for passive cooling strategies.

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