Good daylighting design can exploit use of lighting controls

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

North and south oriented facades, internal courtyard, limited depth, and large windows shielded this building from direct solar radiation.

At this office building in the University of Brasilia daylighting is the main lighting source thanks to the building shape, the internal courtyard, and well-designed solar protections. Daylighting and view out with high quality improve user´s satisfaction in the workplaces. Energy use for lighting is high and it could be exploited using electric lighting controls.

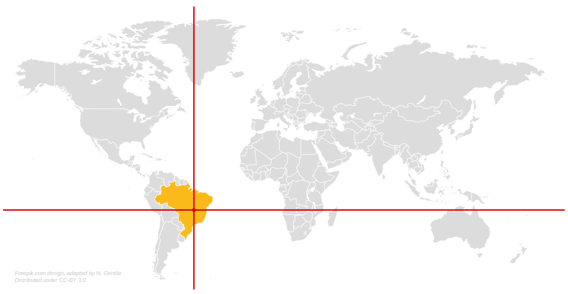
Figure 1. Office building at the University of Brasilia campus.

The project

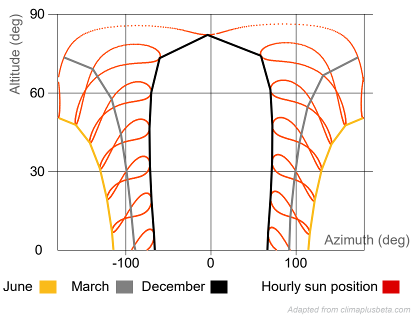
The office building at the University of Brasilia (UnB) is located in the Darcy Ribeiro Campus, near to the Scientific and Technological Park and houses the Deans' offices for 'Research and Innovation' and 'Graduate Studies'. The building was chosen because of its good daylighting design, as well as its potential for lighting control use. The main facades are North and South oriented, and the offices are distributed alongside them, with large windows shielded from direct solar radiation via external horizontal brise soleil in North facades, solar control films and curtains in South facades. The building has an internal courtyard and the office rooms have limited depth, which improves the daylighting performance. Since daylight is abundant in the whole building, there is a huge energy saving potential from the installation of lighting control systems. The building floor area is approximately 4000 m² and around 150 users work from 7:30 am to 7:30 pm.

Monitoring

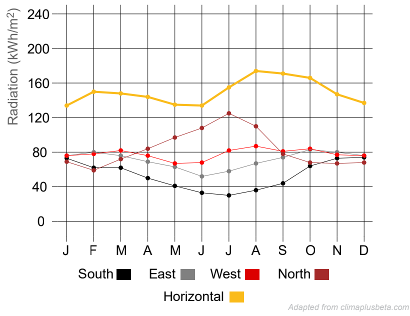
Photometric measurements were taken in selected occupied rooms, located along the North and South facades (figure 3). The assessment included measurement of horizontal/vertical/cylindrical illuminance and external view quality. The measurement points were located on a grid, as suggested by the CEN standard. External view quality was evaluated based on CEN criteria. The first monitoring was performed on 7th May 2019 at day and night times, with overcast sky and global illuminance values between 28 300 and 77 000 lux. The second monitoring was performed on 10th November 2020 at daytime, with clear sky



Location: Brasilia , Brazil
-15.80°, -47.87°



Sun path for
Brasilia, Brazil



Global horizontal and vertical radiation for
Brasilia, Brazil

IEA SHC Task 61 Subtask D

Monitored by **Ayana Dantas, Flavia Bukzem, Gabrielle Toledo, Igor Silva, João Francisco Walter Costa** and **Adriana Sekeff**, LACAM, University of Brasilia
More info **Prof Cláudia Naves David Amorim**, University of Brasilia, clamorim@unb.br

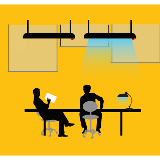


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Figure 2. Internal courtyard of the building.

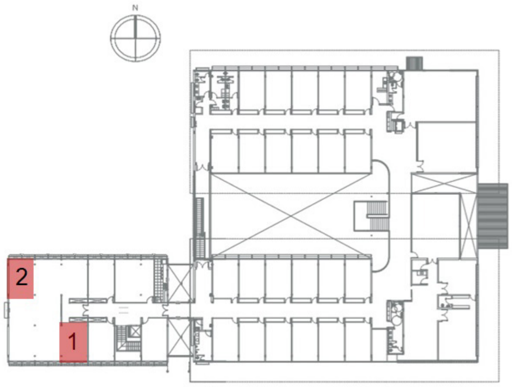

Figure 3. Plan with the monitored rooms 1 (North) and 2 (South).

Figure 4. Picture from monitored Room 1 (South).

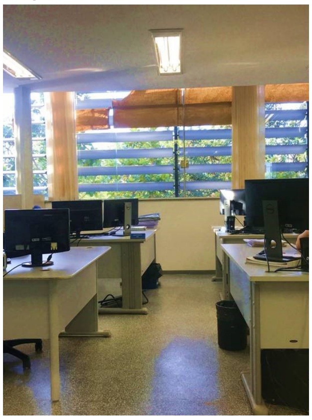

Figure 5. Picture from monitored Room 2 (North).

and global illuminance values between 81 000 and 120 000 lux. All measurements were performed in two representative office rooms on 2th floor (figure 1), Room 1 in South façade, with 22.65 m2 area and 6.00 m deep (figure 4), and in Room 2 in North façade (figure 5), with 24.36 m2 area and 5.47 m deep. The limited depth of rooms ensures a good of daylight. Internal reflectances are as follows: floor 59%, walls 85%, ceiling 80%, partitions 70%. Windows have 6 mm simple clear glass with visible light transmission of 89%.

Energy

The electric lighting system consists of efficient fluorescent T5 recessed luminaires 2x32W providing lighting at 4000 K. The lighting power density is around 10.56 W/m². The buildings at University of Brasilia are not provided with individual energy meters, so a simulation with Design Builder Software of the building was carried out to verify energy consumption, based on a survey of the location. The results are presented in Table 1.

The total energy use is around 182.69 KW/h/m²/year, where lighting accounts for approximately 62% and air conditioning 20%. With these data, the building's potential for modernization and automation of electric lighting is evident.

Table 1. Yearly energy use for different building services (kWh).

Lighting	Air conditioning	Other
428 914	118 069	116 138

Photometry

The field monitoring was conducted with three different conditions: daylighting, electric lighting and day+electric lighting (Table 2). The results show adequate conditions of horizontal illuminance according to NBR ISO/CIE 8995-1. Regarding uniformity, values are just a pinch below the recommended minimum (0.5).

Directionality of light was measured via HDR photographs of a diffusive sphere (figure 7). The directionality values are above recommended limits (strong and moderately strong). Accentuated shadows are present on objects, especially in the South room. According to the method developed by Cuttle in 1971, the vector-scalar illuminance values found are between 1.91 and 2.70, which represents a strong discomfort. Room 2 (North), with solar control elements, does not have as much discomfort as room 1, but it is still classified as "moderately strong".

Regarding view out assessment, photographs of the view were taken at a height of 1.20 m from the floor, simulating a seating person. The following results for both room 1 (South) and 2 (North) were obtained (Table 3). The evaluation (Table 2) shows that view out is rated as 'high' for room 1 according to the EN 17037- Daylight in Buildings, while is rated 'medium' for room 2.

Due to the pandemic Coronavirus conditions, the monitoring was interrupted in 2020. To complement monitoring, some computer simulations were performed, namely Daylight Factor (figure 8) and Annual Daylight Glare Probability (figure 10), using the software Grasshopper and DIVA for Rhino. The simulated values of verage Daylight Factor range from 3.93 to 12.21%, showing potential glare, especially in Room 1 (south). Simulations shows that there are potential critical glare occurrences especially in Room 1 (south) (figures 9 and 10). These potential glare situations can be avoided if, for example, solar films (with reduced visible light transmission of 70%) were added to windows, as simulated in figure 10.

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Table 2. Measured illuminance, uniformity, and directionality of light.

	E_{avg} (lux)	E_{max} (lux)	E_{min} (lux)	U_0 E_{min} / E_{avg}	Directionality E_v / E_s
Room 1 South - 7 May 2019 (clear sky)					
Daylight	687	1580	200	0.29	-
Electric light	411	542	230	0.56	-
Day+ Electric	1119	1740	630	0.56	2.7
Room 1 South - 10 November 2019 (clear sky)					
Daylight	1901	5250	490	0.25	-
Day+ Electric	2328	5210	1006	0.43	1.9
Room 2 North - 7 May 2019 (clear sky)					
Daylight	349	880	97	0.27	-
Electric light	251	400	99	0.39	-
Day+ Electric	899	1900	330	0.37	2.0
Room 2 North - 10 November 2019 (clear sky)					
Daylight	710	1120	280	0.39	-
Day+ Electric	886	1415	390	0.44	2.0

Circadian potential

Equivalent Melanopic Lux (EML) values were calculated using the Lucas toolbox (Lucas et al, 2014) and evaluated against the Lighting for the Circadian System criteria of the WELL v2 building standard. The credit requires verification of the EML value received at the eye of the occupant during specific times of occupation, awarding a number of credits. Results are showed in Table 4.

When combining day- and electric lighting, 100% of the workstations reach 200 EML. The second requirement is that all workstations must have at least 150 EML with electric lighting alone. In room 01, only 50% meet the recommendation and in room 02, no workstation reaches the required minimum.

Table 3. View out quality according to EN17037:2018.

Room	Criteria	Results	Rate
1	Horizontal sight angle	> 54°	High
	Distance of view	> 50 m	High
	No. layers	3	High
	General view rate		***High***
2	Horizontal sight angle	> 54°	High
	Distance of view	> 50 m	High
	No. layers	2	Medium
	General view rate		***Medium***

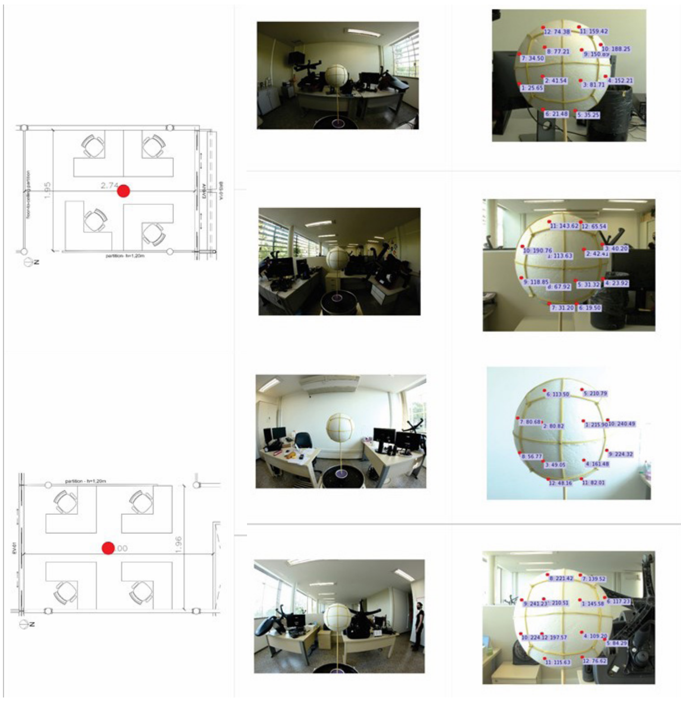

Figure 7. HDR photographs of the sphere to calculate daylight directionality in Room 1 – South (top) and Room 2 - North (bottom).

User perspective

The building hosts 150 employees, and 17 valid responses were collected for a survey handed out to the employees working in the monitored rooms. The survey included 45 questions structured in three sections: general data, social and physical climate, and user experience with lighting. It was distributed to 17 users who work in the monitored rooms.

Overall 42.3% of respondents are male, 53.8% are female, between 18 and 56 years old, working 5 days a week from 8 am to 5 pm. 85.2% of respondents are located less than

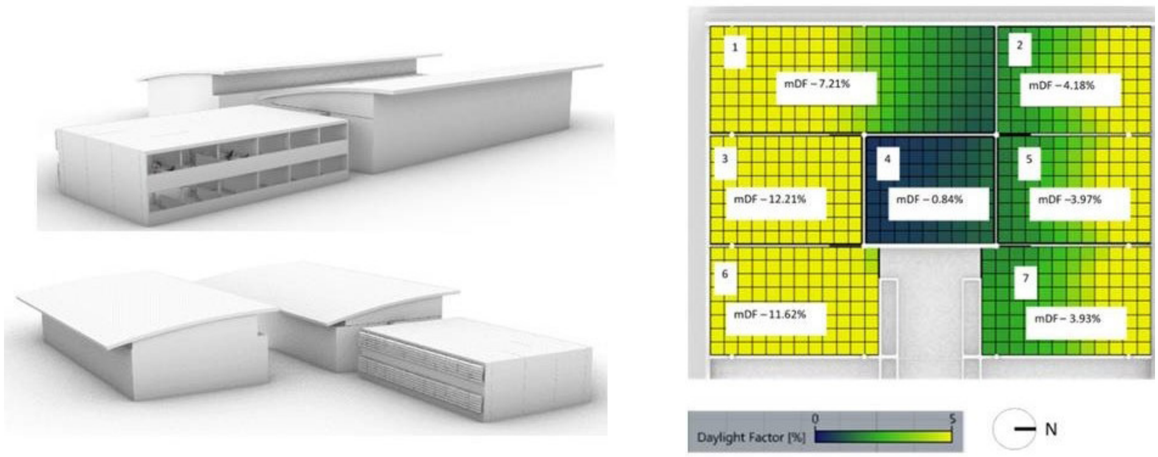

Figure 8. Building model and simulated Average Daylight Factor values in building plan, including Rooms 1 and 2.

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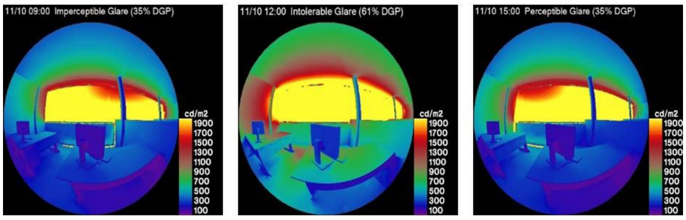


Figure 9. Point in time glare in South facing room, 10th November at 9 a.m. (left), 12 p.m (center) and 3 p.m. (right) with clear sky.

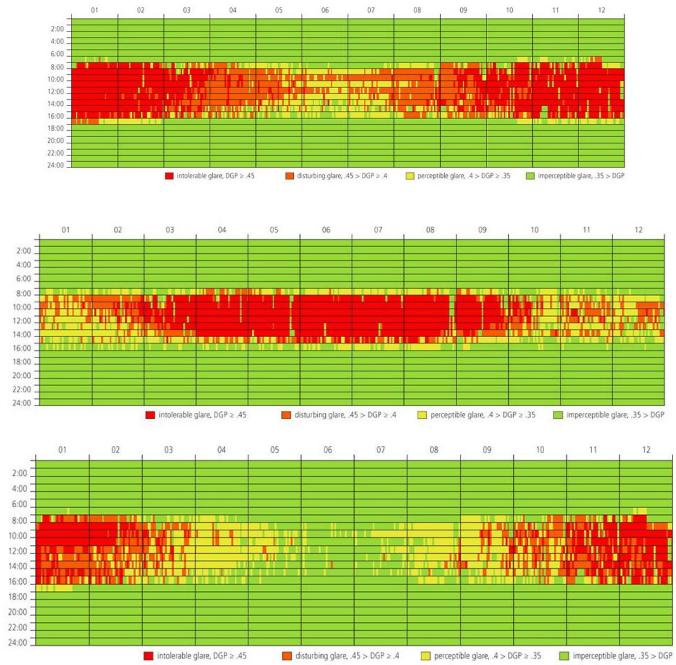
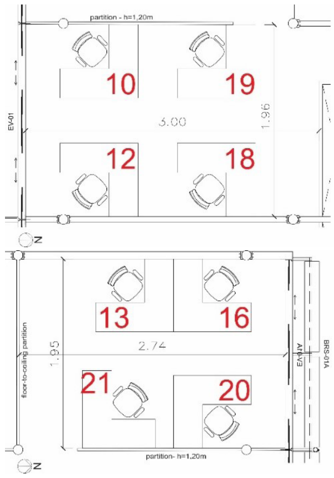


Figure 10. From top to bottom: Annual Glare Probability for South room, North room, and South room with solar film added (LT 70%).

5 meters from the window and 70.4% work with a monitor. Most work environments are shared. 74% of respondents consider that work requires a lot of concentration. 77.7% answered that they felt tired in the last four weeks, the main causes being the fatigue of the routine, the demand for work and the route between the residence and the work. Regarding daylighting in the work area, 75% of respondents are very satisfied with daylighting and 88.2% are satisfied or very satisfied with the overall impression of the environment. 88% responded that they have a lot of light in their work area, but 48% declare to have discomfort with daylight, what confirms the monitoring results. 60% of users prefer to work only with daylighting and 40% prefer the combination. 76% say they have medium or a lot of control over daylighting. Regarding electric lighting, 47% responded that they have a lot of electric lighting in the work area, 70.5%

> ***"There is a lot of daylight, but we don´t like to close the curtains"***

> ***View out is much appreciated***



ROOM 01 (south) - Equivalent melanopic lux (EML) values			
Workstation	Electric lighting	Day+electric lighting 07/05/2019 (clear sky)	Day+electric lighting 10/11/2020 (overcast sky)
10	192,68	838,08	1351,95
12	195,79	1207,85	1222,57
18	142,96	1138,69	772,28
19	139,23	670,73	696,78

ROOM 02 (north) - Equivalent melanopic lux (EML) values			
Workstation	Electric lighting	Day+electric lighting 07/05/2019 (clear sky)	Day+electric lighting 10/11/2020 (overcast sky)
13	124,31	692,31	438,97
16	130,53	916	837,13
20	48,48	336,02	230,65
21	131,77	754,74	573,4

Table 4. EML values in room 1 (South) and 2 (North).

responded that they have medium or a lot of control over lighting and 58.8% usually feel little or no discomfort with electric lighting.

Lessons learned

The integrated daylighting design in the building was relatively successful, both due to the orientation of the main facades (north/south) and the building form. Office rooms are not very deep and can take advantage of daylight during daytime and also from high quality view out, especially in South façade, which can compensate glare occurrences. Despite this, problems with reflections and glare from daylight were detected in the simulations, in South façade, that has no solar protection, but also in North facade. These problems could be reduced with the addition of solar control films in glazing, reducing daylight but preserving view out, very much appreciated.

Users are satisfied with daylighting, which most of them prefer as sole source of illumination. They have also a good perception about their control over daylighting. While the office can rely on quite efficient light source, it is clear that the building could largely improve its lighting energy performance regarding electric lighting if adequate daylight-linked controls were installed.

Further information

Amorim, C.N.D.; Gentile, N. ; Osterhaus, W. ; Altomonte, S. (2020). Integrated solutions for Daylighting and Electric lighting: IEA SHC Task 61/EBC Annex 70 Subtask D - Proposal and first results. In *Proceedings of the 35th International Conference on Passive and Low Energy Architecture*. v. 3. p. 1739-1744.

Santos, A.C. and Amorim, C.N.D. (2019). *Iluminação, aspectos fotométricos e ritmo circadiano: aplicação de protocolo de monitoramento em edifícios de escritório*. Proceedings of the XXV Congress of Scientific Initiation 2019, University of Brasília, Brazil.

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Acknowledgements

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