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DAYLIGHT SUFFICIENCY OF INDOOR ENVIRONMENTS UNDER CLIMATE CHANGE SCENARIOS

SUFICIENCIA LUMÍNICA DE AMBIENTES INTERIORES EN ESCENARIOS DE CAMBIO CLIMÁTICO

SUFICIÊNCIA LUMÍNICA DE AMBIENTES INTERNOS EM CENÁRIOS DE MUDANÇA CLIMÁTICA

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RESUMEN

El desempeño bioclimático de edificaciones en escenarios de cambio climático ha sido ampliamente estudiado desde la perspectiva termo-energética, pero escasamente abordado desde la suficiencia lumínica interior. Esta escasez está relacionada con la invariabilidad de los datos de radiación en los archivos climáticos disponibles de escenarios futuros. La presente investigación propone identificar los impactos que, sobre la suficiencia lumínica, tendría la variabilidad de datos de radiación en archivos climáticos de escenarios futuros. La metodología incluye la adaptación de archivos climáticos disponibles y la realización de simulaciones computacionales de luz natural para espacios de trabajo hipotéticos localizados en Medellín, Colombia. Los resultados evidencian diferencias en la métrica Spatial Daylight Autonomy – SDA de hasta 18% en diversos escenarios futuros. Como conclusión, se plantea la necesidad de afinar las predicciones sobre la disponibilidad lumínica exterior que permitan optimizar las evaluaciones de desempeño lumínico en escenarios de cambio climático.

Palabras clave
iluminación natural, cambio climático, radiación solar.

ABSTRACT

The bioclimatic performance of buildings under climate change scenarios has been extensively studied from a thermo-energy perspective but hardly studied at all from the perspective of indoor daylight sufficiency. This shortcoming is related to the invariability of radiation data in the available weather files of future scenarios. This research proposes identifying the impacts that the variability of radiation data in weather files of future scenarios would have on daylight sufficiency in indoor spaces. The methodology includes the adaptation of available weather files and the running of daylight simulations for hypothetical workspaces located in Medellín, Colombia. The results show differences in the Spatial Daylight Autonomy – SDA metric of up to 18% in different future scenarios. In conclusion, the need is outlined to refine predictions of outdoor daylight availability that allow improving daylight performance evaluations under climate change scenarios.

Keywords
daylight, climate change, solar radiation

RESUMO

O desempenho bioclimático de edifícios em cenários de mudança climática tem sido amplamente estudado sob a perspectiva termoenergética, mas dificilmente abordado sob a perspectiva da suficiência lumínica interior. Essa escassez está relacionada à invariabilidade dos dados de radiação nos arquivos climáticos disponíveis de cenários futuros. Esta pesquisa teve como objetivo identificar os impactos que a variabilidade dos dados de radiação em arquivos climáticos de cenários futuros teria na suficiência lumínica em espaços interiores. A metodologia incluiu a adaptação de arquivos climáticos disponíveis e a realização de simulações computacionais de luz natural para espaços de trabalho hipotéticos localizados em Medellín, Colômbia. Os resultados mostram diferenças na métrica Spatial Daylight Autonomy – SDA de até 18% em diferentes cenários futuros. Conclui-se que é necessário refinar as previsões de disponibilidade lumínica exterior para que permitam melhorar as avaliações de desempenho lumínico em cenários de mudanças climáticas.

Palavras-chave
iluminação natural, mudanças climáticas, radiação solar

INTRODUCTION

On our planet, human-induced climate variations are moving at an unprecedented pace. Since 1970, the atmosphere's temperature has risen faster than in any other 50-year period, in the last 2000 years (IPCC AR6 WG I, 2021). In the most recent climate change report (AR6), attention has been drawn to the need to step up measures to ensure a temperature increase below 1.5°C, as estimated at the United Nations Conference on Climate Change, COP21 (UN, 2015).

To achieve this, greenhouse gas emissions would immediately need to be reduced (Intergovernmental Panel on Climate Change [IPCC], 2021). Rodriguez (2010) had already proposed that, if fossil fuels remained the main source of energy until at least 2030, greenhouse gas (GHG) emissions would rise, significantly favoring global warming even further than during the last century.

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) updated global warming scenarios compared to previous reports. In this, five new climate scenarios are considered, the Shared Socioeconomic Pathways (SSPx-y), which evaluate different possible futures of greenhouse gas emissions, land use, and air pollutants. Each of these scenarios is divided into three time periods: short-term, 2021-2040; mid-term, 2041-2060, and long-term, 2081-2100 (IPCC AR6 WG I, 2021). These were considered based on demographic and economic projections.

Table 1 shows the different climate change scenarios, the long-term temperature increase, and the maximum peak it will reach in the period from today to 2100. The last 3 scenarios will not reach their peak before 2100, as they have constant upward trends.

Despite the identification and description of these scenarios, two climate change characteristics that are rarely considered in buildings' bioclimatic performance analyses are highlighted. On one hand, it is acknowledged that climate change, apart from generating gradual variations in climatic conditions, also means abrupt changes in these (Fan, Chen, Fu & Li, 2020). On the other, climatic variations do not just refer to temperature increases but also, among other aspects, to variations in radiation, rainfall, cloudiness, and natural ventilation. For example, Wild (2009) relates changes in solar radiation to climate change and emphasizes that these changes

			Global average temperature change °C	
Scenario	Description	Aligned with SSP	Warming peak	Year 2100
C1	Limit warming to 1.5°C (>50%) with limited or no excess		1.6	1.3
C1a	Limit warming to 1.5°C with Net Zero Greenhouse Gas (GHG) Protocol	SSP1-1.9	1.6	1.2
C1b	Limit warming to 1.5°C without Net Zero GHG		1.6	1.4
C2	Returning warming to 1.5°C (>50%), after exceeding the upper limit		1.7	1.4
C3	Limiting warming to 2°C (>67%)		1.7	1.6
C3a	Limiting warming to 2°C and starting actions by 2020	SSP1-2.6	1.7	1.6
C3b	Limiting warming to around 2°C with Nationally Determined Contributions (NDCs) until 2030		1.8	1.6
C4	Limiting warming to 2°C (>67%)		1.9	1.8
C5	Limiting warming to 2.5°C (>50%)		2.2	2.1
C6	Limiting warming to 3°C (>50%)	SSP2-4.5	the temperature does not reach its peak in 2100	2.7
C7	Limiting warming to 4°C (>50%)	SSP3-7.0		3.5
C8	Exceed warming of 4°C (>50%)	SSP5-8.5		4.2

Table 1. Global warming scenario categories, according to AR6. Source: Preparation by the authors based on information from AR6-WG3 (IPCC AR6 WG III, 2022).

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are generated by anthropogenic activities and not by changes in the sun. In addition, he points out that these variations, in general, are underestimated in climate models. In parallel, in the AR6's *The Physical Science Basis, Working Group 1 - WG I*, it is established that changes have been observed not only in temperature, but also in meteorological and climatic phenomena such as heavy rainfall, tropical cyclones, and droughts in many regions of the world and that, due to the temperature increase, the water cycle is expected to intensify, generating heavier rainfall and its variability over time (IPCC AR6 WG I, 2021).

CURRENT OUTLOOK OF RESEARCH ON THE BIOCLIMATIC PERFORMANCE OF BUILDINGS IN THE CONTEXT OF CLIMATE CHANGE

In addition to research on the threats that entire communities and buildings face due to climate change-associated natural disaster risks, several studies focus on evaluating the bioclimatic performance and the habitability of buildings in climate change scenarios. Some of them focus on designing buildings that have a good thermal performance, but at the same time can withstand the increase in temperature, which would involve a higher energy consumption (Pajek & Košir, 2021). Others generally look at the influence that the effects of climate change have on the energy performance of a building and from this, analyze the possible mechanisms to adapt or mitigate these (Barea, Victoria, Filippín, Monteoliva & Villalba, 2022; Yassaghi & Hoque, 2019). Some works focus on establishing the percentage of uncertainty that models to establish the consequences of climate change on buildings have compared to energy consumption (Fonseca, Nevat & Peters, 2020), as well as those which analyze, on a global scale, how the building's outdoor climatic conditions affect the changes that occur for indoor comfort (Congedo, Baglivo, Seyhan & Marchetti, 2021). Different efforts have focused exclusively on energy consumption. Joarder Price and Mourshed (2009), among others, warn that, due to the projected temperature increase, the already-built structures run the risk of being uninhabitable in the future, if they do not use additional cooling systems. On the other hand, according to Berardi and Jafarpur (2020), the increase in outdoor temperature produces a greater use of cooling or heating systems, which translates into an increase in energy consumption. Finally, some research focuses its attention on evaluating the future effects on the energy performance of buildings located in tropical climates, to establish, at the design stage, more efficient strategies to face climatic variations (Vong, 2016)

With this panorama, it is evident that there is a reasonable number of studies focused on climate change and its links with thermal performance or energy consumption in buildings. However, regarding daylight, there is a gap. Hence, given the lack of research where climate change and light sufficiency or performance are linked, at least three possible approaches are proposed here to approach this issue under likely future climate change scenarios, specifically, regarding daylighting in built spaces. The first approach is to address daylight and health based on the need to optimize protection against increased exposure to ultraviolet rays (Joarder *et al.*, 2009) and from the views outside and the health of people in general (Lee, Szybinska, Geisler Selkowitz & Heschong, 2022).

Another possible approach, where there is no bibliographic evidence, focuses on the effects on light sufficiency in current buildings that could be generated after applying adaptation strategies to optimize energy efficiency associated with air-conditioning-based consumption or to meet thermal comfort needs in climate change scenarios with a significant increase in temperature.

The third approach, on which this work is mainly focused, looks at possible variations in global horizontal radiation, normal direct radiation, and horizontal diffuse radiation in a certain geographical location, associated with climate change, due to changes in cloud cover, pollutants, and the combination between these factors. These changes imply variations in outdoor light availability. Regarding this approach, there are multiple investigations that emphasize the role of solar radiation on local light availability from different perspectives: (i) generation of sky types using radiation data or the relationship between solar radiation and local light availability (Dervishi & Mahdavi, 2013; Fakra, Boyer, Miranville & Bigot, 2011; Perez, Ineichen & Seals, 1990; Perez, Seals & Michalsky, 1993); (ii) differences between the solar radiation data from the climate files, measurement data, and calculated data, and their impact on the estimated light performance through computational simulations (Bre, e Silva Machado, Lawrie, Crawley & Lamberts, 2021; Fan, 2022; Monteoliva, Villalba & Pattini, 2017; Wang, Wei & Chen, 2019); and (iii) impact of the climate file used in the results of computer simulations (Arango-Díaz, Parra, Puerta & Salazar, 2021; Arango-Díaz, Piderit & Ortiz, 2022; Bellia, Pedace & Fragliasso, 2015a; Bellia *et al.*, 2015b; González Cáceres & Díaz Cisternas, 2013; Hosseini, Bigtashi & Lee, 2021; Iversen, Svendsen & Nielsen, 2013; Sun, Li & Xiao, 2017).

Despite the importance of the role of daylight in buildings and the need to predict the bioclimatic performance of buildings in future scenarios being acknowledged, there is no evidence of research that addresses, within the framework of climate change, the variability of solar radiation and its incidence on the light performance of buildings.

CLIMATE FILES TO ASSESS BIOCLIMATIC PERFORMANCE IN FUTURE SCENARIOS

Faced with the importance of predicting the bioclimatic performance of buildings within the framework of climate change, just as Vong (2016) presents, it became necessary to review the climate files normally used for thermo-energetic simulations. Currently, several tools are available that modify climate files based on the future temperature increase scenarios defined by the IPCC (Table 1).

Belcher, Hacker, and Powell (2005) developed a method called *morphing*, where climate data are generated that allow making thermal simulations for the building design process, taking into account what the climate could be like in the future. This method uses current climate files that, based on a series of algorithms, predictively transform the average monthly temperature data. It considers the four possible scenarios that come from the 2007 IPCC special report: A1 - low emissions; A2 - medium-low emissions; B1 - medium-high emissions; and B2 - high emissions. It is highlighted that *morphing* does not consider perceptible variations in radiation associated with climate change scenarios and, finally, that thanks to this method, several tools have been developed that facilitate building climate files such as, for example, Meteonorm and CC World Weather Gen (Vong, 2016).

According to Remund Jan *et al*. (2014), Meteonorm is a global climatological database that is used to make calculations, simulations, and research on solar energy. It is based on a stochastic system that, depending on data taken on the typical annual climatic behavior in different places of the world, results in monthly averages that are interspersed in the different future scenarios. This procedure uses between 1 and 4 models to make the calculations, considering clear sky conditions and the maximum possible radiation values each month. For solar radiation, the data used by this tool are obtained from measurements made over 20 years since, for longer periods, there is a 2 to 3% difference in the measurements that all weather stations show. The other parameters are collected from the averages corresponding to the 1961-1990 and 2000-2009 intervals.

On the other hand, CC World Weather Gen was developed to generate data from an automated process, where climate files are produced that can be used in climate change scenarios (Jentsch, James, Bourikas & Bahaj, 2013). To do this, it uses the data produced by the HadCM3 A2 model of the IPCC Data Distribution Center (Jentsch *et al.*, 2013), since it has the parameters required to make the climate files. This tool contains the meteorological averages of the climate scenarios and the real climate sequences (Vong, 2016), and, in that way, projects the climate change scenarios.

Finally, Weather Shift TM, developed as a collaborative project between Arup North America Ltda. (ARUP) and Argos Analytics LLC, uses the *morphing* method, from the combination of 14 global climate models - GCM that have currently been simulated in two of the emission scenarios, 4.5 and 8.5, known as Representative Concentration Pathways (RCP), and converts them into cumulative distribution functions (CDF) (Troup & Fannon, 2016). This allows the percentages to have a distribution that mitigates, to some extent, the intermodal uncertainty and stochastic behavior of the climate, through which a frequency probability is given. However, this does not mean that it generates total confidence in the projection made (Troup & Fannon, 2016).

Faced with this context, where solar radiation variations of climate files are not considered for scenarios that also allow reviewing the future light performance of buildings, this research aimed to identify the impacts that the use of climate files, where solar radiation data are altered due to climate change, would have on the evaluation of the light sufficiency of indoor spaces. In this sense, a comparison of existing climate files for the city of Medellín, Colombia, was made with the official data of the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM), and the climate file with the most similarity was chosen. From the climate file in .epw format, a modification of the radiation of the files was made to evaluate the variations using the findings described by Wild (2009).

METHODOLOGY

To identify the impact on the light performance of variations in the solar radiation of climate files for future scenarios, comparisons of computational simulation results were made on hypothetical spaces located in Medellín (lat. 6.25N, long.75.5W, alt.1450 m.a.s.l.), using the intervened climate files.

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Criterion	Climate file name	Description of the modification
10% increase in global solar radiation	WF-2a	Diffuse radiation and direct radiation increase proportionally by 10%
	WF-2b	The direct radiation increases and the diffuse radiation remains the same as WF-1
10% decrease in global solar radiation	WF-3a	Diffuse radiation and direct radiation decrease proportionally by 10%
	WF-3b	The direct radiation decreases and the diffuse radiation remains the same as WF-1

Table 2. Modifications of climate files of future scenarios. Source: Preparation by the authors.

Based on the corrections made for a current climate file, four additional climate files were built, using four solar radiation variation criteria for future scenarios. In total, the five climate files were used to make computational simulations in three hypothetical spaces with two orientations.

CLIMATE FILE USED

Medellín is a tropical Andean city that has an average temperature of 22°C and a stable climate, with a predominance of partly cloudy skies throughout the year. In previous research, some inconsistencies have been detected in the city's climate files (Arango *et al*. 2021). Due to these inconsistencies, which are related to the global solar radiation data and diffuse and direct radiation data, it was necessary to make manual adjustments to the climate file used for Medellín. These inconsistencies refer to the differences, hour by hour, of the global solar radiation data and the sum total between normal direct radiation and horizontal diffuse radiation. Therefore, the adjustment consisted in ensuring that, for each hour, the sum total of the horizontal diffuse radiation and the normal direct radiation of the climate files was the same or very similar to the global radiation data of this one. For this purpose, a summation was made, hourly, between the diffuse radiation and the direct radiation of the climate file.

Subsequently, it was identified which percentage of this added value was from diffuse radiation and which percentage was from direct radiation. These percentages were used to recalculate the hourly data in the climate file of normal direct radiation and horizontal diffuse radiation, using the global radiation data. This climate file, in modified .epw format, was named WF1 and was used as input to build new climate files with future radiation scenarios.

CLIMATE ARCHIVES OF FUTURE SCENARIOS

Since the climate files available for future scenarios do not incorporate variations in solar radiation and, consequently, would not show changes in the light availability or light performance of buildings, starting from the 10% variation in radiation reported by Wild (2009) and based on the WF1 climatic archive, 2 criteria for the modification of climate files were considered. The criteria and the description of the new climate files are explained in Table 2. The modifications of the climate data were made in Microsoft Excel.

COMPUTATIONAL SIMULATION

For the computational simulations, Dynamic Daylighting software was used (Marsh, 2020), which is validated with Radiance and DIVA/DAYSIM as described on the website. The reflection parameters taken for the walls were 0.60; for the floor, 0.40; and in the sky, 0.70. The analysis grid was defined at a height of 0.75m above floor level, with a distance of 0.25 between cells. The metrics that were analyzed were *Daylight Autonomy* (DA) [300 lx] and *Spatial Daylight Autonomy* (SDA) [300 lx; 50%], considering a schedule between 8 am and 6 pm, over an annual time period.

HYPOTHETICAL MODEL

For the computational simulations, three hypothetical environments with two different orientations were contemplated: north and west. The geometry of the models considers the typical areas and heights of the uses proposed in the city of Medellín. The types of glazing were also chosen considering those used most for office buildings. The description of the models is summarized in Figure 1.

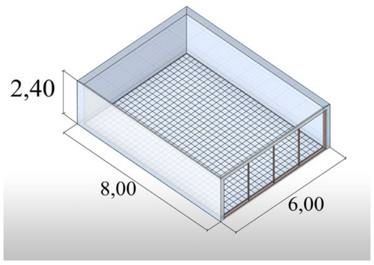
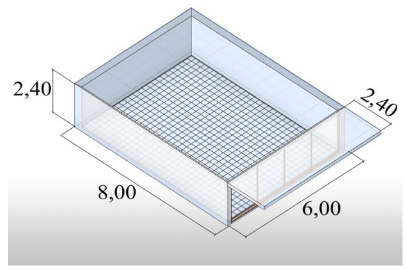
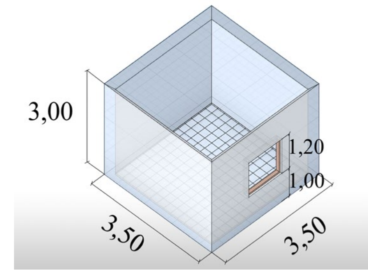
OLT 40	OLT 50 APV °45	HLT 90
		
8.00 x 6.00 x 2.40m office with floor-to-ceiling glass, Light transmittance - TL = 40%	8.00 x 6.00 x 2.40m office with floor-to-ceiling glass, TL = 50% and 45° vertical protection angle	3.50 x 3.50 x 3m room, with 1.20 x 1.20m window, 1m ashlar, glass with TL = 90%

Figure 1. Summary of the models. The units of measurement are in meters (m). Source: Preparation by the authors.

RESULTS AND DISCUSSION

In this research, the results were analyzed from two points of view. Firstly, an analysis of the sky types and solar radiation in future scenarios was made, and secondly, a comparative analysis of computer simulations was carried out.

SOLAR RADIATION IN FUTURE SCENARIOS

The result of adapting the climate files is laid out below. Figure 2 shows the hourly average global solar radiation of the three adapted climate files, WF1, WF2, and WF3, compared to the official data for 2016 and 2017 of the Colombian IDEAM (IDEAM, 2019). Even though the average Global Solar Radiation of WF1 is 172 Wh/m² and that of IDEAM data is approximately 180 Wh/m², differences of up to 100 Wh/m² are evident in the radiation data for certain times.

As a complement, Figure 3 shows the frequency of global radiation values, in ranges between 7 am to 6 pm for the manipulated climate files compared to the official IDEAM data. This shows a higher frequency of high global solar radiation values for the WF2 files.

These differences in radiation data are also recorded in the sky types which, in terms of the *Clearness Index* (Perez *et al.*, 1990), would be generated from the analyzed climate files. Table 3 expresses the frequency of the sky types in 3 of the climate files. It is clear that the methodology used to adapt the radiation data modifies the time-frequency that the sky types would be generated with, mainly in sky types 1 and 2, which correspond to overcast/cloudy skies. This finding is also observed in Figure 4, where the differences are most clearly noticed mainly between 9 am and 5 pm on dark days. The apparent low impact of the radiation

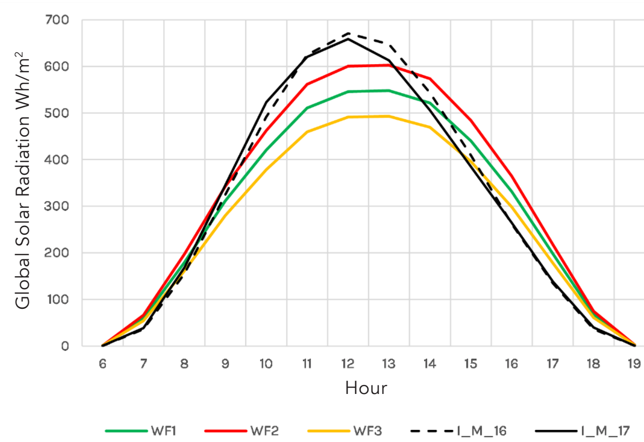


Figure 2. Global solar radiation from climate files used vs. official data of IDEAM for 2016 and 2017. Source: Preparation by the authors.

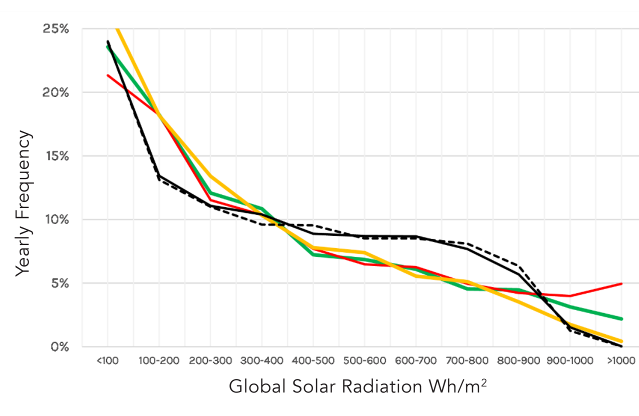


Figure 3. Comparison of global solar radiation frequency values by ranges. Source: Preparation by the authors.

	Clearness Index							
	1	2	3	4	5	6	7	8
WF1	43%	12%	10%	8%	9%	8%	3%	7%
WF2b	21%	30%	11%	9%	9%	9%	3%	8%
WF3b	50%	9%	8%	7%	9%	7%	3%	6%

Table 3. Frequency of sky types in climate files according to the Clearness Index, which uses a scale from 1 to 8, where 1 is overcast/cloudy sky, 4-5 is partly overcast/intermediate, and 8 is clear/clear sky. Source: Preparation by the authors.

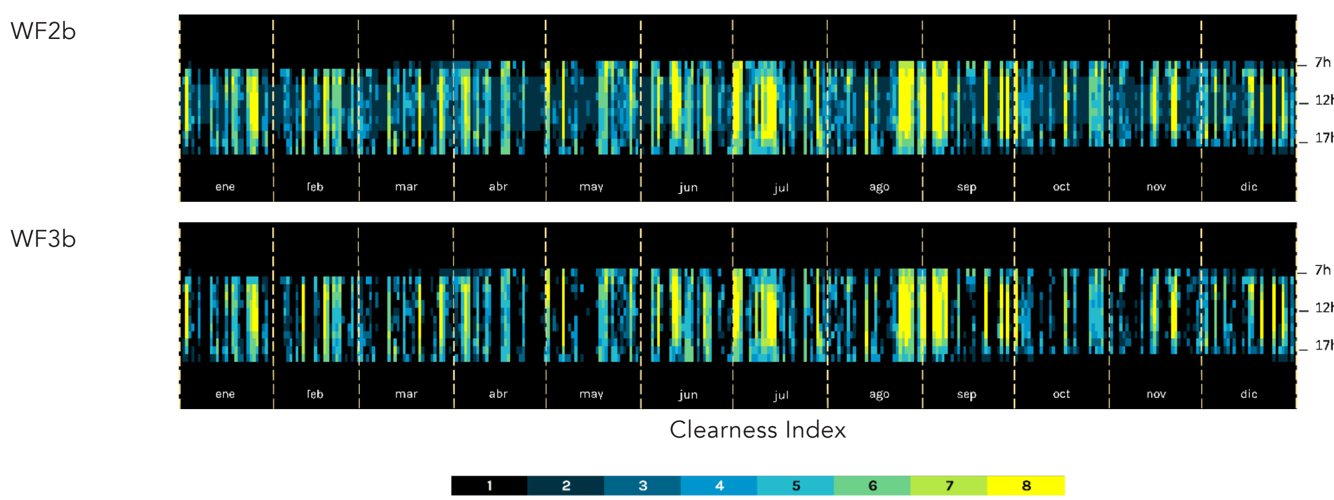


Figure 4. Distribution of sky types according to the Clearness Index with a scale of 1 - 8 for the WF2b and WF3b Files.

data modifications on the frequency distribution of the sky types does not necessarily mean minor differences in the outdoor light availability, since very different light availability could be obtained with the same sky type. However, variations are evident, above all, in the sky types in the morning and those in the late afternoon, when there is less light availability for the city of Medellín.

DIFFERENCES IN LIGHT SUFFICIENCY

Table 4 illustrates the DA and SDA results for the 3 hypothetical models in the studied orientations. The results show a considerable variation in the SDA results of each hypothetical model in the different scenarios, while the DA results do not show as much variation.

The analysis of the SDA results was carried out from two approaches for each model in each orientation: (i) differences between the SDA values for the simulations performed with the WF1 climate file and with the other climate files, and (ii) maximum differences between the SDA values. Regarding the first approach, differences of up to +14% are seen using the WF2a climate file in the model with the best light performance, OLT40, in the North orientation, and -14% with the WF3a climate file in the HLT90 model, with a smaller window typical of high-rise houses in Medellín, with a West orientation. The minor differences of ±4% were recorded for the two orientations of the OLT50 APV 45° model. These differences suggest the error that would be generated in the light sufficiency assessment of indoor spaces in climate change scenarios when using a current climate file. They refer to both an increase in the space with sufficient light and a decrease, depending on the climate file used.

The second approach, the maximum differences between SDA values for each case in each orientation, highlight the variability in the annual assessment of light sufficiency that indoor spaces could suffer in the future due to the variability of solar radiation. Differences of up to 22% were recorded in the OLT40 model North orientation, up to 18% in the OLT40 model West orientation, up to 7% in the OLT50 APV model 45° North, up to 8% in the OLT50 APV model 45° West, up to 18% in the HLT90 model North, and up to 21% in the HLT90 model West.

Although it would be necessary to include more models to confirm this, these results suggest that for spaces with a higher proportion of glass on the

Code	Orientation	Climate file	DA (300 lx)	sDA [300lx, 50%]
OLT40	N	WF1	74%	83%
		WF2a	77%	97%
		WF2b	73%	82%
		WF3a	71%	75%
		WF3b	73%	79%
	O	WF1	77%	91%
		WF2a	80%	100%
		WF2b	78%	97%
		WF3a	74%	82%
		WF3b	76%	87%
OLT50 APV 45°	N	WF1	48%	46%
		WF2a	52%	49%
		WF2b	47%	45%
		WF3a	43%	42%
		WF3b	47%	44%
	O	WF1	51%	50%
		WF2a	56%	54%
		WF2b	52%	52%
		WF3a	47%	46%
		WF3b	46%	49%
HLT90	N	WF1	45%	44%
		WF2a	49%	52%
		WF2b	42%	37%
		WF3a	40%	34%
		WF3b	44%	41%
	O	WF1	50%	54%
		WF2a	54%	61%
		WF2b	48%	46%
		WF3a	45%	40%
		WF3b	48%	49%

Table 4. Results of DA and SDA scenarios. Source: Preparation by the authors.

façade and without included shading devices, namely, mostly exposed to radiation, as well as for spaces with small windows and without solar protection elements on the façade, the variability in the annual light sufficiency assessment using SDA could be greater. Meanwhile, for spaces with horizontal solar control elements and less favorable lighting performance, the differences would be smaller.

Despite not being the goal of this research, if the modifications that buildings would have in the future to adapt to thermal conditions or to reduce air conditioning consumption were considered, it would be expected that the SDA values could decrease even more. Likewise, the probability of glare could increase if modifications are not made in scenarios with increased direct solar radiation.

In general, the model with the greatest distances in lighting results with the SDA metric is the OLT 40, with a difference compared to WF1 of 13.9% and between scenarios, of 22.3% (see Figure 5). While the space with the least variations is the OLT 50 APV °45, where the greatest variation is 3.9% compared to the WF1 scenario, and between scenarios, it is 7.5%. These variations between scenarios, 22.3% and 7.5%, represent the maximum differences detected and those that could be reached in the lighting performance if variations in the radiation data of the climate files are considered.

As for the climate files generated, it is evident that for all models there were greater differences in the base case with the scenarios of the proportional increase of direct and diffuse radiation, WF2a, and proportional

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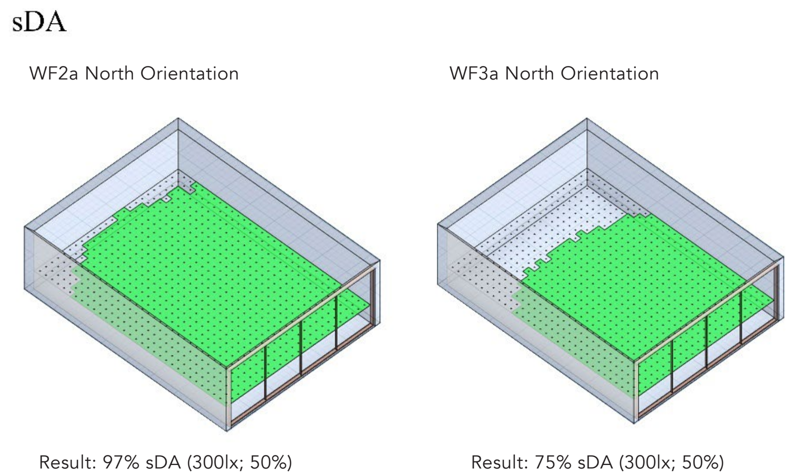

Figure 5. Comparison of SDA results for the OLT40 model. Source: Preparation by the authors.

decrease of direct and diffuse radiation, WF3a, with the scenarios where the diffuse radiation remained the same and only the direct, WF2b and WF3b were increased. This indicates, preliminarily, that if the changes in radiation detected by Wild (2009) are more or less proportional in the diffuse radiation and direct Radiation, the changes in the lighting performance of indoor spaces could be greater than in other scenarios. Therefore, for greater precision on the impact of climate change on the variability of light performance, it will be necessary to define how the *dimming* and *brightening* cycles described by Wild (2009) would be given.

CONCLUSIONS

This article addressed the evaluation of the lighting performance of indoor environments considering future climate change scenarios.

In the process, no climate sources or files were found that could be used to review the indoor or outdoor light availability based on changes in solar radiation or cloud cover. Despite this, and with the findings of Wild (2009) on 10% alterations in global solar radiation associated with climate change, modified climate files were built based on data from the climate files currently used for the city of Medellín. Although these files were not useful for predicting what global solar radiation would look like in the future, they did help identify the changes in local light availability that could be achieved considering several global solar radiation change scenarios.

With the results of the computer simulations, the following was concluded: on one hand, there are differences of up to 14% in SDA evaluations, when comparing a current scenario with a future scenario of increased global solar radiation, and 10% when the current scenario is compared with a future lower radiation scenario, added to SDA differences of up to 22.3% for all cases of the same simulated model. This shows the level of uncertainty that could be generated regarding lighting performance in the future with current simulation results. These percentages could increase uncertainty in other case studies. Such uncertainty is directly related to inaccuracies in estimates of buildings' energy consumption, light sufficiency, and glare probability.

On the other hand, although it is not part of the goals of the research, the results also allow foreseeing the variations in the light performance of buildings where adaptations are made to the façade to minimize thermal gains in climate change scenarios. For example, although a building such as the OLT 40 currently has an SDA of 91%, if it adds eaves and changes its glass to favor energy efficiency, such as in the OLT 50 APV 45° case, this value will decrease significantly depending on the climate change scenario. Faced with this outlook, the importance of considering the lighting performance of indoor spaces in climate change scenarios is highlighted.

It is also highlighted that, although the number of models evaluated was limited, the results allow preliminarily concluding that the differences between current and future lighting performance would be more evident in environments with glazed facades without solar control elements.

Finally, these findings also draw attention to the need to deepen the study of outdoor light availability in different climate change scenarios where modifications in solar radiation, in the sky types of each locality, and, of course, in the lighting performance of indoor environments are considered. For this, it is essential to have climate files that include climate change scenarios, not from the thermal point of view but from the light.

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