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# Building information modeling applied to daylight dynamic simulation from the perspective of future and urban climate: A case study in Brazil

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ABSTRACT

The EN 17037:2018 standard, titled “Daylight in Buildings”, is recognized as a step in the right direction concerning daylighting and has been used as the basis for the recently revised Brazilian standard. In this context, this study aims to delve into the understanding of the daylight performance in buildings in Brazil by analyzing the advancements and challenges in NBR 15215/15575:2022. Two methods will be employed: the computational daylight performance simulation method and the abacus method, following the revision of NBR 15575:2022, in a Housing of Social Interest (HIS) located in the city of Belem, Brazil. Since it is a digital prototype and not a physical one, the reliability of the simulations was verified by comparing the results obtained with the abacus method, which also allowed for an analysis of the case study using this alternative approach from the standard. The study aims to identify the best workflow for applying the standard, based on an investigation of dynamic simulation software and the impact of future-urban weather files, seeking to propose improvements to the standard. The results demonstrate the efficiency and accuracy of building information modeling, specifically the AftabRad plugin, for dynamic simulations in accordance with normative criteria, as well as the need to include urban weather files in the standard.

## 1. Introduction

Daylighting is essential for human well-being, influencing both physical and psychological factors in indoor environments. The ability to accurately predict daylighting is crucial in the design decision-making process. Research, such as that conducted by Du et al. [1], demonstrates that visual connection with natural elements enhances the quality of the environment, promoting satisfaction, health, and productivity. Furthermore, exposure to daylighting contributes to improving sleep and reducing eye fatigue, which is particularly relevant in healthcare buildings where design techniques balance natural and artificial lighting [1–3].

Essential assessments should consider both quantity and quality of light, focusing on factors like lighting uniformity, glare prevention, and controllable intensity for user comfort. Maximizing daylight usage through design strategies can significantly reduce electricity consumption for artificial lighting [4]. Embracing the EN 17037:2018 [5] [standard is a positive step for European designers, defining adequate daylighting when a specified illumination level is maintained for at least half of the daylight hours.

The authors Sepúlveda, Luca, Varjas, and Kurnitski [6] address parameters from EN 17037:2018 to guide daylighting in buildings. These parameters include daylighting measured in lux, uniform light distribution for specific needs, and glare limits for user comfort. Rynska and Yanchuk [7] note that EN 17037:2018 provides two ways to justify appropriate levels of daylighting: one based on the daylight factor and another on the illuminance at the working plane.

Sepúlveda, Luca, Varjas, and Kurnitski [6] validate the practical applicability of subjective user assessments by aligning them with the more objective evaluations of the EN 17037:2018 standard. This enhances overall comprehension. Another study [8] emphasizes the significant contribution of daylight analysis based on EN 17037:2018 to understanding its influence in architectural design. The study underscores the need for advanced and reliable approaches in assessing

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daylight for architectural projects. For detailed guidelines on achieving visual comfort, direct reference to the EN 17037:2018 standard is essential [9].

According to authors Waczynska, Sokol e Martyniuk-Peczek [10], one of the main objectives of EN 17037:2018 is to promote the health and well-being of building users. The standard recognizes that daylight is crucial for our health and well-being, and its absence can lead to health problems, including eye fatigue, insomnia, and even depression. For this reason, the standard provides guidelines to ensure that buildings have an adequate level of daylight in all habitable spaces.

Advancements in Brazilian standards have been based on EN 17037:2018, the European standard for daylighting in buildings. Its primary purpose is to enhance the visual comfort of building occupants while improving energy efficiency and environmental performance. The standard provides guidance on the quantity, quality, and distribution of daylight within habitable spaces and addresses the prevention of direct sunlight. It establishes criteria for measuring daylighting and evaluating its impact on energy consumption [11].

In October 2022, the Brazilian Building Performance Study Commission presented the restructuring of section 13 of ABNT NBR 15.575 [11] concerning luminous performance. It is important to note that ABNT NBR 15.575 [11] works in conjunction with ABNT NBR 15215, which provides information on lighting assessment and calculation methods for the design and evaluation of constructed buildings. Recently, Part 2 of ABNT NBR 15215 [12] was published, aiming to update calculation methods and include the availability of external lighting through dynamic computer simulations. Two sky models, one from the Commission Internationale de L'éclairage (CIE) and the other from Perez are considered by ABNT, 2022 [13].

Meeting the need for daylighting in buildings requires a suitable provision of daylight in a significant portion of the area within spaces during a considerable part of the daytime throughout the year. The assessment of this daylight provision should take into account the specific characteristics of the building, external obstructions such as self-shading and environmental influences, as well as local climate conditions. NBR 15215/15575:2022 [11,12] establishes criteria for evaluating daylight provision based on two aspects: sufficiency of target illuminance and minimum illuminance uniformity, which must be simultaneously met [11,12].

Therefore, the use of more dynamic sky models enables a detailed study of lighting dynamics in different locations across the country. The CIE and Perez models, in turn, exhibit a good ability to reproduce the dynamics of various sky types, allowing some models to represent, albeit partially, the distribution of partly cloudy skies. In all cases, there is an appropriate reproduction of lighting levels [14,15]. Additionally, another crucial aspect is the advancement in the analysis of daylighting in environments illuminated by it. ABNT NBR 15215-3 [12] addresses the evaluation of daylighting in indoor spaces, encompassing criteria such as view, sunlight, glare, and illuminance to assess the quality of daylighting in a space.

NBR 15575:2022 outlines two approaches to assess natural light provision in buildings based on local climatic conditions. Method 1, Simplified Assessment Using Abacus, employs predefined criteria for a calculation process that evaluates minimum performance in diverse environments. Method 2, Assessment Using Computer Simulation, is a precise but complex approach applicable to any space. It involves specialized professionals and software to calculate annual daylight autonomy, considering architectural variables and hourly climate data for simulated illuminance values [11].

The integration of climatic data is crucial for assessing climate impacts on constructions in urban areas, influenced by population growth and human activities driving climate change. This leads to issues like the heat island effect and heatwaves, resulting in prolonged exposure to solar radiation conditions [16]. The UWG software proves valuable for quantifying climate change impact, providing customized urban climatic data and optimizing daylight use in construction projects by considering urban landscape geometry and land-use classification [17]. Studies by Bellia, Pedace, and Fragliasso emphasize the importance of meteorological files in dynamic daylight simulations for significant data on annual and monthly light exposures [18].

Natanian and Auer stress the significance of incorporating microclimates into urban design evaluations through an integrated digital workflow, especially crucial amid rising urban density. The study underscores the importance of design parameters tailored to local microclimates for promoting sustainable development in urban constructions [19]. In another study, Ciancio et al. simulated a constant increase in average temperatures until 2080, revealing heightened electricity demand for cooling. These simulations emphasize the necessity of evaluating how climatic conditions directly impact the energy efficiency of the built environment [20].

Zeng and He emphasize the importance of considering local climatic conditions in designing energy-efficient buildings, with solar irradiance identified as a key factor influencing energy-saving potential [21]. Conversely, studies by Gapski, Marinoski, Melo, and Guths indicate that radiation variation, influenced by surface solar reflectance, is more significant in dense urban areas than less dense ones [22]. In urban solar radiation research, building height is identified as a crucial independent variable, significantly impacting radiation levels. The study underscores the importance of open spaces for maximizing sunlight penetration and promoting solar radiation production [23].

The studies by Lee et al. emphasize the need to incorporate climate modeling, simulation tools, and measurements in methods for assessing natural light in buildings, highlighting the importance of further research to maximize its benefits [24]. In turn, the research by Rastegari, Pournaseri, and Sanaieian underscores the relevance of reflectance distribution and geometry in optimizing daylighting, highlighting the reliability of occupants' well-being index concerning natural light. Both studies advocate for the integration of natural light in building design to enhance occupants' experience, indicating a clear preference for this element in the built environment [25].

Li, Chen, and colleagues introduce an innovative method for daylight metric determination based on diffuse illuminance and direct sunlight variables, offering a practical tool for challenging development projects. This approach enhances energy efficiency, empowering architects and engineers to design more sustainable buildings [26]. Asdrubali et al. stress the significance of dynamic simulation in assessing green building performance, revealing a potential 30 % reduction in energy consumption [27]. Metrics like DA, UDI, and annual daylight factor contribute to efficient daylighting assessment, enabling optimized lighting design and reduced energy consumption in real buildings [28].

High urban density reduces daylighting in buildings due to surrounding structures, compromising indoor quality and increasing reliance on artificial lighting. The European standard EN 17037:2018 addresses this by setting minimum requirements for natural light provision, focusing on room geometry and window area to floor area ratio. Implementation aims to establish parameters for well-lit and acoustically sound indoor environments, promoting optimal conditions for daylighting, improving quality of life, and enhancing energy efficiency [29].

The literature highlights a gap regarding the influence of urban climate data and future scenarios on daylighting performance. Dynamic simulation, considering local and global climate changes, is a growing trend in studies of thermal performance and resilient cooling, directly influenced by solar radiation. In this context, this research introduces a method using dynamic simulation through a BIM plugin that aligns well with the evaluation metrics of European and Brazilian daylighting performance standards.

## 2. Methodology

To identify the advancements and challenges related to lighting performance evaluation, the computational simulation method of NBR

15215 [12] and EN 17037 [5] was applied to a prototype of low-income housing (HIS) located in the city of Belem, Para, Brazil. The city was chosen due to its critical equatorial hot and humid climate scenario, along with the influence of urban heat islands, global warming, and heatwaves. In June 2023, a collaborative study between CarbonPlan and The Washington Post warned that it will be the second hottest city in the world by 2050 (2041–2070) [30].

Simulations with weather files from 2020 and 2050 (2041–2070), with two different Local Climate Zones (LCZ), and with and without built surroundings, were carried out to analyze the combined effect of local and global climate changes on lighting performance, with the aim of providing normative insights. Six combinations were analyzed:

- Environment 1: Original weather file 2020 with Surroundings in Revit.
- Environment 2: Original weather file 2020 without Surroundings in Revit.
- Environment 3: Urban weather file LCZ 1 (Compact High-Rise 2020 – UWG) with Surroundings in Revit.
- Environment 4: Urban weather file LCZ 1 (Compact High-Rise 2020 – UWG) without Surroundings in Revit.

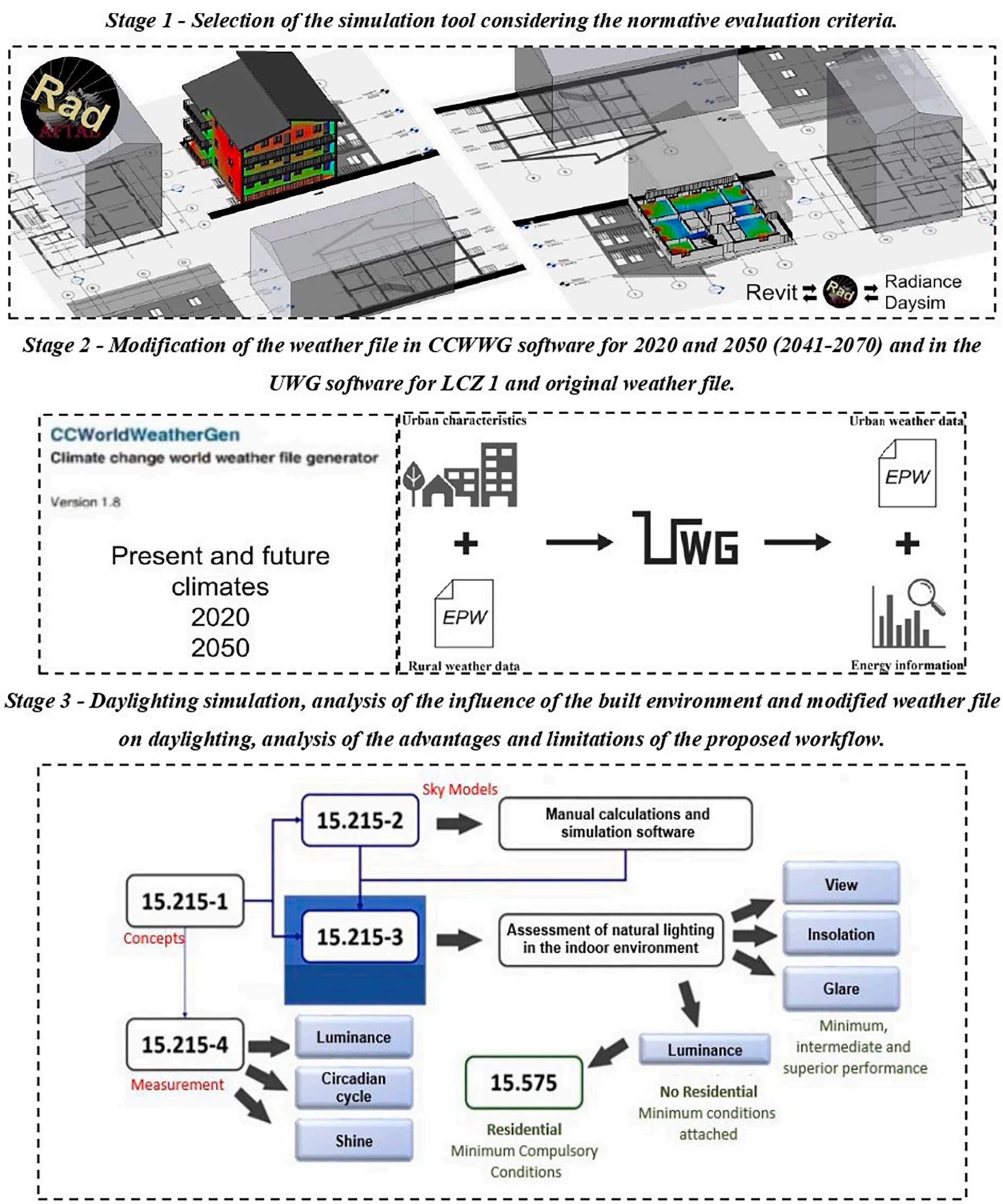



**Fig. 1.** Methodology Step-by-Step. .002 Building Daylight Study Committee by Roberta Vieira G Souza.
Source: Step 1: AftabRad website, Step 2: CCWWG and UWG websites, Step 3: translated of ABNT/CE-002:135

- Environment 5: Future weather file 2050 (2041–2070 – CCWWG) with Surroundings in Revit.
- Environment 6: Future weather file 2050 (2041–2070 – CCWWG) without Surroundings in Revit.

For modeling future and urban climate, the weather files transformed for future climate in CCWWG (Climate Change World Weather Generator) were subjected to a new transformation for urban climate in UWG (Urban Weather Generator*)*. These weather files, transformed for the future and urban climate, will have an impact on global radiation, direct and diffuse, together with the built environment modeled in Revit. For each environment, the normative criteria of NBR 15215/15575:2022 [6,12] for daylight autonomy, uniformity, glare, exposure, and view were simulated, this step by step is illustrated in Fig. 1.

### 2.1. Stage 1 – Selection of the simulation tool and for the normative evaluation criteria

The computational simulation method requires a representative space model that takes into account the relevant architectural variables for daylighting performance. Both methods focus on the absolute annual internal illuminance, calculated based on external daylighting availability conditions determined by hourly climatic data. This method utilizes simulated illuminance values on the reference plane to determine the Daylight Autonomy (DA), Daylight Glare Probability (DGP), View Analysis (according to [5]), and Exposure to Sunlight (according to [5]). To perform the calculation, a validated computational program is required. The simulation involves modeling the building and its surroundings, defining the grid points of the analysis plane, and selecting the weather file. The simulation tool needs to attend the criteria for each of the assessing daylighting performance parameters for Brazilian standards and EN 17037:

- Dynamic computational simulation – calculates daylighting levels throughout the year; collecting data every hour; it employs local radiation data; utilizes annual climatic files; calculates Daylight Autonomy (DA) and Useful Daylight Illuminances (UDI);
- Daylight Glare Probability (DGP) – evaluates areas with significant glare; glass facades; and presents visual discomfort levels;
- Exposure to sunlight – duration measured in hours;
- View analysis – window aperture provides adequate visibility; Observation of the sky is conducted from indoor environments; Each layer achieves minimum, medium, and high levels (minimum: horizontal vision $\geq$6 m, medium: horizontal vision $\geq$20 m, and high: horizontal vision $\geq$50 m).

For the selection of the most suitable software for modeling the case study and simulation in accordance with NBR 15215/15575:2022 [11,12] and EN 17037 [5], the advantages and limitations of the main dynamic daylighting simulation software were analyzed. The following criteria were assessed regarding the advantages and limitations of each software: the calculation method used, the ability for customization, usability, reliability, and efficient technical support:

1. DIVA plugin (now Climate Studio) for Rhino – enables advanced simulations of daylighting, assessing the project's performance by measuring light levels. Using sophisticated methods, it calculates light input, taking into account the sun, building orientation, and topography. In addition to simulated shadows, it analyzes visibility factors. It's important to note that DIVA is not a BIM platform, requiring additional efforts from the designer [18]. Recently Climate Studio added the Revit plugin to export the Revit model to Climate Studio.
2. Ecotect-Daysim – Autodesk launched in 2008 as environmental simulation software for enhancing building performance across energy efficiency, daylighting, thermal comfort, and acoustics. The tool simulated daylighting through ray tracing, assessing light performance at different times and seasons to optimize designs based on available lighting conditions. However, Ecotect Analysis was discontinued in 2015, with no ongoing support or updates. Presently, Autodesk provides alternative tools such as Insight, which integrates with the 3D modeling software Revit for comprehensive environmental analysis [20,21].
3. Revit-plugin lighting analysis – Allows dynamic analysis of daylighting. Insight Lighting Analysis plugin. Cloud-based rendering. Allows the simulation of Spatial Daylight Autonomy (sDA) and Annual Solar Exposure (ASE). This tool generates daylight autonomy for LEED v4 certification but does not separate environments as per NBR 15215/15575:2022 analysis.
4. Daysim and Radiance in their native versions – In the late 1980s, Greg Ward, affiliated with the Lawrence Berkeley National Laboratory, introduced a groundbreaking innovation by introducing the Radiance software for reverse ray tracing. This advancement led to the development of the DAYSIM program, enabling the execution of daylighting simulation studies [22]. The Daysim, crucial for dynamic simulation of daylighting, employs the Perez sky model and the Radiance algorithm [23]. It integrates lighting controls and artificial illumination, producing exportable results for programs such as Ecotect and SketchUp. Radiance, a sophisticated software, collaborates with Daysim for comprehensive simulations, as highlighted by Berardi and Wang [24], encompassing Natural Daylight Autonomy (DA) and Useful Daylight Illuminances (UDI).
5. Sketchup-Daysim-Radiance – included in the OpenStudio plugin for SketchUp, does not provide illuminance visualization, only graphics, and its accuracy has been questioned.
6. Dialux – does not perform dynamic simulation.
7. Revit-plugin AdfrabRad – Daysim – developed in 2018 and regularly updated, enables advanced global lighting analyses in Revit (2018 to 2024) by exporting 3D models to Radiance/Daysim. It provides flexible interfaces for lighting simulations, contributing to improving the performance of constructions, reducing energy consumption, and creating healthier environments. Its direct communication with Radiance, highlighted by Miri, and its potential in residential energy efficiency [25,26,27,28].

Table 1 compares daylight tools and the criteria for each of the assessing daylighting performance parameters. The choice of Revit-plugin AftabRad – Daysim was made due to its numerous advantages, including its compatibility with the Brazilian standard, an efficient user interface, and technical support, making it suitable for the research at hand.

According to Inanici et al. [31], there are three procedures for validating computer programs: analytical validation, which covers limited domains of light propagation and is applied in simple analyses, such as theoretical assumptions for specific project stages; comparative validation, which involves comparing the results of computer simulations between programs; and experimental validation, which consists of comparing the results of physical models or real environments with the illuminance results. Since the project has not been constructed, model calibration cannot be done through measurement, and the reliability of the results was assessed by comparing the simulation results with results from the abacus method.

### 2.2. Stage 2 – Modification of the weather file considering global (CCWWG) and local (UWG) climate changes

Considering that climate change has been influencing the thermal performance of housing, future weather files were generated to assess the impact of global warming on the past, present, and future of housing units. The Climate Change World Weather File Generator for Worldwide Data (CCWorldWeatherGen) tool was used to modify weather files. This tool utilizes the morphing method to adapt EnergyPlus Weather (EPW)

**Table 1**
Simulation Software X Evaluation Techniques.

| Software | DA | UDI | DGP | Exposure to sunlight | View Analysis | Notes: |
|---|---|---|---|---|---|---|
| DIVA – Rhino | x | x | x | x | x | Not a BIM platform |
| Revit –lighting analysis | x | x | – | – | – | SDA – ASE |
| Ecotect Analysis | x | x | x | – | – | Daysim, Discontinued in 2015. |
| Revit-Aftab RAD | x | x | x | x | x | Daysim / Rcontrib,BIM platform |

Source: Authors, 2023.

and TMY files to the climate projections of the SRES-A2 scenario from the HadCM3 model of the 3rd IPCC report. 3 weather files (2020, 2050 (2041–2070)) were generated from the climate progression of the previous weather file from 1964 to 2020. The SRES-A2 scenario and RCP8.5 scenario are considered equivalent and represent high emissions.

The weather files (2020, 2050 (2041–2070)) were modified to urban standards LCZ 1 (Compact High-Rise) and original weather file (Compact Low-Rise) using the Urban Weather Generator software. The Urban Weather Generator (UWG) is a powerful tool used to generate detailed and customized urban climate data. The UWG plays a crucial role in preparing climate data specific to urban areas that can be used as input in simulations. The UWG can model urban climates while considering the specific characteristics of urban areas, such as building geometry, surface reflectance, vegetation density, and other factors. This results in more precise and representative climate data for urban areas compared to conventional climate data. The climatic files contain hourly solar radiation data derived from hourly cloud cover information. These files encompass all the data used in BIN and EPW files. The influence on internal daylighting within buildings depends on how these urban characteristics impact the availability of both direct and diffused sunlight. A more profound understanding of these factors is essential for designing energy-efficient buildings that leverage daylight, thereby reducing the reliance on artificial lighting.

### *2.3. Stage 3 – Simulation inputs in Revit + Aftab Rad plugin and Abacus method for simulation validation*

Revit has a vast library of predefined materials that can be directly applied to model elements like walls, floors, ceilings, doors, windows, and more. These materials come with physical properties such as texture, color, gloss, transparency, and reflectance, allowing for a faithful visual representation of elements in the model. After creating the digital model, the Aftab RAD plugin was used in Autodesk Revit software. Before commencing the analysis, it is necessary to configure: the grid points for daylight illuminances and DGP analysis, the sky type; the interior zones of the building for the analysis and the height of the reference plane. Daylight illuminances and DGP were calculated for each point of the grid. The grid was set to be 0.5 m distant from the wall, the grid points were 0.75 m apart and 0.75 m above the floor.

For simulations in the Aftab Rad plugin in the Revit software, the following analyses will be conducted: dynamic daylight metrics Daysim 3.1 and Rcontrib, probability of glare during the day (DGP), view analysis according to standard EN 17037:2018, and exposure to sunlight also according to standard EN 17037:2018. To evaluate lighting performance using the Daysim software, the Aftab RAD plugin was utilized within Revit. This plugin enables simulation as Daysim/Radiance works directly within its graphical interface.

After implementing the simulation method, the DL Abacus method [32], an alternative simplified method from NBR 15575:2021, was also applied to the case study. This method uses predefined criteria to calculate the "P" index, which is the ratio between the width and depth of each space in the project. Next, the external obstruction angles, both vertical and horizontal, are determined on the floor plan. With this data, the weighted angle for the final evaluation verification is calculated. Since the project has not yet been built, it is not possible to calibrate the simulated model with real measurements [32]. The DL Abacus method is suitable for this purpose because its results were developed based on simulations, making it an appropriate solution for the design phase, which is crucial for evaluating optimized performance solutions.

## 3. Case study

### *3.1. Case study modeling in the Revit software*

The choice of the city of Belem, Para, is due to the critical climatic conditions in the region (Bioclimatic Zone 8). The project aims to serve the "Level 1″ income bracket of the *Minha Casa Minha Vida* housing program, with a maximum family income of up to R$ 1,600. The housing model consists of a three-story building on pilings, with three apartments per floor. Each apartment has an area of 44.71 m$^2$ and a ceiling height of 2.80 m. The apartments are accessed through a peripheral corridor that connects to a stairwell block on the side facade. Fig. 2 shows a 3D view of the site layout, and the model in Revit for subsequent simulation. The chosen housing follows the project and construction specifications defined by the Ordinance N° 725 of the Ministry of Cities, dated June 15th, 2023, aiming to incorporate architectural strategies that make the best use of the region climatic conditions. The project consists of 50 cm brises on the east facade that shade from 10:30 in the morning onwards and on the west façade it has 1.2 m balconies that shade until 3:30 in the afternoon.

## 4. Results

### *4.1. Modification of the weather file considering global (CCWWG) and local (UWG) climate changes*

The following figures (Fig. 3) compare the annual solar radiation (diffuse, direct normal, and global horizontal) from the weather files: Original weather file 2020 and Urban weather file LCZ 1 (Compact High-Rise) 2020. Fig. 3 shows that in a compact, high-rise area with a predominance of concrete surfaces, there is likely to be a significant amount of global solar radiation reaching the ground. This is because of the lack of vegetation or other obstructions that would block sunlight. Therefore, these areas tend to receive a good amount of sunlight throughout the day. The presence of tall buildings in a Compact Low-Rise (original weather file 2020) may create shadows that reduce the amount of direct solar radiation reaching nearby building surfaces. However, concrete surfaces can reflect direct solar radiation, providing some direct lighting in exposed areas. While the presence of concrete may reflect some of the direct solar radiation, it can also absorb heat, which may result in some emission of diffuse solar radiation, especially during the day when heated concrete emits heat in the form of infrared radiation. However, the amount of diffuse radiation may still be relatively lower compared to more tree-covered areas.

Fig. 3 shows that in densely built urban areas (LCZ 1 2020), it is common to have more obstructions, such as tall buildings and structures, which can block global solar radiation. This result in less available sunlight at ground level and the amount of direct sunlight reaching building surfaces compared to less urbanized areas. Therefore, direct interior lighting can be limited in densely urban areas. In densely populated urban areas, diffuse solar radiation, which is sunlight scattered by the atmosphere, may be more prevalent due to the reflection

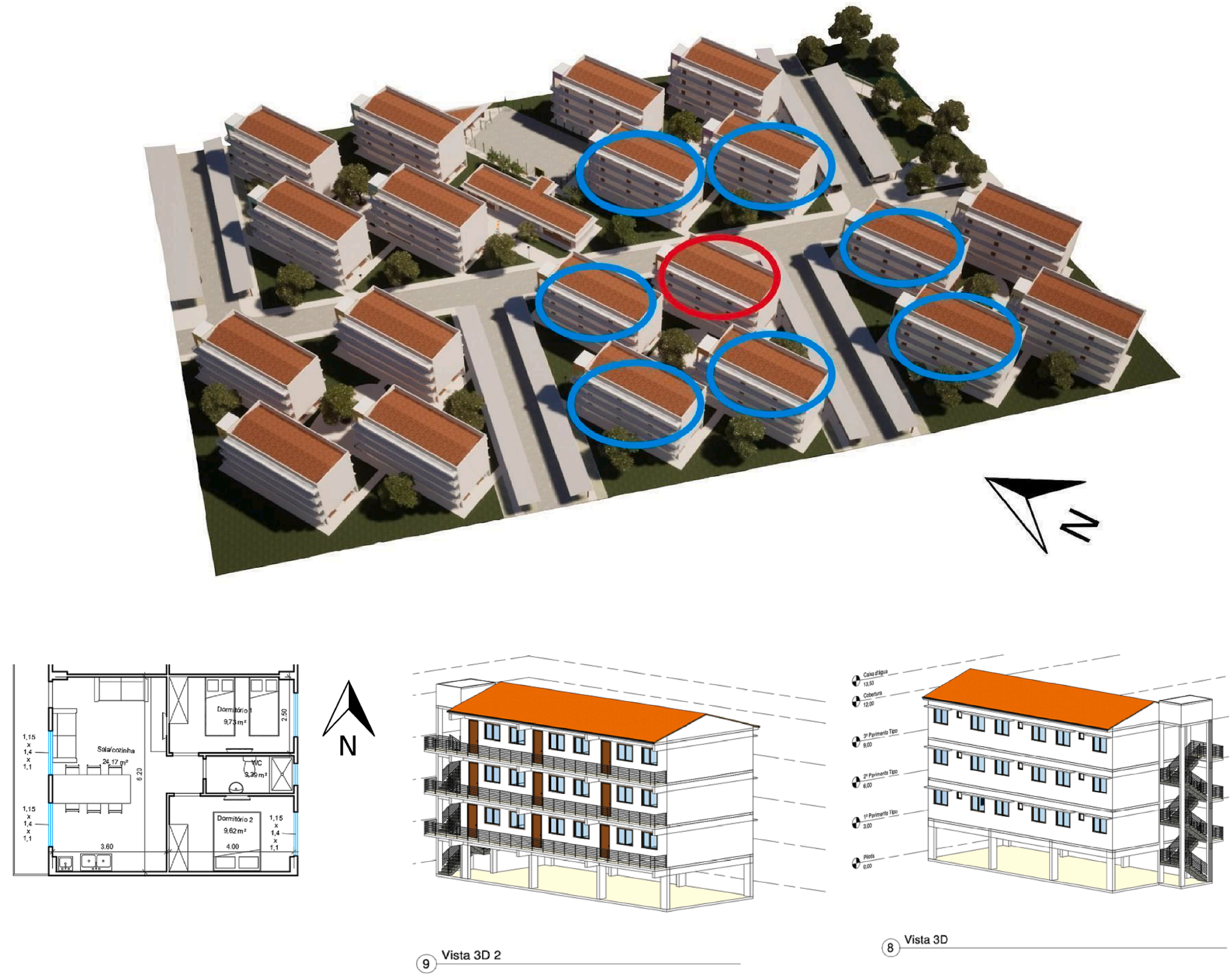



**Fig. 2.** 3D site plan view. .
Source: Authors, 2023

and scattering of light on building surfaces and in the urban environment. This can contribute to diffuse lighting in interiors. In sequence, compares the annual solar radiation (diffuse, direct normal, and global horizontal) from the original weather files (Compact Low-Rise) from 2020 and 2050 (2041–2070). The Future weather file 2050 (2041–2070 – CCWWG) with Surroundings in Revit reflects an increase in urbanization, which influences climate changes and, consequently, leads to greater exposure to global solar radiation. This is due to an increase in direct solar radiation, subsequently increasing the reflection of solar radiation in the area. This means that sunlight falls more directly on the surface, resulting in a reduction of direct solar radiation and an increase in diffuse solar radiation. This change implies losses in direct lighting intensity but results in gains in the overall uniformity of lighting within a building.

### *4.2. Dynamic simulation Daysim 3.1 – Aftab Rad*

To conduct the dynamic simulation, Daysim 3.1 was used, obtained through the Aftab Rad plugin. The results obtained were the Useful Daylight Illuminances (UDI) and Daylight Autonomy (DA):

– UDI (Useful Daylight Illuminance): assesses the amount of usable natural light available in a space, considering the illuminance levels that are effectively usable for daily activities, ranging from 100 lx to 2000 lx. The mathematical definition of UDI can be described as follows [5]:

$$UDI_{100-2000} = \frac{Time during which 100 \leq \text{E} \leq 2000\,\text{lux}}{Total time} \times 100\%$$

Where:

- E is the illuminance measured in lux.

– DA (Daylight Autonomy): is a measure that evaluates the duration for which an indoor space is adequately lit solely by natural light, without the need for artificial lighting. The mathematical definition of DA can be described as follows [5]:

$$\text{DA} = \frac{T_{DA}}{T_{total}} \times 100\%$$

where:

- $T_{DA}$ = is the total time during which natural lighting is sufficient to meet the lighting requirements of the space.
- $T_{total}$ = is the total time considered for the analysis (e.g., a one-year period).

The Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA)

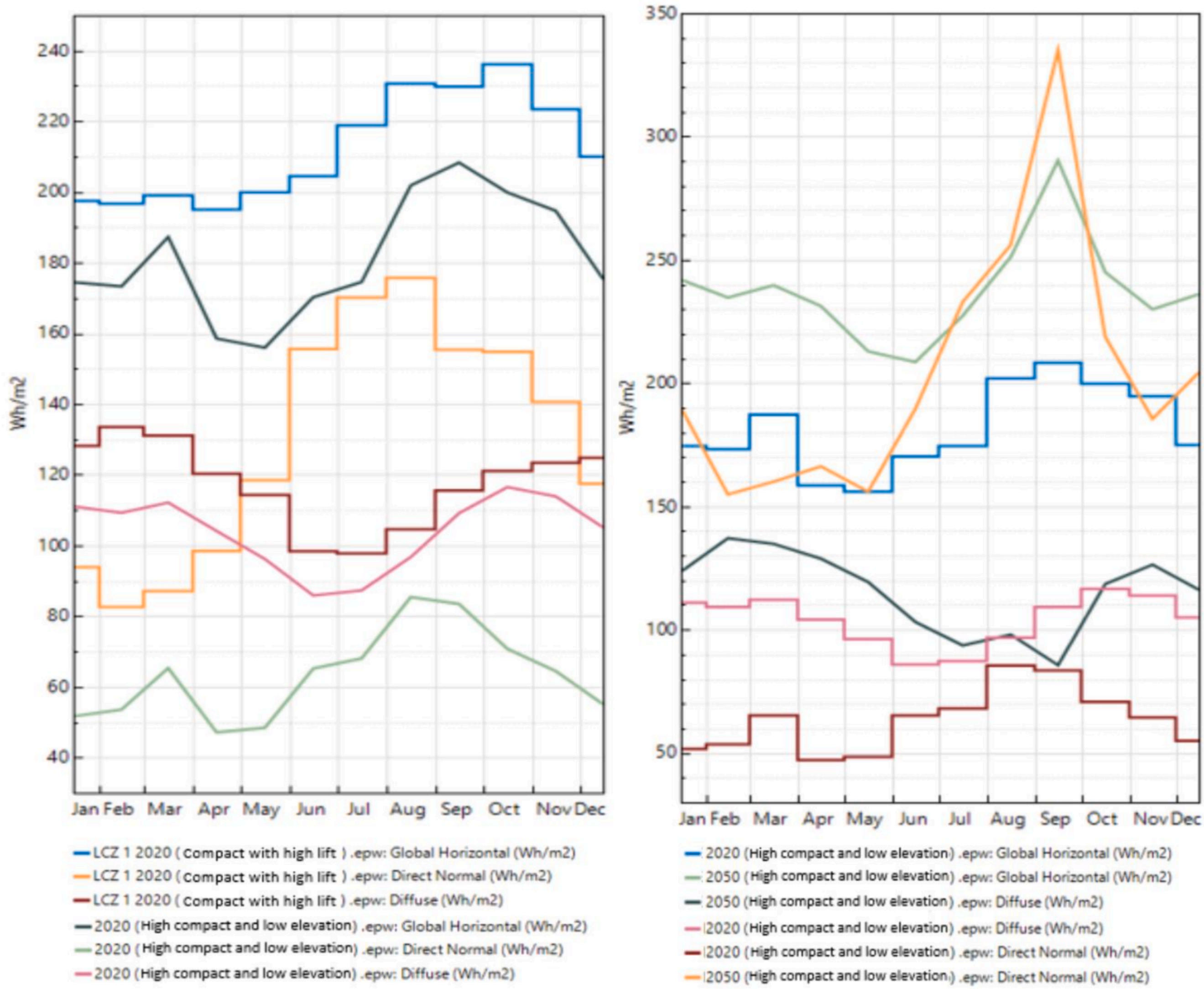



**Fig. 3.** Urban weather file LCZ 1 (Compact High-Rise) 2020 – UWG and original weather file 2020 Solar Radiation. .
Source: Authors, 2023

are classified by the NBR 15575:2022 as follows (Table 2). Comparing to EN 17038, Brazilian standard proposal have lower levels, except the fraction of space for target level, for medium and high levels.

The results of Useful Daylight Illuminance (UDI) aimed to identify the percentages of hours throughout a year during which the illuminance at the reference plane falls between 100 and 2,000 lx, as shown in Fig. 4. According to the proposal of NBR 15.575 [8] to meet uniformity criteria, there should be a minimum of 60 lx in the environment with a minimum fraction of 75 %. Therefore, for the original weather file 2020 and considering the surroundings, the results showed useful illuminance over 84 % and 85 % in the bedrooms, and 76 % in the living room/kitchen. On the other hand, when not considering the surroundings, the variation ranged from 85 % to 87 % in the bedrooms and increases to 92 % in the living room/kitchen. Comparing with the results from the Future weather file 2050 (2041–2070 – CCWWG) without Surroundings in Revit, the living room/kitchen, showed the bigger difference, decreasing from 92 % to 74 %.

In the Urban weather file LCZ 1 (Compact High-Rise) 2020 – UWG areas (using a weather file modified by the UWG) and considering the surroundings, UDI variation ranged from 86 % to 88 % in the bedrooms and 79 % in the living room/kitchen. In the case of not considering the surroundings UDI increased by one percentage point in each room. As expected, results showed a better distribution of illuminance when surroundings are not considered.

**Table 2**
Proposal NBR 15575:2022- Daylight provision recommendations Residential buildings.

| Level of recommendation | Target Illuminance $E_T$ (lx) | Fraction of space for target level $F_{plane,\%}$ | Minimum target illuminance $E_{TM}$ (lx) | Fraction of space for minimum target level $F_{plane\ min,\%}$ | Fraction of daylight hours $F_{time,\%}$ |
|---|---|---|---|---|---|
| Minimum | 200 | 40 % | 60 | 75 % | 50 % |
| Medium | | 55 % | | | |
| High | | 70 % | | | |

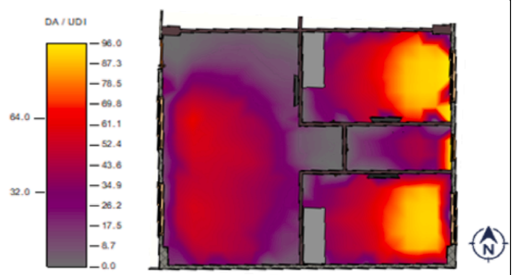
Source: NBR 15575:2022 [11].

The results obtained allow for evaluating the proportion of hours throughout the year when daylight meets the criteria of Daylight Autonomy (DA), which establishes the average percentage of daylighting required for a space, according to the proposals of NBR 15575:2022 [11]. According to this standard, the target fraction of the minimum area of the space is classified into three levels: minimum 40 %, intermediate 55 %, and superior 70 %. For the original weather file 2020, considering the surroundings, the results were 60 % and 61 % in the bedrooms and 48 % in the living room/kitchen. In the original weather file 2020 areas, excluding the surroundings, the variation ranged from 62 % to 65 % in the bedrooms and 62 % in the living room/kitchen.

Considering the surroundings, in the Urban weather file LCZ 1 (Compact High-Rise) 2020 – UWG areas (weather file modified by the UWG), the variation was from 68 % to 69 % in the bedrooms and 56 % in the living room/kitchen. When not considering the surroundings in the Urban weather file LCZ 1 (Compact High-Rise) 2020 – UWG areas, the variation ranged from 66 % to 67 % in the bedrooms and 63 % in the living room/kitchen. Regarding the results obtained when using the future weather file 2050 (2041–2070) – CCWWG, considering the surroundings, it was noted that the bedrooms achieved a Daylight Autonomy of 65 % and 66 %, while the living room/kitchen reached 56 %. On the other hand, when the surroundings were not considered, the

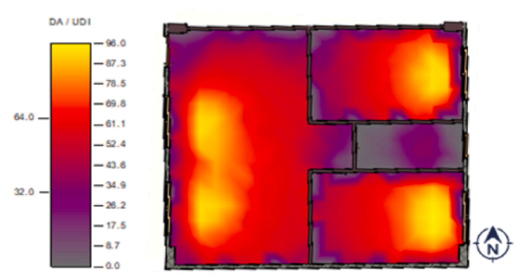
% of hours of the year with daylight

**Original weather file 2020 with Surroundings in Revit**



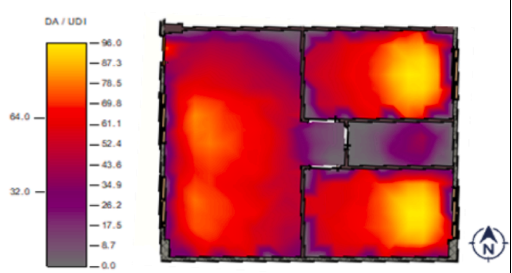

| Room | DA % | Level | UDI % |
|---|---|---|---|
| Bedroom 1 | 60.0 | Med. 55% | 84.0 |
| Bedroom 2 | 61.0 | Med. 55% | 85.0 |
| Room/kitchen | 48.0 | Min. 40% | 79.0 |

**Original weather file 2020 without Surroundings in Revit**



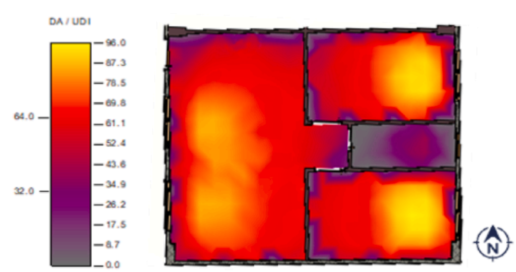

| Room | DA % | Level | UDI % |
|---|---|---|---|
| Bedroom 1 | 62.0 | Med. 55% | 85.0 |
| Bedroom 2 | 65.0 | Med. 55% | 87.0 |
| Room/kitchen | 62.0 | Med. 55% | 92.0 |

**Urban weather file LCZ 1 (Compact High-Rise 2020 - UWG) with Surroundings in Revit**



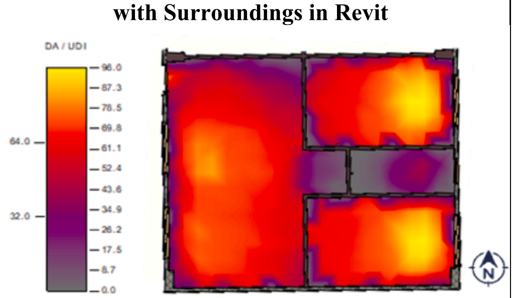

| Room | DA % | Level | UDI % |
|---|---|---|---|
| Bedroom 1 | 68.0 | Med. 55% | 86.0 |
| Bedroom 2 | 69.0 | Med. 55% | 88.0 |
| Room/kitchen | 56.0 | Med. 55% | 79.0 |

**Urban weather file LCZ 1 (Compact High-Rise 2020 - UWG) without Surroundings in Revit**



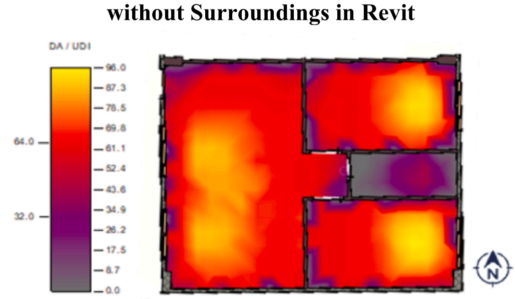

| Room | DA % | Level | UDI % |
|---|---|---|---|
| Bedroom 1 | 65.0 | Med. 55% | 83.0 |
| Bedroom 2 | 66.0 | Med. 55% | 84.0 |
| Room/kitchen | 56.0 | Med. 55% | 76.0 |

**Future weather file 2050 (2041-2070 - CCWWG) with Surroundings in Revit**




| Room | DA % | Level | UDI % |
|---|---|---|---|
| Bedroom 1 | 65.0 | Med. 55% | 83.0 |
| Bedroom 2 | 66.0 | Med. 55% | 84.0 |
| Room/kitchen | 56.0 | Med. 55% | 76.0 |

**Future weather file 2050 (2041-2070 - CCWWG) without Surroundings in Revit**




| Room | DA % | Level | UDI % |
|---|---|---|---|
| Bedroom 1 | 60.0 | Med. 55% | 82.0 |
| Bedroom 2 | 61.0 | Med. 55% | 83.0 |
| Room/kitchen | 58.0 | Med. 55% | 74.0 |

**Fig. 4.** DA and UDI – Tables and images. .
Source: Authors, 2023

bedrooms achieved a Daylight Autonomy of 60 % and 61 %, and the living room/kitchen reached 58 % (Fig. 4).

### 4.3. Exposure to Sunlight: EN 17037:2018 – Aftab Rad

Table 3 show the recommendation levels from EN 17037 and NBR 15215-3. It is important to note that, according to the EN 17037:2018 [3] standard, in indoor environments with indirect daylighting, the recommended limit for exposure to sunlight is 150 W/m$^2$, considering continuous exposure. Furthermore, in accordance with the recommendations, it is suggested that at least one indoor space within the building can receive sunlight for a certain period, taking into account three levels of sunlight exposure. In NBR 15.215–3 [12], Level I corresponds to less than 1.5 h of solar exposure. In this case, the minimum thermal performance requirement established by NBR 15575 must be met for bioclimatic zones 1 to 5. In bioclimatic zones 6, 7, and 8, this criterion does not need to be verified.

The results obtained for the original weather file 2020, indicated a sunlight exposure of 4 h and 23 min in the bedrooms and 2 h and 23 min in the living/kitchen area, considering the surroundings, original weather file 2020 3 h and 34 min when excluding the surroundings. In the LCZ 1 2020 areas, using the climatic file modified by UWG, sunlight exposure was 4 h and 31 min in the bedrooms and 2 h and 10 min in the living/kitchen area, considering the surroundings, and 3 h and 34 min in the living/kitchen area, without the surroundings.

For the future weather file 2050 (2041–2070) – CCWWG areas, considering the surroundings, sunlight exposure was 4 h and 48 min in the bedrooms and 2 h and 32 min in the living/kitchen area. However, when not considering the surroundings, the results were 4 h and 48 min in the bedrooms and 3 h and 34 min in the living and kitchen area (Fig. 5).

### 4.4. Glare Probability DGP (Daylight Glare Probability) – Aftab Rad

The DGP (Daylight Glare Probability) metric is used to assess the likelihood of visual discomfort caused by excessive glare in an environment. It is calculated based on an empirical formula that relates various measurable physical quantities, such as the luminance of glare sources, the illuminance at eye level, and the solid angle of the glare source. These parameters help determine the level of glare perceived by individuals. The mathematical definition of DGP can be described as follows [12]:

$$DGP = 5,87x10^{-5}xE_v + 9,18x10^{-2}xlog\left(1+\sum_i \frac{L_{s,i}^2 x\omega_{s,i}}{E_v^{1,87}xP_i^2}\right) + 0,16$$

**Table 3**
Recommendation for Daily Sunlight Exposure.

| Level of recommendation for exposure to sunlight | Sunlight exposure | |
|---|---|---|
| | NBR 15215–3 | EN 17037 |
| Level I / | *Compliance with the minimum thermal performance criteria of NBR 15.575 | 1.5 h |
| Level II | 1.5 h | 3.0 h |
| Level III | 3.0 h | 4.0 h |

*Only for bioclimatic zones 1 to 5, where:
Minimum: The minimum daily indoor air temperature, in degrees Celsius, should be greater than or equal to the minimum daily outdoor air temperature, in degrees Celsius, plus 3 °C.
Intermediate: The minimum daily indoor air temperature, in degrees Celsius, should be greater than or equal to the minimum daily outdoor air temperature, in degrees Celsius, plus 5 °C.
Superior: The minimum daily indoor air temperature, in degrees Celsius, should be greater than or equal to the minimum daily outdoor air temperature, in degrees Celsius, plus 7 °C.

Source: 15215:2023 and EN 17037:2018 [5,12].

where:

- $E_v$ = Illuminance at eye level, expressed in lux (lx), measured on a plane perpendicular to the line of sight. This value is crucial for the experience of glare in positions oriented towards daylight in a space. It is also used to determine the adaptation level.
- $L_s$ = Luminance of the glare source, expressed in candelas per square meter (cd/m$^2$). In the case of daylight apertures, it refers to the luminance of the sky and/or sun as seen through the aperture.
- P=Position index, describing the reduction in glare perception due to the angular displacement of the source from the occupant's line of sight. For daylight apertures, the position of the visible sky within the field of view indicates the magnitude of the position index; the further from the center of vision, the lower the position index.
- $\omega_s$ = Solid angle subtended by the glare source, expressed in steradians (sr). In the case of daylight apertures, it refers to the apparent size of the visible area of the sky to the observer. The larger the visible area, the greater the solid angle.
- i = Number of glare sources.

In general, the Daylight Glare Probability (DGP) assessment can be used for spaces with vertical or inclined openings for natural light, but it does not apply to spaces with skylight openings. When evaluating natural light glare, it is necessary to consider the complex distribution of luminance in the field of view, as well as the size, intensity, and location of the glare source in relation to the line of sight [12].

To obtain the glare probability, the Time Series DGP was calculate in the Aftab Rad plugin accordingly with EN 17037:2018 methods, and the results were obtained in the 3D model in Revit. Glare levels were classified by the NBR 15215-3 recommendation, as follows: imperceptible for values less than 34 %, noticeable for values between 34 % and 38 %, disturbing for values between 38 % and 45 %, and intolerable for values above 45 %.

For original weather file 2020, considering the surroundings, it was observed that the bedrooms have a perceived but not disturbing glare with a probability of 35 %. In the living room/kitchen, the glare is not significantly noticeable. When the surroundings of original weather file 2020 were not considered, the bedrooms experienced an increase in glare, but it remained noticeable and not disturbing, reaching 38 %. In the living room/kitchen, facing west, there was a significant increase in glare, which was noticeable and often disturbing, reaching 42 % (Fig. 6).

In the case of urban weather file LCZ 1 (Compact High-Rise) 2020 – UWG, when considering the surroundings in the bedrooms, the glare was noticeable and often disturbing, with a probability of 39 %. In the living room/kitchen of the same LCZ, the glare was not significantly noticeable, with a probability of 25 %. When the surroundings were not considered, urban weather file LCZ 1 (Compact High-Rise) 2020 – UWG showed an increase in glare in the bedrooms, keeping it noticeable and often disturbing, at 42 %. In the living room/kitchen, the glare remained imperceptible, registering 28 % (Fig. 6).

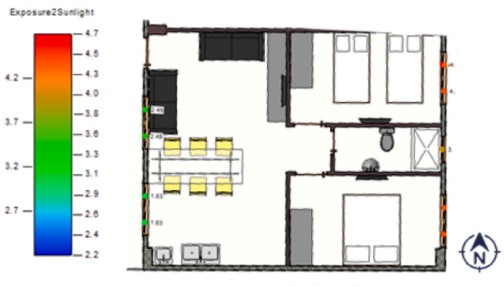
For future weather file 2050 (2041–2070) – CCWWG, with the increase of direct solar radiation, even considering or not the surroundings, the glare probability reaches intolerable levels in the bedrooms and in the living room/kitchen without surroundings (Fig. 6).

### 4.5. Simplified method – DL abacuses method for simulation validation

This tool enables the evaluation of performance levels in environments that conform to surrounding conditions, using abacuses. This evaluation was applied to a Low-Income Housing (HIS) as a benchmark for assessing the reliability of simulations. The geographical zoning of this area falls within the first range, which includes parallels with latitudes ranging from 5°N to 9.9°S, as illustrated in Fig. 7.

The established criteria for the spaces have been fully met. The Low-Income Housing (HIS) has a rectangular shape, as seen in Fig. 8, with a

**Original weather file 2020 with Surroundings in Revit**




| Room | Exp. (h) (%) | Level |
|---|---|---|
| Bedroom 1 | 4h23 | Level III |
| Bedroom 2 | 4h23 | Level III |
| Room/kitchen | 2h23 | Level II |

**Original weather file 2020 without Surroundings in Revit**


| Room | Exp. (h) (%) | Level |
|---|---|---|
| Bedroom 1 | 4h23 | Level III |
| Bedroom 2 | 4h23 | Level III |
| Room/kitchen | 3h34 | Level III |

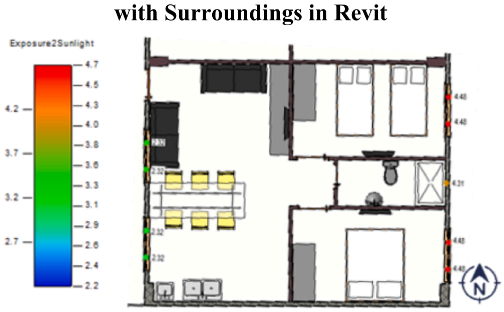
**Urban weather file LCZ 1 (Compact High-Rise 2020 - UWG) with Surroundings in Revit**


| Room | Exp. (h) (%) | Level |
|---|---|---|
| Bedroom 1 | 39% | Disturbing |
| Bedroom 2 | 39% | Disturbing |
| Room/kitchen | 25% | Unnoticed |

**Urban weather file LCZ 1 (Compact High-Rise 2020 - UWG) without Surroundings in Revit**

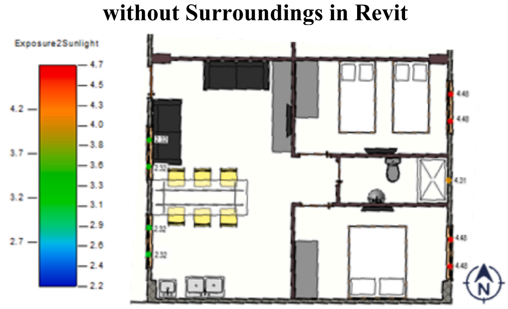

| Room | Exp. (h) (%) | Level |
|---|---|---|
| Bedroom 1 | 42% | Disturbing |
| Bedroom 2 | 42% | Disturbing |
| Room/kitchen | 28% | Unnoticed |

**Future weather file 2050 (2041-2070 - CCWWG) with Surroundings in Revit**




| Room | Exp. (h) (%) | Level |
|---|---|---|
| Bedroom 1 | 45% | Intolerable |
| Bedroom 2 | 45% | Intolerable |
| Room/kitchen | 30% | Unnoticed |

**Future weather file 2050 (2041-2070 - CCWWG) without Surroundings in Revit**




| Room | Exp. (h) (%) | Level |
|---|---|---|
| Bedroom 1 | 48% | Intolerable |
| Bedroom 2 | 48% | Intolerable |
| Room/kitchen | 46% | Intolerable |

**Fig. 5.** Sunlight Exposure – Results. .
Source: Authors, 2023

ceiling height of 2.80 m. The distribution of spaces in the HIS is organized as follows:

1. **Sector 1 (Living Room):** It has a width of 3.50 m and a depth of 3.60 m;
2. **Sector 2 (Kitchen):** It features a width of 2.65 m and a depth of 3.60 m;

   It is worth noting that Sector 1 and 2 (Living Room/Kitchen) include an access balcony with a depth of 1.10 m.
3. **Sector 3 (Bedroom 1):** It has a width of 2.50 m and a depth of 4.00 m;
4. **Sector 4 (Bedroom 2):** It has a width of 2.40 m and a depth of 4.00 m.

The identification of these sectors can be more clearly seen in Fig. 8, where each sector is represented by a distinct color.

The openings meet the minimum criteria required for all sectors, which consist of an area equivalent to 1/6 of the total floor area of the space, regardless of whether or not they include a balcony when present.

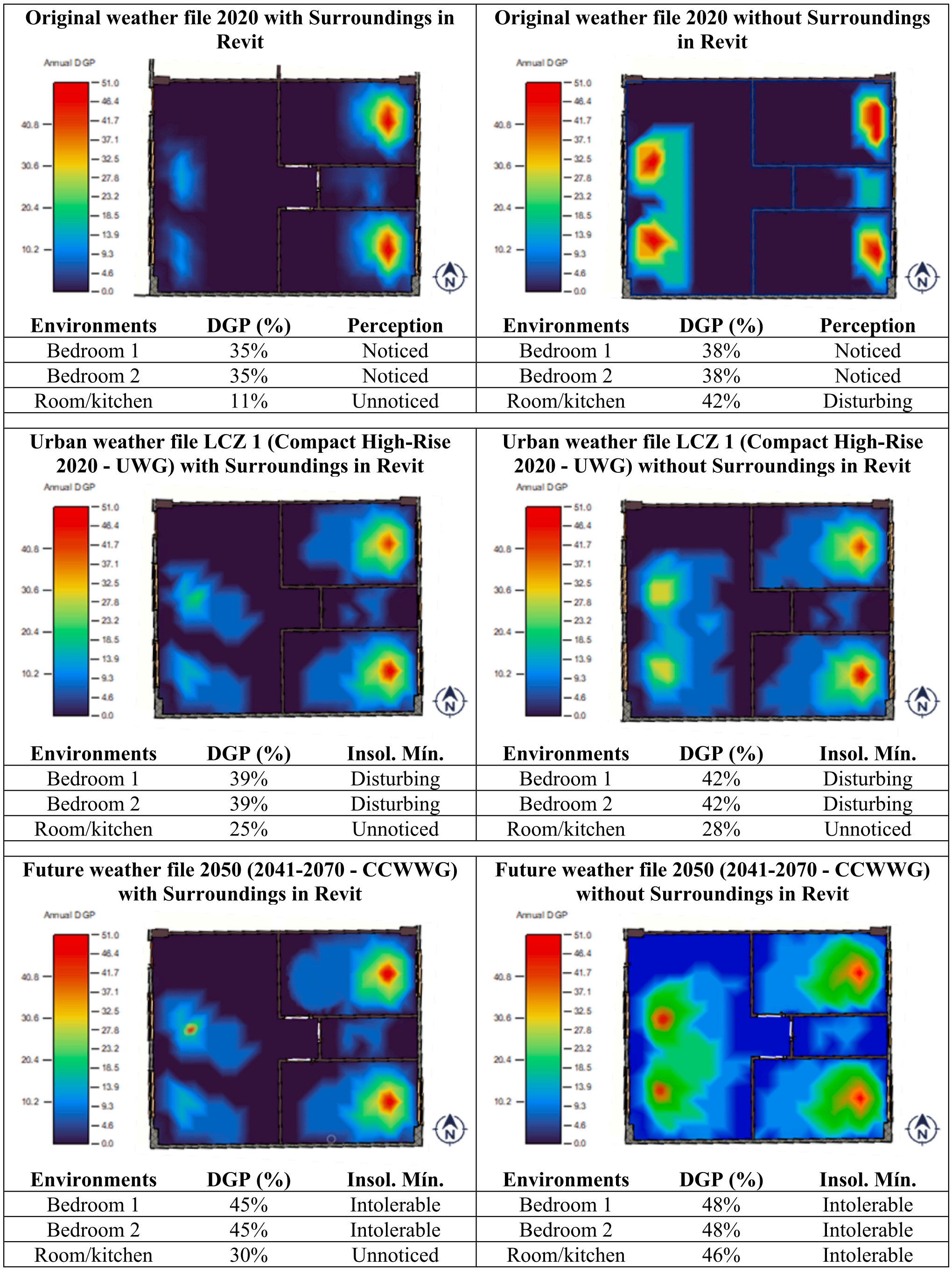



**Fig. 6.** Glare Probability Analysis. .
Source: Authors, 2023

All openings in the sectors are fitted with 6 mm clear double glazing with a visible transmission of 76 %. Furthermore, all internal ceiling surfaces have a minimum reflectance of 70 %. The floor-to-ceiling height complies with the established limit, measuring 2.80 m. The window head also meets the requirements with a height of 2.20 m, whereas the minimum requirement is 2.00 m. The immediate surroundings exhibit a minimum reflectance of 40 %. Following the assessment and adherence to the established criteria, it was possible to calculate the "P" index (ratio between the width and depth) for each sector of the space. Subsequently, the obstruction angles within the environment are examined, the final angle weights the vertical angle and the horizontal angle. The results of this calculation are presented in Table 4.

The assessment of the performance class for daylight adequacy and uniformity is conducted at the intersection of the lines containing information about the space and the column containing information about external obstructions, as defined in Fig. 9. To meet the minimum criteria, it is considered that the space must fulfill the requirements for sufficiency and comply with the established criteria. In Fig. 9, sectors 1 and 2 appear in blue, and sectors 3 and 4 in red.

1. Sector 1 – Factor: Minimum Target Fraction >40 %.
2. Sector 2 – Factor: Minimum Target Fraction >40 %.
3. Sector 3 – Factor: Intermediate Target Fraction >55 %
4. Sector 4 – Factor: Intermediate Target Fraction >55 %

The analysis of the results reveals remarkable consistency with the

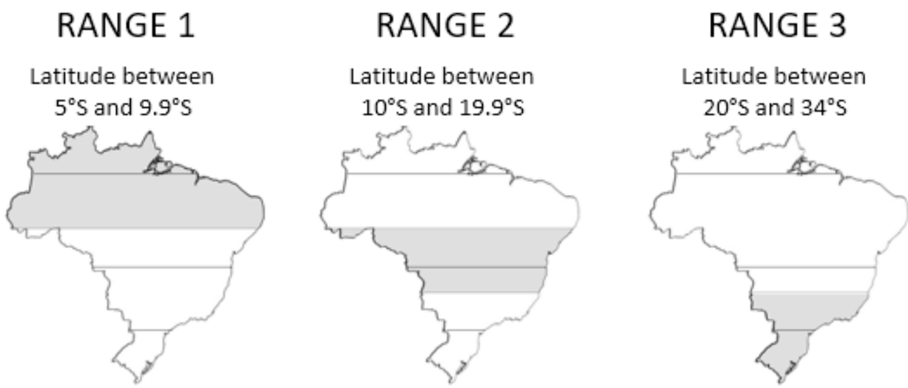



**Fig. 7.** Daylight Geographical zoning of Brazil. .
Source: CE-002:136.001 (2022)

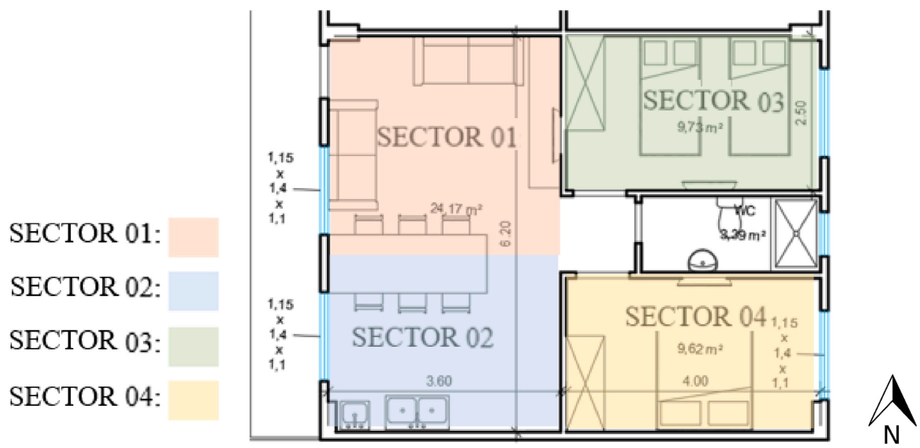



**Fig. 8.** Room Sectorization. .
Source: Authors, 2023

data from the dynamic simulation conducted using Daysim. Regarding the combined areas of the living room and kitchen (Sectors 1 and 2), the calculated fraction of the minimum target area is 40 %, aligning precisely with the results obtained by Daysim. In relation to the bedrooms (Sectors 3 and 4), calculations performed using an abacus indicate an intermediate area fraction of 55 %, while the exact results from Daysim range between 60 % and 61 %, conforming to the target intermediate area fraction of 55 % stipulated by the standard.

It is crucial to emphasize that the results of the computational simulations provide substantial accuracy in calculating daylight autonomy throughout the year. All the data mentioned were acquired through a unified electronic spreadsheet, which follows the previously described procedure. This spreadsheet provides a systematic and organized approach to calculate and verify the luminous performance of Low-Income Housing (HIS) in accordance with the guidelines outlined in NBR 15575:2022 [8]. This makes the analysis and evaluation process more efficient and accessible.

It is noteworthy that the results of the dynamic simulation using Daysim 3.1 coincided with the calculations obtained through the simplified approach using abacus. However, for the analysis of daylighting using the Rcontrib software, the DA results significantly exceeded the results obtained by the simplified method based on abacus. This observation indicates a significant disparity in results obtained through computational assessment tools. It is highlighted that the more accurate and reliable software appears to be AftabRad for Daysim 3.1, where computational simulation demonstrates greater accuracy in assessing daylight autonomy (DA).

## 5. Discussions

When compared to other software solutions discussed in the literature, the Revit plugin adfrad-daysim has overcome some limitations of other available software. These limitations revolve around data visualization, illuminance levels per area, lack of Building Information Modeling (BIM) compatibility, and the absence of a digital twin path for the simulated model. This absence of a return path generated additional work for the designer. It is worth noting that the used standards require modeling the built environment at a microclimatic scale but does not necessitate using modified climatic files for urban context simulations at a local climatic scale. However, this study has demonstrated the necessity of such modifications for a more precise assessment of lighting performance, following the same trend as thermal performance evaluation.

Using the Revit software in conjunction with the AftabRad plugin, we explored the variables of daylighting by employing a weather data adapted for different urban scenarios, considering both built and non-built environments within Revit. Additionally, we conducted a simulation using the adjusted weather data to reflect the climate conditions predicted for the year 2050 (2041–2070).

In original weather file surroundings 2020 areas, the availability of daylight indoors can be significant due to the amount of global solar radiation reaching the ground. However, the presence of tall buildings shadows can limit direct illumination in specific areas. Utilizing the original weather file surroundings 2020 and considering the surroundings based on analysis criteria proposed by NBR 15575:2022, the results in terms of uniformity (UDI) throughout the year met the standard

**Table 4**
"P" Index – Results.

| Result of calculating the "P" index for the sectors. | | | |
|---|---|---|---|
| **Sectors** | **Calculation: W/P** | **Index "P"** | |
| Sector 1 | 3,50/3,60 | 0,97 | |
| Sector 2 | 2,65/3,60 | 0,73 | |
| Sector 3 | 2,50/4,00 | 0,62 | |
| Sector 4 | 2,40/4,00 | 0,60 | |
| **Vertical Angle** | | | |
| **Sectors** | **Angle 1** | **Angle 2** | **Angle 3** |
| Sector 1 | 59,6° | 34,9° | 62,4° |
| Sector 2 | 59,6° | 34,9° | 62,4° |
| Sector 3 | 57,0° | 31,9° | 40,5° |
| Sector 4 | 31,9° | 40,5° | – |
| **Horizontal Angle** | | | |
| **Sectors** | **Angle 1** | **Angle 2** | **Angle 3** |
| Sector 1 | 27° | 36° | 54° |
| Sector 2 | 22° | 27° | 67° |
| Sector 3 | 5° | 17° | 31° |
| Sector 4 | 9° | 39° | – |
| **Weighted angle result.** | | | |
| **Sectors** | | | **Weighted angle** |
| Sector 1 | | | 41,56° |
| Sector 2 | | | 42,89° |
| Sector 3 | | | 13,88° |
| Sector 4 | | | 12,44° |

Source: Authors, 2023.

requirements for the evaluated spaces. Meanwhile, the Daylight Autonomy (DA) results indicated that the bedrooms met the intermediate goal established by NBR 15.575:2022. However, the combined living room and kitchen area only met the minimum goal. It is important to note that the recommended levels from the Brazilian standard are lower than those specified EN 17037:2018. According to Sepúlveda *et al.* [6] users prefer daylighting than artificial lighting. The study demonstrated that qualitative assessment in Estonia offices align with quantitative assessments defined by the EN 17037:2018, highlighting a potential weakness in the Brazilian standard levels. However, it is worth mentioning that the Brazilian standard only refers to residential buildings, which typically do not include detailed activities that require higher levels of illumination.

In the case of LCZ 1 2020 results, it was observed that the Daylight Autonomy (DA) values were lower when the surrounding context was not considered compared to the results that did take the surroundings into account. This difference can be attributed to external obstructions from tall elevations, which promote the propagation of diffuse radiation, consequently increasing light uniformity in the indoor spaces of the HIS building.

In regions classified as Compact Low-Rise (original weather files) 2050 (2041–2070), the amplification of solar radiation reflection implies an increase in diffuse solar radiation. This means the scattering of sunlight through the atmosphere before reaching the ground. This alteration may lead to a reduction in the intensity of direct lighting in housing units, indicating a decrease in the amount of direct sunlight penetrating indoor spaces. On the other hand, the increase in diffuse solar radiation contributes to greater uniformity in general lighting of housing units, which can be advantageous in terms of distributing light evenly across all indoor areas. These findings correlate with the results of Daylight Autonomy (DA), which were lower without considering the surroundings than when they were considered. This difference is attributed to external obstructions that aid in the propagation of diffuse radiation. Diffuse radiation benefits lighting uniformity. The Useful Daylight Illuminance (UDI) results were also relatively high when the surroundings were considered and lower when they were not.

Compact Low-Rise are urban areas that tend to receive a significant amount of global solar radiation but may face challenges related to direct lighting due to tall building presence. Specific design strategies and architectural technologies are crucial to maximize daylighting in buildings in these areas, especially to lower levels of the building. In LCZ 1 2020 areas, the availability of daylight indoors can be challenging due to the obstruction of direct solar radiation by nearby buildings. However, in this case, diffuse sunlight can still be harnessed to provide indoor lighting, albeit at varying levels depending on building layout and orientation. This shows the importance of architectural strategies [7,24,32], such as skylights and lighting control systems that can be employed to compensate for the limitations imposed by urban density, as well as considering building orientation, the use of materials and building elements that maximize daylight entry, are essential.

Based on the data from Compact Low-Rise and considering the surroundings in the analysis of the Daylight Glare Probability (DGP), it can be concluded that in the bedroom, although a certain level of daylight glare has been detected, it does not pose a significant problem as it falls within the "noticed but not disturbing" range. On the other hand, in the living/kitchen area, the level of daylight glare was even lower and is not perceived according to the standard, indicating that the lighting design for these spaces is appropriate. This analysis is crucial to ensure the

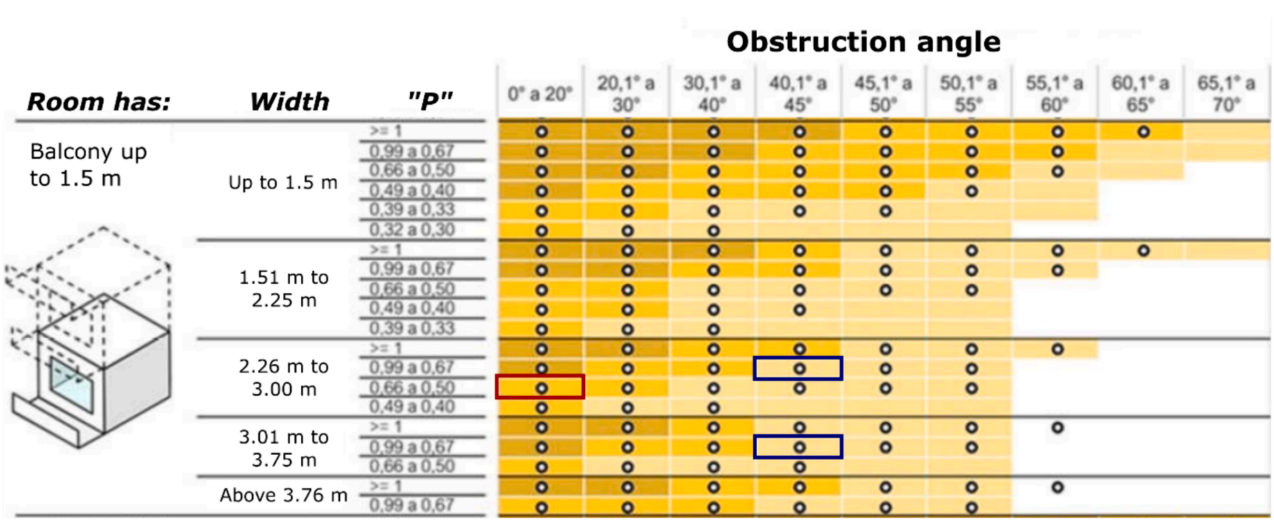



**Fig. 9.** Assessment of sectors. .
Source: Adapted from Vasquex et al. [32]

safety and visual comfort of the occupants in the analyzed spaces and can serve as a reference for future lighting projects. However, when the surroundings are not considered, glare values increase significantly, resulting in noticeable and often disturbing glare both in the living/kitchen area and in the bedrooms.

In the analysis of solar exposure in the LCZ 1 area in 2020, without considering the surroundings, a significant increase of 1 h and 24 min was observed in the living/kitchen area. Conversely, there was no increase in solar exposure in the bedrooms. For the Daylight Glare Probability (DGP), in LCZ 1 2020, considering the surroundings in the bedrooms, glare is perceived and often disturbing, while in the living/kitchen area, glare is not significantly perceived. When the surroundings are not considered, LCZ 1 2020 exhibits an increase in glare in the bedrooms, maintaining it as perceived and often disturbing, while in the living/kitchen area, glare remains imperceptible.

Considering the Compact Low-Rise scenario, with weather data for 2050 (2041–2070) areas, there was a significant increase in sunlight exposure in all rooms compared to other LCZs, with results falling into the "intolerable" range in the bedrooms for both scenarios, with and without surroundings. Glare is often related to sunlight exposure [6], and according to Sepúlveda *et al.* [8], the provision of daylight in buildings is limited by the risk of overheating. This is an important issue to consider on building designs, especially on climates such as Belem, a city located in an extremely hot and humid (0A, ASHRAE 169-2013 [33]).

In summary, it can be considered important to employ appropriate design strategies to enhance the performance of daylighting in Affordable Housing (HIS). The results showed a substantial impact of the urban and future climatic context on levels of global, direct, and diffuse radiation, affecting internal levels of daylight autonomy, exposure, and glare. Rynska et al. [7] emphasize that increasing site coverage significantly impacts the vertical daylight factor on building facades, thereby affecting daylight availability. A decrease in access to direct and indirect daylight can influence not only building energy needs but also occupant wellbeing and health [24,34,35]. Recognizing that daylighting design influences thermal-energetic performance and related aspects, future research could assist in creating a performance correlation indicator among thermal, lighting, energy efficiency, and initial cost performance standards to evaluate multiple design solutions simultaneously. This could be included as design option catalogs to provide insights for designers.

## 6. Conclusion

The objective of this study was to analyze the criteria regarding lighting performance in residential buildings in Brazil. To achieve this, an analysis of the normative changes introduced in NBR 15215-3 and NBR 15575:2022 [8,9 4–8] was conducted. Two methods were employed to determine the lighting performance in a Low-Income Housing Unit (HIS) located in Belem, Para. These methods included computational simulation and a simplified approach using tables. Since this was a project phase and not an actual construction, the reliability of simulations was assessed by comparing the results obtained through computational simulations with those calculated using tabular methods to validate the process.

Throughout the analysis, the advancements in the NBR 15215:2022 and EN 17037:2018 standards were taken into account, playing a fundamental role. These advancements allowed for the incorporation of simulations covering glare probability, exposure to sunlight, and view analysis, all essential for an effective design. The integration of dynamic computational daylighting simulations according to NBR 15215/15575:2022 [8,9] played an extremely important role in this context. It enables a precise evaluation of daylighting performance in housing units, identifying potential issues, and offering opportunities for design optimization. This was confirmed through the simplified tabular method.

The results revealed that the Aftab Rad plugin is an effective and accurate tool for dynamic simulations in accordance with the normative criteria. In light of these findings, this study played a crucial role in enhancing the application of the norm by examining the effectiveness of dynamic simulation software and the inclusion of future urban climate data. The importance of incorporating urban-future weather files into the norm highlights the need for updates and improvements to make the process more comprehensive and aligned with the ever-evolving urban environment. Furthermore, it is essential to emphasize the need for updating lighting standards to ensure the safety and comfort of users in various environments. Regularly revising the norm is critical to incorporate new technologies and ensure adequate lighting levels for activities conducted in spaces.

The application of a case study provides replicability and insights for enhancing these standards, employing a simplified and computationally robust method, in line with simulation trends and dynamic metrics considering the combined impact of local and global climate changes. The proposed method aims to disseminate the application of the standard by identifying the most productive and effective way to implement it. Additionally, it seeks to quantify the impact of local and global climate changes on lighting performance in buildings to encourage the inclusion of this criterion in daylighting performance regulations.

## CRediT authorship contribution statement

**Michelli Gonçalves Michelon:** Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Greici Ramos:** Writing – review & editing, Supervision. **Majid Miri:** Writing – review & editing, Software. **Leonardo Junior da Rocha Menezes:** Writing – review & editing. **Márcio Santos Barata:** Writing – review & editing, Supervision. **Bruno Ramos Zemero:** Writing – review & editing, Visualization, Supervision, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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