Daylighting Analysis: A Contribution to the Urban Planning of the City of Marilândia - ES (Brazil)

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Abstract. Daylighting is one of the environmental resources that deliver quality to the built area by making it more comfortable and efficient and by promoting people’s well-being, besides reducing the consumption of electrical energy. The amount of daylighting indoors is related to the construction features, whose parameters are those of the urban legislation, as well as to the location features where the building stands. This research aimed to get a better knowledge of the interference of the urban typologies of Marilândia, Espírito Santo (Brazil), in the availability of daylight in the internal environment. The methodology consisted of the identification and representation of the main typologies found in the city, or of those which might be built due to the current construction law; computer simulations of three sky patterns CIE (3, 7 and 12) using the Tropplus 6 program; and the analysis of the results. Founded on this analysis, it was possible to see that the application of the current urban legislation has favored the better use of daylighting inside the constructions through the allowed front setback, which is three meters, and the number of floors allowed in each building, which is eight. As for the use of daylighting, the Typology 03 presented the best performance, making it possible to have a more comfortable environment with better energy savings potential.

1. Introduction

The incorporation of more sustainable practices in the projects and urban planning has proved to be a necessary behavior when facing issues such as environmental, economic and social crisis. The Global Footprint Network [4] warns that the world is using its natural resources 50% more than the planet’s regenerative capacity. On the subject of environmental issues, Keeler and Burke [8] suggest the cities address the challenges by implementing policies for development based on the three main pillars of sustainability: economic, environmental and social. Among these measures, the reduction of energy and natural resource consumption shall be highlighted, as well as the adoption of practices aimed at protecting local environmental resources [8, 17].

In this connection, the daylight stands out for being natural, non-polluting energy source and at no cost. Its use contributes to reducing the energy expenditure of a construction [15, 17]. In the Brazilian scenario, the existing buildings are responsible for 50% of electricity consumption. In contrast, studies indicate that the use of daylighting has a potential for energy saving up to 64.9% for commercial buildings [15]. Therefore, the best use of daylight can reduce the sizing and the overloading of the
artificial lighting system during the period of the day and, if properly designed, it can also contribute to reducing the use of artificial cooling system.

Daylight is the light source nearest to the human visual response, a fact that, added to factors such as quantity, illuminance distribution, among others, it contributes to a higher visual quality in the illuminated environment, reducing the physical eye strain. Daylighting also regulates the circadian system, interfering in hormone levels, such as melatonin and cortisol, which are related to sleep disorders and depressive symptoms [5]. In summary, daylighting produces a positive effect on the human being’s behavior, productivity, development, and health [5, 9, 16].

Several authors have guided researches comparing the urban form and the climate features to the daylighting availability in the built environment. The States and Cities are currently responsible for establishing guidelines for the urban planning of their territories aiming at ensuring the adequate use of daylight in both the interior and surroundings of the buildings [6, 9, 10, 16, 17]. Considering that daylight availability is conditioned by the building characteristics of the surroundings, according to the parameters established by the legislation, this research aimed at verifying the interference of the urban building typologies of Marilândia/ES in the availability of daylight inside the constructions.

The Federal Law nº.10.257 [3] has adopted public order and social interest regulations that deal with the urban property management in order to ensure public welfare, security, and environmental balance. The Article 41 says that all Cities with 20.000 inhabitants or more, and facing other specific situations, shall have a Master Plan. However, despite these constraints, it is pertinent that municipalities have a Master Plan, aiming at planning and sustainable growth based on pre-established rules.

In the light of this context, the city of Marilândia/ES – LAT 19°24’ and LONG 40°32’- is presented as the subject of this research study (Figure 1 and 2). The city is located in the north region of Espírito Santo State (Brazil). It has a territorial extension of 309.018 square kilometers, 12.353 inhabitants, and tropical climate [12]. The city regulatory law that deals with urban land use is the Building Code (Law nº.1.042/12), approved on November 21st, 2012, which establishes basic guidelines such as maximum height of buildings, front, side, and rear setbacks, among others [11]. Considering all the criteria defined by the City Statute, the elaboration of a Master Plan for the city of Marilândia is not mandatory, given the fact that the municipality does not have the required minimum number of inhabitants.

![Figure 1. Location of the City of Marilândia/ES. Source: Adapted from Jones dos S. Neves Institute](image)

Among the urban parameters established by the Building Code, the most important ones are those that deal with setbacks and building heights. The required setbacks are the following: front – minimum of three meters; side – 1.5m opening facades up to the second floor, and 1.5m + 0.10m (per floor) from
As for the height of the buildings, the maximum number of floors is eight. However, despite the setbacks required by legislation, most of the constructions in the city are semi-detached buildings aligned at the front boundary of the area which have floors above the ground level advancing over the sidewalk, according to Figure 3. These features are partly due to the nonexistence of rules at the time those buildings were erected. Besides that, it is noticeable that there is a predominance of four-story buildings, which was the height allowed by the Building Code until November, 2013, when an amendment allowing up to eight-story buildings was passed. In spite of this change, the predominance of that typology still remains since the approval of the amendment is recent. Other factors that contribute to the remaining of that typology are the following: four-story buildings do not require elevators; they do not require the elaboration of fire-prevention projects, either. The lack of the mentioned requirements reduces the cost of construction considerably.

Considering that the daylight availability is conditioned by, among other factors, the surrounding features, which result from the parameters established by the legislation, this research aimed at verifying the interference of the urban building typologies of Marilândia/ES in the availability of daylight inside the constructions.

2. Methodology

The methodology adopted was based on Hoppe et al [7], Laranja [9] and Leder [10], and complemented with relevant information in order to achieve the objective of this research. The subject
of this study was the City of Marilândia (ES, Brazil), where the typology of the construction pattern in
the urban area was verified, as well as the typologies of the buildings that might be erected due to the
current local legislation – the Building Code. After defining which typologies would be studied,
scenarios representing such typologies were created, and simulations using the software TroLux 6 were
conducted in order to collect data about interior illuminance of a predefined environment. In the analysis
of the results, the values of the average global illuminance of defined points and the percentage of the
UDI (Useful Daylight Illuminance) obtained from the three simulated typologies were considered.

2.1 Characterizations of the typologies

Based on the analysis of the registration database of the city of Marilândia, on visits to the location
which was the object of study, and on photographic records, it was possible to observe that the city has
a predominant typology characterized by two-way streets; road widths of 8 to 10 meters; sidewalk
widths of 1 to 1.5 meters; four-story semi-detached buildings aligned at the front boundary of the land,
and floors above the ground level advancing over the sidewalk. Founded on these observations and
considering the small differences in streets, it was determined that, instead of the analysis of specific
streets, the analysis of a representative model of the prevalent building typology of the city, which is
called typology 01 (Figure 4), would be done. Another aspect that was observed was the fact that there
has been a tendency towards urban modernization in some areas as well as urban expansion due to the
new Building Code, although there is still the predominance of four-story buildings as mentioned before.

Obstructions can be highlighted among the external parameters that interfere with the availability of
daylight in building interiors [6, 10]. In addition, several studies demonstrate the relationship between
the height of obstructing buildings as well as the distances between them and the access to daylight [6,
9, 18]. Therefore, two other typologies based on the current city legislation were defined: the first one
introduced by the 2013 amendment took into account eight-story buildings, and was called Typology
03 (Figure 6); and the second one considered four-story buildings whose height was the maximum
allowed before the above amendment. This latter one was called Typology 02 (Figure 5). In both
typologies, three-meter front setback was required. As a result, those three typologies were modeled,
simulated, and analyzed as illustrated in Figures 4, 5, and 6.

| TYPOLOGY 01 |
|-------------|
| **Description:** four-story buildings (height=12m); road width combined with sidewalk width totaling 11m; without front setback; floors above ground level advancing over the sidewalk. |

Figure 4. Characterization of Typology 01.
2.2 Computer Simulations

The main tool to collect data was the computer simulations using the program TropLux 6, which allows daylighting simulation in indoor environment, taking into consideration climate and architectural features of tropical regions. Among the specificities, it is important to highlight the configuration of solar reflectance index of internal and external surfaces, and the type of sky in the locality according to CIE patterns. Three types of CIE sky patterns were adopted. They represent minimum, intermediate, and maximum values of sky luminance patterns [9], as follows: 3 (overcast), 7 (partially cloudy), and 12 (clear).

As for the days and times considered, the NBR 15215-4 [1] recommends that the lighting be evaluated on different occasions and at different times, aiming to get more accurate results. Thus, the simulations were done every single day from January to December, and every full hour from 7:00 o’clock a.m. to 5:00 o’clock p.m.

The characteristics of the internal environments were defined according to the specifications established by the Build Code of the municipality in question, and in a complementary way, by the Build Code of the City of Vitória [13]. So, the environment model developed has floor-to-ceiling height of 3
meters, width of 2.80 meter, and length of 3.90 meters [11]. Such environment has opening façade facing the outside and placed in the center of the wall. These opening dimensions are in conformity with Article 140 of the Building Code of Vitoria, which establishes that the dimensions must be proportional to 1/8 of the occupancy rate [13]. Therefore, the opening has an area of 1.5m² (1.50mx1.00mx1.10m), and is composed of clear plain glass. The internal reflections were adopted according to Laranja [9], NBR ISO/CIE 8995 [2] and Hoppe [6], and they are the following: floor = 0.2, walls = 0.5, and ceiling = 0.8.

Regarding the characteristics of the external environment, the analyzed scenarios consist of north-oriented building whose internal environment has been analyzed and of three obstructing buildings. The reflectance of the external vertical (buildings) and horizontal (roads) surfaces were defined according to Laranja [9], Strømann-Andersen and Satrup [18] and Hoppe [6], namely, the average reflectance value of the opaque closures is 40%, and the average reflectance value of the road is 20%, considering that, for the definition of the latter one, the types of local pavement - asphalt and cobblestone - were also observed.

The decision on the place and on the number of points evaluated in an internal environment was based on NBR 15215-4 [1]. The analysis took into consideration the ground floor of a building, since it is the floor which faces the most critical situation as far as the access to daylight is concerned. The lowest number of points found was 16. However, it was decided to consider 20 points in order to achieve increased accuracy of response data. The point-locating mesh is composed of 4 lines and five columns, at a distance of 0.56m and 0.65m from one another respectively. The work plan in question is at 0.78m from the floor, as illustrated in Figure 7.

![Figure 7](image_url)

**Figure 7.** Floor plan and schematic cross sections showing the point-locating mesh measuring the illuminance of the analyzed internal environment model.

### 2.3 Analysis of Results

This research considered that lighting involves global illumination from sunlight and reflective particles. Furthermore, it was determined that daylight availability inside the analyzed environment is characterized by the illuminance level with adequate values to the accomplishment of activities regarding the environment. According to NBR ISO/CIE 8995-1 [2], the illuminance level recommended to rooms where activities such as writing and reading are done is 500lx. Thus, at first, the alterations in the light level caused by urban parameters of each studied typology were observed. Another metric evaluation conducted was the UDI percentage [14], which consists of the characterization of the illuminance occurrences at determined intervals of sun lighting in a one-year period, as exemplified in
Figure 8. In this regard, it was verified the satisfactory daylight (500lx<UDI<2000lx), observing the undesirable daylight (E<2000lx).

| RANGES       | ILLUMINANCE CHARACTERISTICS          |
|--------------|-------------------------------------|
| < 100 lx     | Insufficient.                       |
| 100 lx < UDI < 500 lx | Enough, but it requires some additional light. |
| 500 lx < UDI < 2000 lx | Enough and required.                |
| 2000 lx <    | Not required. Thermal or sight discomfort. |

Figure 8. Characterization of the illuminance intervals, highlighting the UDI range.

3. Results
In agreement with the adopted methodology, the simulations were conducted considering the three established typologies, and the results of those simulations were presented in two stages. In the first stage, the average global illuminance was evaluated, observing whether the obtained values fit the ones recommended by NBR ISO/CIE 8995-1, of 500 lux. In the second stage, the values of the UDI’s were compared.

3.1 Analysis of the average global illuminance
Regarding all types of sky, according to Figure 9 and Table 1, it was verified that Typology 02 provides an increase of illuminance levels when compared with the other analyzed typologies, that is to say, the use of indicators required by the city’s urban legislation without the 2013 amendment is the scenario which allows the highest light percentage. Yet the current legislation (with the 2013 amendment), represented by Typology 03, provides an increase of daylight when compared to Typology 01. In this regard, it can be stated that the adoption of the three-meter front setback, required by the current legislation, contributes to a higher amount of daylighting in internal environments, even when the increase of number of floors per building is considered (from 4 to 8 floors), supporting the fact that the effect of obstructions can be minimized when there are wider setbacks between buildings [6].

As for the illuminance recommended by NBR ISO/CIE 8995-1, none of the typologies achieved adequate levels when considering skies 3 and 7. Regarding Typology 01, the illuminance provided when considering sky 12 does not comply with the above-mentioned norm.

Figure 9. Average Global Illuminance for Typologies 01, 02 and 03.
Table 1. Variation percentages of average global illuminance for Typologies 01, 02 and 03

| SKY 3 | SKY 7 | SKY 12 |
|------|------|------|
| T1 – T2 | T2 – T3 | T1 – T3 |
| 166% | -31% | 84% |
| T1 – T2 | T2 – T3 | T1 – T3 |
| 287% | -36% | 149% |
| T1 – T2 | T2 – T3 | T1 – T3 |
| 396% | -37% | 211% |

3.2 Analysis of UDI (Useful Daylight Illuminances)
Under prevailing overcast sky conditions, the Typology 02 was the one that presented the best results, since it allowed an increase of the sufficient and desirable percentage (500lx/2000lx), and a decrease of insufficient illuminance (E>100lx). As for Typology 01, regarding sky 3, it presented the highest indices of insufficient illuminances (E>100lx) to the detriment of percentages characterized as sufficient (100lx/2000lx). Under clear and partially cloudy sky conditions, the Typology 03, which is based on the current urban legislation, presented the best performance, since it achieved the highest levels between 500lx/2000lx and the lowest percentages above 2000lx simultaneously. Thus, as regards to sky type 7 and type 12, considering North facing orientation, the highest obstructions contribute to better light conditions, once they help block the direct solar radiation while the reduced number of floors (typology 02) promotes an increase of undesirable levels (2000lx<E).

4. Final Considerations
Legislations that regulate the municipalities regarding the use of territory establish limits on land occupation, providing, this way, access to daylight in built environment. The analysis of different building typologies (01, 02 and 03) through computer simulations allowed the assessment of the interference of urban parameters required by legislation, namely the setbacks and heights of buildings concerning the daylight availability inside the buildings. With respect to illuminance, it was observed that the Building Code, approved in 2012, which restricted the number of floors to four (before the amendment), allows a considerable increase in illuminance in regard to all types of sky analyzed. However, the current legislation, represented by Typology 03, though more permissive, also provides higher daylight levels when compared to the building standard that was being applied to the city before the approval of the Building Code (Typology 01).

In regard to UDI parameter, the Typologies 02 and 03 make possible an increase of sufficient and desirable light (500lx<UDI<2000lx) concerning sky type 7 and type 12. However, it was observed an increase of excessive illuminance (2000lx<E) regarding typology 02. Therefore, the highest obstructions contribute to better lighting levels in the internal environment depending on the sky conditions and building orientation. In contrast, the reduced number of floors must be combined with sun control.
devices in openings in order to reduce thermal loading, and, as a consequence, avoid the need for cooling systems which rises electricity consumption.

In view of the above, considering the analyzed typologies and the established parameters for the simulations, it was concluded that, in locations where the prevailing sky conditions are clear or partially cloudy, the Typology 03, which deals with the adoption of three-meter front setback and eight-story building, is the scenario which displays better performance as far as the daylight availability is concerned. Thus it was verified that the current urban legislation embraced by the city of Marilândia favors the use of daylight in buildings, contributing to the environmental comfort, as well as to energy savings due to the reduction of the use of artificial light sources.

It is important to highlight, nevertheless, that the simulations were all North oriented, which means that this research is just part of a broader study. Its results, however, have demonstrated that simulation strategies can become a valuable tool for the definition of public policies and urban planning for the city of Marilândia, promoting a better quality of life of its citizens.

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