Influence of zoned use and occupancy on Daylight Autonomy in high-rise mass housing in Colombia

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Abstract
Adequate use of daylight is a valuable strategy to promote energy efficiency and well-being in living spaces. This paper aims to evaluate daylight autonomy (DA) in a high-rise mass housing room based on zoned use and occupancy considerations. Using the Grasshopper for Rhino plug-in, computational simulations of daylight autonomy (DA) were performed. Parameterization of a) window/wall ratio, b) window position and c) balcony depth was studied considering the different eye positions induced by the standard room layouts, instead of the standard homogeneous grid-based technique suitable for office analysis. The results allowed us to identify how light performance varies in a space with diverse uses in high-rise mass housing in Colombia.

Key Innovations
- The definition of the DA metric was adapted to allow a better assessment in living spaces where different visual tasks are performed.
- Implementation of the DA metric in the Colombian tropics.
- Evaluation of the zoned space in order to take advantage of the light availability in these zones.

Practical Implications
To implement daylighting metrics such as DA in high-rise housing in the Colombian tropics to determine how to provide a better use and zoned occupation of the spaces that compose it from the development of visual tasks.

Introduction
Housing has always been characterized as a space for rest, sharing, leisure and performance of both school and work activities. Considering such a wide range of activities and visual tasks, we consider it is necessary to rethink the way we design homes so that they are aimed at a positive benefit both for the development of tasks and for the health of the people who inhabit it. Low-budget housing in Colombia is not designed to guarantee high quality lighting ambiances since the Technical Regulations for Lighting and Public Lighting (República de Colombia, 2010; Cálculos & Interior, 2017) make mandatory regulations that, for the most part, are for working and school buildings.

Daylighting plays an important role in the performance of visual tasks and in the well-being of people (Figueiro et al., 2018), as well as in favoring the energy efficiency of spaces (Yu & Su, 2015). In the case of low-budget housing in Colombia, most of the spaces in such dwellings are multipurpose since different activities must be carried out in the same room. For instance, the dining room or the bedroom are usually transformed into a study place, a sewing workshop or an office during several hours a day. Due to lack of space and now in the pandemic enclosures it becomes necessary to give a shared use to a single room. The problem is that normally the daylight that enters the space that is predetermined for the dining room is not optimal for reading and studying and this can cause, with the constant routine and in a not so long term, vision problems, alertness (Inacini, 2017), sleep quality, performance and even metabolic problems (Konis, 2017).

In almost all cases certain activities make it necessary for some occupants to use artificial lighting once the daylight is too low or does not even reach the study area (Mousavi, 2018). Daylighting in side-lit rooms is uneven and more demanding visual work should be performed near windows, but the furniture layout can generate severe restrictions to this. The room layout in a small room in a low budget apartment tower is strongly affected by the presence of such a big object as a bed and obtaining the best possible relation with the window is not always possible (Giraldo, 2018). When the window is narrow there is usually several times lighter close to the window than in parts of the room farther from the window and the Daylight Autonomy metric (Christoph F. Reinhart 2006), suitable for open plan offices and mostly uniform illuminated spaces, could induce some misleading suggestions when narrow windows and definite user positions are considered.

The facades designed for the standar high rise dwellings in Colombia do not have regulations that ensure the correct and adequate light distribution and intensity in the interior spaces. Aluminum is an expensive metal in the country so the small sized openings are frequent, making the use of electric lighting mandatory and originating energy consumption that could have been avoided. Besides, visual tasks that are not developed with adequate lighting and can even generate unfavorable consequences for the occupants who stay there all day are a common situation. By not considering the daylighting in the space, it does not generate an adequate use and occupation of

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this, generating spaces that may be well set but the lighting conditions for these are incorrect.

In these low-budget homes it is normal to find that the same type of window is used for each room, whether it is a dining room, a kitchen or a bedroom, as if all these rooms require the same light intensity, an erroneous assumption. In many cases, the lack of daylighting makes food preparation difficult in the case of the kitchen, and in some others, it generates direct glare in the early morning hours, in the case of bedrooms. This inadequate lighting causes some people to decide to carry out activities in other rooms where they are not supposed to do so, such as eating in the bedrooms or performing visual tasks with high lighting requirements in the dining room.

Life is currently mutating, which makes it necessary to rethink how spaces are being designed. The daylighting conditions should consider what kind of work or tasks are used in every sector of a room because each of them has different lighting conditions (Mousavi, 2016). As a result of the current pandemic situation spaces are more zoned. Simultaneous online activities as work and study creates that perhaps in a house where four people live, the living-dining room is transformed into an office, a study area and even an architectural workshop. Therefore, this type of approach is necessary at the research level, to obtain information that speaks of human factors in relation to daylighting in housing to show how these spaces are shared and used. Focusing on tasks and visual trades that the occupant must perform will continue and maybe become a rule during the pandemic situation.

The objective of this research focused on analysing a living-dining room of a house in a zoned manner, using the Daylight Autonomy (DA) metric, if each zone has an individual value and not a global one for the total space. The simulations were performed under the sky conditions of the city of Medellin including zoning by space use and occupation. Small grids of points located at the height of the working plane was taken, thus comparing the annual entry of light into that space with four configurations of facades commonly used in this type of housing.

Methodology

The realization of the geometry and orientation of the space was modeled in Rhinoceros software and the Grasshopper plugin (Roudsary, 2013), which was also used for the creation of the point meshes in the work plane, as well as to determine the materials of the space and the thermal zones that compose it through the Honeybee plugin version 0.66 and Ladybug version 0.69.

For this research, a housing space was analyzed under the sky of the city of Medellin using the EPW climate file of Clima Colombia: MEDELLIN SYNTH.epw. The dimensions of the space considered were: 4.0 m wide, 6.0 m deep and 2.2 m high, with a series of four facades with the following characteristics: balcony with a 1.0 m overhang, 2.0 m balcony, windows measuring 1.20 m wide and 2.0 m high and wall to wall windows as shown in Figure 1. The evaluated orientation was southeast, which represents an intermediate condition of radiation exposure (Correa & Ramirez, 2017). A 24-point grid was defined in its interior, which is located throughout the length and width of the room and a single access of daylight. From this the raised facades were four, Figure 2.

Figure 2: Floor plan indicating the grid patterns evaluated and the corresponding zones in the room.

The materials used were also standard, the walls and ceiling are white with index of reflection 0.7, the floor has a light grayish tone with an index of reflection 0.5 to avoid alterations due to color reflectance, and the glass has a transmittance of 0.88. The metric used was DA (Daylight Autonomy), which uses the illuminance of a work plane as an indicator of whether the percentage of natural light entering that space annually is sufficient, i.e., whether it exceeds 300 lx. (Reinhart et al., 2006), (Reinhart, 2002), (Elzeyadi & Batool, 2017).

Figure 1: Architectural configurations evaluated.
For the Radiance parameters -ab 5 was used. The data is 288 in total for the proposed facades, and for arbitrarily considering when each point 50% of the time is greater than 200 lx, 300 lx and 500 lx for the purposes of this work.

Although the regulations of the Technical Committee CEN/TC 169 of Europe (Fontoynont, 2014) talk about natural lighting in buildings, for the purposes and purposes of this work we will focus on the Technical Regulations for Public Lighting (RETILAP), taking the values of the spaces that are named there and that despite not being spaces designated for housing, they are similar to those found today in a home, such as living rooms, reading rooms, offices, drawing tables, workshops and even classrooms.

To find the lighting performance of the space evaluated with the different facades, it was necessary to perform 12 simulations, with a single mesh of points on the work plane at 0.72 m to obtain a total of 24 data per facade corresponding to a percentage of annual illumination at each point.

These data were then grouped and averaged over the entire grid of points per façade to establish the comparison between how objective it is to have an overall value for the space and to have an individual value for each point evaluated. In addition, the data were organized in three sectors, dividing them as follows: back, middle and front (i.e., the points closest to the facades) generating a sectorization of these to recognize the location of these in the evaluated space. Table 1.

Table 1: Division and distribution of the grid of points over the evaluated space.

<table>
<thead>
<tr>
<th>Sectorization of points in the space</th>
<th>Back</th>
<th>Middle</th>
<th>Front</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>9</td>
<td>13</td>
</tr>
</tbody>
</table>

Results and Discussion

When the DA metric is used without zoning, we obtain a value for the entire space, i.e., it does not consider the zoned use and occupation that the people who live there will give it, because as mentioned above, this space can have a myriad of uses that require an adequate amount of light. When evaluated as a whole and without segmenting, we can see that at first glance the spaces with different variations of facades have a performance greater than 40% depending on the amount of lux with which they have been evaluated, of course, the more lux required for the development of certain activities, the lower the performance of the space, as shown in Figure 3.

Evaluating spaces by a global value shows that it is not very productive for the use and occupation that the space may have, since this is not an indicator of which areas do not have adequate lighting in which it is necessary to know these values by zones in order to have a better lighting performance of the space, thus allowing the occupant to also have a good development in the performance of visual tasks.

Figure 3: Average lux availability per facade without sectorization.

When this evaluation is performed, we can observe how the performance of Facade 2 is constant in each of the sectors. Showing that the space with the facade device that this one present can have a better light availability that is acceptable for the realization of visual tasks such as office work, conference rooms and even a classroom. In Facade 4 for example, the use that can be given to the space is reduced, since the sector at the back does not have the optimal conditions to perform this type of visual tasks, since the device that this façade has is a balcony with a depth of 2.0 m and this does not allow the light availability to be constant in the space.

Figure 4: Average DA illumination by zones plus the average DA of each facade, when 50% of the time the light input is greater than 300 lx.
Similarly, when an activity is performed at the bottom of the space, for example, on facade 1 there is a 32% discrepancy with respect to the average DA, i.e., the difference between seeing the DA metric averaged over the entire space to seeing it zoned across the space.

According to the minimum values found in the RETILAP for reading, observation and general work areas, 200 lx are required, in the space evaluated and with the consideration of the different facades, we can observe in Figure 5 how the lighting behaves in the points and also shows that the points that are in the front, that is, the openings and balconies, are those that have higher lighting percentages than those in the back of the space, also demonstrating that almost the entire space 50% of the time has the conditions to perform the aforementioned activities.

![Figure 5: Differences between averaged DA and zoned DA.](https://doi.org/10.26868/25222708.2021.31040)

In the figure, it can be observed that the points that are in the front sector and there may even be visual glare, causing the need to have the right space according to the use it will have. Figure 7 shows the behavior of light availability per point when 300lx is required.

Massive high-rise housing in Colombia has certain particularities in the use of its spaces, one of these for example is to have a sewing workshop in the dining room, this being a visual task that requires 500 lx because it requires detail, as well as a drawing office or for example an architectural workshop. We can observe in Figure 8 that as more lighting is required in the space; the background sector decreases in the percentage of light availability. The performance of visual tasks that require high precision becomes more difficult and it becomes necessary to be closer to the elements that make up the facade, whether a window or a balcony, Facade 2, which is composed of a window that covers almost the entire facade of the site, shows that this type of element in the facades is one of the most helpful for a correct distribution of lighting that enters the space.

![Figure 8: Light distribution (500 lx) of the points in the sectorized space.](https://doi.org/10.26868/25222708.2021.31040)

In Figure 8 it becomes more evident that when the lighting requirements for the development of activities that require precision, most of the proposed facades, except for Facade 4, are functional for this type of visual tasks. The use that can be made of the space would be centred only in the front sector and there may even be visual glare, causing fatigue and lowering the performance of people performing such visual tasks.
Conclusion

A space should be considered to have adequate lighting according to the light levels required for the activity to be carried out in that space, and for this purpose the regulations (RETI LAP) should consider these levels in residential spaces, not only for living-dining rooms, but for all rooms and even circulation areas, since each space requires different lighting conditions due to its use and occupancy.

The results show that for facades that allow greater access to daylight, such as Facade 2, there is less discrepancy between the average DA value and the zoned DA. In addition, the average DA is always above the bottom zone for each facade, while the front zone always gives a negative number, being more illuminated than the average DA. While in the facades with less access to daylight (Facade 1 and Facade 4) the average DA value is more like the evaluation of the middle zone and very different from the front or back zone. This result shows that the evaluation by zones is more useful than an average evaluation for the whole space because it allows decisions to be made about the distribution of interior furnishings and that what is valued as well-lit may be not so good when the results are observed, disaggregated, and in consideration of the user and their positions within the space.

References


