Daylighting: an approach from urban to room scale

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Abstract. This paper aims to compare the daylighting results provided by two specific software tools dedicated to the preliminary design stage. The first one, DIAL+\textsuperscript{a}, focuses on the room scale while the second one, CitySim, aims to provide a decision support at the urban scale. On one side we have a bottom-up approach, which matches the point of view of architects or building designers and, on the other hand, a "top-down" approach that fulfil the needs of urban planners and energy stakeholders. The case study focuses on a small open-space office that we looked at from three different positions in a given building located in the neighborhood "Barrio de las Nieves" in the city of Bogota. The output of both tools are analysed on a annual basis, through the comparison of the number of hours during which the indoor illuminance exceeds 300 lux for two specific points respectively located at 1.50 and 4.50 m from the glazed façade. This work shows that, if the two approaches yield similar results for the first point (close to the façade), however, for the second point (back of the room) the results are significantly divergent. This leads us to believe that both approaches are useful in assessing the daylight constitution for workplaces located in the “first rank”, but, for deeper locations, where the internal reflected component is dominating, a detailed analysis should be preferred.
1 Introduction

In the current context of cities’ densification, the analysis of the daylighting potential at the urban scale is not always an easy issue to address. However, recent works on the beneficial effects of light on the health of occupants showed that it is important to propose concrete methods of approach, so as to incorporate this issue in the early design stages. This paper proposes to compare two possible resolution methods. The first one deals with a rather detailed analysis of the internal space, but incorporating a coarse description of the external environment. It is based on the use of DIAL4 software [Paule 2011]. The second approach is based on a detailed analysis of flows on the urban level and offers a simplified analysis of daylight availability in the interior spaces. This approach is based on the use of CitySim software [Robinson 2011]. This study compares the results of both approaches through the analysis of 3 "typical" offices rooms positioned in one of the existing buildings.

2 Description of the urban context

We chose to perform this comparison in the city of Bogota, in the Barrio de Las Nieves. In this changing neighborhood, the recent construction of large office towers has drastically altered the original urban landscape, made up of small buildings built in the twentieth century. The first step consisted in working on 3D information available for the selected urban area that has been provided by the Universidad Jorge Tadeo Lozano in Bogota. To be able to use the information for both approaches, we had to convert the original file (stl) into .skp format. We then selected one of the existing buildings which is situated in an intermediate area (see red area on Figure 1). Nearby high buildings are located in the South-East and North-West sectors, and distant but very high towers are located on the West sector.

![Figure 1: 3D model of Barrio de las Nieves in Bogota (the selected building is marked in red).](image)

1 http://www.dialplus.ch: last visited 06-23-2016
2 http://citysim.pro: last visited 06-23-2016
3 Acknowledgement to Prof. Misael Ricardo Franco Medina, Profesor asistente UTADEO-Architectural Program
In order to compare different representative situations, we decided to successively analyze three specific room positions within the selected building (see Figure 2).

- Position A corresponds to a West oriented façade and the reference altitude of the room is 23 m above the outdoor ground (0 ref. = ground floor of the selected building).
- Position B corresponds to the same orientation as previous, but the room is located at 52 m above the ground floor.
- Position C corresponds to a South oriented façade and the room is located at 23 m above the ground floor.

The comparison between A and B is useful to show the influence of the floor altitude within a dense urban context and the comparison between A and C points out the impact of very high buildings on the daylight availability.

2.1 Room’s parameters

We have then described a reference room to perform the daylighting simulations. This is a small open office (7.80m x 5.20 m) equipped with four windows as shown in Figure 3. The floor area is 54 m² and the glazed area is 14.40 m², which corresponds to a Window to floor
ratio (WFR) of 0.27. In addition to the geometrical parameters, the photometric characteristics of the room are as follows (reflectances, visible and energy transmittances):

- $\rho_{\text{floor}} = 0.30$, $\rho_{\text{walls}} = 0.50$, $\rho_{\text{ceiling}} = 0.70$, $\tau_{\text{glazing}} = 0.70$, $g_{\text{glazing}} = 0.70$

2.2 Weather data

The meteorological data used with both methods are strictly the same and have been generated with the software Meteonorm\(^4\). Concerning the distant horizon, no data was available for Bogota, we have therefore considered that the far-field horizon was 0° in all directions.

2.3 Daylighting appraisal

The methods used by the 2 tools are based on different approaches:

- On one hand, CitySim simulations are based on the hourly calculation of the incident flow on the different surfaces composing the urban scene. The indoor daylight contribution is calculated using a view to the vault provided by the glazing from two reference points at desk level (0.8 m). The first point is situated at 1.5 m from the glazing and the second point at 4.5 m. In the daylight calculation, the direct component is determined using the luminance of the two times 145 Tregenza patches for both the sky and ground and the luminance of the shading surfaces (which include the inter-reflections in the urban canyons). The internally reflected component is determined using the split-flux method [BRE 1996], assuming that the room reacts

\(^4\) www.meteonorm.com: last visited 06-23-2016
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like an integrating sphere. The reflectance of the ceiling, walls and floor are respectively considered to be 0.7, 0.5 and 0.3. Details about the calculation method can be found in [Robinson 2006].

- On the other hand, DIAL+ performs Radiance simulations\(^5\) to calculate daylight factor values and uses the diffuse outdoor illuminance (hourly step) to estimate the diffuse daylight autonomy according to the required indoor illuminance [Paule 2008]. It thus does not take into account the direct component.

To overcome the issue of the shading device management, which is quite unpredictable, [Paule 2015], we decided to consider that the windows are equipped with a "theoretical" blind device such as:

- When there is no sun, the blinds are raised.
- When the sun hits the façade, the position of the blinds allows blocking the direct component and the incoming light flux (reflected and diffuse components) is high enough to let the electric lighting off.

2.4 Electric lighting

The electric installation is as follows:

- Downwards luminaires
- Luminaires efficacy: 80%
- Dust factor: 80%
- Lamp type: LEDs
- Power: 40 W
- Luminous efficacy: 100 lm/W
- Number of luminaires: 12 (3 rows of 4 luminaires)
- Global installed power: 8.9 W/m\(^2\)
- Regulation system: Continuous dimming during the opening hours.

Figure 4 below shows the illuminance distribution due to this installation.

2.5 DIAL+ Approach for the description of outdoor environment

The software embeds an intuitive interface allowing the user to quickly specify all the room parameters (geometry, photometry, walls composition and occupation parameters according to the room function).

Regarding the description of the outdoor environment, the process is as follows:
1. Make a screen shot of the studied area (satellite view centred on the selected building),
2. Trace the contour of the surrounding buildings,
3. Enter the height of the surrounding buildings,
4. Locate the centre of the studied room,
5. Enter the altitude of the room (vertical distance from the ground floor).

In this process, the main difficulty lies in the identification of the basis perimeter (ground floor level) of the surrounding buildings. Actually, as the inter-reflection between the different buildings are not considered, the back part of the surrounding buildings has no influence on the daylight simulation, therefore, the precision is only important for the faces that are viewed from the selected rooms (see Figure 5).

![Figure 5: The description of the surrounding buildings should be precise enough only for the faces viewed from the selected room.](image)

Considering that the original file describing the studied area contains a great number of existing buildings, it has been decided to simplify the scene in only keeping the buildings whose maximum height was above 23m (namely the altitude of Room A and C). Figure 6 hereafter shows the corresponding buildings (blue colour). All the lower buildings are considered as part of the outdoor ground and the reflection coefficient has been set to 0.20.
2.6 CitySim Approach for the description of outdoor environment

The graphical user interface CitySim Pro embeds an import feature of AutoCAD DXF 2000 file format using the 3DFACE primitive. To export the geometrical file from Sketchup, an extension plugin in ruby is provided with CitySim Pro. However, prior to the export, the geometrical file has to be organised in such a way that each building under study lies in a different layer, the ground surfaces in a layer GROUND and the shading surfaces in a layer SHADING. The steps required to produce daylight results from a Sketchup input file is as follows:

1. Simplify the 3D model:
   As the simulation time is an increasing function of the number of surfaces for the irradiance and illuminance calculation, limiting the number of surfaces is an essential step to keep a reasonable time frame for the study. Therefore, the initial 3D model was cut to the zone of interest and the grounds (roads, pavements, etc.) were removed from the model.

2. Prepare different layers in the model:
   Each building under study must be in a separate layer, and shading buildings must be placed in a layer named SHADING. The resulting scene is then exported to DXF format (using the extension stp_to_dxf_3DFACE).

3. Import the DXF file in CitySim Pro:
Use the import feature to import the file in the GUI of CitySim. In our case, only one building is considered in our daylighting study (coloured in yellow and red in Figure 8).

4. Run the simulation:
Save the CitySim XML file and edit the physical characteristics of the surfaces. In our case we consider a shortwave reflectance of 0.2 for all surrounding surfaces and for the ground. Edit the properties of the surfaces of the room under study with providing:
g-value of 0.7 and glazing ratio of 0.5333. After what the simulation is run using the CitySim Solver together with the climate file from Meteonorm.

5. Analyse the results:
The results for daylight are provided in the _DL.out file for each surface of the building. The file comprises desk illuminance (0.8 m) for a point near the window (1.5 m away) and in the back of the room (4.5 m away from the window), together with an additional illuminance due to inter-reflections computed using the split-flux method. By using a simple Excel sheet, Daylight Autonomy (continuous or not) can be calculated and the corresponding electric consumption for lighting determined using the installed power for each hour of the year.

In this process, the main difficulty lies in the preparation of the 3D model. The manual work of removing (useless) surfaces and adding buildings in layers is more time consuming than the simulation process itself.

3 Results and discussion

3.1 Outdoor masks

3.1.1. DIAL+
As DIAL+ is dedicated to room-scale analysis, the outdoor environment is represented as viewed from the windows. Figure 9 hereafter shows the respective stereographic projections of the urban landscape viewed from the different rooms. Rooms A and B are facing West and thus are hit by the sun during all the afternoon. The surrounding buildings located in that direction area are quite far and, therefore, the frontal horizon is almost clear. The only high masks are due to buildings located on the North and South. The variation of altitude between Room A and B is expressed by the different angle height of the outdoor buildings on the projection. Room C is South-West oriented and is facing a huge building right in front of it.

\[\text{Figure 9: Schematic representation of the outdoor masks respectively viewed from the different rooms.}\]

3.1.2. CitySim
In order to compute the masks due to the surrounding buildings, CitySim considers the view to the outside world through a fully-glazed façade above 0.8 m from two points inside the room. The resulting two masks for each point are superimposed with the luminance distribution of the sky, ground and surrounding façades of other buildings.
3.2 Daylighting contribution

3.2.1. DIAL+Lighting

Figure 10, Figure 11 and Figure 12 display the results obtained with the lighting module of DIAL+. The comparison between Rooms A and B shows that the daylight availability is identical for the point located at 1.50 m from the façade. Regarding the indoor point (4.50 m from the façade), the difference is still limited. Regarding Room C, the presence of the very high building located right in front of the façade leads to a significant reduction of the daylight availability, particularly in the back part of the room (dist. from façade = 4.50 m). In comparison with Room A, the covering of lighting needs in Room C is divided by 2.5 (29.5% vs. 73.5% of the opening hours).

Figure 10: Percentage of time during which the indoor illuminance exceeds 300 lux in room A (8AM-6PM).

Figure 11: Percentage of time during which the indoor illuminance exceeds 300 lux in room B (8AM-6PM).
3.2.2. CitySim

The daylight contribution for the two reference points in each room is calculated using the sky, ground and surrounding surfaces' luminance. In order to go from the usual radiance calculation (see Figure 13) to the luminance one, the luminous efficacy of the sky from the Perez All-Weather model is considered. Finally, the Simplified Radiosity Algorithm computes the inter-reflections in the urban canyons. When looking at Figure 13, we notice not surprisingly that the horizontal surfaces (roofs) are those that receive the greatest amount of radiation (red color). Figure 14 illustrates that the flux received by room C is significantly reduced by the presence of the surrounding building.
3.3 Analysis of the results

3.3.1. Daylight autonomy WITHOUT outdoor masks

Table 1 and Table 2 allow comparing the results obtained with the two methods without outdoor masks. For the point located close to the façade (1.50m) the results are almost identical. For the second point (4.50m from the façade), the difference between the two methods is still limited. It may be noted that without outdoor mask, the daylight contribution of the back part of the room remains significant.

<table>
<thead>
<tr>
<th>Daylight Autonomy [%]</th>
<th>Distance from façade = 1.5m</th>
<th>DIAL+</th>
<th>CitySim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room A</td>
<td>95.0</td>
<td>95.5</td>
<td></td>
</tr>
<tr>
<td>Room B</td>
<td>95.0</td>
<td>95.5</td>
<td></td>
</tr>
<tr>
<td>Room C</td>
<td>95.0</td>
<td>95.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Comparison of the results for the point located at 1.50 m from the façade WITHOUT outdoor masks. (Annual average percentage of time (8AM-8PM) during which the indoor illuminance exceeds 300 lux)

<table>
<thead>
<tr>
<th>Daylight Autonomy [%]</th>
<th>Distance from façade = 4.5m</th>
<th>DIAL+</th>
<th>CitySim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room A</td>
<td>82.0</td>
<td>93.0</td>
<td></td>
</tr>
<tr>
<td>Room B</td>
<td>82.0</td>
<td>93.0</td>
<td></td>
</tr>
<tr>
<td>Room C</td>
<td>80.5</td>
<td>92.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Comparison of the results for the point located at 4.50m from the façade WITHOUT outdoor masks (Annual average percentage of time (8AM-8PM) during which the indoor illuminance exceeds 300 lux)
3.3.2. Continuous daylight autonomy WITH outdoor masks

Table 3 and Table 4 allow comparing the results obtained with the two methods with outdoor masks. Here again, for the point located close to the façade (1.50 m) the results are almost identical. However, for the second point (4.50 m from the façade), there is a significant difference between the results obtained with the two methods. This is particularly noticeable for Room C (cf. Table 4).

<table>
<thead>
<tr>
<th>Distance from façade = 1.5m</th>
<th>DIAL+</th>
<th>CitySim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room A</td>
<td>95.0</td>
<td>95.4</td>
</tr>
<tr>
<td>Room B</td>
<td>95.0</td>
<td>95.4</td>
</tr>
<tr>
<td>Room C</td>
<td>92.0</td>
<td>93.4</td>
</tr>
</tbody>
</table>

Table 3: Comparison of the results for the point located at 1.50m from the façade WITH outdoor masks (Annual average percentage of time (8AM-8PM) during which the indoor illuminance exceeds 300 lux)

<table>
<thead>
<tr>
<th>Distance from façade = 4.5m</th>
<th>DIAL+</th>
<th>CitySim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room A</td>
<td>73.5</td>
<td>92.6</td>
</tr>
<tr>
<td>Room B</td>
<td>78.5</td>
<td>92.8</td>
</tr>
<tr>
<td>Room C</td>
<td>29.5</td>
<td>80.7</td>
</tr>
</tbody>
</table>

Table 4: Comparison of the results for the point located at 4.50m from the façade WITH outdoor masks (Annual average percentage of time (8AM-8PM) during which the indoor illuminance exceeds 300 lux)

3.3.3. Electric lighting consumption

In this section we compare the results obtained with the two methods regarding the annual lighting electricity consumption. In both cases, we made a hourly based analysis assuming that, at each time step, the specific power is linked to the daylighting autonomy and the dimming system (cf. §2.4) just gives the required amount of light in order to reach 300 lux on the work plane. For DIAL+, the mean value of daylight autonomy is used to control the whole room. For CitySim, the room is divided in two zones and the luminaires are controlled according to the values at 1.50 and 4.50 m from the façade.

Table 5 shows that without outdoor masks, the results obtained with the two methods are within the same range. On the other hand, when taking into account the outdoor masks, the gap becomes more important (cf. Table 6). For Room C, which is seriously impacted by surrounding buildings, the ratio between DIAL+ and CitySim is above 2.36.

<table>
<thead>
<tr>
<th>Annual lighting electricity consumption [kWh/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHOUT Masks</td>
</tr>
<tr>
<td>Room A</td>
</tr>
<tr>
<td>Room B</td>
</tr>
<tr>
<td>Room C</td>
</tr>
</tbody>
</table>

Table 5: Annual lighting electricity consumption WITHOUT outdoor masks (8AM-8PM).
### 3.3.4. Influence of the reflected component

As shown before, the main divergence between the two methods is observed for Room C and the gap is particularly high at the back part of the room (point located at 4.50 m from the façade). This suggests that the problem lies in the calculation of the internal reflected component (IRC), which is dominating in these cases. Actually, in CitySim, the calculation of this component is based on a split-flux method [BRE 1996] and the result is a fixed value assigned to all points of the room. The initial version of DIAL software (DIAL-Europe [de Groot 2003]), which was based on the same calculation technique was facing the same problem and tended to overestimate the results.

In order to test this hypothesis, we relaunched the simulations by setting to 0 the values of the indoor reflectance (floor, walls and ceiling). Table 7 confirms that if the room is completely black (IRC = 0), the results given by DIAL+ and CitySim are much closer.

### 4 Conclusions

The paper presents a comparative daylighting study between two pre-design tools: DIAL+ and CitySim. Even if each software is based on different methods and assumptions, the idea is to evaluate the order of magnitude of the results provided. For this, the case-study of three rooms in an office building in Bogotà was chosen. Two rooms at different heights on a feebly obstructed façade, and one room on a highly obstructed façade. The results show that the two approaches yield similar results for the three rooms in a zone close to the façade, however, for a zone at back of the room the results are significantly divergent. This leads us to believe that both approaches can be used indistinctively in assessing the daylight constibution for workplaces located in the “first rank” (near the window), even in dense urban context. For deeper locations (workplaces located in the back part of the room) a detailed appraisal of the daylight should be carried out in order to correctly estimate the internally reflected component. However, to the extent of the presence of large urban masks reducing the direct component of natural lighting in these areas, the successive implementation of the two approaches presented here (top-down "with CitySim and" bottom-up "with DIAL +) allows targeting all the daylighting issues in the early stage design.
In the near future, a link between DIAL+ and CitySim could be envisaged, by exporting the obstructing buildings in RADIANCE format from CitySim and importing in DIAL+ whose rendering engine is RADIANCE. This procedure could automate the process of the masks definition.

References


