Effect of atrium geometry and reflectance on daylighting in adjacent rooms

Ferreira T, Bournas I, Dubois M-C

Energy and Building Design, Department of Architecture and the Built Environment, Lund University, Box 118, SE-221 00, Lund

th0712fe-s@student.lu.se

Abstract. Atria are implemented in buildings to increase daylight, foster interaction and provide ventilation. However, their implementation can be complex if good daylight is to be achieved. This research proposed an investigation about the atrium parameters that affect daylight conditions in a case study. This evaluation concentrated in the atrium geometry and the wall reflectance values. Overall, the outcomes demonstrated that shifting the atrium from an enclosed to a semi-enclosed one can double the daylight in the atrium adjacent rooms. Moreover, it is possible to achieve better daylight in the adjacent rooms by keeping the same floor area of the building.

1. Introduction

In cold climates, heating and electrical lighting represent the largest share of the building energy demand of commercial buildings. Thus, increasing daylighting to reduce the reliance on electric lighting is an effective approach to decrease the energy demand while increasing user comfort [1]. Proper building design coupled with innovative daylight harvesting technologies might bring the electrical lighting demand to considerably lower levels [2]. However, for office buildings located in dense urban zones, such as city centers and economical districts, daylight harvesting can be difficult to realize due to the high level of obstructions. In addition to providing side windows to fetch daylight into the building, atria have been implemented in different parts of the world as a strategy to provide natural light indoors [3]. The case study chosen for this investigation was not only the winner of an architectural competition, but it also contained an atrium which needed much improvement in terms of daylighting. Often, this type of competition can generate a series of non-feasible projects where the daylight aspect is neglected in the evaluation [4].

2. Objectives

The main objective of this study was to improve the design of the building by analyzing different geometries and properties to determine which variables can positively and significantly affect daylight harvesting. Apart from maximizing the daylight conditions in the atrium’s adjacent rooms (AR) by utilizing climate based metrics, the additional aims were to verify how much of the area could comply with the Swedish building regulations [5] and how much of the original floor area would be lost in case changes in the geometry would be required. The research focused mainly on analyzing the effect of the geometry and surface reflectance, which according to the literature review, were the most influential parameters for daylighting in atria.
3. Method
The case study was simplified for research purposes, but without compromising the project and its current features. The dependent metrics studied included the daylight factor (DF) and spatial daylight autonomy (sDA). Simulations and analysis were performed using the software according to Figure 1.

3.1. Case study
The project is located in the Swedish city of Gothenburg. The nearest existing buildings were modelled since they significantly influence the daylight conditions of the study case. The building consists of eleven floors (4760 m² of area each), where various functions are distributed. The daylighting zone investigated in detail consisted of a four-meter deep area from the atrium facade.

3.2. Daylight model
Table 1 shows the Radiance rendering settings used in the simulations. An accurate but rather optimized set of parameters was chosen due to the large grid size and amount of simulations required. The values of Table 1 return reasonably accurate rendering performance [6].

| Ambient bounces (ab) | Ambient division (ad) | Ambient sampling (as) | Ambient resolution (ar) | Ambient accuracy (aa) |
|---------------------|-----------------------|-----------------------|-------------------------|-----------------------|
| 4                   | 512                   | 256                   | 128                     | 0.15                  |

The occupancy schedule was set from 9h to 17h with a one-hour break during week-days. The window-to-wall ratio (WWR) for the atrium facades was kept constant at 40% and a glass light transmittance of 0.73 was adopted. The light reflectance values for external and internal walls, floor, ceiling, surroundings and ground were set to 0.40, 0.70, 0.40, 0.80, 0.35 and 0.25 respectively.
3.3. Parametric Scheme

The geometrical approach to improve daylighting consisted of: wing suppression, wing splaying and façade light reflectance changes. A parametric study with these variations was set-up, see Figure 3. Since the wing suppression triggered floor area losses, these adjustments were followed by a volume addition (tower), which had the same number of floors as the suppressed wings. Splaying of the inner walls was performed in four steps, from 5° to 20°. The grid assessed varied according to each alternative, see Figure 3. The wall light reflectance values (LRV) were changed from 30% to 70%.

![Figure 3. Parametric study. Wing suppression was performed in steps of two floors.](image)

4. Results

Firstly, an investigation was carried out to verify how the AR in the current project were performing in terms of daylight level, so their results could be compared to the parametric modifications. In addition, the scenarios, both current and future, were assessed in terms of sDA and grid area with a DF above 1%, which is the benchmark for the Swedish building code or building environmental certification system Miljöbyggnad 3.0.

4.1. Effect of geometry

4.1.1. Spatial daylight autonomy

Figure 4 presents the results for the wing splaying options.

![Figure 4. sDA for cases a, b, c and abc.](image)
Splaying the walls of the atrium inwards brought an increase of the sDA in the AR. In case a, the sDA rose from 35% to 44%. Both cases b and c reached a maximum sDA of 41% for an angle of 20°. When all wings were combined (case abc), daylight proved to increase sharply compared to changes in one wing at a time. Consequently, the sDA peaked at 53% when the walls were splayed 15°.

In the wing suppression cases, the increase of sDA was substantial regardless of the tower position. By suppressing eight floors in option a1, the sDA almost doubled compared to the existing (base) case. Case a3 showed to have the best performance in terms of daylight autonomy. In general, all the options within cases a performed similarly. On the other hand, b3 exhibited a lower performance in relation to cases b1 and b2 due to the tower that is blocking the sky view angle towards southeast. Lastly, the suppression of eight floors sharply increased the sDA from 34.5% to 77% in case c3. This steep increase on c cases can be explained by the fact that the atrium was exposed towards southeast.

**Figure 5.** sDA for cases a1 to a3, b1 to b3 and c1 to c3.
4.1.2. Grid area with daylight factor (DF) above 1%

Figure 6 displays the grid area with a DF above 1% as a function of the floor area losses. Each point on the graph corresponds to one modification step (2, 4, 6 and 8 floors). The grid area is the sum of the correspondent grids on the eleven floors. The floor area losses or gains are presented in relative values to the original total floor area. The daylight factor provides a good idea whether a given space has a potential to fetch daylight under overcast sky conditions. It is widely used by certification systems, such as Miljöbyggnad 3.0, as well as by the Swedish regulation BBR. Hence, it has been chosen to demonstrate the percentage of grid area that is achieving a DF of 1% or above.

Figure 6. Grid area with DF above 1% area losses/gains for the wing suppression cases.

Figure 6 shows that case a3 lost approximately 5% of the building floor area to achieve the same DF results as a2. Case a1 had the worst performance among all a cases in relation to floor area losses. The grid area of DF above 1% in option b1 increased from 37% to 64%, while the building floor area increased by 5% in relation to the base case. Case b3 demonstrated a significant increase of 11% in the building floor area. The c cases had the highest grid area of DF above 1%. Conversely, the floor area losses were large, particularly in option c3, where 11% of the floor area was lost.

4.2. Effect of light reflectance

4.2.1. sDA and area of daylight factor (DF) above 1%

The aim was to study the potential of light reflectance values to boost daylighting in the AR, while keeping the same WWR of 40% along the inner atrium facade. Five LRV were tested 1) 30% 2) 40% 3) 50% 4) 60% and 5) 70%. The second option corresponds to the base case. The results shown in Figure 7 reveal a gradual but moderately strong impact of LRV on sDA.

Figure 7. sDA and grid area with DF above 1% for the LRV cases.
The sDA values for the changes on the LRV did not increase substantially if compared to the significant effects caused by the geometric changes. A material that could potentially contribute with an LRV of 70%, would increase the sDA for the studied grids from 29% to 37%.

5. Discussion and conclusion

According to the simulations carried out in this research, the geometry proved to significantly affect daylighting in the adjacent rooms (AR). It can be generally observed that the sDA values dramatically increased as the number of floors were suppressed on each wing (different geometries resulted in different outcomes). Conversely, the wing splaying strategy had a smaller effect compared to wing suppression. Regarding the grid area with DF above 1%, the a cases showed different results in terms of area losses as the daylight conditions increased. The b cases have all succeeded not only in raising the grid area of DF above 1%, but also in increasing the building floor area. Despite the substantial increase in grid area of DF above 1% in all c cases, these cases created significant building floor area losses, which is undesirable. By just changing the LRV of the inner walls, the grid area with a DF above 1% increased from 33% to 41%.

Thus, the general research findings are concluded below:

- The actual atrium configuration does not allow daylight to penetrate properly into the adjacent rooms, as the atrium is high and the floor plans are deep;
- Researches, such as the one carried out by [7], pointed out that building with different heights is more beneficial in terms of daylighting than creating an atrium surrounded by walls with the same height. This research is in line with those findings since it showed that a semi-enclosed atrium with different geometrical configurations yielded better daylight conditions in the AR than any other transformations;
- Opening the geometry towards different cardinal orientations can increase the useful daylight illuminance differently. Opening an atrium towards the north direction is beneficial as the light coming from this orientation is uniform and no shading devices are needed. On the other hand, the south orientation can take advantage of the sunlight to increase the level of illuminance in an office building, but a shading system (in windows of AR) is extremely important in this case to avoid overheating and glare in the AR;
- Changing the geometry in the early stages of design revealed to have a greater impact on the daylight performance of the AR, compared to splaying and LRV. Conversely, the LRV strategy may not be qualified as a primary approach in deep atria, since it does not have the potential to dramatically increase the natural light levels in the AR but a combination of appropriate geometry and high LRV may lead to a much greater level of sDA.

References

[1] Wong, I.L., 2017. A review of daylighting design and implementation in buildings. Renew. Sustain. Energy Rev. 74, 959–968.
[2] Cammarano, S., Pellegrino, A., Verso, V.R.M.L., Aghemo, C., 2015. Daylighting Design for Energy Saving in a Building Global Energy Simulation Context. Energy Procedia 78, 364–369.
[3] Samant, S., 2011. Atrium and its adjoining spaces: a study of the influence of atrium facade design. Archit. Sci. Rev. 54, 316–328.
[4] Sørensen, N.L., Frandsen, A.K., Øien, T.B., 2015. Architectural Competitions and BIM. Procedia Econ. Finance 21, 239–246.
[5] Boverket, 2015. Mandatory provisions on the amendment to the Board’s building regulations.
[6] Radiance Settings, 2018, viewed 5.8.18, <http://radsite.lbl.gov/radiance/refer/Notes/rpict_options.html>.
[7] Saratsis, E., Dogan, T., Reinhart, C.F., 2017. Simulation-based daylighting analysis procedure for developing urban zoning rules. Build. Res. Inf. 45, 478–491.