Use of Different Complex Fenestration Systems in Office Spaces in Chile: Analysis of the Energy Consumption and Visual Comfort of Occupants at the Early Stages of Their Design Process

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Abstract. Office buildings around the world are mostly designed with high window-to-wall (WWR) facades, regardless of the type of climate where they are located. Chile, a country with a high climate diversity from north to south and from the coast to the Andes, is no exception to this situation. In order to improve the thermal and visual performance of office buildings, it has been shown that complex fenestration systems (SFC), which include an external solar protection system, are effective to control the incident solar radiation and lighting transmission. However, the effectiveness of these systems depends to a large extent on an appropriate CFS design. Some studies of office buildings in Chile show that a high percentage of CFS has not been designed correctly. To support the early stages of the design process of office buildings in Chile and to assist in the design of solar protection systems as part of a CFS, oficity, an easy-to-use tool was designed. In an office space and considering different facades of solar protection systems, the tool allows the development of simultaneous simulations of its total energy consumption (heating, cooling, and artificial lighting), together with the evaluation of the occupants’ visual comfort. The tool performs the simulations in just a few seconds, which makes it appropriate to support the preliminary stages of the building's design process. The tool is compatible with PCs, smartphones, and tablets. The back end of oficity uses EnergyPlus for annual energy simulation and Radiance for annual lighting simulation. The use of these validated software makes the results of the simulations highly reliable. The tool considers 23 different climates of Chile. This research shows the analysis of an office space in different cities of the country, with variations in its orientation and the protection systems that are recommended for different climates.
1. Introduction
In recent years, office buildings in different cities of the world have been designed with a high window to wall ratio (WWR) on its facade. This type of facade generates high solar heat gains, causing indoor problems of overheating with consequent high cooling energy consumption, along with problems of visual and thermal comfort of users. In Chile, this situation is no different from the rest of the world (Fig 1). More than 65% of the city's office buildings have a WWR higher than 60%. On the other hand, some measurements made in this type of building show deficiencies in the design of the solar protection system of complex fenestration systems (CFSs) that have been designed for specific buildings. At the same time, while some CFSs show these deficiencies, in the context of a measurement campaign of office buildings in Santiago-Chile for measuring solar and lighting transmission through glazed facades within certain CFS, a semi-transparent fabric used as solar protection device showed to be highly effective in reducing solar heat gain and avoiding the glare risk [1].

Figure 1. Office buildings in Santiago.

Another study also carried out in office buildings in Santiago-Chile showed that the WWR, the type of glazing, and the use of external solar protection systems strongly affect the energy cooling and heating energy consumption in this type of buildings. The use of 50% of WWW, with selective double glazing and an external solar protection system, decreased in about 60% the cooling energy demand in a simulated office building of the city, compared to the same building with the identical type of glazing, but with a 100% of WWR [2].

On the other hand, laboratory measurements of CFSs showed that fabrics and perforated screens are effective in reducing the solar and the natural lighting in indoor spaces. This reduction, both solar and lighting transmission, reached more than 90% with perforated screen systems (with up to 20% of perforation) and fabrics with up to 10% of opening factor when considering a north-facing facade [3].

Because thermal performance and visual comfort in office spaces are highly dependent on the design of the CFS, and since there are deficiencies in the design of facades in existing buildings in Chile, it is essential to support the CFS design from the beginning of the building design process. With this purpose,
an easy to use tool has been developed, which is also fast in its calculations and reliable in its results. This tool is oficity, which can perform simultaneous simulations to estimate the total energy consumption of an office space while analyzing the indoor visual comfort conditions. This simulation only takes a few seconds and can be performed on a PC, Smartphones, and Tablets. The tool is free and is available on the website, www.oficity.cl.

Chile is a country with a wide diversity of climates, from a desert north with high solar radiation and the south with cold weather and, in some cases, with high rainfall. There are also significant climatic variations between coastal and Mediterranean cities located between the Coastal Range and the Andes.

The purpose of this paper is to show a tool to support the design of CFSs, in the early stages of the design of an office building, in order to achieve the minimum total energy consumption, ensuring the visual comfort of the occupants of these type of buildings. The tool considers different cities of the country. Some of them are considered in this paper in an attempt to show the effectiveness of the tool when considering different climates.

2. The tool: oficity.

The tool calculates the consumption of cooling and heating energy in a particular space that is supposed to be inserted in an office building that could contain a variety of spaces in its design, with different orientations. To the heating and cooling energy, the required lighting energy to reach a certain threshold in space is added.

The back end of oficity uses EnergyPlus for annual energy simulation and Radiance for annual lighting simulation. The use of EnergyPlus and Radiance allows the results of the simulations to be highly reliable in the early design stages. The tool is based on a modified dtimestep Radiance program that only calculates the workhours, period of the day with solar radiation, which allows reducing the simulation time.

The simulated space that can be represented in the tool is an office module (Fig. 2). Dimensions and orientation of the space can be changed and defined according to the user’s request. Calculations assume that there is an appropriate level of ventilation for achieving indoor air quality. The office has an automated dimmable lighting system of 10 W/m² to add artificial lighting when necessary.

Inputs of the tool are the following: City; Glazed; Shading system of the CFS; façade orientation; dimensions of the space: height, width, and depth; window-to-wall ratio and number of occupants.

It is important to emphasize that the tool considers the simultaneous evaluation of lighting and thermal performance, which is crucial to analyze during the design process of a building [4, 5].

![Figure 2. Simulated office space](image-url)
tinted glazing (Fig 3). Glazed systems available are simple glazed, clear glazed, double, and triple glazed. Low e glazing is also considered.

In the case of tinted glazing it is possible to change the solar heat gain coefficient; In the case of horizontal louvers and vertical louvers, it is possible to set the tilt angle, spacing, and width of the louvers; In the case of perforated screens, where it is possible to change the percentage of perforation.

Oficity incorporates 23 Chilean cities considering the most representative climates of the country, from north to extreme south.

The results of oficity consider the following metrics: (i) The total energy consumption for heating, cooling, and artificial lighting. (ii) The spatial daylight autonomy (sDA) [6]. sDA indicates the percentage of the area that achieves a minimum of 300 lx during at least 50% of the annual work hours; and (iii), the annual sunlight exposure (ASE), which indicates the percentage of the area with more than 1000 lx of direct radiation during more than 400 h of work hours.

Figure 4 shows the result (a screenshot of the oficity results) for a west-facing office space, with three occupants in the city of Santiago. The space is 3 m high, 4 m wide, and 5 m deep. It considered a tinted glass with a solar heat gain coefficient of 50% and a WWR of 50%. It can be seen that this office space shows a high total energy consumption (consumo energético anual), which is concentrated in 100% in cooling energy consumption. The sDA is considered acceptable (green color; preferable), which indicates that the space uses the highest amount of natural lighting usage time, however, ASE is very high (red color, higher than 10%), indicating that there is a high risk of glare in the analyzed space. In the figure, “desempeño luminico” means lighting performance.

Figure 4 shows the same office but with a CFS that considers a horizontal louver, with louvers of 12 cm width, 15 cm spacing, and 30° tilt angle. There is a significant decrease in cooling energy, and in terms of visual comfort, both ASE and sDA reach the expected values. There is a high use of natural light and a low risk of glare. It should be noted that the study of these two cases took only a few minutes.
Figure 4: Results of a west oriented office space in Santiago with no solar protection system.

Figure 5. Results of a west oriented office space in Santiago with a solar protection system.

3. Methodology
For the space described above, the total energy consumption and the value of the visual comfort parameters are calculated: ASE and sDa. The space is 3 m high, 4 m wide, and 5 m deep. It considered a tinted glass with a solar heat gain coefficient of 50% and a WWR of 50%. For different cities in Chile. Table 1 shows the latitude and some climatic data of these cities. Cities represent different climates of Chile: desert (Calama and Antofagasta), Mediterranean (Santiago and Temuco), and Mild (Concepcion) with coastal influence.
Table 1. Climate data of different cities

|                  | Antofagasta | Calama    | Santiago (Pudahuel) | Concepción | Temuco      |
|------------------|-------------|-----------|---------------------|------------|-------------|
| Latitude         | 23°39′ S    | 22°27′ S  | 33°27′ S            | 36°49′ S   | 38°44′ S    |
| Climate          | BWk         | Bwk       | Csb                 | Csb        | Csb         |
| Desert           | Cold Desert | Mediterranean | Mediterranean | Mediterranean |
| Mean T°          | 16.4        | 12.1 C°   | 13.6 C°             | 12.2 C°    | 11.2 C°     |
| Min T°           | 13.7        | 2.0 C°    | 6.7 C°              | 7.7 C°     | 6.3 C°      |
| Max T°           | 20.1        | 23.0 C°   | 22.4 C°             | 17.7 C°    | 17.7 C°     |
| Mean Humidity    | 77          | 37%       | 72%                 | 82%        | 82%         |

Source: Instituto Nacional de Normalización, 2008.

4. Results

Table 1 shows the total energy consumption of the west oriented office space in different cities. In the first case, the facade does not have a sun protection system, and in the other, the horizontal louver system described above is the one considered.

Table 2. Energy consumption and visual comfort

| CITY         | Shading     | Total energy consumption kWh/m² year | ASE % | sDA % |
|--------------|-------------|-------------------------------------|-------|-------|
| SANTIAGO     | No shading  | 115                                 | 47    | 93    |
|              | Vertical Louvers | 67                                    | 0     | 77    |
| CALAMA       | No shading  | 135                                 | 63    | 100   |
|              | Vertical Louvers | 49                                    | 0     | 57    |
| ANTOFAGASTA  | No shading  | 147                                 | 53    | 100   |
|              | Vertical Louvers | 61                                    | 0     | 83    |
| CONCEPCION   | No shading  | 118                                 | 47    | 100   |
|              | Vertical Louvers | 45                                    | 0     | 93    |
| TEMUCO       | No shading  | 100                                 | 43    | 100   |
|              | Vertical Louvers | 41                                    | 0     | 93    |

It is observed that in all cases, there is a high consumption of cooling energy because there is no solar protection on the facades. This consumption decreases significantly with a solar protection system (vertical louvers). It is also noted that the solar protection system, in most cases, allows visual comfort with high autonomy of daylight. ASE equal to zero, which is present in all cases with solar protection, indicates that this protection would not allow direct solar radiation to enter the space. sDa under 75% indicates that in the case of Calama, the design of the protection would probably have to be changed to allow more natural light to enter but ideally preventing direct radiation from reaching the interior.
5. Conclusions
This paper shows the capabilities offered by a new tool for assessing the impact on energy consumption and the visual comfort of office building occupants. The tool has been created to support the design process of office buildings in their early stages. For this, it was crucial that the tool was easy to use and provided results highly reliable in the least amount of time possible. In fact, the tool generates results as fast as 10 seconds. Additionally, the tool uses highly reliable software such as EnergyPlus and Radiance, which allows very reliable results as well.

Also, the tool allows simulating office spaces of various sizes and orientation, with different numbers of occupants. At the same time, it is possible to perform thermal and lighting behavior of office spaces in different climates, as expected. It is possible to conclude that this tool is very appropriate to support office buildings architects during the early stages of an office building design. It allows evaluating the impact of different shading devices to make efficient decisions at this stage of the design of an office building.

Acknowledgment
This work was funded by the National Commission for Scientific and Technological Research (CONICYT), Chile, under research grants FONDECYT 1141240 and FONDECYT 1181686. The authors also gratefully acknowledge the research support provided by CEDEUS under the research grant CONICYT/FONDAP 15110020.

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