Climate-based daylighting analysis in an open-plan office due to boundary conditions

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Abstract

During the first stages of building design, issues like local climate or surrounding buildings are determinant. Also the configuration of every space depends on its orientation due to solar access, among others. The impact of these boundaries conditions on daylight illuminances in an open-plan office space is studied in terms of Daylight Factor (DF), Daylight Autonomy (DA) and Useful Daylight Illuminances (UDIs).

Climate conditions in the location determine the characteristics of the daylight source, such as the ratio between diffuse lighting and global lighting, for a building located in a specific area. However, surrounding buildings and elements which may block daylight in the space hold more weight than the orientation of glazed façades, but are not always taken into consideration in daylighting studies.

Keywords: Climate-based Daylight Modelling, Daysim, external conditions, building design, location, orientation, external obstruction

1 Introduction

Considering the daylight that enters a building is fundamental, both as a means of reducing the consumption of electric lighting and in terms of its influence on visual comfort conditions, user moods, solar gains and qualitative aspects of the illuminated space [1-2]. This amount of daylight is highly dependent on building design and its boundary conditions.

From the mid twentieth century onwards the general calculation method only considered fixed and stable sky conditions, which meant that the study of daylight under an Overcast Sky was only indicative of diffuse illumination conditions, avoiding sunlight, and did not take illumination variability into account. However, the recent appearance of climate-based metrics such as Daylight Autonomy and Useful Daylight Illuminances [3] provides further information on the variable behaviour of daylight throughout the year. This means it is once again possible to take daylight into account when making decisions that affect architectural design.

In the initial design phases the conditions of the surrounding location are a key factor when drawing up the initial plans for the future building. In this sense, this study analyses the influence of external conditions, including the location of the building, the orientation of façades with openings, and possible frontal obstructions from the surroundings, have on the daylight conditions of an open-plan office space with two opposing glazed façades.

This parametric study is the development of the Subtask "Ergonomic analysis of lighting conditions in work or study places" of the Spanish project 'Tecnocai: efficient and smart technologies oriented to healthy and comfortable interior environments'. This paper focuses mainly on daylighting analysis of boundaries conditions of buildings; spatial aspects (e.g. window-to-wall ratio) and solar protections (e.g. overhangs) will be reported in separate publications in correspondence to the three building design phases established during the project.

2 Antecedents

2.1 Daylight availability

The discussion about the limitations of Daylight Factor has been widely reported [3-6]. As Daylight Factor doesn't include the contribution from sunlight, only diffuse light, it isn't very useful in climates where clear and sunny skies prevail. Moreover, as it excludes sunlight, the Overcast Sky Model is widely used in correspondence to a possible real sky condition when there is only diffuse daylight.

So another limitation of Daylight Factor is the implications of using the Overcast Sky Model. As its luminance is cylindrically symmetrical, the DF does not take the orientation of the glazed surface into account.

However, while its simplicity is its major advantage, the sky model does not allow us to consider the variability of annual daylight in the space under study. Climate-based Daylight Metrics, developed recently, allow us to establish the annual daylight amount for a given space using hourly or sub-hourly calculations of the illuminance of every point on the workplane [6-7].

In order to obtain this information, it is necessary to have the distribution data for the luminance of the sky vault in the same time-step. Perez's All-weather Sky Model [8] provides information on luminance distribution in the sky vault through irradiance measurements. In the absence of monitored data on luminance distribution, these data can be obtained from climate files [9].

Both Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) metrics are tools that make possible to process a large amount of illuminance data (up to 4380 hourly values in correspondence with the amount of daytime hours) for each point of the workplane. Both metrics analyse the illuminance data by establishing a time range for study and a suitable illumination level for carrying out visual tasks [3-7].

Daylight Autonomy (DA) is defined as the percentage of the year during which there is a minimum threshold of illumination provided only by daylight [3]. The purpose of the Useful Daylight Illuminance is to determine when daylight levels are of use to the user. It is currently measured using three metrics to express the time percentage in which the following illuminance ranges are obtained: less than 100 lx (very dark), more than 2000 lx (excessive light) and between 100 and 2000 lx as a useful range [3, 5]. These ranges may vary as more data on user preference is obtained.

The key advantage of dynamic performance metrics for daylight is that they consider the amount and nature of daily and seasonal variations of daylight, as well as irregular meteorological events, for a specific location [3-7, 9-10].

2.2 Conditions of the location: climate, orientation and obstructions of the surroundings

Daylight illumination levels are dynamic and temporal dependent. The climatic local conditions of the geographical location of the building strongly influence on daylight accessibility, since the hours and amount of light available decrease the farther away we move from the equator, among others [10-11].

Climate files incorporate global, diffuse and direct irradiance measurements [12] that are used to obtain the luminance sky distribution through Perez's All-weather Sky Model, but also global, diffuse and direct illuminance hourly data are incorporated.

Criteria for daylight metrics shouldn't be universal, e.g. the LEED criterion of 'an average of 2% DF' throughout the space, as daylight is climate-dependent [4]. Some dynamic daylight studies have been developed for specific locations, but it's hard to find studies where a wide range of different climate types and latitudes [10, 13] have been taken in consideration.

As there is still a discussion about continue using Daylight Factor or move to dynamic daylight metrics [1, 10], it is important to know how much representative is Daylight Factor, based on diffuse illuminance, for the local climate. In this way, *Nicol et al.* [13] classify the five local climates into the occurrence of three sky conditions, highlighting the difference between northern and southern locations.

Today, when an architect designs a building for any location throughout the world, considering the impact of local climate would be very useful to not applying his daylighting solutions unconsciously, e.g. high frequency overcast sky location to high frequency sunny sky location and vice versa.

If only the geometry of solar trajectories is taken into account, solar incidence in a space depends on the latitude of the building's location and on the orientation of the building's glazed façades. In addition to producing high levels of illumination, direct solar incidence produces a major thermal charge in the summertime. The development of urban planning studies as regards the solar access of buildings is based on the location-orientation binomial [14-15].

Regarding to daylight metrics discussion, meanwhile Daylight Factor is insensible to orientation, a study considering dynamic simulations for every orientation would highlight the difference between those metrics that is very important in places where direct daylight is relevant [5, 10].

In hot and dry climates, it is particularly important to take into consideration the orientation and obstructions in the surroundings, not only to ensure a minimum reception of daylight, but to avoid overheating of their interior spaces [2, 16-17]. In order to reduce the energy demand for HVAC and lighting systems, architectural design must be as compatible with the climate as possible [18-19].

In modern urban cities, many buildings are constructed close to each other, the obstructions of urban surroundings suppress the direct solar component during some or all hours of the day [20]. The shading effect from nearby building can be significant and reflected components can be the main sources of interior lighting [2, 21-22] if they are not shaded [15]. This should be especially taken into account with dense construction as the presence of obstructions has repercussions on the availability of daylight and causes increased energy consumption [23].

D.H.W. Li has a large experience analysing dense urban environments [21, 23], but for the authors knowledge, the effect of the surrounded obstructions are studied in terms of Daylight Factor, so a dynamic daylight analysis would be useful to consider the variability of daylighting performance not only due to building design, but rather the surrounded environment.

3 Methodology

The values for DF, DA and UDI are obtained using the Radiance-based software Daysim [9-10]. The international database of climate records for energy calculations (IWEC) provided the climate data used [12].

3.1 Description of the model

The model under study is an open-plan office measuring 20 m x 12 m x 3.5 m. Openings are distributed in two opposing façades. There are 6 windows on each façade measuring 1.35 m x 0.90 m each, with a sill-height of 1 m, and giving a window-to-wall-ratio of 17.50% (10% window-to-floor-ratio). As the authors were looking for the maximum daylight availability of this space, there are no interior partitions and glazings have a very high transparency, but not completely transparent as a void, to consider some real and existing cases. Although we've placed work stations parallel to the glazed façades, their location is not fixed, so the whole area is treated as the task area. The workplane is found 0.80 m from the floor, with sensor points every 0.20 m (Figure 1). There is a minimum distance of 0.5 m between sensors and walls to avoid boundary effects.

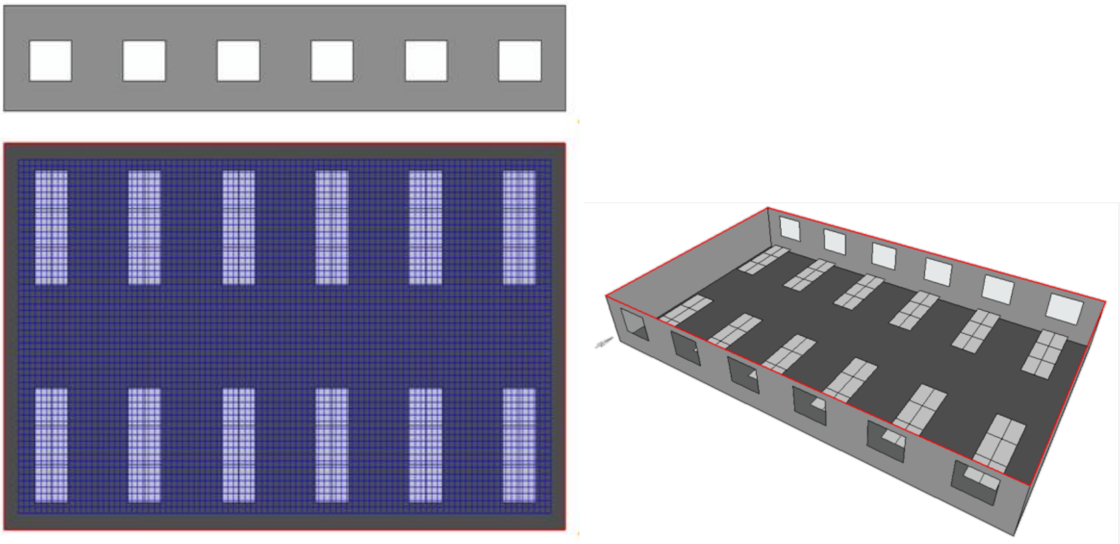


Figure 1. Reference open-plan office model: Southern front view, plan and perspective

Table 1 shows the optical characteristics of the model:

Initial conditions	
Glazing transparency	90%
Floor reflection coefficient	30%
Ceiling reflection coefficient	75%
Wall reflection coefficient	55%
Furniture reflection coefficient	35%

Table 1. Optical characteristics of case study.

3.2 Lighting requirements of office spaces

In order to calculate the dynamic daylight performance metrics it is necessary to define the time range for which they have to be calculated, as well as the minimum lighting level desired.

As it is an office, the time range under study is from 8:00 h to 18:00 h. As regards the minimum lighting level, European Standard EN 12464-1 on Lighting of Workplaces [24] suggests an average maintained illuminance of 500 lx within the working area for office tasks.

In terms of DF, an average maintained illuminance of 500 lx can be understood as the minimum DF value to be reached to obtain this level of indoor illumination, considering outdoor illuminance with an annual frequency of 50% in the time range specified (Figure 2). Once this minimum DF value is obtained, the percentage of sensors on the workplane exceeding this value is represented in the analysis graphs.

This criterion requires the calculation of the value of diffuse horizontal illuminance with a frequency of 50%. To do so, a cumulative curve was calculated for available diffuse horizontal diurnal illuminance, using the data included in the IWEC climate archive for the locations under study and the value for diffuse exterior illuminance for 50% of the year was obtained. Given that we aimed for a minimum illuminance of 500 lx, the minimum DF value for each location was obtained. Figure 2 shows the location of the reference model as an example.

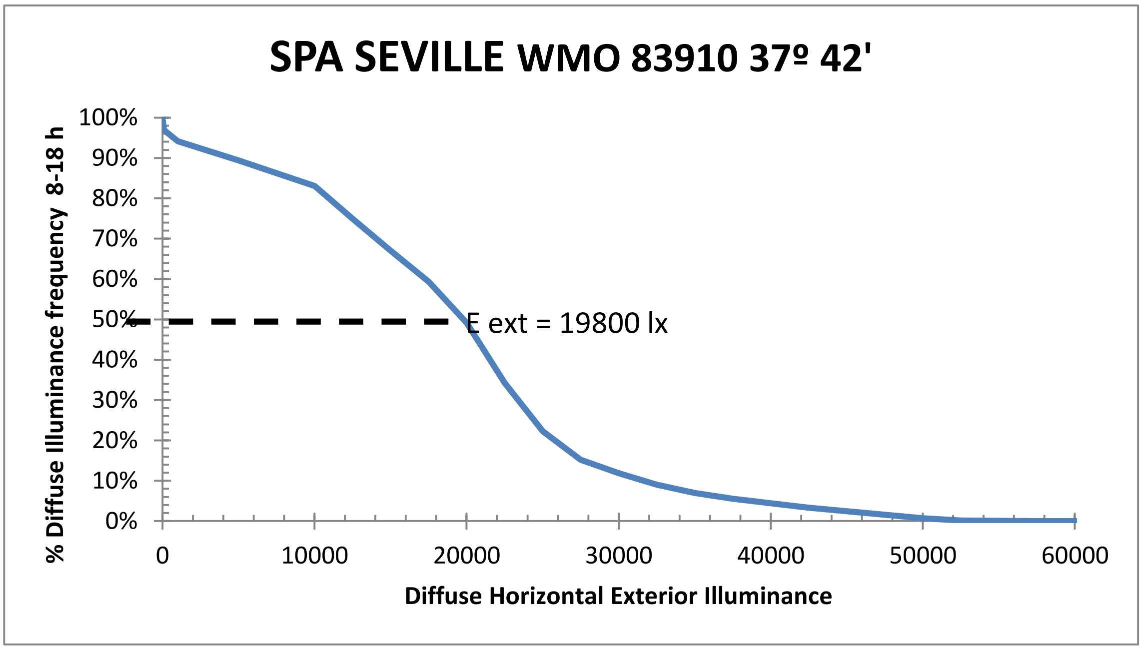


Figure 2. Cumulative curve of Diffuse Horizontal Illuminance from 8:00 h to 18:00 h. Values taken from the energyplus weather climate file for Seville (Spain).

In terms of DA for the calculation range considered, an average maintained illuminance of 500 lx requires the determination of the time percentage in which each point exceeds this minimum lighting value. Once DA values for each point had been established, the percentage of sensors of the workplane with a DA of 50% or above was represented in a graph.

3.3 Proposals

3.3.1 Location

As seen above, the location of the building determines the availability of outdoor daylight based on local climate conditions. In the EnergyPlus weather database [12], arranged by World

Meteorological Organization (WMO) region and country, IWEC climate files can be found for 34 capitals of the countries within WMO region 6 (Figure 3) corresponding to Europe and other non-European countries. These cover latitudes between 31°78' (Jerusalem, Israel) and 64°13' (Reykjavik, Iceland).

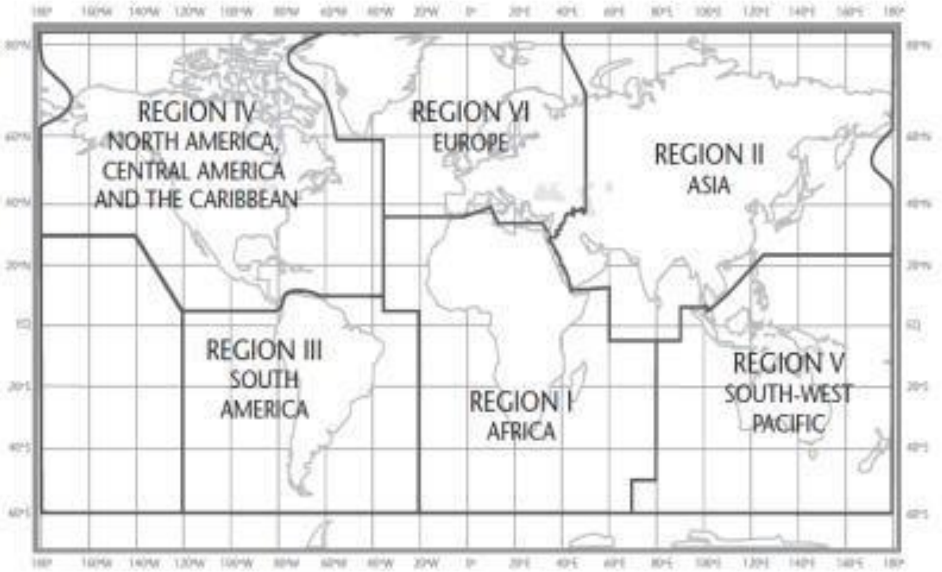


Figure 3. Limits for WMO Regions.

In addition to Seville, twelve capitals of countries within WMO region 6 were chosen for this study, following Köppen's climate classification and the value of E_{ext} with 50% frequency from 8:00 h to 18:00 h (the minimum DF value desired), thus obtaining the most representative locations. Köppen's climate classification was considered as there are some capitals with almost the same latitude but different climate and authors suppose that Köppen's classification will highlight the relationship between cloudiness and climate, despite the usual latitude classification.

Table 2 shows the different locations, Köppen's climate classification, latitude, value of diffuse horizontal illuminance with a 50% frequency during daytime and resulting DF to obtain 500 lx on the workplane.

Country	City	WMO Station	Köppen	latitude	E_{ext}	DF
ISL	REYKJAVIK	40300	Cfc	64,13	11300	4.42
NOR	OSLO	14880	Dfb	59,90	13100	3.82
RUS	MOSCOW	276120	Dfb	55,75	16200	3.09
POL	WARSAW	123750	Cfb	52,17	16000	3.13
UKR	KIEV	333450	Dfb	50,40	18500	2.70
FRA	PARIS	71490	Cfb	48,73	17600	2.84
BIH	BANJA LUKA	132420	Cfb	44,78	18300	2.73

ROM	BUCHAREST	154200	Dfa	44,50	19200	2.60
ITA	ROME	162420	Csa	41,80	20400	2.45
PRT	LISBOA	85360	Csa	38,73	19000	2.63
ESP	SEVILLE	83910	Csa	37,42	19800	2.53
SYR	DAMASCUS	400800	Bsh	33,42	17600	2.84
ISR	JERUSALEM	401840	Csa	31,78	17800	2.81

Table 2. Region 6 WMO selected locations. Cfc = Maritime Subarctic climates or Subpolar Oceanic climates; Dfb = Moist continental; Cfb = Marine west coastal; Dfa = Humid continental; Csa = Mediterranean climate; Bsh = Hot semi-arid climates.

3.3.2 Orientation

If local climate conditions have an influence on the availability of outdoor daylight, building orientation is closely linked to solar geometry.

The office spaces studied were designed using bilateral daylight, that is to say, with openings on two opposing façades. In the case under study, light accesses through the north and south façades. Several orientations were suggested for this study, with rotations of 45°, 90° and 135° in relation to the model of reference.

3.3.3 External obstructions

In previous sections, models were considered in isolated settings, with no obstructions preventing solar access or blocking off the view of part of the sky vault. Offices tend to be located in urban spaces that are occupied to a greater or lesser density, and therefore, depending on the urban planning conditions, the evolution of the city, the elevation (floor height) of the offices, etc., they have elements in their surroundings that obstruct and limit access of daylight.

Although these obstructions can be found in different areas of the outer hemisphere of the façade plane, the greatest obstruction to daylight, involving the greatest reduction of availability, is frontal obstruction (parallel to the façade plane).

Just as the solar position is expressed in polar coordinates, the elevation of the obstruction in relation to the windowsill is also represented using polar coordinates. It is possible to examine the different combinations of possible building height and separation by defining different angles. Given that the maximum solar elevation for latitude 37° (Seville, Spain) is 72’8°, four angles between 0° (no obstruction) and 75° have been used to represent the possible panorama.

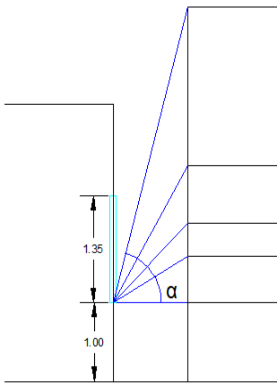


Figure 4. Frontal obstruction angle

While the reference model represents maximum availability, the greatest frontal obstruction angle represents the greatest reduction, and thus the range in which the availability of outdoor daylight in urban surroundings is obtained.

3.4 Daylight simulation software

The different parameters were calculated with DAYSIM. This RADIANCE-based program uses the Daylight coefficient method developed by Tregenza in 1983 along with the Perez All-Weather Sky model to calculate the levels of lighting for each of the sensors defined for the work plane for each hour of the year [9-10].

By defining an annual schedule and a minimum illuminance on the workplane, DAYSIM calculates the Daylight Factor (DF), Daylight Autonomy (DA) and Useful Daylight Illuminances (UDIs), as well as other parameters.

4 Results

The values of the Daylight Factor, Daylight Autonomy and Useful Daylight Illuminances for every sensor of the workplane were calculated for each model, and then, the percentage of grid sensors above DF and DA criteria, as defined above, to reach 500 lux during 50% of the time range, were calculated. These values will be presented for each proposal described above: locations, orientation and obstruction; comparing each model results with the original model results.

The results of the original open-plan office placed in Seville, with North-South glazed façades and without obstructions are shown in table 3.

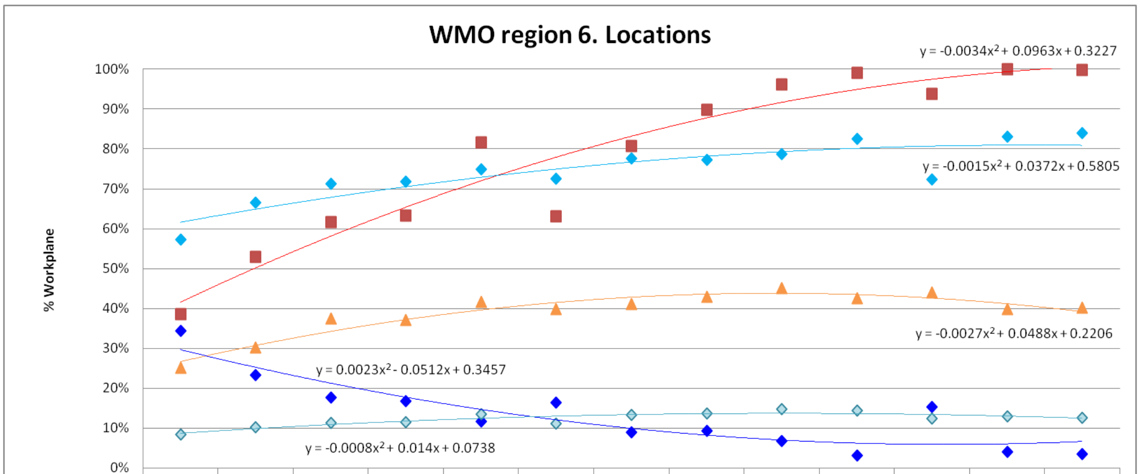
Initial conditions: Results	
DF criterion	43.92%
DA criterion	93.81%
UDI < 100 lux	15.19%
UDI 100-2000 lux	72.41%
UDI > 2000 lux	12.39%

Table 3. Results for the original open-plan office.

The difference between considering only diffuse exterior illuminance or including the direct component for the period of time specified is reflected in the difference in DF and DA criteria values, and covers almost 50% of the workplane. Most of the workplane remains within the comfort range (100-2000 lux) and only an average of 30% remains outside this range.

4.1 Location

Figure 5 shows the results obtained for the different locations studied following the procedure described above:



	REYKJAVIK 64º 13'	OSLO 59º 90'	MOSCOW 55º 75'	WARSAW 52º 17'	KIEV 50º 40'	PARIS 48º 73'	BANJA LUKA 44º 78'	BUCHAREST 44º 50'	ROME 41º 80'	LISBOA 38º 73'	SEVILLA 37º 42'	DAMASCUS 33º 42'	JERUSALEM 31º 78'
DF criterion	25.17%	30.14%	37.44%	37.03%	41.58%	39.75%	41.14%	42.97%	45.08%	42.56%	43.92%	39.75%	40.08%
DA criterion	38.50%	52.81%	61.69%	63.25%	81.53%	63.08%	80.69%	89.83%	96.11%	99.11%	93.81%	99.92%	99.75%
UDI<100 lux	34.38%	23.28%	17.58%	16.79%	11.65%	16.32%	9.00%	9.24%	6.69%	3.13%	15.19%	3.98%	3.51%
UDI 100-2000 lux	57.23%	66.49%	71.23%	71.76%	74.95%	72.46%	77.67%	77.19%	78.64%	82.57%	72.41%	83.05%	83.94%
UDI>2000 lux	8.41%	10.16%	11.28%	11.46%	13.43%	11.19%	13.35%	13.57%	14.70%	14.38%	12.39%	12.99%	12.58%

Figure 5. Influence of location for an unobstructed North-South oriented open-plan.

Location represents a relative important issue. In general, it can be observed that as latitudes decrease, the percentage of the workplane exceeding DF and DA criterion, as well as $UDI_{100-2000}$, increase but not in the same range.

The percentage of the workplane achieving DF criterion presents two different patterns. In higher latitudes, from Reykjavik to Kiev, the value increases almost lineally, but from Kiev (50°) to Jerusalem

(31°) the values are more stable, being around 40%. The occasional deviations from the tendency curve are due to the climate characteristics of specific locations.

Regarding to the percentage of the workplane achieving DA criterion, there is a great difference between the highest and lowest latitude, being around 60%. Also, there are some deviations the trend curve, some of them of relevance, as the results obtained for Kiev or Paris.

If DF criterion represents the percentage of the workplane achieving some certain lighting requirements by diffuse daylighting and DA criterion is due to global daylighting (diffuse and direct), the difference between both metrics represents the relevance of direct daylighting for that specific location.

In this series five values can be distinguished. The minimum difference corresponds to the highest studied location with a value of 13%, revealing the lesser presence of sunlight in Reykjavik. The second step has a value around 24%, corresponding to locations between 50° and 60°, except Kiev that, together with Banja Luka, has a difference of 40%, representing the third step. The differences are higher and also the presence of sunny days throughout the standard weather file.

For latitudes from 50° to 35°, the difference between the percentages of the workplane achieving 500 lux for 50% of the specified time range are up to 50%. And finally, for lower locations, this difference is around 60%. Excluding minor deviations, these differences highlight the adequacy of using climate-based daylight modelling, especially for differences up to 40%, covering the major part of the studied territory.

However, UDI values are more stable against the change of location. The percentage of the workplane within the comfort range is between 55% and 85%, increasing as latitude decreases. The variations between the different locations are due mainly to the variation of the percentage of points of the workplane below 100 lx. While the percentage of excessive illuminance remains approximately 12.6%, the percentage of workplane with illuminances below 100 lux reaches a maximum of 34.38% at the highest latitude, decreasing to a minimum of 3.5% in the most southern location following a quadratic function.

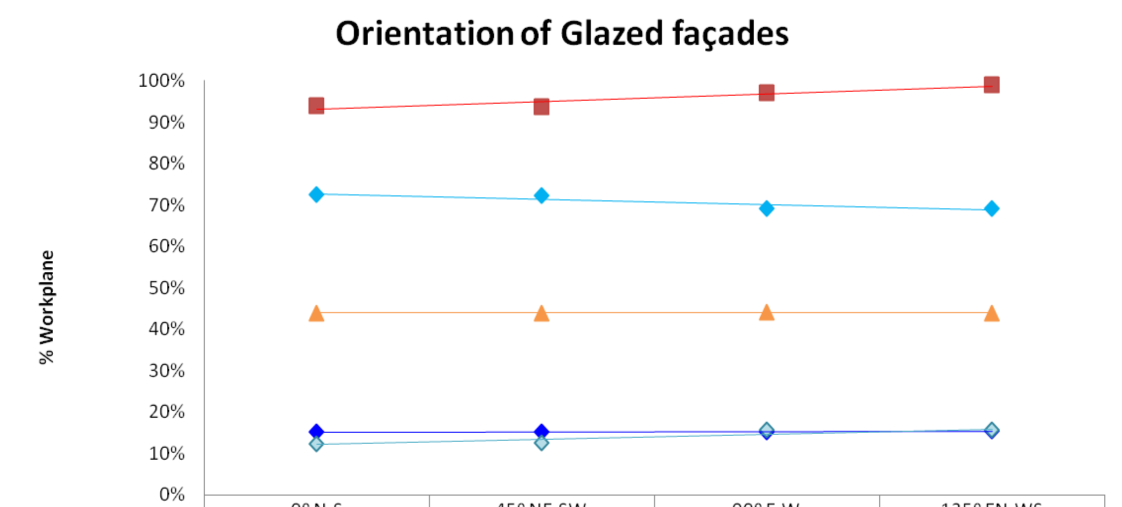
It can be also observed that $UDI_{>2000}$ and $UDI_{100\text{-}2000}$ values present almost the same pattern, as both trend lines are almost parallel. It is curious how the absolute values of deviations from trend lines for $UDI_{<100}$ and $UDI_{100\text{-}2000}$ have the same value but different sign. For locations where the trend $UDI_{100\text{-}2000}$ is higher than the calculated value, it seems to be compensated with a lower trend $UDI_{<100}$ than the calculated value and vice versa.

The constancy of $UDI_{>2000}$ values could indicate an intrinsic characteristic for this space, as it seems that this value does not depend on location. Of course, it is only studied the illuminances on the workplane, and although this value represents a higher probability of discomfort glare, there are some other factors involved in glare, so the impression having the same glare probability in every location has to be complemented with other more specific studies about glare.

4.2 Orientation

In general, Figure 6 shows that for a space of these characteristics, bilateral daylighting and 35% wwr, the orientation has no relevance. The constancy of the values, combined with the previous series, is indicating intrinsic daylighting characteristics for this space, respect to location and orientation.

As the calculation of DF is based on the overcast sky condition, with a cylindrical luminance distribution, it is expected that the results for DF criterion as orientation varies will remain constant.



	0º N-S	45º NE-SW	90º E-W	135º EN-WS
DF criterion	43.92%	43.86%	44.14%	43.86%
DA criterion	93.81%	93.72%	96.92%	98.97%
UDI<100 lux	15.19%	15.16%	15.24%	15.35%
UDI 100-2000 lux	72.41%	72.23%	69.18%	69.06%
UDI>2000 lux	12.39%	12.63%	15.59%	15.59%

Figure 6. Influence of orientation for an unobstructed open-plan office in Seville.

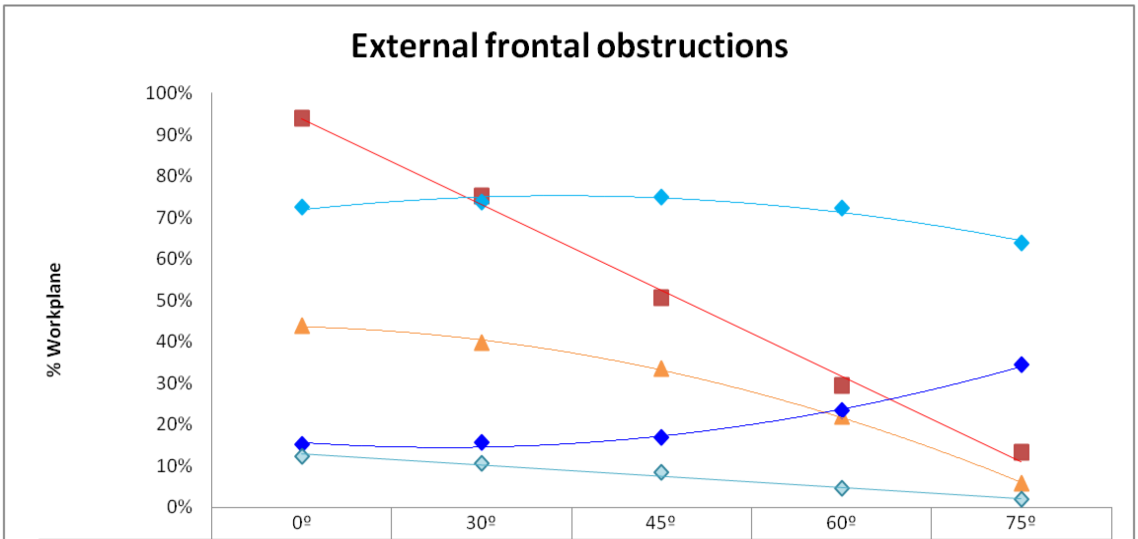
Regarding the percentage of the workplane achieving DA criterion, it presents minimal differences between cases (5.16%) and it is always over 90% of the workplane. It reaches its minimal value for N-S orientation and its maximum value for NE-SW orientation. An increasing tendency is observed in the percentage of the workplane with excessive illuminance, and the opposite tendency in the percentage within the comfort range, but presenting very low variations, 3.2% for $UDI_{>2000}$ and 3.35% for $UDI_{100\text{-}2000}$.

As it is expressed above it seems that the characteristics of this space, with its glazing surface distributed into two opposing façades, may be responsible for the minimum variation in values.

4.3 Frontal obstruction

Figure 7 shows that the presence of frontal obstructions can be as relevant as glazing size. As the obstruction angle increases every metric decreases except $UDI_{<100}$. The percentage of the workplane achieving DA criterion decrease linear and dramatically. The difference between extreme cases is up to 80%. DF criterion achieved also decreases but softly and the difference between extreme cases is of 40%.

It is observed that with angles of 60° or wider the space is mainly illuminated with the diffuse component (Figure 7) due to the low difference between DA and DF criterion, being around 7.5%.



	0º	30º	45º	60º	75º
DF criterion	43.92%	39.64%	33.47%	22.00%	5.81%
DA criterion	93.81%	75.08%	50.58%	29.42%	13.31%
UDI<100 lux	15.19%	15.64%	16.76%	23.25%	34.33%
UDI 100-2000 lux	72.41%	73.71%	74.85%	72.20%	63.85%
UDI>2000 lux	12.39%	10.68%	8.43%	4.55%	1.84%

Figure 7. Influence of frontal obstructions for a North-South oriented office in Seville.

As regards UDIs, the major percentage in the comfort range is found with a 45° obstruction angle, and displays parabolic behaviour. In any case, values are around 71% and the maximum difference is up to 11%. Maybe the wide range of illuminances that $UDI_{100\text{-}2000}$ covers combined with the specific characteristics of the studied space gives the impression of being relatively insensitive to variations. By other hand, curiously an angle of 45° for surrounded obstructions has been used for ages as an indicator of maximum obstruction to achieve some conditions of solar access, so it seems that Vitruvius's intuitions were more scientific than it is thought.

The presence of frontal obstructions decreases $UDI_{>2000}$ lineally but this decreasing is up to 2.7% for each case. But as the angle of obstruction increases, so does the percentage of the workplane below 100 lx; this UDI range shows a parabolic growth. The reduction of the other UDI ranges is used in increasing $UDI_{<100}$ being as much as 34.33% of the workplane, increasing around 15% the original value.

5 Discussion and conclusions

Determining the levels of illumination provided by artificial lighting is a common practice, widespread and easy-to-calculate. This is not the case with daylight due to its variability. This was one of the reasons which prompted the development of new climate-based, dynamic daylight performance metrics, to analyse daylighting conditions throughout the year.

After a decade daylight metrics founded on climate-based simulations have begun to be considered as the basis for the future building guidelines, and these one-parameter studies are thought to make steps in that direction. Once it is known the individual influence of every parameter involved in daylighting, in this case the external parameters, its relevance is highlighted and correction coefficients can be applied.

An analysis of daylight illuminances in terms of Daylight Factor, Daylight Autonomy and the three ranges of Useful Daylight Illuminances for a bilateral daylit open-plan office has been made.

In the initial phases of architectural planning, when future building location conditions are being considered, it is important to take into account the availability of daylight depending on location, and to know how the built-up surroundings affect indoor conditions [10, 16, 20-22] in order to make decisions to make maximum use of daylight within illuminance ranges that are useful for carrying out visual tasks.

An open-plan space with several windows in its Northern and Southern façades has been considered. Although the model is defined, the results could be applied to bilateral daylit spaces which total window-to-wall ratio is of 35%, being 17.5% for each façade, giving a window-to-floor ratio of 10%, with visual tasks that requires 500 lux from 8:00 h to 18:00 h.

The climate characteristic to a location conditions the daylight availability. The difference between considering diffuse illuminances or global illuminances to achieve a specific target, 500 lux on the workplane during almost 50% the time range considered, is lower in northern European regions than southern regions. The lowest difference is up to 13%, and it could be considered to be within the uncertainty for daylight simulation, but this value is a singular case.

It is observed that in European regions below latitude 50° the difference is around 50% and this is up to 60% in regions between 35° and 30°. The results highlight that global illuminance should always be taken into account in daylighting studies. In any case, if the decision is made to calculate DF given its simplicity, a specific coefficient should be applied to expand results.

As the base case model has a high window-to-wall ratio and bilateral daylighting, the orientation does not play a relevant role, in difference with studies which orientation has been studied in one side daylighting spaces [19, 21]. Although it can be said that one-side-lighting spaces are more common than bilateral spaces, having two opposite glazed façades as lighting source for a common space is not as singular as it is thought. A comparison with equivalent side-lighted spaces should be made to find if there is a direct relationship, and it is possible to add different effects from a simple to a more complex situation.

The configuration of this space, its high window-to-wall ratio, determines in a certain way the percentage of the workplane permanently within a UDI range. It can be seen how if this space might be built in any location, there is always around 12.60% of the workplane above 2000 lux; or if the orientation is changed, there is always around 15% of the workplane below 100 lux. These values are showing intrinsic characteristics of the daylight performance for this type of space.

Once these characteristics are known, some architectural design decisions can be made to reduce the percentage of the workplane above 2000 lux and below 100 lux. Also it has to be considered that as illuminances above 2000 lux represent a risk of glare, and the portion of the workplane within glare risk seems to be almost constant, there are some factors involved in discomfort glare that have not been considered in this study.

Compared to the proposed reference model, and due to its geometrical characteristics, the built-up surroundings are the factor with most influence on daylight conditions. The presence of obstacles reduces till 80% the percentage of the workplane achieving a Daylight Autonomy of 500 lux, and up to 40% the ratio above DF criterion. An angle of obstruction of 45° combines the maximum value of UDI with a value of 50% of the workplane achieving DA_{500}, and that could represent a threshold affecting to urban planning. Curiously this angle is linked with rule of thumbs about skylines used for ages to sure a solar access [22].

Looking the results it is appreciated that the obstacles can be as relevant in daylight conditions as window size. However, $UDI_{100\text{-}2000}$ seems to be insensitive to these changes, probably due to the wide range of illuminances that it covers.

Although DAYSIM incorporates the commonly UDI range, the limits are based on human factor considerations, so these limits could change as further studies on human daylight satisfaction are carried out. However, some intermediate limits are suggested by *Nabil and Mardaljevic*5 that could give more accuracy and sensitive performance to the presence of obstacles, and to any variation of any parameter involved in daylighting in general.

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