

## Article

# Transition Planes for Visual Comfort: Out View with Complex Fenestration System Design at Restaurants in Spain

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**Abstract:** This work deals with daylighting for quality indoor atmospheres, considering building skins. In recent years, almost all retrofit facades of restaurants are highly glazed façades, boosting glare, sun ray absorption and overheating inside. Most of the time, they are not integrated with daylight control; therefore, lighting and out view requirements are not so balanced. Taking into account this daylighting complexity, an alternative façade system is proposed to simulate by Radiance. Previously, perception simulations are compared with measured data, in order to discretize the simulations. In addition, for one point three different view are assessed as: work plane, relation plane and the out plane. Subsequently, two virtual façade models, windows combined by complex fenestration system (CFS) as prismatic film (PF) and highly glazed façade, are tested according to daylighting. For that, three indexes have been used: daylight glare probability (DGP), daylight glare index (DGI) and daylight autonomy (DA). The results show that the proposed complex façade has a good light contribution with less absorption, while maintaining the outside view. In addition, the DGI is needed to test the out plane, because DGP is more suitable for lower luminance; therefore, each visual plane should be assessed regarding different visual comfort conditions, or parameters and methods. Accordingly, the mean DGI result of window combined by CFS is approximately lower in 5% than highly glazed façade. However, the DA of highly glazed is higher in 5%, but the DA of window combined by CFS is enough, above 80%. Definitely, the complex scene at restaurant with the proposed integrated façade system improves light performance and indoor atmosphere.

**Keywords:** daylight; discomfort glare; visual comfort; complex fenestration systems; radiance; restaurants



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## 1. Introduction

It is already well known that daylighting is healthy for the wellbeing of the human [1]. However, it is not easy to obtain an accurate balance between light level and light perception, which configure visual comfort [2]. In this context, another high demand parameter is outside view [3]. Many times, this outdoor view strongly affects indoor light balance, especially when highly glazed façades are used. Large homogeneous transparent façades cause difficulties to manage direct, reflected and diffuse daylight along the space [4]. The various light components that build a complex scene are hard to equilibrate with a highly glazed façade. It is probable that these complex atmospheres need more complex façade designs in order to achieve light balance and avoid glare.

According to a previous study of side-view atmospheres under outdoor midday high luminance [5], 56 simulation scenarios of restaurants are assessed in Barcelona. It is shown that almost all cases have a window with outside views, almost half cases have highly glazed façade and almost all new or retrofit cases have highly glazed façade. It was also evidenced that there are difficulties in complementing daylight, sun protection and outdoors views.

Furthermore, transition planes can affect lighting perception. It is known that human perception works with contrast and not with absolute values. Usually, in some activities, it is necessary to have an intermediate-relation plane and out-rest plane in order to have visual comfort and to keep attention [6]. However, in daylight metrics is common to use basic workplanes to evaluate, owing to simplify the real complex scene [7]. Sometimes, these calculations are simplified and do not get very close to the real situation, only considering one workplane condition. Moreover, Suk [8] confirms that a higher glare source luminance is tolerant in a view direction parallel to windows compared to a view facing windows and also discovered that the daylight glare index (DGI) metric shows higher evaluation accuracy than daylight glare probability (DGP) when daylight is the only light source. The metric of light level as daylight autonomy (DA) is useful to know if we have enough light to use some taskover time. The DA is a reference and common index which allows indicating the daylight enough contribution to the indoor space [9]. However, DA does not give information about light distribution, geometry, brightness and color along the scene. Glare metrics give information about brightness, the contrast between a glare source and a background [10], but the usual comparisons do not fully explain the adaptation aspects around all the complex scene of one activity. This is a complex problem because the range of light perception is large and the adaptation, as well. In this field of complex scenes, although there is not a very suitable tool to assess the large range of perception, a calculation of a third plane is considered in addition to the source and background planes. In this context, more complex scenes are wanted to describe, because most of the time a comparison is made between different objects seen. This is very common with daylighting because the adaptation range is high and comparing is usual, especially in complex daylighting implied visual scenes [11,12].

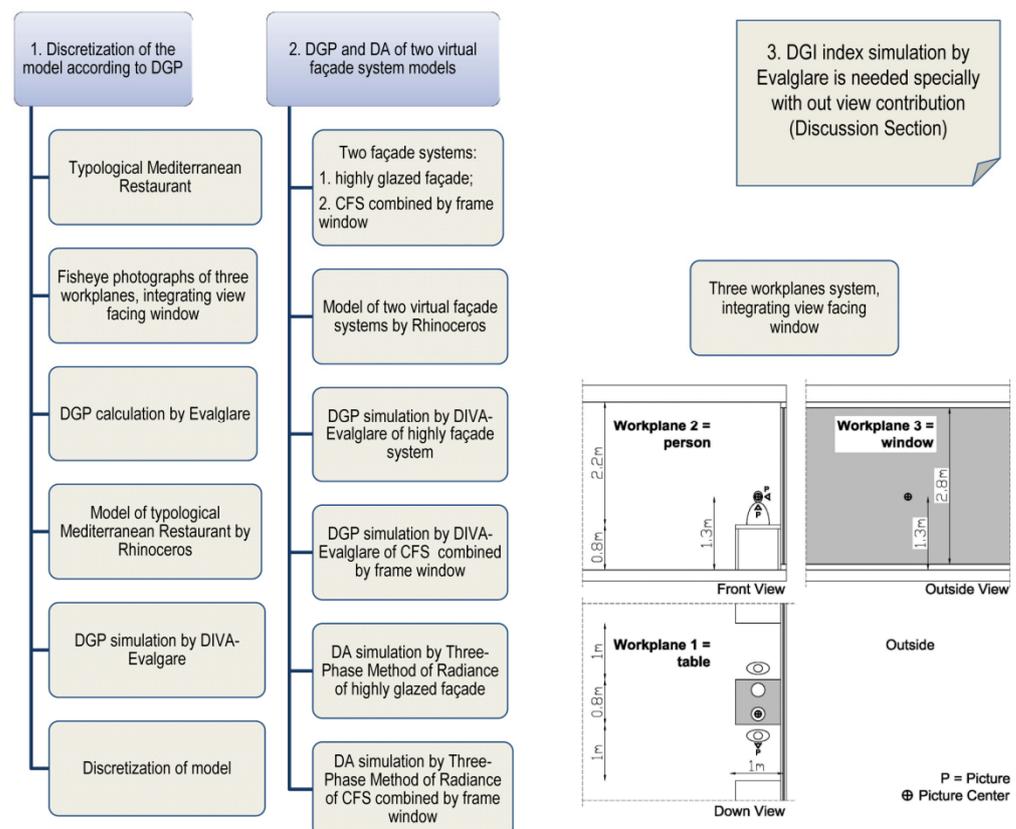
There is much work done in the sense of profiting daylighting [13–15]. Accordingly, complex fenestration systems (CFS) are mostly elements that redirect daylight [16–18]. In the PhD dissertation of Basurto [19], a CFS as a prismatic film (PF) combined with window is proposed and she showed that indoor daylight distribution is better than only with the window. This PhD was oriented to office study, while the PhD, Light and Taste: Third, plane side-view combined with CFS atmospheres under midday clear sky [20], was about restaurants, and the present study is part of it. In this research, it was shown that the CFS strategies separating with outside view requirements without interferences or obstructions from lighting requirements and daylight evaluation methods are useful for restaurants, especially in this typology with high outdoor view demand of restaurants. In addition, an overhang placed between the prismatic film and the window was proposed as solar protection. On the other hand, the performance of the conventional large window with CFS showed that the daylight contribution is similar than with the highly façade, but the glaring perception is better with the smaller window option. The light behavior of this kind of more complex façade has been studied as in works of Scartezzini and Courret [21] who proved that anidolic redirecting systems provide a significant improvement of daylight factors monitored in overcast conditions in comparison to a reference facade (conventional double glazing) and as a consequence a substantial improvement of the daylighting autonomy is expected. In addition, in the work of Ochoa and Guedi [22], that the anidolic concentrator provides high illuminance levels in quantitative terms was tested by simulation and the lightshelf provides a “safer” approach by reducing the contrast between levels at the view window.

Therefore, in offices, it has been proven that CFS improves the light contribution. Nevertheless, these complex façade systems have not been tested at restaurants. On the other hand, when the outdoor view is a large part of the visual field, it is necessary to search an accurate glare method. Consequently, the aim of this study is to assess the CFS combined by frame window at restaurant, in order to balance light contribution and visual comfort with outside view, which is in high demand in this restaurant activity. For that, the simulation method will be used and two virtual façade systems are going to compare; window combined by CFS and highly glazed façade. To compare the quality of

atmospheres with outside view, the three daylight indexes are proposed: the DGP, DGI and DA. In this context, consider that people choose quality atmospheres or places for leisure time such as, for instance, quality restaurants and also for this activity, the computation and simulation method is a convenient method to explore relationships, achieve a better understanding of these complex situations at a reasonable cost and help to achieve better and healthier conditions [23–25].

## 2. Methodology

Once the simulation conditions are clear, a virtual model by Rhinoceros will be built to assess the two façade systems: highly glazed façade and CFS combined with frame window façade system. The used simulation tools are: Radiance, Three-Phase Method of Radiance, Evalglare and DIVA, Radiance's based plug-in for Rhinoceros. The Three-Phase Method is used to obtain illuminance data along the year and consequently DA and Evalglare is used to obtain glare indexes as DGP and DGI for workplanes. The most common place preference for dining at the restaurants with valued surroundings is next to a window with outside view [26]. Accordingly, tables for two people, adjacent to glazed façades, were chosen. It is important to consider the definition of the most representative local visual fields that contribute to the overall visual field. Furthermore, it is necessary to consider the visual planes that contribute to a sit dinner point of view: WP1 (work plane), towards the down visual field (position of the food and drinks in a restaurant place); WP2 (relation plane), towards the front visual field (position of the accompanying person); and WP3 (out plane), towards the out visual field (see Figure 1).



**Figure 1.** Methodology description and proposed three workplanes system for visual field evaluation.

As already mentioned, human senses and the brain commonly work by contrasting and comparing values, not with absolute ones [27]. Thus, analyzing only one view as outside or down cannot be practical or enough because the perception of the luminance level is affected by the previous vision [28].

Therefore, the extreme window or table luminance values are smoothed by an intermediate view, in contrast to the classical method of the luminance source against the background luminance [29]. The adaptation of the vision and mind could be important. Thus, it might be interesting to add an earlier visual plane's luminance data to the glaring methods. Dynamic state methods could approximate more to the overall real visual field and perception than steady state methods.

Accordingly, three visual planes, table, a person in front and window are proposed as a new method to describe the overall scene, because these represent the situation in the most quality restaurant [5]. The DGP of each workplane's picture is calculated, at least for the table plane and the person in front plane, in order to get the mean and geometric mean DGP taking into account the proposed visual planes' pictures' DGP. Thus, the objective is to get a weighted DGP result of the overall scene. The real pictures of the three visual planes have been taken to compare with simulated pictures by DIVA and to check if the measured pictures are close to the simulated ones according to computed parameters.

Hence, the method of Radiance, which is the basis of all used tools, is one of the most reliable programs to simulate daylight because it has the option to set the parameters and all calculations [30]. The used method aims to demonstrate that the calculation by simulation is feasible at a reasonable cost and constitutes a good approach to assess light virtual complex scenes [31,32].

In addition, in the field measurements, we used two measuring instruments. The first is a digital camera (Canon EOS 600D, with Canon objective EFS 18–55 mm, Canon, Tokyo, Japan) fitted with a circular fisheye lens (Gloxy; Front Filter Size, 67 mm; conversion factor, 0.42×; thread Size, 46 mm, Gloxy, Tokyo, Japan). The second instrument is a device to measure the illumination level (the Hagner Digital Photometer TP200, B. Hagner AB, Solna, Sweden). The measuring range is 0.1–200,000 lx and the accuracy is ±3% (±1 in the last digit). The luminance meter (cd/m<sup>2</sup>) acceptance angle is approximately 1/30°. The limits are sufficient to verify the measurements taken in our study, as the margins have not been exceeded in any case.

### 3. Results

#### 3.1. Discretization of the Model According to DGP

With reference to know the characteristics of the simulations, the selected representative Mediterranean restaurant is called Sal Café. This restaurant is located on the waterfront with seascape and it has a highly glazed façade with a long overhang. However, in this restaurant two window systems have been considered, highly glazed façade and window façade system. Then, some indicative illuminance measurements were taken (on 22 July 2014 at 10:00 Solar Time with clear sky, lat. 41.3° N long. 2° E) to check the incoming vertical eye level illuminance data to each visual plane's picture: table, a person in front and window (see Table 1). In addition, three pictures we have taken, for each workplane, to describe the overall visual field (see Figure 2).

**Table 1.** This is a table. Incoming illuminance and luminance data of real pictures.

Window Systems	Parameters	WP1 (Table)	WP2 (Person)	WP3 (Window)
Highly glazed	Illuminance (E, lux)	2350	3500	9350
	Luminance (L, cd/m <sup>2</sup> )	348	320	4900
Window	Illuminance (E, lux)	780	1240	4073
	Luminance (L, cd/m <sup>2</sup> )	45	166	1823



**Figure 2.** Real pictures of Sal Café restaurant with each workplane: table, a person in front and window. For each picture, the High Dynamic Range (HDR) of three exposures,  $-2$ ,  $0$  and  $2$ , has been obtained and they are ISO 400 and  $8.0 \text{ M } 3456 \times 2304$  image quality (Canon EOS 600D, with Canon objective EFS 18–55 mm).

Then, a virtual model of this restaurant is built to get the appearance of pictures from each workplane. The visualization and real pictures are compared to ensure if the calculations on virtual pictures are acceptable (see Figure 3).



**Figure 3.** Simulated pictures of Sal Café restaurant with each workplane: table, a person in front and window.

Among different basic glare metrics (CGI, DGI, UGR, VCP and DGP), two are designed to assess daylight: DGI and DGP. However, only DGP incorporates vertical eye illuminance as a non-contrast-based aspect of the metric [33–35]. The daylight glare probability index (DGP) is considered a more practical method [36–38]. Therefore, the luminance distribution with the DGP index is firstly tested [39]. It is necessary to check the formula to ensure which parameters are determining:

$$DGP = c_1 \cdot E_v + c_2 \cdot \log \left( 1 + \sum_i \frac{L_{s,i}^2 \cdot w_{s,i}}{E_v^{a_1} \cdot P_i^2} \right) + c_3$$

where

$E_v$ , vertical eye illuminance (lux)

$L_s$ , luminance of source ( $\text{cd}/\text{m}^2$ )

$w_s$ , solid angle of source (-)

$P_i$ , position index (-)

$c_1 = 5.87 \cdot 10^{-5}$ ;  $c_2 = 9.18 \cdot 10^{-2}$ ;  $c_3 = 0.16$ ;  $a_1 = 1.87$

Possible scaling of glare obtained by the DGP value includes

Imperceptible:  $DGP \leq 0.35$  (35%)

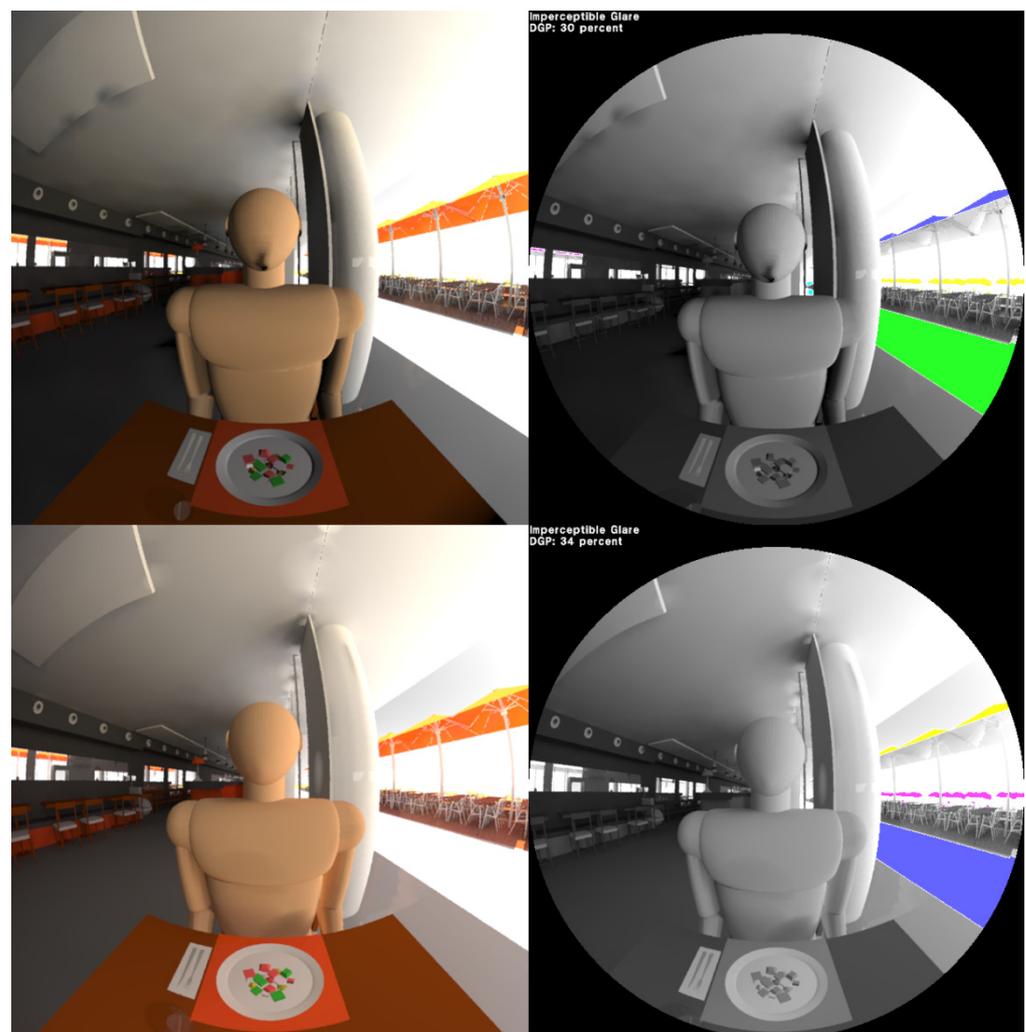
Perceptible:  $0.35$  (35 %)  $< DGP \leq 0.40$  (40%)

Disturbing:  $0.40$  (40 %)  $< DGP \leq 0.45$  (45%)

Intolerable:  $DGP > 0.45$  (45%)

Therefore, as the simulated pictures are obtained by DIVA, the DIVA's parameters that are related with incoming illuminance, the luminance of source, the solid angle of source and position index could be determining for the DGP results. Checking the parameters of DIVA, apart from sky condition, it has been detected that the image quality affects to incoming illuminance and luminance of source. In addition, the surface features, size and position of the glare source are important.

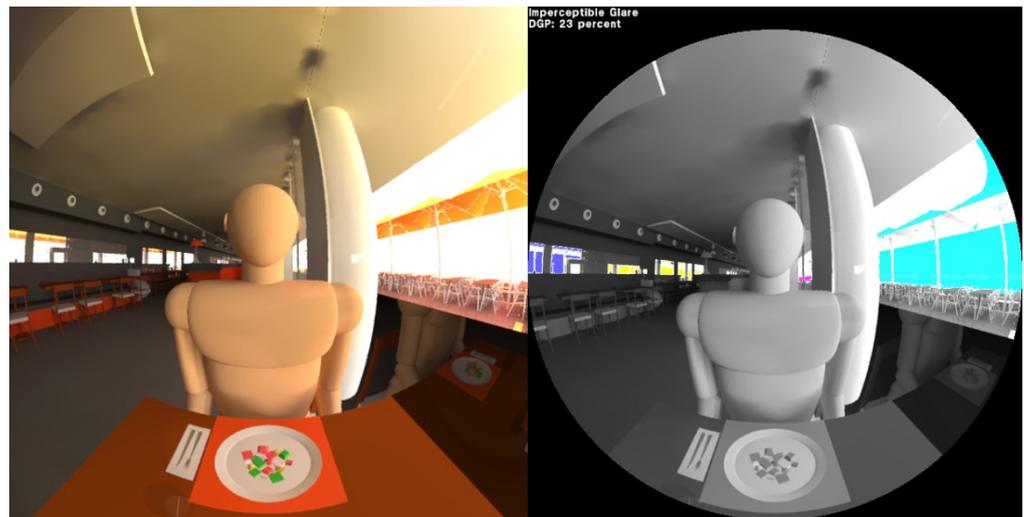
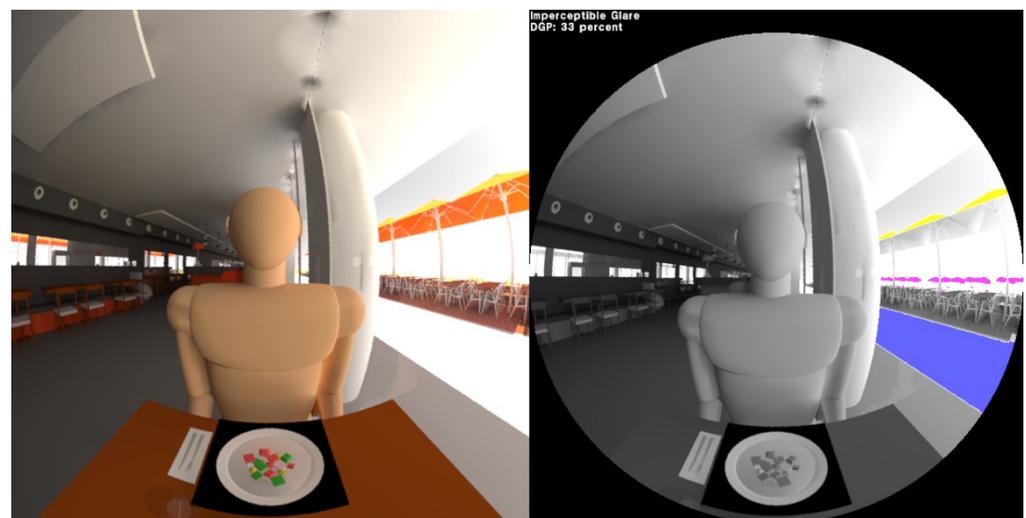
In that context, the second workplane is chosen, because it is the most representative picture of the overall visual field and for DGP this luminance range works better, in order to detect the surfaces that have to be more carefully modelled to get results of simulated pictures closer to real pictures' glare results. The simulation of different image quality has been done to ensure which one is closer to the real one, with a reduced computer time (see Figure 4). There is a considerable difference between low-quality results and medium quality results (see Table 2). However, high-quality results are slightly higher than medium quality results. Therefore, low quality and medium quality are selected to compare and have a basic reference with reduced computing time. Furthermore, glare source and background behavior have been studied to check the variation of DGP results (see Figures 5 and 6 and Table 3).



**Figure 4.** Low quality and Medium quality visualization and Daylight Glare Probability (DGP) result with glare source image of second workplane; person in front.

**Table 2.** Comparison of incoming illuminance and DGP results of real and simulated pictures.

Pictures WP2, Front View	Incoming Illuminance (lux)	DGP (%)
Real	3500	36
Simulated (Low Quality)	1943	30
Simulated (Medium Quality)	2688	34

**Figure 5.** Changing the pavement glaring surface color, the results of visualization, DGP results and glare source image. The change was from clear grey (R, 0.35; G, 0.35; B, 0.35) pavement to black dark (R, 0; G, 0; B, 0) pavement.**Figure 6.** Changing the tablecloth background surface color results of visualization, DGP results and glare source image. The change was from clear orange (R, 1; G, 0.1; B, 0.01) tablecloth to dark black (R, 0; G, 0; B, 0) tablecloth.

Therefore, the incoming picture illuminance should be close to measured incoming illumination. In addition, the modelling of the glare source is very important, especially the surface finish, size and position. The surface features of glare source may have more importance than background surface features because of the exponents on luminance (see Figure 6).

**Table 3.** The variation of DGP results changing the color of glare source surface or background surface.

Changes	DGP (%) of WP 2, Front View (Medium Quality)	
	Clear	Dark
Pavement (Glare Source)	34	23
Tablecloth (Background)	34	33

In the same way, to get reference data of window façade system light performance, other real pictures have been taken. The pictures have been taken with the same point of view as the glazed façade system following the mentioned three workplanes. A provisional opaque filter has been implemented to frame two small windows and two large windows (see Figure 7).



**Figure 7.** Real pictures of window façade system of Sal Café restaurant with each workplane; table, a person in front and windows (in the left, small window; in the middle, medium right window; and in the right, central large window). Indications for glare source surface; table WP, part of the window in the right; person WP, the window in the right; and window WP, the window in the centre.

Two small windows are considered; one for each dinner place. The windows are equal and they are small to frame the outside view of each customer. Each window is 40 cm wide and 20 cm high and they are placed at eye level of dining people. The façade system is 2 m wide and 2.7 m high, with the two small windows or two large windows placed at the top. The below one is 2.7 m wide and 40 cm high and the above one is 2.7 m wide and 80 cm high. The obstruction of the out view and outdoor connection of this type of façade is about 60%, 3 m<sup>2</sup>.

In the same way, in the virtual model is implemented an opaque filter to frame two small windows and two large windows. The visualization and real pictures are compared to ensure if the calculations on virtual pictures are acceptable (see Figure 8).



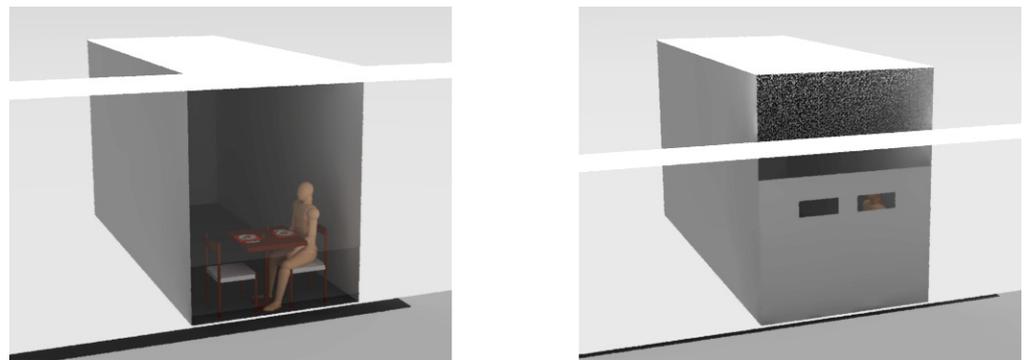
**Figure 8.** Simulated pictures of window façade system of Sal Café restaurant with each workplane; table, a person in front and window.

Therefore, if in the simulated visualization it is taken into account incoming illuminance level according to the type of the sky with real illuminance data using the *gendaylit* program, the relevance background surfaces and glare source surfaces features according to visual plane requirements, the DGP results will be acceptable. It seems that as reference, measured incoming illuminance level and the measured luminance of glare source can help to calibrate the light performance of the scene.

### 3.2. DGP and DA of Two Virtual Façade System Models

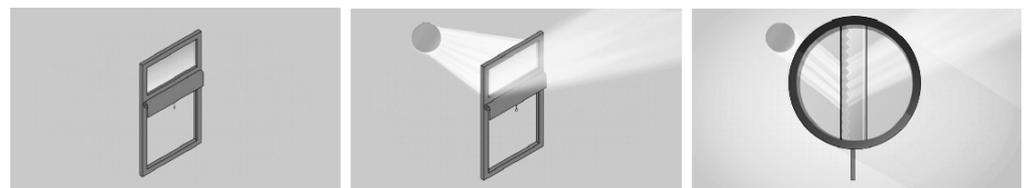
The virtual model as prototype is built to obtain accurate façade system light contribution. The virtual prototype is a simple room. The façade in which is intended to intervene is oriented to the south. The module has 2 m in width, 5 m in deep and 2.7 m in height. There is a table with 0.7 m × 0.7 m and two chairs of 0.5 m × 0.4 m. There is some food on the table and a sitting person. Inside, there are a white high reflecting ceiling, a medium reflecting plane grey walls and a low reflecting plane grey floor.

Two façade systems are assessed in the virtual model. One of these is a highly glazed façade system with outside overhang placed at the top. The other one is a small window combined by a prismatic film CFS with outside overhang placed below the CFS (see Figure 9).



**Figure 9.** The virtual model with two façade systems; a highly glazed façade; and a window combined by prismatic film Complex Fenestration System (CFS).

The 3M™ Daylight Redirecting Film is designed to move excess light close to the window and redirect it deeper into the building to increase the daylighting penetration [40] (see Figure 10). Bringing natural light deeper into the space helps to provide many benefits of natural light for more occupants, as well as reducing the need for artificial lighting, which can contribute to saving energy.



**Figure 10.** The description of how 3M™ Daylight Redirecting Film works [19].

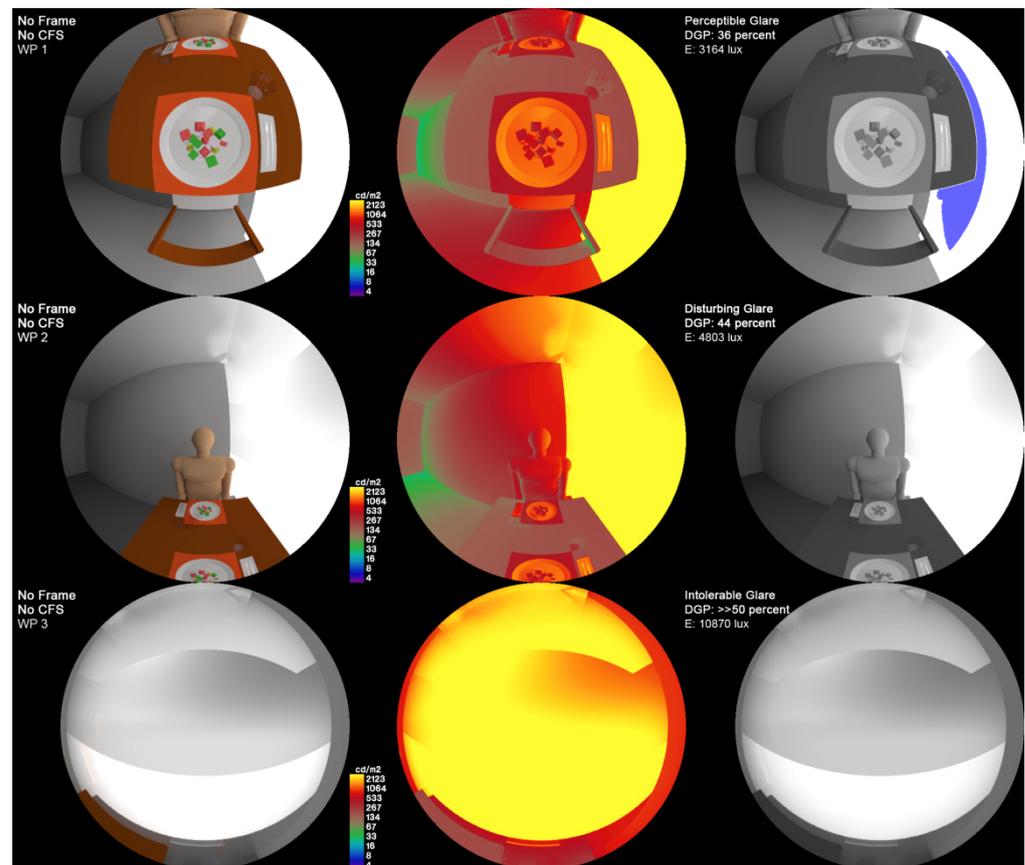
In the simulation, the BSDF material type loads an XML (eXtensible Markup Language) file describing a bidirectional scattering distribution function. Real arguments to this material may define additional diffuse components that augment the BSDF data. String arguments are used to define a thickness for proxied surfaces and the “up” orientation for the material. The BSDF file is obtained from Chantal Basurto Dávila’s PhD as Film3M\_145x145\_9142012\_t.xml [19].

### 3.2.1. Highly Glazed Façade's DGP

The glass is a material of DIVA. It is called `Glazing_DoublePane_Clear_80`. It is double glass with glass material features; `rtn`, 0.87; `gtn`, 0.87; and `btn`, 0.87.

The overhang has plastic material with features of; `red`, 0.9; `green`, 0.9; `blue`, 0.9; `spec.`, 0; and `rough`, 0.

The point-in-time DGP features are the following ones; image quality, medium quality; sky condition, clear sky with sun (CIE Clear Sky); date and time, 07 22 11; camera type, 180 deg. Fisheye: radiance parameters, `-ps 4 -pt .10 -pj .9 -dj .5 -ds .25 -dt .25 -dc .5 -dr 1 -dp 256 -st .5 -ab 3 -aa .2 -ar 256 -ad 2048 -as 1024 -lr 6 -lw .01`; (for person and window view, default, `-vu 0 0 1`; and for table view, `-vu 1 0 0`); image size, `[x y]`: 800 600; and geometry density, 100 (see Figure 11).

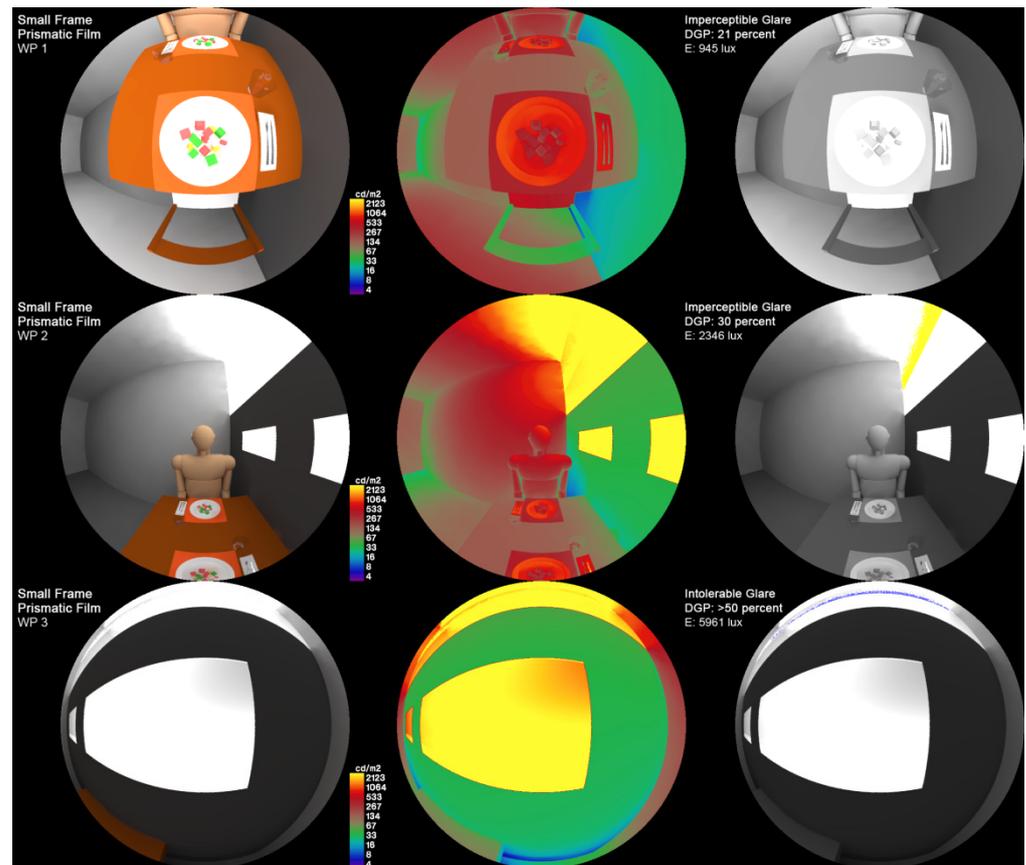


**Figure 11.** Visualization, false color image and glare source image with DGP value of highly glazed façade system from a point of view and the work plane, relation plane and out plane that contributes in this complete visual field.

### 3.2.2. Window with CFS's DGP

In this façade system, the materials and glare parameters are the same as the other façade system. The difference is that there is an opaque material as plastic material with features of; `red`, 0.1; `green`, 0.1; `blue`, 0.1; `spec.`, 0; and `rough`, 0.

Furthermore, the overhang is below of the top part of the façade. It has the same material as the other façade type. In the top part of the façade, there is a prismatic material as CFS (see Figure 12).



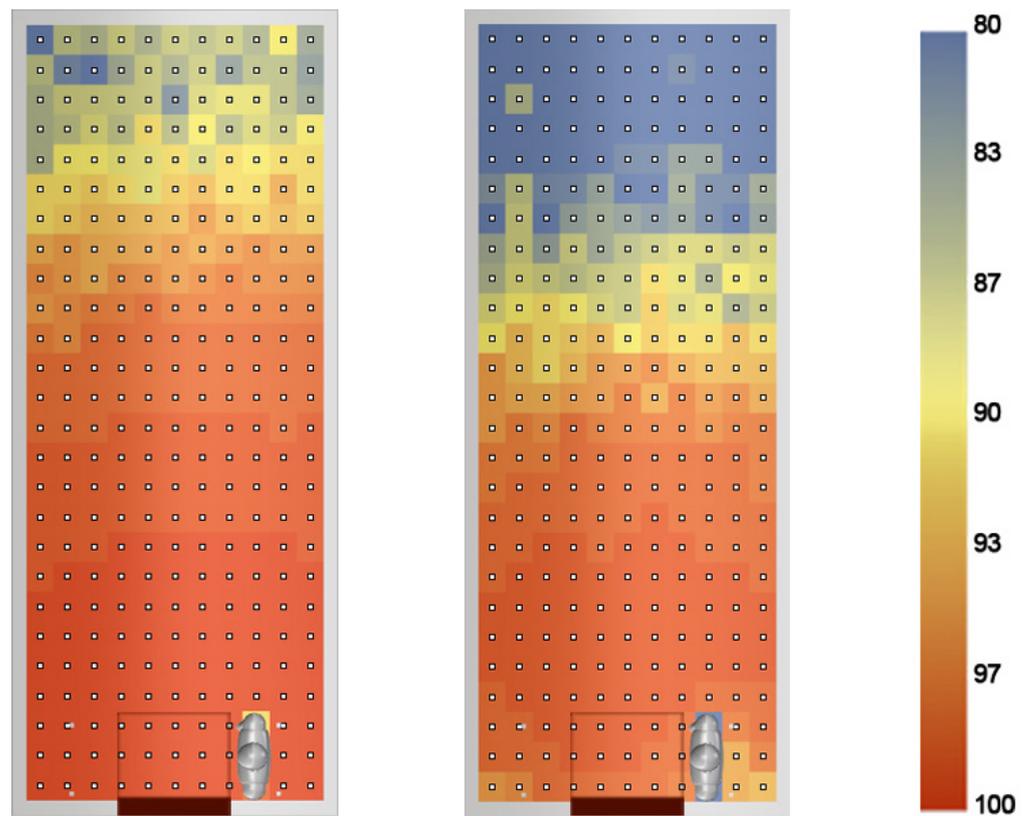
**Figure 12.** Visualization, false color image and glare source image with DGP value of window combined by prismatic film CFS façade system from the same point of view and the work plane, relation plane and out plane that contribute in this complete visual field.

### 3.2.3. Highly Glazed Façade's DA

The daylight autonomy is obtained by the Three-Phase Method. Then, for each façade system, View Matrix, Daylight Matrix, Transmission Matrix and Sky Matrix phases are required. The *rfluxmtx* program is used to get Daylight Matrix and *dctimestep* program is used to compute all matrix together to have RGB irradiance values for each of the 8760 h/year simulated time steps. The *rmtxop* is the program to convert RGB irradiance values to illuminance values for each of the 8760 h/year simulated time steps. The time step has been hourly, from 11:00 to 17:00 in all year. The illuminance target has been 300 lux. Once the hours of each sensor that has been more than 300 lux in the occupancy schedule have been computed, the results are uploaded to DIVA (see Figure 13).

### 3.2.4. Window with CFS's DA

In this case, the daylight autonomy is also obtained by the Three-Phase Method and it has followed the same process and methodology (see Figure 13).



**Figure 13.** Daylight autonomy (DA) distribution; on the left, highly glazed façade system; and on the right, window combined by prismatic film CFS façade system.

#### 4. Discussion

After obtaining results of DGP and DA of the two analyzed façade systems it is necessary to compare them. According to DGP of different workplanes; in the table, there is 15% less with window combined by prismatic film CFS; in the person in front, there is 14% less with window combined by prismatic film CFS; at the window, it was detected that there is a problem because the outside view is very close to outdoor glare performance. The DGP works for interior environments; consequently, the DGP results for the window are more unacceptable; therefore, for this workplane, the daylight glare index (DGI) is used. It is more tolerable for high luminance because it works with the threshold method, allowing it to adapt the luminance threshold to outdoors [8]. The  $-b$  parameter is used in Evalglare to add the outside luminance and get more logical results. The DGI is described by different level scales (see Table 4).

**Table 4.** Daylight Glare Index (DGI) scaling according to different levels.

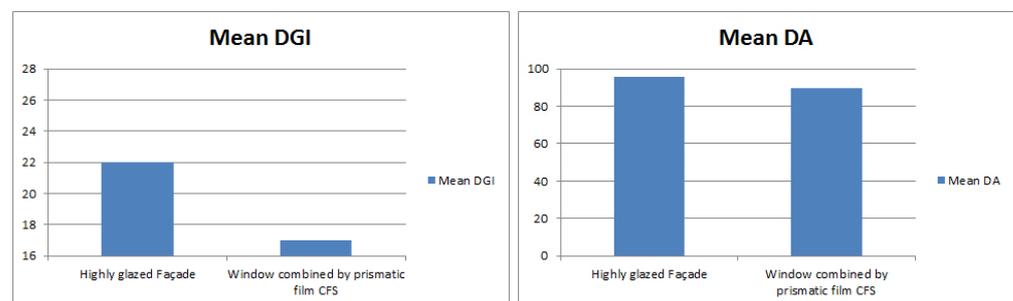
Perception	Level	Percentage (%)
Comfort	Just perceptible	16
	Noticeable	18
	Just acceptable	20
	Acceptable	22
Discomfort	Just uncomfortable	24
	Uncomfortable	26
	Just intolerable	28
	Intolerable	28

Therefore, the DGI results of the three planes are used to get arithmetic mean and geometric mean. These arithmetic mean and geometric mean there are close to 5% less

with window combined by prismatic Film CFS. The mean DGI of highly glazed façade is acceptable with 22% and the mean DGI of window combined by prismatic film CFS façade is just perceptible with 17% (see Table 5 and Figure 14).

**Table 5.** DGP and Daylight Autonomy (DA) results for highly glazed façade system and window combined by prismatic film CFS façade system, with medium quality images.

Façade Systems	DGP (%)		
	WP1	WP2	WP3
Highly glazed	36	44	>>50 no reliable
Window combined by PF CFS	21	30	>50 no reliable
	DGI (%)		
Threshold luminance (cd/m <sup>2</sup> )	Default	2000	3000
Highly glazed	17	21	27
Window combined by PF CFS	(<16) ≈ 10	17	25
	Arithmetic Mean of DGI	Geometric Mean of DGI	
Highly glazed	22	21	
Window combined by PF CFS	17	16	
	DA (%)		
Highly glazed	95		
Window combined by PF CFS	90		



**Figure 14.** Arithmetic mean Daylight Glare Index (DGI) and mean DA results for highly glazed façade system and window combined by prismatic film CFS façade system.

With reference to DA of the two façade systems, there is 5% less with window combined by prismatic Film CFS than with highly façade system. Both have more than 80% of the autonomy (see Table 5 and Figure 14). Note that, the results of the Three-Phase Method are a little overestimated because it is necessary to subdivide the window into different parts to get more accurately the overhanging shadow.

It is necessary to know real incoming illuminance data to get appropriate DGP of the visualization. Thus, the camera features have to be the same as visualization features. In addition, the outside view is difficult to model properly, but it is important because often it is glare source. However, the glare source and the high threshold luminance of out plane are not so much relevant because the time and the accuracy of attention level are lower and the tolerance to glare is higher. For the background, it could be important to get properly mean light contribution taking into account surfaces positions. Otherwise, the selected simulation method could be very useful to help to get design criteria. The simulation could make easier to assess different complex lighting atmospheres, which could provide more visual comfort.

It seems that window combined by prismatic film CFS façade system could have some advantages. With the window, it can be controlled and framed out the view and CFS can

redirect light deeper into the room, balancing light distribution. Therefore, the window design could be determined to offer an appropriate outdoor view, as well as that the CFS design could be important to redirect enough daylight inside. Finding the balance between light level and light distribution could be easier to get suitable light performance.

Analyzing three visual planes could require much more time [7]; therefore, it could be interesting to choose the representative workplane for each activity, which adds more information according to the other visual planes. However, usually in an activity, we could have a previous light state and that information could be determinant to find the real light perception. On the other hand, in some activities, it could be important to have another visual plane to relax and disconnect from the activity to keep attention over time. That information could be useful to take into account. In addition, sometimes, these dynamics are needed to keep concentration and add that, in this outside view plane, the comfort parameters could be different and we could tolerate more extreme situations.

For future investigation, it could be interesting to continue working with these concepts of different planes: work plane, relation plane and out plane. It could be useful to continue working in analyzing different planes that could help to smooth the absolute contrast. The relation plane smooths the absolute contrast between work and out plane. Consequently, this relation plane helps to adapt to out plane luminance threshold. The models of these complex scenes, which, it has been proven, do not take much computation time, could be closer to real visual fields, visual comfort parameters and heterogeneous visual dynamism.

In addition, it could be added that the analysis of the combination of light level and perception carried out in this study can be used to evaluate other cases to know the amount of lighting provided and the atmosphere it creates. On the other hand, it should be added that the façade system with CFS combined by frame window is useful for any friendly activity adjacent to the window. Nevertheless, if a greater external view is required, these visual comfort conditions would not be valid, but then it will be in another case, which is not frequent, and so the glaring methods would still have to be adjusted further. In this context, if a highly glazed façade is demanded for other reasons as marketing, it has been considered that a bright outdoor environment can disturb privacy and cause vision discomfort.

## 5. Conclusions

In conclusion, the simulation method could be useful to test with more different planes from a visual field that answers to a complex scene. Each work plane, relation plane and out plane should have different visual comfort conditions. On the one hand, when in the plane there is a large outside view the DGI index is better to use with threshold method; for indoors, the DGP suits well the default threshold of factor method. On the other hand, the detail model for each plane should be different. According to one plane, the peripheral details are not so decisive; otherwise, the detail of glare source is very relevant, especially at the work plane. However, for the possible glare source in the other planes, especially at the out plane, the effect could be smoother according to exposure time and attention level. Therefore, these simulation tools help us to understand and speed up the visualizations and calculations of these complex scenes.

Regarding the mean DGI, the results of windows combined by CFS is approximately lower by 5% compared to highly glazed façade (see Table 5). However, the DA of a highly glazed window is higher in 5%, but the DA of the window combined by CFS is enough: above 80% (see Figure 14). Although the simulation becomes more complex, for certain cases, this out plane should be calculated because it could smooth light perception, increasing and decreasing workplane perception and making it easier to keep attention better. In fact, sometimes, the users tolerate these extreme situations if they find more dynamism. This could work when these extreme situations are only for one moment with low accuracy needs of attention and in the rest of time there are more tolerable (less stressful) situations. Furthermore, the earlier workplane's luminance value or in

consequent initial illuminance data, as an intermediate plane, contribute to adaptation aspects, smoothing the high contrast between the two extreme planes. Therefore, it could be interesting, regarding these concepts, to add to glare metrics.

In addition, a complex façade system could help to balance light quality between light level and light perception, improving overall visual comfort. Consequently, light and perception requirements do not have to provide the same element. However, daylight scenes are difficult to evaluate, because the visual perception is very complex and for instance, a façade with a window could provide a gloomy atmosphere. In the future, it could be interesting to difference glare performances for different planes and activities according to the combination of different glare indexes, earlier plane conditions and time and accuracy or attention needed. Moreover, the Three Phase Method would add more subdivision results into the window compared with the Five Phase Method also providing more accurate results. In addition, in the visual field, the combination of light, brightness and colors, diffuse and direct radiation, and size and position of light sources should be considered. Human beings could prefer some heterogeneity and dynamism.

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