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GLAZING FAÇADE MODULES: DAYLIGHTING PERFORMANCE SIMULATION FOR BRAGANÇA, COIMBRA, ÉVORA AND FARO

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Summary

The daylighting performance improvement is one better strategy to reduce the artificial lighting consumption in buildings and obviously requires solar radiation from the exterior. Daylighting comes not only from direct sunlight but also from illumination provided by the sky on overcast days. Particular attention must be given to daylighting while designing a building when the aim is to maximize visual comfort or to reduce energy consumption. Visual comfort of glazing façades is a fundamental characteristic to the global comfort. Additionally, this work reports a part of the results of an ongoing investigation about a new façade system concept: "Façade Modules for Eco-Efficient Refurbishment of Buildings", especially on the daylighting performance of double glazing modules.

Ecotect 5.6 software was used to obtain the daylight factor and illuminance level for four Portugal cities and two double glazing façade modules, composed by green solar control glass and low-e glass; self-cleaning glass and float clear glass. A typical dwelling room (25m²) was simulated. Daylight factor and illuminance level were obtained by means of computational simulations.

These results were compared to daylighting standards and recommendations. Results showed a better daylight performance for double self-cleaning glazing for all cities. A lower performance was observed when using green solar control glass and low-e glass.

Keywords: Façade; Glazing; Daylighting Performance; Ecotect.

1. Introduction

Facade technologies were undergone in the last decades to substantial innovations by integrating specific elements to adapt the mediation of the outside conditions to user requirements, both in the quality of materials and components and in the overall conception and design of the facade system. These improvements include passive technologies, such as multi layered glazing, sun protections, ventilation, daylighting, etc (Castrillón, 2009). The “intelligent glass facades” including the glass performance, such as the late development of reflective, low-e, self-cleaning, absorbent, etc. had a relevant development in the last years.

In this context daylighting is an important aspect. The history of architecture has numerous examples of the daylighting importance in different types of buildings. Daylight stands out as a form modelling, dynamic element that allows the contact between the interior and exterior. Daylighting is fundamental in the integration of architecture with the environment where it is inserted (Scarazzato, 2004). The use of daylight is in all respects, the point of departure to obtain an energy efficient lighting system, this is the global trend increasingly adopted in modern lighting systems. In recent years, there is a major interest in the promotion of a better daylighting project for reasons of energy efficiency and visual comfort.

In Portugal, there are not specific requirements for daylighting, it must be established by tables consulting of recommended illumination levels for different activities, such as the CIBSE guidelines in England, the standard of the CIE (Commission Internationale de L 'Eclairage) or other equivalent sources. Façade glazing elements are important to propose solutions, because through them is possible improve daylighting performance, such as suitable glazing selection and dimensioning.

The most important factors involved in daylighting characterization are: available daylight from the sun; glazed area and positioning of glazed surfaces; glass light transmission characteristics; geometry and internal reflection of surfaces; positioning and reflection characteristics of external obstructions; latitude, season, time and weather conditions. Daylighting calculations are commonly based on the daylight factor and illumination levels.

For daylighting performance analysis, Ecotect software was used to obtain illuminance levels and daylight factor (DF) for glazings. It is an environmental assessment tool that allows simulating a model in terms of thermal, acoustic and lighting, having several detailed analysis functions with a visual and interactive display that presents test results directly within the context of the model of the building. In studies conducted for the development of "Eco-efficient Window" (Cardoso, 2008) results indicated that average values for the illuminance levels and daylight factor (DF) obtained by means of Ecotect software is near from the values measured, ranging in this case between 4% to 7%. This kind of tools can be used for the development of new façades system, as well.

The ideal goal for new façades system would be the development of a dynamic and flexible system in way to adapt to the climatic changes, to the occupants requirements and, however, to adapt to the building. An improvement would be the development of a suitable system that facilitates the assembly of the façade, containing passive elements, glazing and reception of solar energy. Improve the comfort conditions in agreement with the climatic needs and be mounted in agreement with the solar orientations and wanted functions. The main objective of this paper is presenting partial results of an ongoing investigation about glazing modules of a new façade system: "Façade Modules for Eco-efficient Refurbishment of Buildings" on the development (Sacht et al., 2010; Sacht et al., 2011a; Sacht et al., 2011b). The focal point is the daylighting performance of two double glazing modules.

2. Methodology

2.1 Standard Model Definition for Daylighting Performance

The "standard model" was defined considering a one-storey isolated room, with regular geometry 5,0 x 5,0 ($25m^2$), a ceiling height of 2.80m, these dimensions followed the recommendations of the Portuguese Urban Building Regulation “Regulamento Geral das Edificações Urbanas” (RGEU, 2007). Façade modules composition have a total dimension of 2.50 x 2.50 (6,25 m^2), 25 glazing modules (0.50x0.50m^2) (Figure 1).

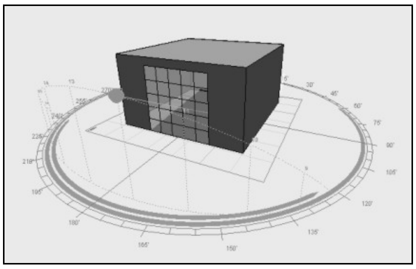


Figure 1Model and glazing modules.

Interior illuminance levels were determined based on a square mesh of points spaced approximately 0.125m, on a horizontal plan 0.80m above the floor. The mesh distance of the interior walls was about 0.10m. The daylight factor (DF) presented is calculated by Ecotect 5.6 from the arithmetic mean points defined by mesh. Based on results were verified acceptable conditions of illuminance level and daylight factor (DF).

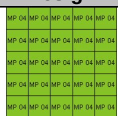
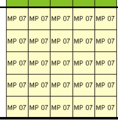
Table 1 presents the values of the surfaces reflectance that characterize the room under study. These values are recommended to interior surfaces of a room (Santos, 2001).

Table 1 Reflectance of Materials

Opaque Surface	Color	Texture	Cleaning	Reflectance	Recommended (SANTOS, 2001)
Walls-Inside	White	smooth plaster - mate	clean	0,6	0,60 – 0,70
Walls-Outside	White	smooth plaster - mate	clean	0,7	-
Ceiling-Inside	White	smooth plaster - mate	clean	0,7	0,70 - 0,85
Ceiling -Outside	Light Brown	smooth mortar - mate	clean	0,3	-
Floor	Light Brown	smooth mortar - mate	clean	0,3	0,15 – 0,30

The net glazing area (window area minus mullions and framing, or ~80% of rough opening) divided by gross exterior wall area (e.g., multiply width of the bay by floor-to-floor height) equals window-to-wall ratio (ASHRAE, 2005). The window-to-wall ratio (WWR) is presented in the Table 2.

Table 2 Façade Settings for Daylighting Performance Simulations.

Cases	Design	Observations
Glazing 04		- Glazing 04 - Glazing Area = 3,75 m² - WWR= 31.6%- Modules 50 x 50 cm - South Solar Orientation
Glazing 07		- Glazing 07 - Glazing Area = 3,75 m² - WWR= 31.6%- Modules 50 x 50 cm - South Solar Orientation

2.2 Glazing Types

Important factors must be observed in the glazing selection, such as: solar factor (or g-value), solar heat gain coefficient, shading coefficient, and visible transmittance, furthermore U-factor resultant of glazing composition. The glasses selected for the standard façade module simulations are from Saint-Gobain Glass. Table 3 presents the main properties of simple glasses.

Table 3 Glass types for standard module.

	Glass Types			
Properties	Cool Lite KNT 155 Green	Planitherm Futur Ultra N	Bioclean	Planilux
Thickness (mm)	4 mm	4 mm	4 mm	4 mm
Solar Factor	0.45	0.63	0.84	0.85
Shading Coefficient	0.52	0.72	0.97	0.98
Visible Transmittance	0.47	0.88	0.87	0.90
U (W/m²K)	5.75	5.73	5.87	5.80

These glasses were used in the computational simulations in Ecotect 5.6. Furthermore, a 12mm air layer between outermost and inner panes was considered. Glass properties were obtained from Window 6.2.33.0 software (LBNL, 2011). Table 4 presents the glazing compositions based on the glasses types presented in Table 4. In addition, cool Lite KNT 155 green is a temperable solar control glass; planitherm futur ultra N is a glass with emissivity extremely low; bioclean is a self-cleaning glass; planilux is a multi-purpose clear float glass.

Table 4 Glazing Properties.

Properties	**Glazing**	
	Glazing 04	Glazing 07
Outermost Pane	Cool Lite KNT 155 Green 4mm	Bioclean 4mm
Inner Pane	Planitherm Futur Ultra N 4mm	Planilux 4mm
U (W/m²K)	1.66	2.69
Solar Factor	0.28	0.40
Shading Coefficient	0.33	0.46
Visible Transmittance (%)	0.42	0.71
Relative Heat Gain (W/m²)	217.72	311.28

2.3 Ecotect 5.6

Ecotect 5.6 tool offers a range of lighting analysis options. The main focus is on daylighting analysis. It implements the Building Research Establishments (BRE) split flux method[1] for determining the natural light levels at points within a model. This is based on the Daylight Factor concept which is a ratio of the illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor illuminance. Figure 2 presents the main screen of Ecotect for daylighting calculation.

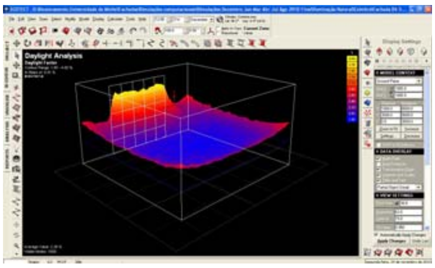


Figure 2 Ecotect Main screen.

Currently, the new version of Ecotect software is “Autodesk Ecotect Analysis”. It is now sustainable design analysis software with a comprehensive concept-to-detail sustainable building design tool. Ecotect Analysis offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs. This new version also allows simulation types shown in older versions (thermal performance, solar radiation and daylighting) whole-building energy analysis; water usage and cost evaluation; shadows and reflections (Autodesk Ecotect Analysis, 2011). For correct assessment of the values in daylighting simulations was required to produce the climate file from "epw" file (EnergyPlus) to “.wea” file in Ecotect 5.6. According to the latitude of the location the outside illuminance is calculated. Although the exterior illuminance obtained by software Ecotect present differences of the real situation, it is known that such values depend on the latitude of the location and do not affect the daylight factor obtained by computational simulation.

2.4 Daylight Factor (DF)

The DF is defined as the quotient (expressed as a percentage) between illuminance at a given point on a plan within inside a room due to a distribution of sky illuminance measurements known, and the outside luminance on a horizontal plane from a hemisphere that sky. The daylight factor can be a significant parameter to quantify the daylighting under overcast sky conditions. However, under certain conditions it

[1] The "Building Research Establishments" BRE method of daylight factor (FLD) excludes indirect gain solutions resulting from reflection of light in multiple surfaces to illuminate a space, considering only the direct gain. The analysis of these natural lighting conditions with this software can be performed using two types of sky (overcast and uniform). Those skies correspond to standard models by the "Commission International of L'eclairage" (CIE).

has limitations. For example, under partly cloudy sky conditions, the daylight factor may be 0.2 to 5 times the amount for overcast skies (Goulding et al., 1994). If on overcast skies daylighting is satisfactory, on sunny days will probably be adequate. The daylight factor of an optimized construction in terms of daylighting, allows the solar radiation entrance, as much as possible inside a room, which can go against the requirements of comfort. However, the DF does not allow verifying the recommended illuminance levels to achieve a particular visual task. Table 5 presents indicated daylight factor.

Table 5 Daylight Factor for Residential Buildings.

Daylight Factor: Residential Buildings					
Room	A Green Vitruvius (1999)		Goulding et al. (1994)	CIBSE (1999)	
	Minimum	Average		Minimum	Average
Bedroom	0.3%	1%	0.5% (¾ of room length)	0.3%	1%
Kitchen	0.6%	2%	2% (center)	0.6%	2%
Living Room	0.5%	1.5%	1% (center)	0.5%	1.5%

Reference: A Green Vitruvius (1999); Goulding et al. (1994); CIBSE (1999).

2.5 Illuminance Levels

For an overcast sky, regardless of solar orientation, the level of radiation is the same; therefore the effect of the orientation factor do not appears in the daylight factor calculation. However, the simplification introduced by the use does not consider the location and building orientation, season, time of day, radiation direct effect and variation of conditions and sky. In this way is need to observe the illuminance levels on specific days in the summer and winter solstices, for example, to get an idea about these two different periods. For the evaluation of illuminance levels within the space were considered: the summer (June 21) and winter (December 21) solstices (Figure 3), at 12:00 P.M. and overcast sky standard CIE and solar orientation south. South solar orientation was chosen because presented the best results in thermal performance studies performed before for this façade system.

Figure 3 a-b Conditions of Daylighting Simulation: 3D Illustrative Diagrams. Winter Solstice, December 21, 12:00 (a); Summer Solstice, June 21 , 12:00 (b)

To determine the illuminance levels and the DF was considered a distribution of CIE Standard Overcast Sky luminance. The Ilumination level was calculated according to the latitude of the location, with different values for each city analyzed. Results were compared with recommended values (Table 6 and 7).

Table 6 Illuminance by Location.

Cities	
Location	**Ilumination Level (lux)**
Bragança	6000
Coimbra	6500
Évora	7000
Faro	7500

Reference: Ecotect 5.6.

Table 7 Illuminance Level: Residential buildings

Illuminance Level: Residential buildings		
Room	Goulding et al. (1994)	CIBSE (2002)
Hallway	50 – 100	-
Bedroom	-	-
Living room	200	100 - 300
Dinner room	100	100 - 300
Kitchen	200	150 - 300

Reference: Goulding et al. (1994) and CIBSE (2002).

3. Results

3.1 Daylighting Performance

Daylight factor (DF) and illumination level verification was made by means of comparison with values according to A Green Vitruvius (1999); Goulding et al. (1994) and CIBSE (1999) for residential buildings. Illuminance levels was based on Goulding et al. (1994) and CIBSE (2002) recommended values.

3.1.1 Bragança

Figure 4 and 5 presents charts of daylight factor (DF) and illuminance levels. Table 8 presents the values obtained on horizontal plan (0,8m) of the simulated room. Daylight factor values were obtained from Ecotect 5.6. The higher average of illuminance level was obtained with the glazing 07 use. The glazing 04 showed lower daylighting performance.

Figure 4 Bragança - Glazing 04: Daylight Factor (a) and Illuminance Level (b)

Figure 5 Bragança - Glazing 07: Daylight Factor (a) and Illuminance Level (b)

Table 8 Bragança: Daylight Factor and Illuminance Level.

Façades	DF (%)	DF Verification (%)		
		Bedrooms 0.3% a 1%	Living Rooms 0.5% a 1.5%	Kitchens 0.6% a 2%
Glazing 04 $_{31,6\%}$	3,26	OK	OK	OK
Glazing 07 $_{31,6\%}$	6,11	OK	OK	OK
Façades	**Illuminance Level (Lux)**	**Illuminance Level Verification (Lux)**		
		Bedrooms 100-200 lux	Living Rooms 100-300 lux	Kitchens 150-300 lux
Glazing 04 $_{31,6\%}$	136,54	OK	OK	-
Glazing 07 $_{31,6\%}$	151,21	OK	OK	OK

In relation to average of illuminance levels obtained for overcast skies, these values were not in agreement to recommended values for kitchens for glazing 04 use. However, higher illumination levels can be obtained near the glazing. Daylight factor found prove that glazing form and dimensions provide the recommended values for all verified areas.

3.1.2 Coimbra

Figure 6 and 7 presents charts of daylight factor (DF) and illuminance levels. Table 9 presents the values obtained on horizontal plan of the simulated room. Again, the higher average of illuminance level was obtained with the glazing 07 use and the lower performance for glazing 04.

a b

Figure 6 Coimbra: Glazing 04 – Daylight Factor (a) and Illuminance Level(b)

a b

Figure 7 Coimbra: Glazing 07 – Daylight Factor (a) and Illuminance Level(b)

The illuminance level of both glazings is not adequate for kitchens. However, higher illumination levels can be obtained near the glazing. It is important observe recommended illuminance levels to achieve a particular visual task. Daylight factor found, prove that glazing form and dimensions provide the recommended values for all verified areas.

Table 9 Coimbra: Daylight Factor and Illuminance Level

Façades	DF (%)	DF Verification (%)		
		Bedrooms 0.3% a 1%	Living Rooms 0.5% a 1.5%	Kitchens 0.6% a 2%
Glazing 04 $_{31,6\%}$	3,49	OK	OK	OK
Glazing 07 $_{31,6\%}$	5,81	OK	OK	OK
Façades	**Illuminance Level (Lux)**	**Illuminance Level Verification (Lux)**		
		Bedrooms 100-200 lux	Living Rooms 100-300 lux	Kitchens 150-300 lux
Glazing 04 $_{31,6\%}$	148,16	OK	OK	-
Glazing 07 $_{31,6\%}$	163,81	OK	OK	-

3.1.3 Évora

Daylight factor (DF) and illuminance levels are presented in Figure 8 and 9. Table 10 presents the values obtained on horizontal plan of the simulated room for Évora latitude.

a b

Figure 8 Évora: Glazing 04 – Daylight Factor (a) and Illuminance Level(b)

a b

Figure 9 Évora: Glazing 07 – Daylight Factor (a) and Illuminance Level(b).

Table 10 Évora: Daylight Factor and Illuminance Level

Façades	DF (%)	DF Verification (%)		
		Bedrooms 0.3% a 1%	Living Rooms 0.5% a 1.5%	Kitchens 0.6% a 2%
Glazing 04 $_{31,6\%}$	3,34	OK	OK	OK
Glazing 07 $_{31,6\%}$	5,86	OK	OK	OK
Façades	**Illuminance Level (Lux)**	**Illuminance Level Verification (Lux)**		
		Bedrooms 100-200 lux	Living Rooms 100-300 lux	Kitchens 150-300 lux
Glazing 04 $_{31,6\%}$	159,56	OK	OK	OK
Glazing 07 $_{31,6\%}$	176,41	OK	OK	OK

About to average of illuminance levels obtained for overcast skies, these values were in agreement to recommended values for all spaces. Daylight factor found, prove that glazing form and dimensions provide the recommended values for all verified areas. The higher average of illuminance level was obtained with the glazing 07 use.

3.1.4 Faro

Figure 10 and 11 presents charts of daylight factor (DF) and illuminance levels. The higher average of illuminance level was obtained with the glazing 07 use. The glazing 04 showed lower daylighting performance (Table 11). The values to average of illuminance levels obtained for overcast skies were in agreement to recommended values.

Figure 10 Faro: Glazing 04 – Daylight Factor (a) and Illuminance Level(b)

Figure 11 Faro: Glazing 07 – Daylight Factor (a) and Illuminance Level(b)

Table 11 Faro: Daylight Factor and Illuminance Level

Façades	**DF (%)**	**DF Verification (%)**		
		Bedrooms 0.3% a 1%	Living Rooms 0.5% a 1.5%	Kitchens 0.6% a 2%
Glazing 04 $_{31,6\%}$	3,30	OK	OK	OK
Glazing 07 $_{31,6\%}$	5,86	OK	OK	OK
Façades	**Illuminance Level (Lux)**	**Illuminance Level Verification (Lux)**		
		Bedrooms 100-200 lux	Living Rooms 100-300 lux	Kitchens 150-300 lux
Glazing 04 $_{31,6\%}$	170,96	OK	OK	OK
Glazing 07 $_{31,6\%}$	189,44	OK	OK	OK

4. Conclusions

The glazing that presented better thermal performance in other studies (Sacht et al., 2011a; Sacht et al., 2011b; Sacht et al., 2011c) presents also better daylighting performance. Glazing 07 (double self-cleaning glazing) presented better daylighting performance than glazing 04 (double green solar control glazing).

Visible transmittance has a direct relation to daylighting performance. Based on simulation results and visible transmittance values was observed that medium to high values of visible transmittance leads to a better performance of a glass in terms of daylighting. Medium to high visible transmittance glazings are relatively clear and provide sufficient daylight and unaltered views; but, they can create glare problems. It depending on the visual tasks, window size and glare sensitivity. This type of glazing can provide satisfactory illuminance levels.

The glazing color is the first property for glazing selection and can thus constrain or complicate daylighting design as observed for glazing 04. Studies about glazing in façades system can give an important contribution for the energy consumption reduction with heating systems and improve the daylighting performance.

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