EFFECT OF DIFFERENT DESIGN PARAMETERS ON THE VISUAL AND NON-VISUAL ASSESSMENT CRITERIA IN OFFICE SPACES

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ABSTRACT

Light entering the human eye does not only enable the performance of visual tasks, but also influences the health and well-being of humans via non-visual effects. A substantial amount of people in the Western society spends the majority of their work time indoors. Well-designed lighting positively impacts the visual comfort and well-being of people working in offices.

Current standards for office lighting design are solely based on enabling the visual tasks via recommendations for photometric quantities such as the maintained illuminance on the task and surrounding areas and/or the glare limitation. The luminous radiation that contributes to the health related non-visual effects is not addressed in these recommendations at all. It is therefore essential to include the impact of effective luminous radiation in the lighting design process.

This paper discusses the necessary distinction between photometric quantities on one side and effective luminous radiation on the other side. It investigates the effect of design parameters such as ‘window size’, ‘exterior ground plane color and luminous reflectance’ on the visual and non-visual effects for different view directions. Simulations have been conducted for the IEA Task 27 reference office using the light software tool Radiance

The findings show reverse influence of the exterior ground plane color and luminous reflectance on the visual and non-visual effects of light. While the exterior ground plane luminous reflectance plays an important role on the visual evaluations, its color is the most influential design parameter for the non-visual evaluations. For the optimal health related non-visual effects of light, findings suggest using bluish exterior ground plane and placing the work plane facing the window.

Keywords: lighting recommendations, window size, exterior ground plane color and luminous reflectance, view direction

INTRODUCTION

Light is essential not only for its visual effects but also for its health-related non-visual effects. Visual effects of light can be categorized into ‘visual performance’ and ‘visual comfort’. Current standards and lighting recommendations are solely based on the visual effects of light. In the standards, visual performance is addressed by recommendations with regard to the maintained horizontal illuminance on the task and surrounding areas. The required maintained illuminance varies depending on the type of task; for typical office work this is usually 500 lx on the (horizontal) work plane. Visual comfort is addressed by recommendations with regard to glare limitations/prevention, which is related to the luminance distribution in the visual field. All these standards have been defined based on solely photometric quantities such as illuminance and luminance, in which the spectral sensitivity of the human eye for photopic vision $V(\lambda)$ has been taken into account. The luminous radiation that contributes to the non-visual effects is not addressed in these recommendations.

The discovery of a third photoreceptor in the human eye, called intrinsically photosensitive Retinal Ganglion Cells (ipRGCs), has highlighted the health-related non-visual effects of light. The spectral sensitivity of the ipRGCs, indicated with $C(\lambda)$ [1], varies from that of a photopic vision and is blue shifted [2, 3]. Recently, a definition of new terminology has been proposed by the Commission Internationale d l'Eclairage (CIE) for the photobiological quantities [4]. According to CIE, photo-biological quantities are to be defined in purely physical terms (radiant quantities) weighted by their spectral sensitivity curve. For instance, when non-visual effects of light are concerned, the vertical effective irradiance with respect to the $C(\lambda)$ ($E_{e,c}$) is the quantity to address/measure, instead of the vertical illuminance at the eye.

In western societies, a substantial amount of people spends approximately 80-90% of their (work) time indoors. A lighting design, incorporating both visual and non-visual effects of light, not only positively impacts the visual performance and comfort of people working in the offices, but also influences their health and well-being. The effect of design decisions on visual and non-visual lighting demands is not fully comparable .

This paper investigates the influence of the design parameters 'window size', 'exterior ground plane (GP_{ex}) color', and 'GP_{ex} luminous reflectance' on the visual and the non-visual light effects for different view directions.

METHOD

Modelling protocol

The (backward) ray-tracing lighting simulation software Radiance [5] was used to investigate the effect of different design parameters on visual and non-visual light effects. Via its spectral distribution and dynamic character daylight is believed to contribute most positively to the well-being of humans. Therefore, it was used as the primary source of light. A standard CIE overcast sky model with a horizontal illuminance in the unobstructed field of 10000 lx was used for the quantitative analysis as it represents a worst-case daylighting condition.

Simulations were carried out for the IEA task 27 reference office room [6]. This reference office (dimensions 3.6 x 5.4 x 2.7 m) has a facade with a single daylight opening containing double pane low E glazing (with normal luminous reflectance of 0.1). The window is located at the south wall and is placed at the center of the wall in order to maintain a view to outside. The window size varies from 10% to 100% Window to Wall Ratio (WWR) with 10% increments. This paper presents the results related to three window sizes of 10%, 50%, and 100%.

In order to study the influence of the GP_{ex} color and luminous reflectance on evaluation criteria (see evaluation criteria section), a GP_{ex} was placed below the modeled room. First, the influence of the GP_{ex} color was studied. Doing so, the GP_{ex} luminance reflectance (ρ) was assumed equal to 20% as a typical ground plane reflectance while its color was changed into pure blue (mimicking sky or sea), pure green (mimicking nature), and grey (mimicking asphalt). Secondly, the influence of the GP_{ex} luminous reflectance was investigated for two extremes of 0% (no light reflection) and 85% (mimicking snow). For comparison purposes, grey colored GP_{ex} is assumed as the base case. Table 1 shows the properties of the different materials used for the GP_{ex} in RGB values.

	R	G	B	Luminous reflectance (ρ)
Pure green	0.000	0.299	0.000	20%
Pure blue	0.000	0.000	3.086	20%
Grey	0.200	0.200	0.200	20%
White	0.850	0.850	0.850	85%
Black	0	0	0	0%

Table 1: Properties of the GP_{ex} materials in RGB values and their luminous reflectance.

Assessment protocol

The horizontal illuminance on the work plane (at the height of 0.80 m from the floor) and the $E_{e,c}$ at the occupants eyes in the sitting position (height of 1.20 m from the floor) were assessed in every design scenario. The $E_{e,c}$ was measured for the four cardinal directions (N, E, S, and W). Horizontal illuminance and the $E_{e,c}$ data were collected on 216 reference points (0.30 m apart in x and y directions).

In Radiance, irradiance is assessed spectrally for three primary RGB channels. In order to convert the spectral irradiance triad (I_R, I_G, and I_B) to irradiance, every spectral irradiance value is multiplied to a coefficient as shown in the following formula [5]:

$$E_e = 0.265\, I_R + 0.670\, I_G + 0.065\, I_B$$

To implement the sensitivity of the human eyes for photometric measurements, e.g., illuminance, in Radiance the irradiance is multiplied by a conversion factor of K_R = 179 lm/W which is Radiance's own value for the luminous efficacy as shown in the following formula [7]:

$$E = 179 \frac{lm}{W} \cdot (0.265\, I_R + 0.670\, I_G + 0.065\, I_B)$$

To derive the $E_{e,c}$, the coefficients were adjusted as shown in the following formula [7]:

$$E_{e,c} = -0.034\, I_R + 0.323\, I_G + 0.558\, I_B$$

In addition to the illuminance and the $E_{e,c}$, glare discomfort was assessed using the Daylight Glare Probability (DGP) as a glare index that gives the most plausible results when daylight is concerned [8]. Glare assessment was carried out for two positions (midline point P1 at 1.2 m distance from the façade, and P2 at 1.2 m from the back wall) facing towards the window.

Evaluation criteria

The visual and non-visual effects of light were assessed based on the following evaluation criteria:

1) Space availability (%A) [9] as the percentage of the work plane area with either E > 500 lx or $E_{e,c}$[1] > 5 W/m^2,
2) $R_{1,2}$ as the ratio between the illuminance or the $E_{e,c}$ of two control points (P1 and P2) in the room,
3) DGP as the index with which the probability of discomfort glare assessed using the criteria defined in [8].

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[1] The value for the $E_{e,c}$ is preliminary for comparison purposes only, since there is no assessment value available yet.

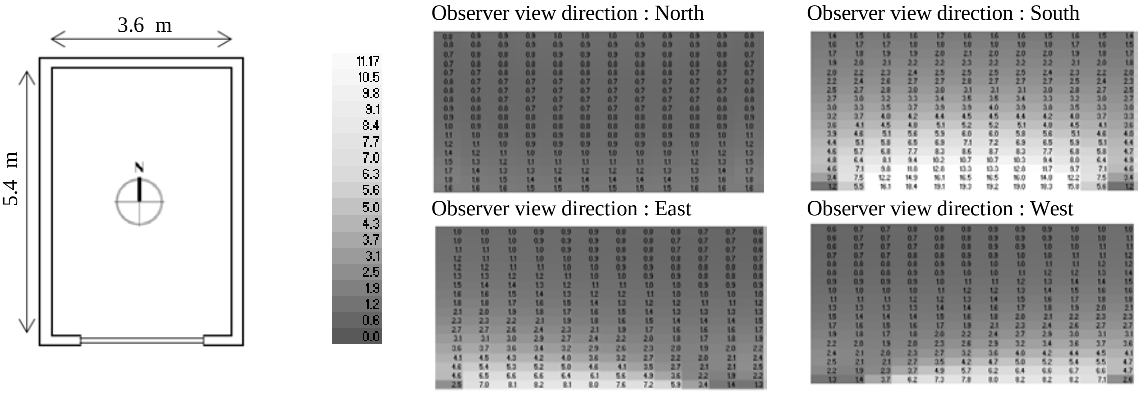
RESULTS AND DISCUSSION

Table 2 shows the influence of the design parameters, i.e. window size, GP$_{ex}$ color and luminous reflectance on the visual evaluation criteria. In general, increasing the window size increases the space availability for the visual tasks and improves the illuminance ratio in the room. The GP$_{ex}$ color does not influence the visual space availability, but its luminous reflectance does. For instance in the design with 50% WWR, compared to the base case (ρ = 20% grey) the visual space availability decreases by 29% for the black GP$_{ex}$ (ρ = 0%) and increases by 55% for the white GP$_{ex}$ (ρ = 85%). The influence of GP$_{ex}$ color on the illuminance ratio is less than 2% while the influence of its luminous reflectance reaches up to 37% in the design with 10% WWR (GP$_{ex}$ white).

WWR	**Ground plane**									
	Blue		**Green**		**Grey**		**Black**		**White**	
	%**A**	**R**$_{1,2}$	%**A**	**R**$_{1,2}$	%**A**	**R**$_{1,2}$	%**A**	**R**$_{1,2}$	%**A**	**R**$_{1,2}$
10% WWR	4%	9.6	4%	9.7	4%	9.7	4%	12.3	5%	6.1
50% WWR	29%	6.0	29%	5.9	29%	5.9	21%	7.4	45%	4.2
100% WWR	49%	4.9	49%	4.8	49%	4.9	42%	5.7	81%	3.8

Table 2: Influence of window size, GP$_{ex}$ color, and luminous reflectance on the visual evaluation criteria

Figure 1 shows the distribution of E$_{e,c}$ over the floor plan for the four cardinal directions (room with 50% WWR; GP$_{ex}$ white). The results show that the E$_{e,c}$ is lowest when the observer is facing the back wall and highest when facing the window. Data from the East and the West view directions are mirrored. In this paper, results related to the South view direction are presented as they show the highest influence.


Observer view direction : North

Observer view direction : South

Observer view direction : East

Observer view direction : West

Figure 1: The distribution of E$_{e,c}$ over the floor plan of the reference office room with 50% WWR for the four cardinal directions (GP$_{ex}$ white).

Table 3 shows the influence of the design parameters, i.e. window size, GP$_{ex}$ color, and reflectance on the non-visual evaluation criteria. In general, increasing the window size increases the non-visual space availability and improves the E$_{e,c}$ distribution in the office room.

WWR	**Ground plane**									
	Blue		**Green**		**Grey**		**Black**		**White**	
	%A	$R_{c,1,2}$	**%A**	$R_{c,1,2}$	**%A**	$R_{c,1,2}$	**%A**	$R_{c,1,2}$	**%A**	$R_{c,1,2}$
10% WWR	7%	8.8	3%	10.0	3%	8.6	2%	7.9	4%	9.1
50% WWR	67 %	4.5	15%	5.4	17%	5.3	13%	5.4	33%	4.7
100% WWR	100%	3.0	35%	3.9	41%	3.8	31%	4.0	65%	3.6

Table 3: Influence of window size, GP_{ex} color, and luminous reflectance on the non-visual evaluation criteria for the South view direction.

The GP_{ex} color has a more pronounced influence on the non-visual evaluation criteria compared to its luminous reflectance. The influence of the GP_{ex} color on the non-visual space availability is higher than the $E_{e,c}$ ratio. Compared to the base case, the non-visual space availability decreases when the GP_{ex} is black and green, and increases when the GP_{ex} is blue and white. The highest influence on the non-visual space availability is observed when the GP_{ex} color is blue. Although the white GP_{ex} (ρ=85%) comparing to the base case resulted in a higher space availability, the magnitude of effects is not as high as compared to the blue GP_{ex} (ρ=20%). For instance, in the design with 50% WWR, the influence of the blue GP_{ex} on the space availability is 2 times higher compared to the white GP_{ex}. Compared to the base case, the largest increase on the non-visual space availability is observed in designs with 50% WWR.

Table 4 shows the influence of the window size, the GP_{ex} color, and luminous reflectance on the discomfort glare assessment for the reference points P1 and P2. As expected, changing GP_{ex} color, and luminous reflectance did not influence the DGP values a lot for overcast sky conditions. Most DGP values are within the imperceptible range (<0,30).

WWR	**Reference points**	**Ground plane**			
		Blue	**Green**	**Grey**	**White**
10% WWR	**P1**	0.19	0.19	0.19	0.20
	P2	0.03	0.03	0.02	0.05
50% WWR	**P1**	0.25	0.25	0.25	0.30
	P2	0.20	0.20	0.20	0.19
100% WWR	**P1**	0.28	0.20	0.28	0.36
	P2	0.20	0.25	0.20	0.22

Table 4: Influence of window size, GP_{ex} color, and luminous reflectance on discomfort glare assessed by DGP.

CONCLUSION

The influences of design parameters 'window size', 'GP_{ex} color', and 'GP_{ex} luminous reflectance' on (non)visual effects for different view directions have been investigated with respect to the three evaluation criteria: 'space availability', 'illuminance or $E_{e,c}$ ratio', and 'discomfort glare'.

In general, increasing the window size increases the *visual* and *non-visual* space availability and improves the illuminance and $E_{e,c}$ distribution in the office room. Although increasing window size increases the DGP values, most of the DGP values are within the imperceptible range.

View direction plays a critical role with regard to the *non-visual* effects on the observer. Facing the window tends to increase the chance of receiving sufficient $E_{e,c}$ at the eye.

Comparisons show reverse influence of the GP_{ex} color and luminous reflectance on the *visual* and *non-visual* effects of light. The highest influence on the *visual* space availability was observed when the white GP_{ex} (ρ=85%) was used. However, with regards to the *non-visu*al space availability, the color of the GP_{ex} (resulting from the spectral reflectance) shows a more pronounced influence compared to its luminous reflectance. Findings show that the *non-visual* space availability is highest when the GP_{ex} is blue. Such findings could lead to a suggestion of using bluish GP_{ex} and placing the work plane facing the window for the optimal non-visual effects of light at no expense to the visual effects.

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