SIMULATION STUDY ON VEGETATIVE SHADING EFFECT ON TO INDOOR SPACE ILLUMINATION AND GLARE

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Abstract

Since earlier research shows that vegetative offers several advantages of airflow and microclimatic condition, the use of this unique aperture to reduce indoor illumination and probable glare is studied using Radiance. Such modeled vegetative shadings simulated in this study shifts down indoor illumination into standard for simple domestic buildings, i.e. below 1000 Lux. Without shading installed before openings, indoor illumination is approximately 1176 Lux. The simulation indicates two important physical factors of vegetative shading, i.e. porosity and frame shape, whilst factor of leaf reflectance is insignificant.

Keywords: vegetative shading, indoor illumination, indoor Glare Index

1. INTRODUCTION

The sun offers so many advantages for us. However, some disadvantages do exist, especially for those living on the tropics, such as too much sunlight that causes unnecessary glare and too much heat gain. In order to control heat gain, buildings shall have adequate both of natural or conditioned means. For building employing natural ventilation such as domestic low cost housings, the presence of large openings is necessary to create adequate natural ventilation. However, such openings like windows and doors are critical elements where too much light and heat can easily enter. The level of sunlight and heat entering openings depends upon their positions (both horizontally and vertically), dimension, materials, and possible shading devices (Givoni, 1976). Once sunlight and heat enter the buildings too much, these should be intercepted with shading devices at the outside of a window -not inside the window-, because once the sun's rays pass through the glazing, they are in the building for good (Johnson, 1981). Since the presence of openings is of importance and shading devices to control sunlight and heat gain is also required, a compromised design of shading devices to do the task but do not impair the airflow is considered. This paper redefines the most effective position and dimension of shading devices to reduce sunlight based on ventilation flow rates calculation carried out prior to this study. From the ventilation flow rates calculation, Mediastika (2000) showed that the most effective position of inlet and outlet windows faces one to another to create cross ventilation. Dimension or model of inlet window which is smaller or less than the outlet window would drive outdoor air to ventilate indoor space. The most effective model for inlet is jalousie and for outlet is casement. These two types of openings will be employed in this study.

2. THEORETICAL APPROACHES

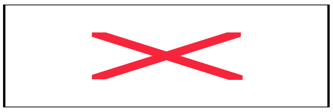
Controlling Sunlight

Buildings on the tropic gain advantages of abundance solar light. Van Harten (1974) defines that comfort illumination of such activities within domestic building lies approximately between 500 Lux and 1000 Lux as the maximum illumination level for small detail visual task. Illumination more than 1000 Lux will causes discomfort or impairment. Such design strategies to reduce indoor illumination are of importance to create more comfortable indoor environment.

Controlling Glare of Day Lighting

Another indication to detect uncomfortable or impairment of visual task caused by too much sunlight is glare. There are two type of glare, i.e. disability glare and discomfort glare. Disability glare is the aspect of glare that lessens the ability to see detail, which does not necessarily cause visual discomfort (McMullan, 1992). Whilst discomfort glare is the glare that causes visual discomfort without necessarily lessening the ability to see detail (McMullan, 1992). The amount of discomfort depends on the angle of view and the type of location. Discomfort glare is type of glare that will be alleviated by such design strategies in this paper.

The research drawn of this paper would not go beyond such qualitative assessment, partly because except what has been discussed above; glare is a very subjective phenomenon, depending very much on human expectation, adaptability and mood. However, still, there are some quantitative assessment could be made to measure whether such condition causing glare, such as using the day lighting glare index. Glare Index is a numerical measure of discomfort glare to be assessed and acceptable limits recommended. Glare is determined by:

 ……………………………………………………………….(1)

And Glare Index (GI) is found from:

$$GI = 10\log_{10} \Sigma G \quad \text{……..}\ \text{………………………………………………………….(2)}$$

Glare Index is an index of glare uses to measure whether source of glare causes glare for given visual tasks. A typical recommended glare index is 19, the minimum is 10 and the maximum is 30. There are several different glare indexes can be adopted as standards of measurement (Koenigsberger et al 1973, Szokolay 1980 and Robbins 1986). However, in general most of the standards have no significant difference and is resumed in Table 1.

Table 1. Glare Criteria and Glare Index
(After, Koenigsberger et al 1973, Szokolay 1980 and Robbins 1986)

Visual Task	Maximum Glare Index	Mean Response to the Maximum Glare Index
Exceptionally severe task (working with very small instruments, such as watch making or repairing)	10	Imperceptible
Very severe, prolonged task (such as gem cutting)	13-16	Perceptible
Severe, prolonged task (such as fine assembly)	16-22	Acceptable
Fairly severe task, small detail (such as drawing)	19-22	Acceptable
Ordinary task, medium detail	25	Uncomfortable
Rough task, large detail	25-28	Uncomfortable
Casual seeing	28	Intolerable

This paper mostly focuses on intolerable to uncomfortable glare.

Prospect of Using Vegetation

Vegetation creates canopy to protect objects down the canopy from climatic condition, such as solar heat, sunlight, and rain. Vegetation canopy is also considered capable of diffusing sunlight thus reducing glare. This consideration is supported by fact that vegetation could also create micro- temperature under the canopy which in most cases lower than the macro- temperature. Trees are the best types of vegetation to create canopies. Unfortunately, trees are not always available in the required position and planting takes time to mature. Fast growing vegetation such as shrubs, climbing, or hanging vegetation is preferred. However, because they grow short, shrubs and bushes are not capable to shade building and thus incapable to create microclimatic condition and to reduce glare. They also, in some cases, grows to fast and thus block the entire airflow and difficult to maintain. The ideal is likely to be climbing vegetation that is planted on a self-designed frame or hanging vegetation placed on containers. These types of vegetation allow us to adjust their porosity and position to suit the requirements. Climbing vegetation grows at the ground whilst hanging vegetation grows on soil put in containers hanging meters from the ground. Based on the easiness of grow and maintain, climbing vegetation which is deliberately grown on a self designed frame is selected for this study. The selected vegetation has to meet several requirements to perform a good diffuser of sunlight, as follows (Johnson, 1981):

- View to the outside cannot be impaired
- The diffuser cannot become a bright source of light
- Light must be broken up and distributed uniformly
- Solar gain must be maintained
- Ventilation must be possible

Concerning the last requirement of permitting natural ventilation, the most important characteristics of vegetation to be assessed are position (particular inlet orientation), porosity and dimension (frame shaping). Whilst for reducing illumination and minimizing glare, beside the above requirements, the most important characteristic seems to be position, porosity, dimension and surface reflectance. Surface reflectance is represented by the unique surface of leaf such as furry or hairy (less reflective surface) and shiny or waxy (more reflective surface).

3. OBJECTIVES

The objective of this study is to see possibility of using vegetation as shading devices to control day lighting illumination and glare. Three factors of vegetative shading, i.e. porosity, frame shaping and leaf reflectance is investigated to see the significance of these factors in order to define the most effective vegetative shading.

4. METHODOLOGIES

Methodologies carry out in this study are as follows: reference study to find and redefine possible design strategies, modeling building design and building elements referring to theoretical approaches and field conditions, and examination using Desktop Radiance 2.0 to calculate indoor illumination and Glare Index.

5. MODELING THE OBJECT

The first step of this research is to develop building model. A simple model of a room of $9m^2$ (3m x 3m) is selected to simplify the simulation by Radiance. This room is designed to have cross ventilation as suggested by ventilation simulation. The inlets use jalousie model and the outlets employ casement model. Sets of modeled vegetative shading devices are attached to inlets and outlets. Physical factors of the shading devices to be simulated are porosity, frame-covering and surface reflectance. Two type of vegetation porosity will be examined, i.e. 35% (representing dense vegetation) and 50% (representing less dense vegetation). Two frame-covering types will be tested, i.e. half-covered frame and full-covered frame. There are also two type of leaf surface reflectance will be assessed, i.e. shiny leaves 41.2 (representing more reflective leaf surface such as Scindapsus sp) and furry leaves 22 (representing less reflective leaf surface such as Stephanotis Floribunda). Both Scindapsus sp. and Stephanotis Floribunda are suggested to use in reality based on easiness of growth and maintain. Leaf reflectance is found by using manual camera focused on the actual object and white paper then converted into reflectance level using Baker Chart. The inlets will be oriented to face north, east, south and west each within period of April (7.5^oSL; exactly upright Indonesia), June (23.5^oNL) and December (23.5^o SL) for 10.00 am, 12.00 am and 02.00 p.m. (14.00).

Table 2. Properties and Cases of the Model

Elements	Properties				
	Code	Reflectance (%)	Transmittance (%)	Reflectance (%)	Roughness (%)
Wall	Off-white 2k205 LESO 91	67.5	0	0	0
Roof	Brown gray 3k312 LESO 91	17.9	0	0	0
Ceiling	Off-white 2k205 LESO 91	67.5	0	0	0
Floor	Concrete-gray RAL 1e105	20	0	3	2
Fence	Off-white 2k205 LESO 91	67.5	0	0	0
Window & door frame	Beige brown RAL 8024	29.47	0	0	0
Window grills	Aluminum LBNL aluminum	88.6	0	80	2
Grass	Grass green RAL 6010	34.17	0	0	0
Paving block	Dark gray 1k134 LESO 91	13.8	0	0	0
Shiny leaves	Green 7k711 LESO 91	41.2	0	0	0
Furry leaves	Green 7k714 LESO 91	22	0	0	0
Window glass	Float glass single pane LBNL – glz - 1	Visual reflectance	Visual Transmittance	Thickness (inc.)	color
		88	12	0.22	clear

Climatic Data of the selected location are:

Latitude: -7.5^0

Longitude: -110^0

Turbidity: 2

Time Zone: -110^0

Sky Condition : CIE Clear

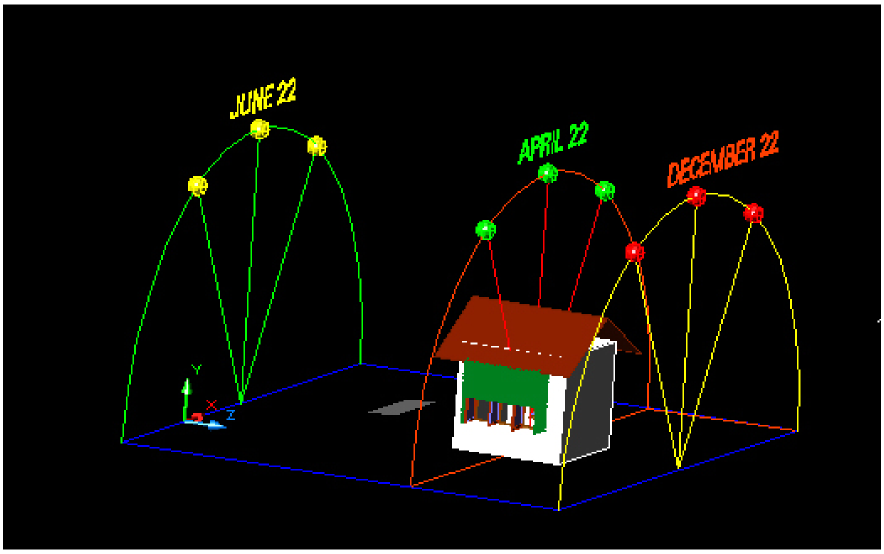


Figure 1. Solar position upon the tested building on selected location

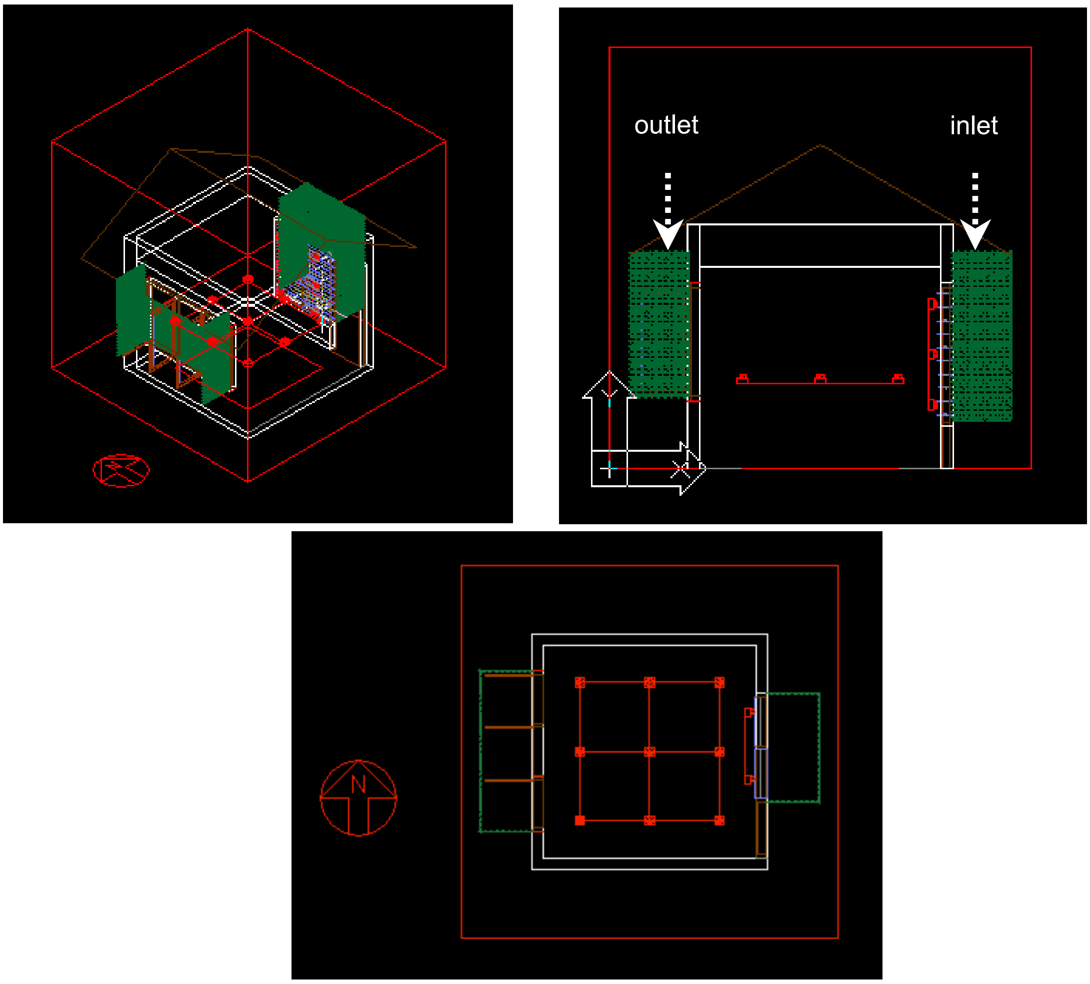


Figure 2a.2b.2c. Axonometri Model, Side Section and Plan

6. COMPUTATIONAL SIMULATION

RADIANCE to Calculate Indoor Illumination

RADIANCE was selected to investigate indoor illumination within the modeled building since authors is literate using this software. Radiance that is developed as a research tool to predict the distribution of visible radiation in illuminated has been used by authors couple of times to predict indoor illumination in earlier research. Radiance takes as input a three-dimensional geometric model of the physical environment, and produces a map of spectral radiance values in a color image. In this study we use AutoCAD to set the model. The 3D model then to be detailed appropriately using the Desktop Radiance library of materials, glazing, luminaries and furnishings. Once the model is complete, the next stage is to define the analysis parameters, i.e. reference grid calculations, building orientation and zone of interest. The Glare Index (GI) was measured on the window from position projected on the seated area of the modeled building.

Table 3. Parametric Matrix for Radiance Simulation

PARAMETER																
Shading									Inlets Orientation				April			
Without shading	Shiny leaves				Furry leaves				North	East	South	West	10.00	12.00	02.00	10.0
	Porosity															
	35%		59%		35%		50%									
	Frame- covering															
	FC	HC	FC	HC	FC	HC	FC	HC								
0									0				0			0
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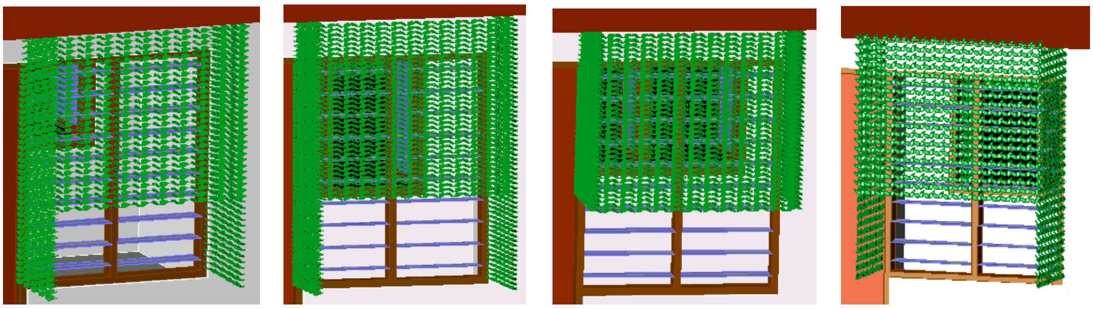
Key: FC= Full -covered frame
HC =Half - covered frame



a b c d

Figure 3a. Shiny leaf of 50% porosity, composed full-covered frame
Figure 3b. Shiny leaf of 35% porosity, composed full-covered frame
Figure 3c. Shiny leaf 35% porosity, composed half-covered frame
Figure 3d. Furry leaf of 35% porosity, composed full-covered frame

Limitation of Computational Simulation

Using computational simulation to investigate such objects is useful of saving time and cost. However, still, there are conditions where the software is difficult represent the unique physical properties of vegetation, such as overlapping among leaves, natural leaf properties and natural color of leaf. Vegetation for this simulation is then represented by models that are specifically designed to be as close as possible to physical property of vegetation in reality. It consists of vegetation density or thickness (represented by porosity) and leaf reflectance.

7. RESULT AND DISCUSSION

Indoor Illumination

Some figures and tables to study indoor illumination is presented as follows.

Figure 6a and 6b. Iso Contour Image and Luminance Image of Shiny Leaves 50% Porosity Full-Covered Vegetative Shading

Table 4. Simulation Result on Indoor Illumination

Orientation and Timing		INDOOR ILLUMINATION (LUX)						
East- Facing Inlets								
1	2	3	4	5	6	7	8	9
Months	Time	Without Shading	After SL50%FC	After SL35%FC	After SL35%FC	After SL35%HC	After SL35%FC	After FL35%FC
	10.00	1198	921	798	798	834	798	832
April	12.00	1138	932	811	811	890	811	858
	02.00	1264	1056	917	917	989	917	891
	10.00	1121	889	750	750	864	750	813
June	12.00	1064	874	755	755	826	755	777
	02.00	1174	949	855	855	928	855	864
	10.00	1182	920	801	801	855	801	836
Dec	12.00	1169	946	858	858	946	858	869
	02.00	1294	1013	955	955	984	955	912
Average illumination of East-Facing Inlets		**1178.222**	**944.44**	**833.33**	**833.33**	**901.78**	**833.33**	**850.22**
South-Facing Inlets								
	10.00	1109	925	827	827	892	827	807
April	12.00	1230	1032	923	923	990	923	871
	02.00	1132	958	843	843	891	843	828
	10.00	1230	993	876	876	948	876	868
June	12.00	1340	1096	954	954	1010	954	921
	02.00	1333	1023	923	923	989	923	918
	10.00	1071	876	783	783	835	783	801
Dec	12.00	1200	955	857	857	925	857	894
	02.00	1088	878	789	789	841	789	804
Average illumination of South-Facing Inlets		**1192.556**	**970.67**	**863.89**	**863.89**	**924.56**	**863.89**	**856.89**
West- Facing Inlets								
	10.00	1294	1033	955	955	1006	955	925
April	12.00	1138	919	833	833	900	833	869
	02.00	1203	900	790	790	863	790	834
	10.00	1275	1005	888	888	966	888	864
June	12.00	1070	872	780	780	837	780	804
	02.00	1130	881	754	754	790	754	805
	10.00	1223	1025	910	910	972	910	878
Dec	12.00	1181	962	823	823	926	823	874
	02.00	1162	892	794	794	845	794	801
Average illumination of West-Facing Inlets		**1186.222**	**943.22**	**836.33**	**836.33**	**900.56**	**836.33**	**850.44**
North-Facing Inlets								
	10.00	1084	903	791	791	803	791	778
April	12.00	1141	948	828	828	894	828	873
	02.00	1048	885	796	796	818	796	777
	10.00	1175	882	778	778	804	778	802
June	12.00	1244	953	809	809	866	809	859
	02.00	1187	882	791	791	815	791	806
	10.00	1144	953	851	851	912	851	826
Dec	12.00	1224	1019	904	904	979	904	885
	02.00	1104	947	832	832	985	832	812
Average illumination of North-Facing Inlets		**1150.111**	**930.22**	**820.00**	**820.00**	**875.11**	**820.00**	**824.22**
Average illumination for all inlets orientation		**1176.78**	**947.14**	**838.39**	**838.39**	**900.50**	**838.39**	**845.44**

Key: SL = shiny leaves
FL = furry leaves
% = percentage of porosity
FC = full-covered frame
HC = half-covered frame
Example: SL35%FC = shiny leaves 35% porosity full-covered frame

The simulation result presented in Table 4 is divided into three groups: columns 3, 4 and 5 to study difference of indoor illumination due to porosity; columns 3, 6, and 7 to study different effect due to frame covering; and columns 3, 8 and 9 to study different effect due to leaf reflectance. It is also divided between East, South, West and North facing inlets. However, since level of indoor illuminations among these four inlets orientation differs only by 50 Lux that is considered rather insignificant (Van Harten, 1974), they could be averaged. From the last row of Table 4, we learn that without shading before openings, indoor illumination is approximately 1176 Lux. This is considered over the standard. Using such vegetative shading, illumination will drop by 100 to 230 Lux, depends on the shading properties. From the last row of columns 3, 4, and 5, we learn that porosity of 35% reduce illumination by 30% more than porosity of 50%. Last row columns 3, 6 and 7 shows that full-covered frame reduce illumination by 18% more than half-covered frame. Whilst from the last row of the last two columns, we learn that such leaf reflectance does not offer significant different (2%) between reflectance of 41.2 and 22 (Please refer to Table 2). From this result, we learn that the most important factor of physical properties of vegetative shading in reducing indoor illumination is porosity. Less porous vegetative shading will descend illumination level of indoor environment. However, since less porous or more dense vegetation will impair very much on air flow for natural ventilation, porosity less than 35% is not suggested to be employed (Mediastika and Binarti 2003)

Glare Index

Besides level of indoor illumination, Glare Index of the indoor environment is also calculated during. The indoor Glare Index is shown in Table 5.

Table 5. Simulation Result on Glare Index

Inlets Orientation	Indoor Glare Index				
	Without shading	After SL50%FC	After SL35%FC	After SL35%HC	After FL35%FC
East- facing inlets	27	27	26	27	27
South- facing inlets	27	27	26	26	26
West- facing inlets	28	27	26	27	27
North- facing inlets	26	25	25	25	26

Calculation shows that, at this stage, the modeled vegetative shading offers rather insignificant reduction of Glare Index. Refer to Table 1, a significant difference of Glare Index is noticed when the difference is at least 3. Whilst, in most cases, such physical properties of objects use in this study could only reduced Glare Index by 1 or 2 as shown by Table 5. The lowest range of Glare Index is observed when the inlet faces North. Within this direction, most modeled vegetative shading shift the Glare Index down to 25, which is the outer limit between uncomfortable and acceptable Glare Index (Please refer to Table 1).

8. CONCLUSION AND RECOMMENDATION

From the investigation made by computational simulation of vegetative shading to reduce glare whilst also concerning airflow for natural ventilation, there are some indications borne out as follows:

1. There are two important factors to be considered in using vegetative shading, i.e. porosity and frame-covering. The less the porosity and the more full-covered frame offer more reduction of indoor illumination. However, concerning prior investigation of airflow, the most effective porosity to be employed is 35%. Leaf reflectance factors of vegetation is less important to be considered.
2. The highest reduction of indoor illumination is gained after vegetative shading of shiny leaf surface with 35% porosity composed in full-covered frame-covering (SL35%FC).

Since leaf reflectance factors is insignificant, besides SL35%FC, the use of FL35%FC (furry leaf with the rest physical factors remain the same as SL35%FC) is also suggested. Using such vegetative shading shifts the indoor illumination of simple domestic building from over the standard down into the standard between 500 Lux and 1000 Lux.

3. Indoor Glare Index calculation shows that such vegetative shadings do not offer significant reduction of Glare Index. However, we learn that North-facing inlet experience slightly less glare than the other inlet orientation.

9. ACKNOWLEDGEMENT

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10. NOTATION

K = Constant

L_s = Luminance of the source of light (candela/m^2)

L_b = Luminance of the background light (candela/m^2)

Ω = Solid angle subtended by the source of light (Steradians)

ω = Solid angle of the source with respect to the eye (Steradians)

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