Using *Radiance* to Compute Optimal Light Source Intensity Distribution from Lighting Performance Goals

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Abstract

A three-step method has been developed to automate the selection of fenestration systems based on specific daylighting performance goals. This paper contains a brief description of the complete method, focusing mostly on the use of the *Radiance* software for the required lighting computations.

Introduction

Daylighting design requires the selection of fenestration systems that best meet specific daylighting performance goals for a given space and exterior conditions (figure 1). With the objective of avoiding a time-consuming trial-and-error process, a method has been developed to deal with this problem in an inverse way, in three consecutive steps [Fernandes 2003] (figure 2):

1) determination of the optimal luminous intensity (i.e., candlepower) distribution of the window based on specific lighting performance goals;

2) determination of the optimal transmission properties of the daylighting/fenestration system based on the luminous intensity distribution determined in step 1 and the exterior conditions;

3) identifying a set of suitable existing fenestration systems, based on the optimal fenestration system determined in step 2.

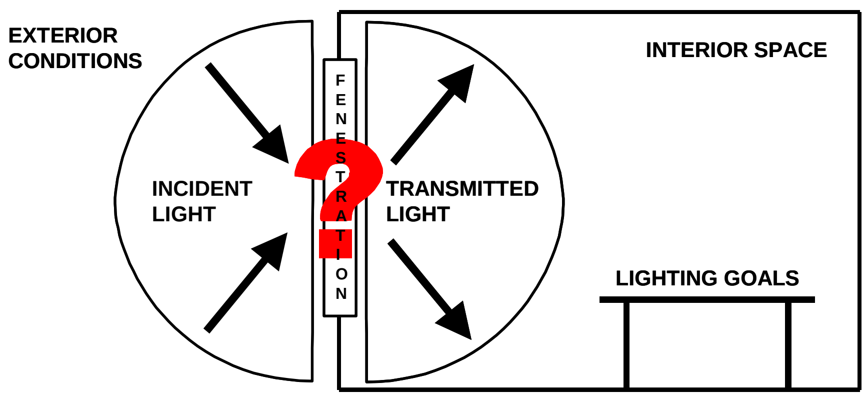

Figure 1 General concept of the method.

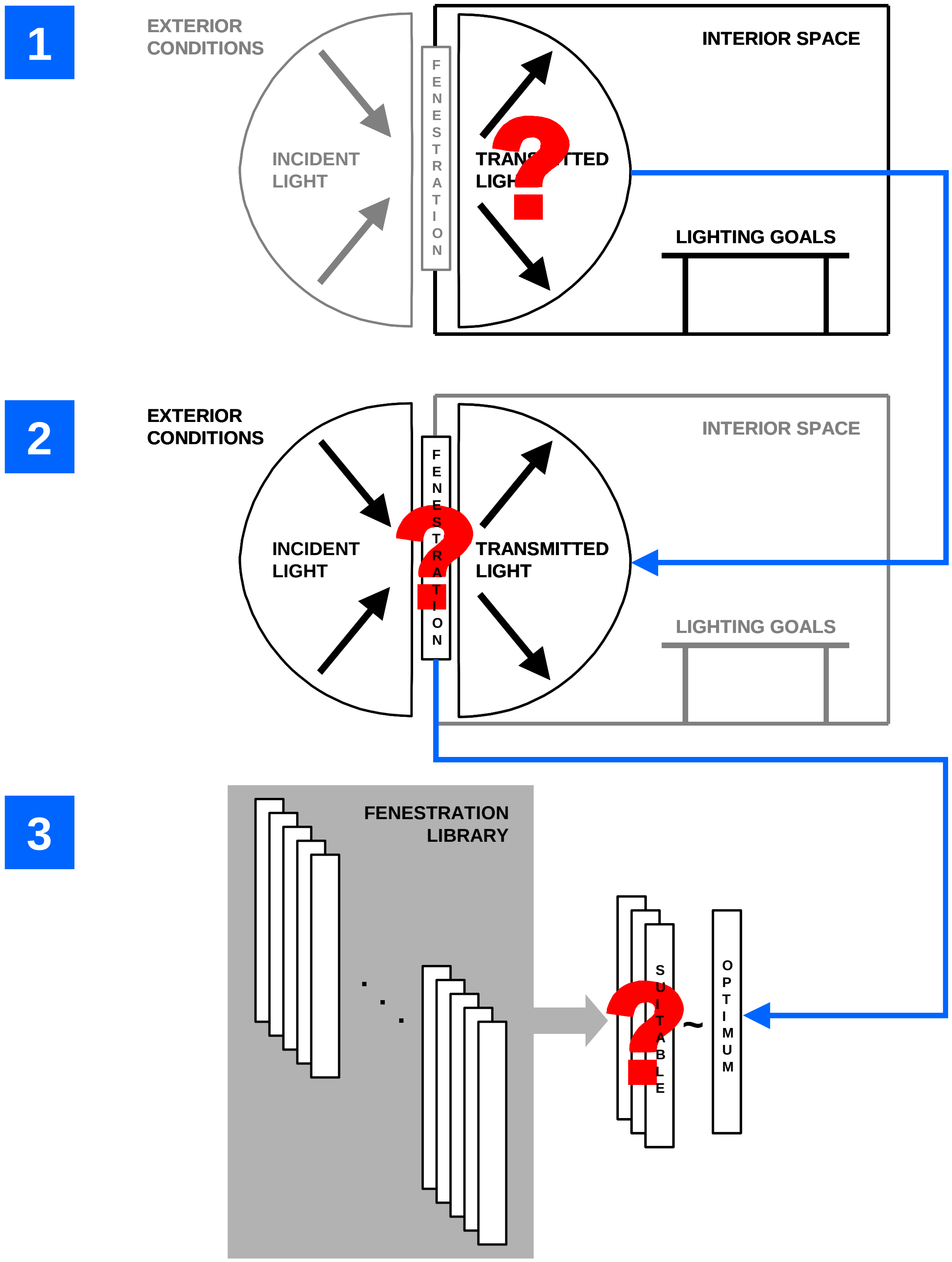

Figure 2 The three steps of the method.

Implementation of the method using ***Radiance***

Step 1 requires the use of a lighting simulation software that can accurately simulate the behavior of light inside the room, such as the *Radiance* lighting simulation software [Larson 1998].

The luminous intensity distribution emitted by a homogeneous window into a room can be arbitrarily discretized into n solid angles.The complete distribution can then be mathematically represented by a vector $\mathbf{\Phi}$, whose components ϕ_i represent the flux emitted into solid angle i by each point of the window:

$$\mathbf{\Phi} = \begin{bmatrix} \phi_1 \\ \vdots \\ \phi_i \\ \vdots \\ \phi_n \end{bmatrix} \tag{1}$$

The illuminance caused by the window at a point in the room is given by

$$E = \sum_{i=1}^{n} c_i \phi_i \tag{2}$$

where c_i depends on the room geometry and surface properties and gives the effect caused at the point by each unit of flux emitted by the source into solid angle i.

Solving equation 2 for the components of $\mathbf{\Phi}$ as a function of E will yield an infinity of illuminance distributions that will cause a certain desired value of illuminance. However, if illuminance is considered at multiple points, e.g., forming a work-plane, it may be possible to find a unique solution. With m points, equation 2 becomes

$$\begin{cases} E_1 = \sum_{i=1}^{n} c_{i1} \phi_i \\ \vdots \\ E_j = \sum_{i=1}^{n} c_{ij} \phi_i \\ \vdots \\ E_m = \sum_{i=1}^{n} c_{im} \phi_i \end{cases} \tag{3}$$

where c_{ij} gives the effect caused at point j by each unit of flux emitted by the source into solid angle i. Equation 3 is a system of m equations and n unknowns. If $m>n$, there are more equations than unknowns, and, in the least-squares sense, a unique solution can be found, i.e., a flux distribution that will produce a work-plane illuminance as close as possible to desired.

This type of solution for step 1 of the method depends on the ability to determine the coefficients c_{ij} with enough precision. The versatility of the *Radiance* software package makes it particularly suited for this application: versatility in room geometry and material properties, and possibility of modeling homogeneous area sources with arbitrary luminous intensity distributions.

Demonstration

What is the optimal distribution emitted from a South-facing window into a typical small office to achieve 500 lx on the desk, as shown in figure 3?

To address the above question, the window's luminous intensity distribution was discretized into 26 solid angles, which offers a good balance between directional resolution and computation requirements (figure 4). The coefficients of c_{ij} were determined using the *-I* option of the *rtrace* program, with default parameters except for the number of allowable reflections (*-ab 7*), to account for interreflection within the room. When solving equations 3 for the optimal distribution, the solution is physically meaningful only if all the components of $\mathbf{\Phi}$ are nonnegative. Therefore, the optimal distribution was determined using a nonnegative least squares (NNLS) algorithm [Lawson 1974]. The resulting optimum is represented in figure 5. The work-plane illuminance obtained with this distribution is represented in figure 6. Except for the points under the cabinet, it is reasonably close to the 500 lx target.

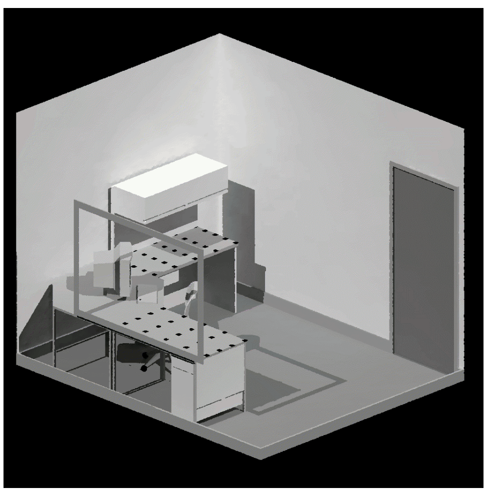

Figure 3 Room configuration. The positions of the 50 work-plane points are represented by black squares on the desk surface. The window frame shows the position of the window.

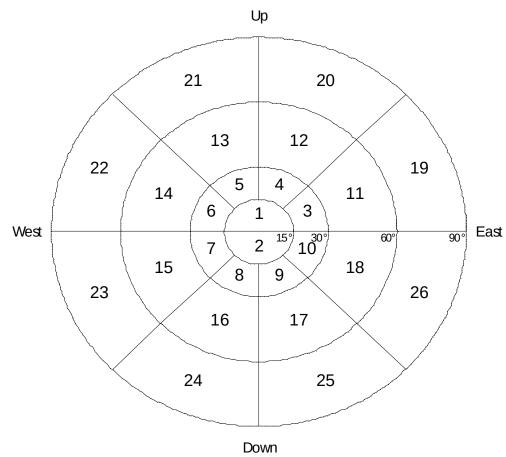

Figure 4 Solid angle discretization.

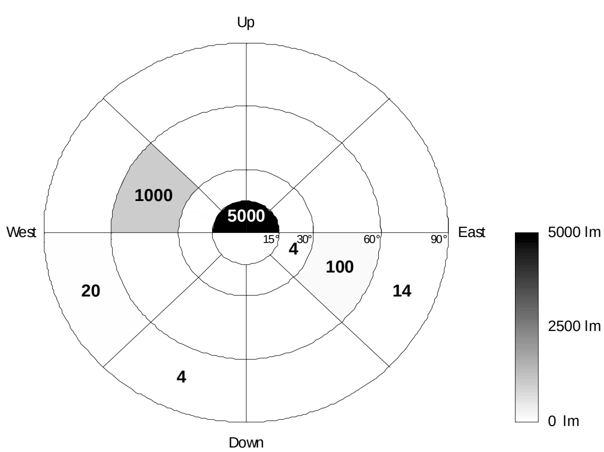

Figure 5 Optimal luminous intensity distribution, showing flux emitted into each solid angle.

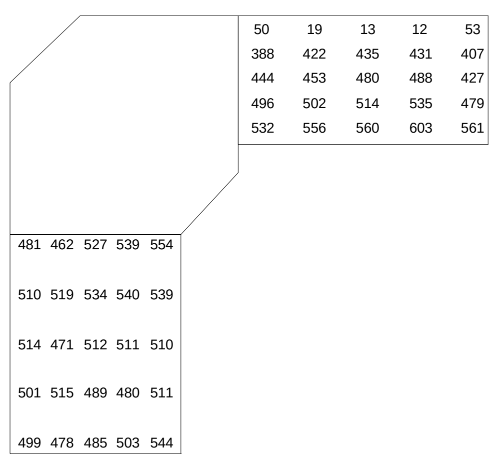

Figure 6 Illuminance (lx) on the work planes obtained with the optimal luminous intensity distribution from the window.

Acknowledgements

This work was supported by Ph. D. Fellowships of the Ministry of Science and Technology, Lisbon, Portugal, and of the Calouste Gulbenkian Foundation, Lisbon, Portugal, and also by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Research and Standards of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

The authors would like to acknowledge Judy Lai for assistance with *Radiance* modeling.

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