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DEFINING DAYLIGHTING FROM WINDOWS IN TERMS OF CANDLEPOWER DISTRIBUTION CURVES

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Abstract: This work describes a method for evaluating quantitatively the daylight admittance of windows under any outdoor conditions in terms that make it possible to calculate interior light distribution. The work is based on a new concept in quantitative daylight analysis, the "Transmission Function Approach", developed by the author while preparing graduate thesis (1976 and 1982) [2], [3], and [4].

The visible daylight flux introduced through a window (or other daylight-admitting aperture) can be considered, from the point of view of the internal space, as being emitted from a point source or from a finite-area uniform source. The photometric properties of those light sources are defined in terms of the well-known candlepower distribution curves. The ways in which this approach can be applied for different window designs are demonstrated.

This approach to the photometric properties of window systems allows one to translate typical daylighting calculation problems into a format in which they can be resolved using traditional electric lighting calculations or computer codes. Even "daylighted-oriented" computer codes are limited as to the geometric complexity of the windows they can model--this method eliminates such limitations. It will also contribute to a better understanding and visualization of the photometric properties of various windows and other daylight-admitting elements. This approach, therefore, may also serve as an educational tool.

Introduction

The sun and sky, as modified by meteorological conditions, are the prime sources of daylight. In addition, those primary light sources interact with the observer's nearby environment, including ground surface, buildings, and other surrounding objects. The results of that interaction create an "external luminance scenario" for observers inside a built space. This scenario may occupy up to a 4π steradian solid angle; however for many practical applications, information concerning 2π steradian of that scenario is sufficient.

The traditional methods for calculating daylight admitted through windows (for example [1]), find all the possible photometric links between the internal point of interest and the external luminance scenario, including reflections and interreflections between the window and the details of the internal space. In these methods the photometric links are quantitatively defined and repeatedly calculated for their contributions to the light level as the result of specific outdoor luminances.

The approach described in this work makes a methodological separation between the outdoors and the indoors in daylighting calculations. A calculated or measured term, the equivalent light source, is defined as an imaginary light source, a point source or a finite area of uniform properties. This source, when installed inside the space in place of the original window, would create an illuminance distribution similar to that created when the window is in place.

One of the potential benefits from separating indoor and outdoor spaces for calculation purposes is that daylighting calculation becomes analogous to electric lighting; thus conventional methods of calculating illumination from electric luminaires can be used for daylight. The designer need not be involved with fenestration details and special daylighting practices or calculations when this approach is used. Thus this approach also makes it possible to analyze the daylight performance of fenestration systems, including complex sun control systems, under all sun and sky conditions. This is a necessary prerequisite for analysis of the annual energy impacts of daylighted buildings.

Method

The basic concept behind the proposed method is that, at the initial stage, the window should be analyzed for its capacity to introduce visible radiant flux (daylighting, in this case) as a result of all possible locations of outside point light sources. The analyses have to be performed separately for each one of those light sources, assigning to each the same normalized intensity value. The results should be kept in a form that preserves their directional properties.

The full set of those properties is called the transmission function ([2], [3]), and each specific window has only one particular form of that function. To use the transmission function to determine what kind of equivalent light source a specific window will be under specific daylight conditions, the following two steps are required:

* The light-introduction properties for each input direction that made up the transmission function must be multiplied by the actual lighting intensity values of each of the real outside light source elements.

* Those results, when superimposed (superposition is possible because of the additive properties of the visible radiant flux), create the equivalent light source properties of the daylight-introducing window.

To reduce significantly the volume of work associated with the creation of the transmission function data base information, it is feasible to assume that the outdoor light sources are located far enough from the window that each one of them can be seen as if radiating only collimated and uniform flux on the window.

The practical meaning of that assumption is that, from the window plane towards the outside, there may correspond, to every direction of observation only one possible external light source, located infinitely far away.

Application

For indoor daylight distribution calculations, there are different options for using the equivalent light source approach:

A. In the Single Transmittance Approach,

1. all visible flux can be assumed to be emitted from a single point source located, for example, at the center of the original window area.

2. the emitted flux may be divided into several point light sources of equal directional properties.

3. the emitted flux may be assumed to originate from a finite light source planar area of uniform photometric properties.

Remark: In all of the above cases, the original directional distribution properties of the radiant flux as defined in the transmission function data base are preserved.

B. In the Multiple Transmittance Approach,

the window can be subdivided into several segments. For each one of the created sub-windows, a separate transmission function data base have to be found. The new sub-transmission functions will be applied in one of the forms: A(1), A(2), or A(3). It should be observed that this subdivision strategy may also compensate for the simplification suggested earlier, that of assuming that the outside light sources are distant enough to shed only collimated and uniform radiant flux on the windows. Choosing between these options is similar to choosing between the options for dimensions of luminaires with respect to their distances from a calculated reference. This is a traditional issue in electric illumination and the same considerations applied to electric lighting can be applied to daylighting.

To complete this concept of the suggested autonomy of indoor daylighting calculations, it may be necessary (depending on the relative size of the window area compared to the interior envelope and its reflectances) to assign an equivalent reflectance property to the window area as seen from inside. This can be either measured, or estimated based on knowledge of the real window details.

The Transmittance Data Base

Knowledge of the specific transmission function data base is essential for using the equivalent light source or candlepower method. Once the transmission function has been established for a particular window system, it becomes a unique and complete property, like a personalized photometric fingerprint of the system, containing all of the possible radiant flux-filtering properties of the system. Thus, this information can be used repeatedly to account for the system's photometric performance in an endless variety of daylighting circumstances.

As mentioned in Refs. [2] and [3], there are two basic methods that can be used to establish the transmission function data base for a particular daylighting system:

(A) A photometric method

(B) A mathematical method

Method (A) is based on experimental photometry. This method requires either a prototype of the real system being analyzed, a representative sample of it, or a photometrically correct scale model of the system. The analysis is performed by illuminating the exterior of the system with a reference beam, and the resulting transmitted flux is directionally scanned.

The author is developing an automated facility, the luminance transmittance scanner, designed to perform these measurements quickly and efficiently.

The advantage of the experimental method is that it is unaffected by the design details of the analyzed system. So long as the correct sample or scale model is provided, the measurements can be performed, and the transmission data base established.

Method (B), the mathematical approach, takes different forms depending on the photometric properties of a particular system. For example, a ray-tracing method may deal with specularly reflective elements but is inefficient for diffusive or semi-diffusive surfaces.

At present, there is no general mathematical method that can be computerized to calculate transmittance data base properties regardless of the photometric properties of the analyzed system and the diversity and complexity of its details. The example presented below is one mathematical approach, the applicability of which is clearly limited by the photometric properties of the analyzed system.

Demonstration of the Method

The particular window design chosen is shown in Fig. 1. A horizontal, sloped overhang is part of the window. The thickness of the frame in which the window is set is accounted for in the analysis. However, this sample analysis will deal only with the direct penetration of light through the windows under consideration. This assumption is applicable when the textures of the window details have very low reflectance, so the quantity of light admitted through reflection and interreflection among those details is insignificant compared to the quantities of light admitted to the inside through direct penetration. It is also assumed in this example that there is no glazing installed in the window frame.

Using these assumptions, the capacity of the example window (see Fig. 1) to transfer collimated uniform flux is directly proportional to the open area it defines when observed from a particular direction, which can be formulated in geometric terms. The full calculated (composed of 2π domain of directions) transmission function data base of this particular window is shown in polar coordinates in Fig. 2.

To translate the transmission function information into specific light source properties, we must weight it with actual external luminance distribution values and the actual dimensions of the window must be defined (for the initial analysis, its geometry may be dimensionless).

Assuming the sky to have a standard "overcast" luminance distribution and the ground (everything below the horizon line) to be of constant luminance (1/5 of the zenith sky luminance), we determine the equivalent candlepower properties of the visible flux introduced by that window, as shown in Fig. 3.

Discussion and Conclusion

The method proposed in this work was demonstrated using photometric quantities (the definitions of those quantities include integration over the photopic curve). However, the same concept can be used in a spectrally separative way, so that for each narrow band of visible spectrum, there is a separate transmission function data base. This might be particularly useful to account for window systems having spectrally selective properties, and for the potentially dynamic quality of daylighting scenarios with respect to their spectral characteristics. The same approach may be applicable to parts of the spectrum outside of the visible range, ie, the I.R. and the U.V.

This work assumed that windows filter only in one way -- from outside to inside. This is because, during the day, light levels outside are so much higher than those indoors that quantitatively significant interaction (with potential feedback) between those two environments exists only in one direction. It also be should realized that quite often, and in particular with multi-element filters, like some fenestration systems, transmittance may be directionally dependent. As a result, the transmission function data base (T.F.D.B.) from outside to indoors, may not be equal to the TFDB from indoors to the outside.

It should be mentioned that it is possible to establish a reflection function in a similar way to the transmission function. If this reflection function is applied to a window as observed from outside, the difference between the functions (transmission minus reflectance) will account for the radiation absorbed within the window system.

This work outlines a step-by-step method to make indoor daylighting calculations possible using electric illumination calculation methods. Thus this approach has the potential to be implemented in daylighting computer codes, as is being done with the 'SUPERLITE' program [5], [6]. This approach also provides a tool for compact visualization of the daylight admittance properties of different fenestration systems.

In addition, this method can be used to design new systems, using interior requirements and external daylight availability as bases for defining properties of the desired transmission function. If an existing system's transmission function will not fit the requirements, a new window system ystem could be designed to meet those expectations.

Acknowledgement

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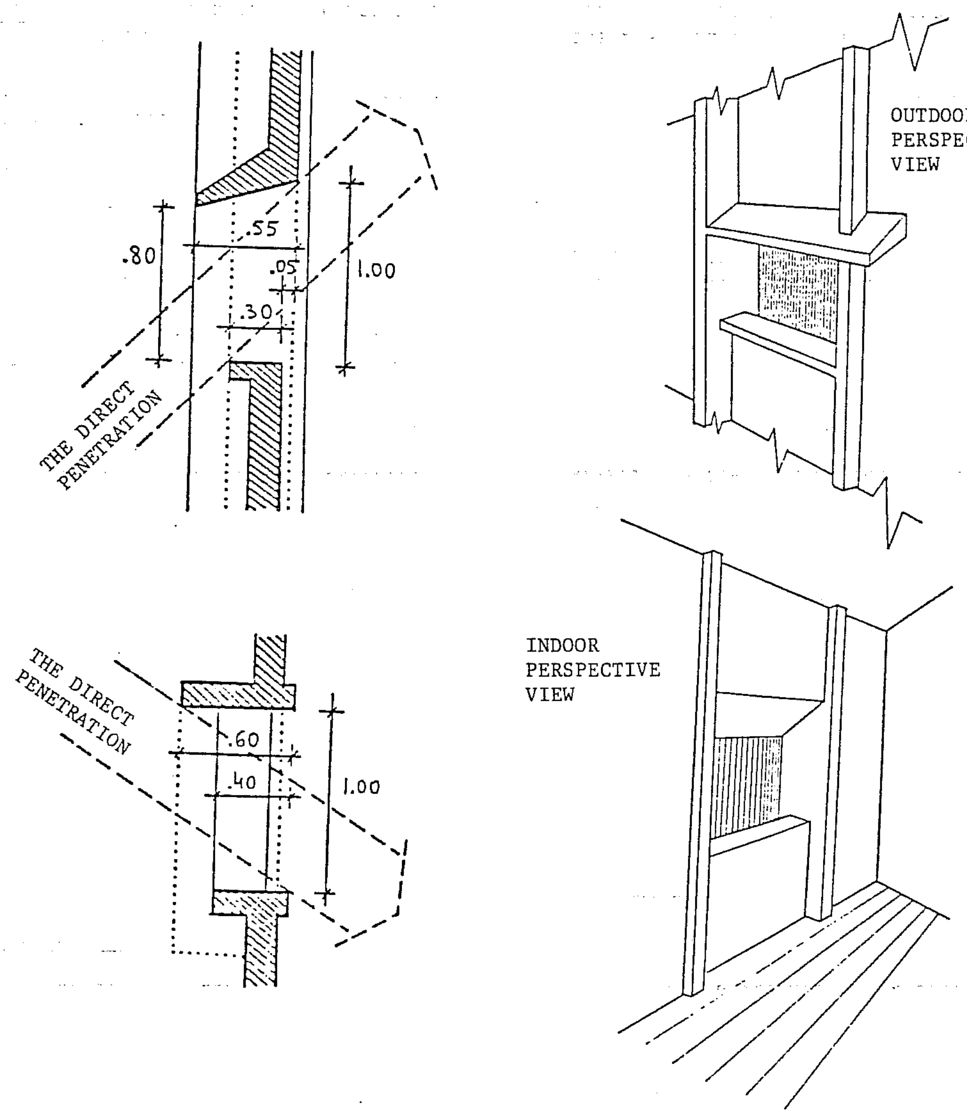

Figure 1 The window system that is being analyzed for its direct daylight admittance capacity, in metric units.

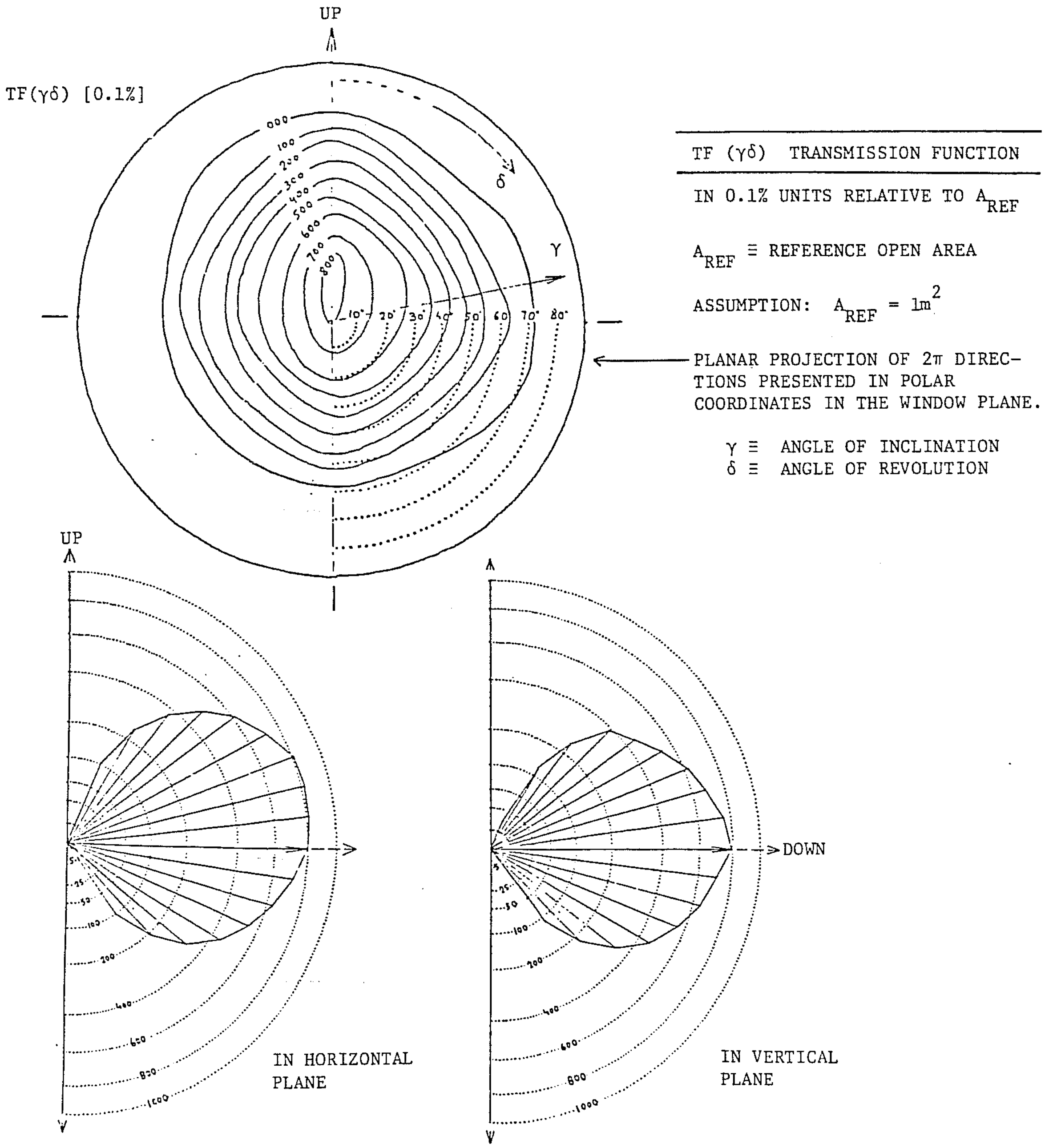

Figure 2 The transmission function data base as calculated for the window system in Fig. 1, in units of 0.1% relative to an open area of 1 m^2.

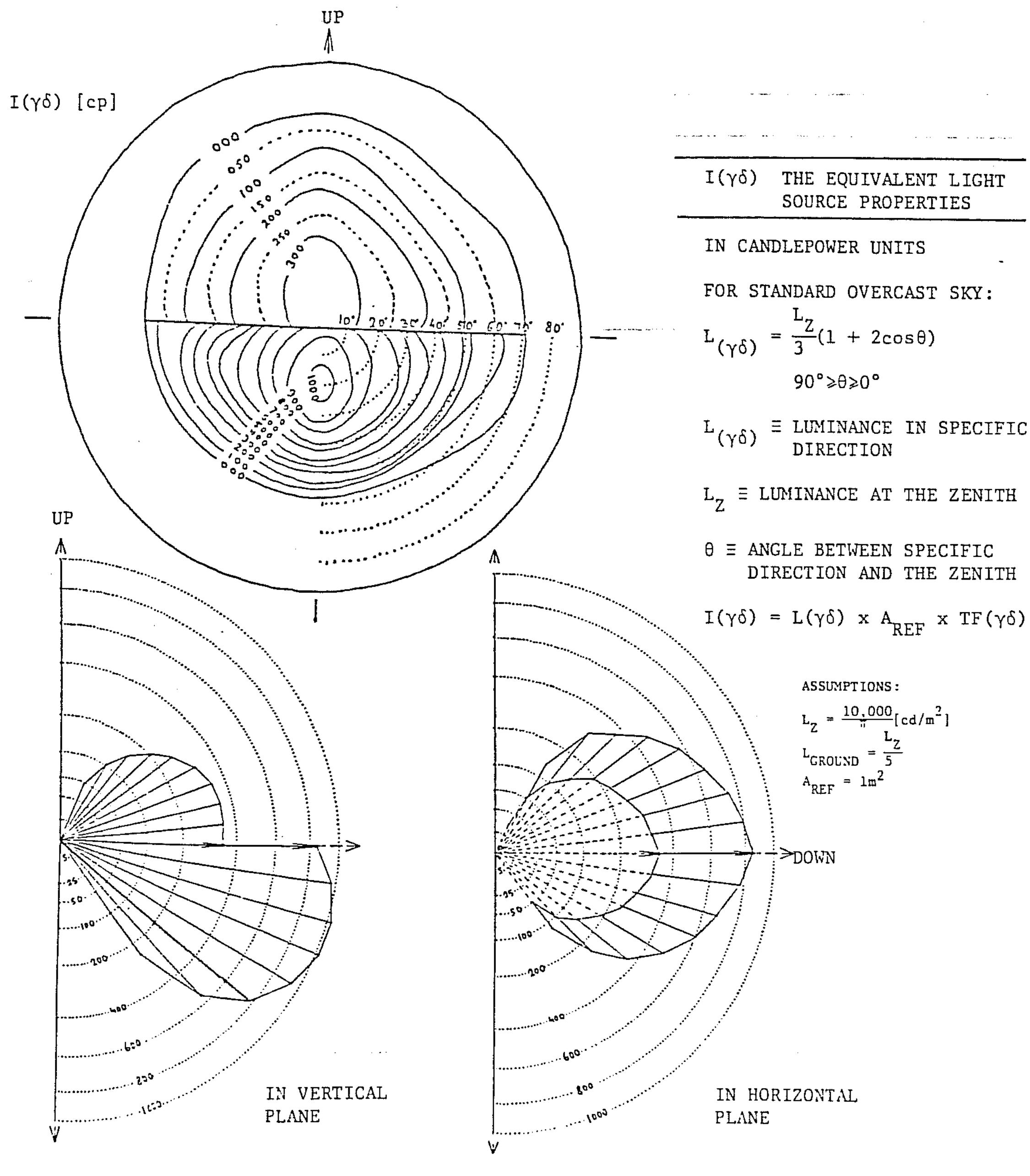

Figure 3 The equivalent light source properties of the window system based on the transmission function data base in Fig. 2, in units of candlepower, for standard overcast sky and uniform ground.