On the benefits of a variable-resolution bidirectional scattering distribution data format

Andrew McNeil and Eleanor Lee

Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley CA USA

Abstract

This summary report adds context to the recent development of a new format for variable-resolution bi-directional scattering data. Specifically we discuss why a high resolution BSDF format is needed, the advantages of a variable resolution data format, and the new capabilities that stem from this development.

Introduction

Generally speaking bi-directional scattering distribution function (BSDF) files contain optical reflection and transmission characteristics for a material used in computer graphics disciplines. LBNL uses BSDF files to characterize optical properties of complex fenestration systems (CFS). Any non-specular window system is considered a CFS including diffusing laminates, daylight redirecting systems such as micro-prismatic films and specular louver systems, and shading systems such as blinds or roller shades. A BSDF file contains the angularly resolved transmission and reflection characteristics of a CFS. Using a BSDF file we can tell precisely how much light is transmitted and in what directions light is transmitted (i.e. up towards the ceiling or down towards the floor) for any sun position and intensity.

Features supporting BSDF files have been added to LBNL's software tools for simulating performance of window systems, including Radiance. The capability to simulate performance of CFS in Radiance is a major step forward.

The BSDF format used in LBNL simulation tools has a limited resolution, which is generally sufficient for determining energy performance of windows and buildings, however Radiance could handle much higher resolution BSDF data. A sensitivity study demonstrated that glare analysis in particular would be more reliable if higher resolution BSDF data was used in the visualization process.

In 2012 a new high, variable-resolution BSDF format was developed. This new format was developed generically to benefit both the computer graphics industry and the window and daylighting industry. The new format is open source — manufacturers, other researchers and software developers are encouraged to use the new format.

High Resolution BSDFs

The Window 6 software tool is capable of generating a BSDF for multi-layered glazing systems including complex fenestration systems. Window uses a fixed resolution angle basis with the relatively low resolution of 145 discrete directional patches. This corresponds to an angular resolution of roughly 10°-15° depending on the specific patch.

To determine whether the Klems resolution was sufficient for daylight calculations we ran similar simulations using three angle bases of increasing resolution. The lowest resolution was the Klems angle basis, the two higher-resolutions were generated by subdividing the Klem's angle basis (see Figure 1).

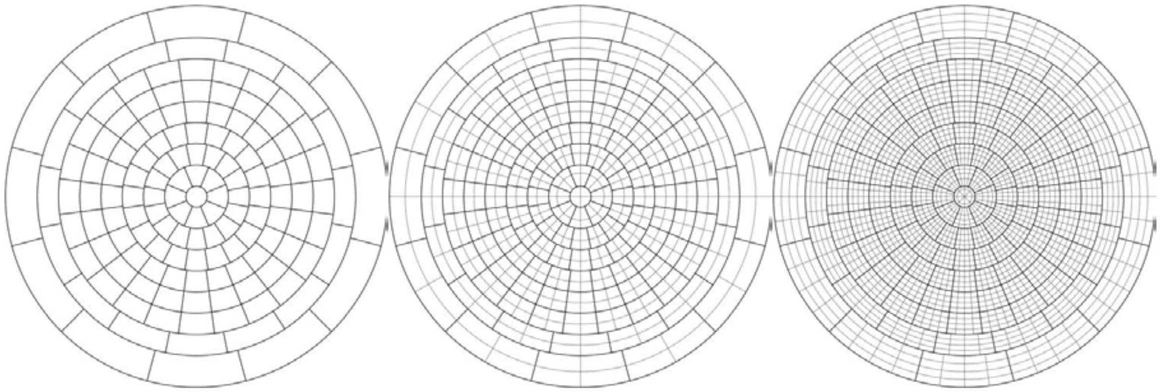

Figure 1. Angular projection diagrams of the Klems (left), 2x-Klems (middle) and 4x-Klems (right) angle bases.

This study demonstrated that the Klems resolution was adequate for determining annualized daylight illuminance performance metrics, however not adequate for determining work plane illuminance at a single time step and for determining glare ratings. This is particularly true for glazing systems that have a peaky transmittance distribution such as specularly reflecting surfaces and clear glazing. Inaccuracies tend to occur most when the sensor point (or view point) is in or near a transmission peak.

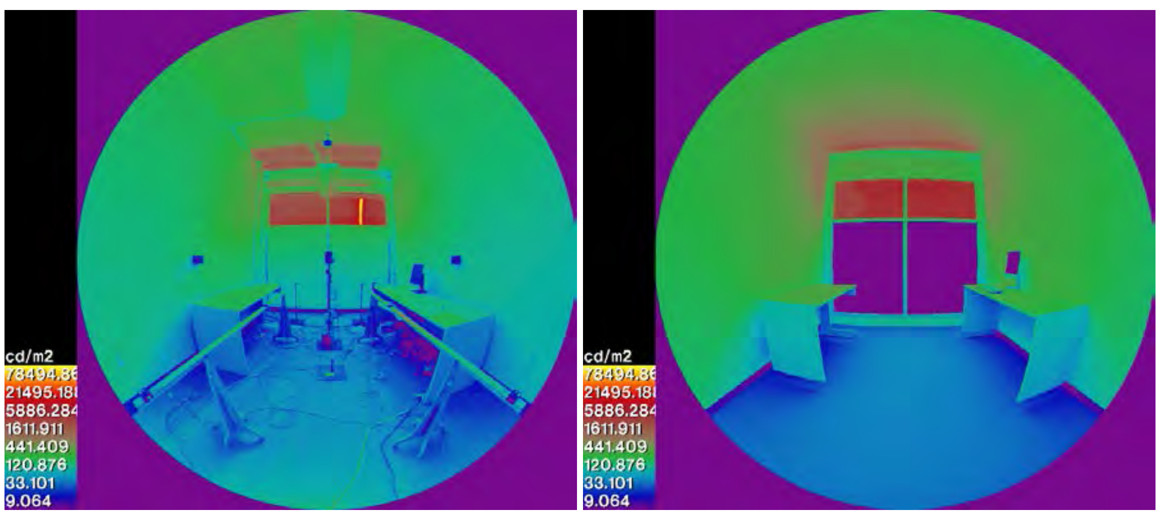

Figure 2. HDR luminance map of micro-prismatic window film (left) and a Radiance simulation of the same film with a Klems resolution BSDF (right).

Figure 2 shows an HDR luminance map of micro-prismatic window film installed in the LBNL windows testbed facility compared to a Radiance simulation of the same film using a Klem's resolution BSDF in a calibrated model of the same space. There is a vertical stripe of high luminous intensity in the right upper window of the luminance map (left image), which represents in-plane scattering of the film. In the simulation, (right image), the intensity of vertical stripe is averaged over many Klems patches and so essentially disappears from the rendering.

A high-resolution BSDF format is necessary to be able to assess glare from complex fenestration systems. High-resolution BSDFs are not required for to improve accuracy of work plane illuminance at individual time steps since the errors do not impact annualized metrics.

Variable Resolution BSDFs

The sensitivity exercise described above also demonstrated that using a fixed high-resolution angle basis increased simulation times proportionally at every stage of the simulation. In addition, the high-resolution angle bases required much more system memory. The computational drawbacks of the fixed high-resolution angle bases made it clear that a variable resolution format was necessary.

A variable-resolution provides efficiency by only requiring additional data where necessary. Areas of the transmittance distribution with little to no change in intensity can be represented with low-resolution data while areas where the intensity changes rapidly can be represented with high resolution data.

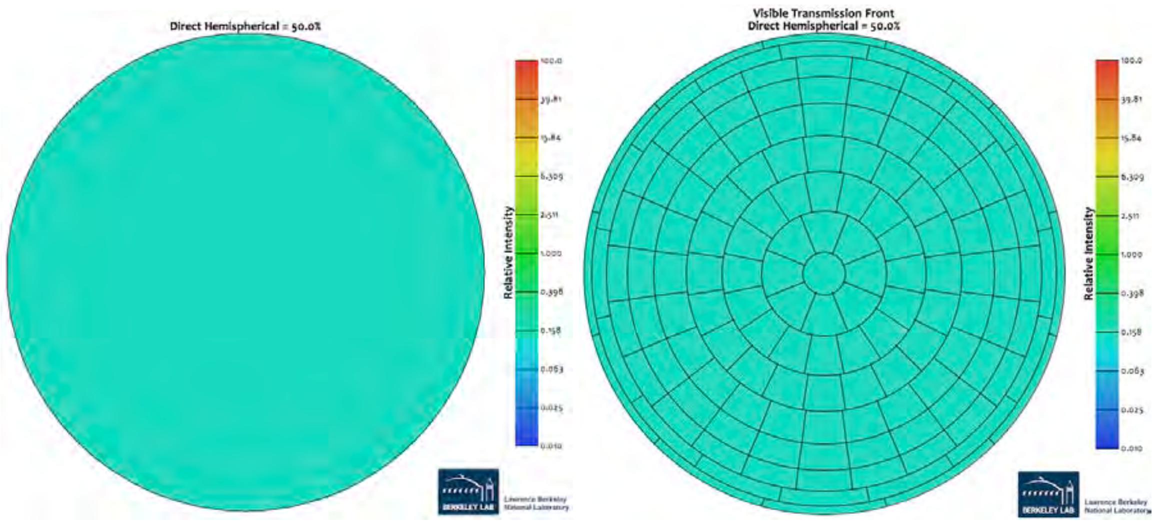

Figure 3. The outgoing energy intensity distribution for a 50% Lambertian diffuser in variable resolution format (left) and fixed Klem's resolution format (right). The hemispherical distribution is projected onto a circle, the color indicates intensity according to the scale on the right of the image.

A 50% Lambertian diffuser has a completely uniform outgoing energy intensity distribution (Figure 3). With a variable resolution data format (Figure 3, left), one value is sufficient to characterize the full distribution. With a fixed resolution Klems format (Figure 3, right) one value is required per outgoing direction.

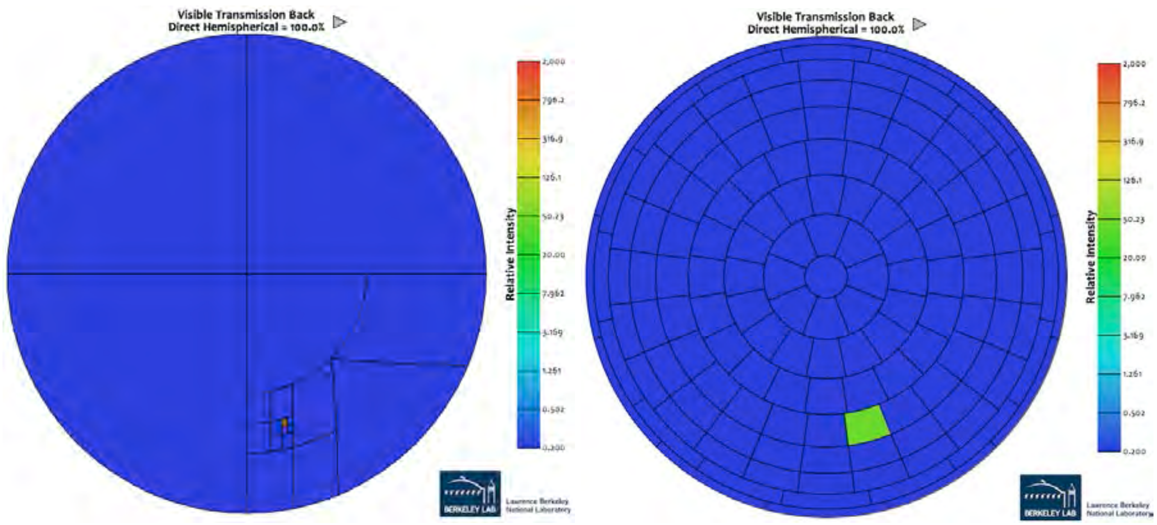

Figure 4. The outgoing energy intensity distribution for a 100% specularly transmitting surface (air) in variable resolution format (left) and fixed Klem's resolution format (right).

The outgoing energy intensity distribution for a 100% specularly transmitting surface has a single intense peak for the specular transmission. The variable resolution BSDF (Figure 4, left) provides a small intense peak using a total of 19 BSDF values for variable sized patches. Comparatively, the Klems BSDF (Figure 4, right) has a much larger less intense peak but requires 145 values for the fixed patch sizes.

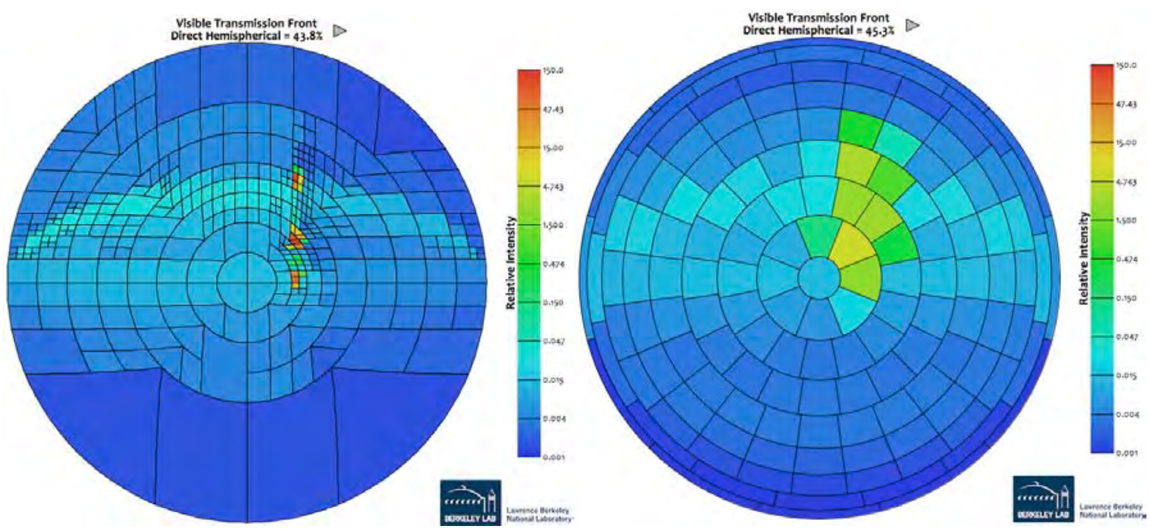

Figure 5. The outgoing energy intensity distributions for a specular louver system in variable resolution format (left) and fixed Klems resolution format (right).

The variable resolution format on the left resolves the three peaks while the fixed resolution format on the right has averaged the peaks into larger patches. The variable resolution format uses more values (448) than the Klem's format (145), however a fixed resolution BSDF would require many more values (4096) to provide the same resolution of the output peaks.

New Capabilities

The development of a new high resolution BSDF format provides the capability of simulating accurate window luminance patterns of complex fenestration systems with peaky outgoing energy distributions. The highly resolved window luminance improves the accuracy of glare assessment for novel redirecting systems. Improved reliability of glare assessment enhances our ability to develop new high-performance daylight redirecting films and systems.

Acknowledgments

This work was supported 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-AC02-05CH11231 and by the California Energy Commission through its Public Interest Energy Research (PIER) Program on behalf of the citizens of California.