GENERATION OF DETAILED SKY LUMINANCE MAPS VIA CALIBRATED DIGITAL IMAGING

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ABSTRACT

Reliable prediction of daylight availability in indoor environments via computational simulation requires detailed and accurate sky luminance models. Sky luminance mapping via digital imaging can provide an alternative to high-end research-level sky scanners and thus support the provision of information on sky luminance distribution patterns on a more pervasive basis. In this paper, we compare variously calibrated sky luminance data derived from real-time digital sky images to photometric measurements. Subsequently we compare the application of a digitally derived sky model with other sky models toward the prediction of illuminance levels in a room.

INTRODUCTION

Daylight simulation applications can help designers test and improve alternative daylight solutions. Moreover, daylight simulation can assist model-based building systems control applications (Mahdavi 2001, Mahdavi et al. 1999). Currently, most daylight simulation applications work with simplified sky luminance models, which are not sensitive to luminance variations in different areas of the sky. However, reliable prediction of daylight availability in indoor environments via computational simulation requires reasonably detailed and accurate sky luminance models. Moreover, such models, to be effective for design support purposes, must be established for various locations over a statistically representative period of time. Toward this end, sky luminance mapping provides the empirical basis. As past research has demonstrated (Roy et al. 1998, Spasojevic and Mahdavi 2005), relatively low-cost sky luminance mapping via digital imaging can provide an alternative to high-end research-level sky scanners.

In the experiment presented in this paper, we used a digital camera with a fish-eye converter toward real-time photography of sky dome. We used four calibration methods to derive detailed sky luminance maps from these images. We then compared these variously calibrated luminance values with the corresponding photometric measurements. Finally, we compared the application of *i)* digitally derived sky luminance maps, *ii)* CIE standard skies (overcast, intermediate and clear), and *iii)* Perez All-weather sky (Perez et al. 1993) toward the prediction of indoor illuminance levels using the case of a scale model of an architectural space.

APPROACH

Measurements

To obtain empirical data for calibration method comparison, we collected photometric data (simultaneous measurements of illuminance levels due to 12 sectors of the sky dome) over a period of 10 days (November 2005) at the rooftop laboratory of TU-Vienna. Parallel to these measurements, we monitored global horizontal illuminance. Illuminance measurements at three points in the scale model were performed over the same period of time.

Digital imaging

Fisheye-images of the sky dome were taken during the same period every 1 minute. From these images non-calibrated luminance values of the sky dome were derived based on algorithms suggested by Roy et al. 1998. Thereby, the entire sky dome was captured in terms of 256 patches with corresponding luminance values.

Calibration

The initial luminance data gained via the above procedure deviated considerably from measured values, thus implying the need for calibration (Spasojevic and Mahdavi 2005). Toward this end, we compared global horizontal illuminance levels derived using camera-based luminance maps to the photometrically obtained illuminance levels. We then considered four options to distribute the resulting "energy difference" across the patches of the sky model:

1. The difference was uniformly distributed across all 256 discrete sky patches (100_256).
2. If the energy difference was more than 10% of the camera-based global horizontal illuminance, then 60% of the difference was concentrated in one patch representing the circumsolar region

and the rest was uniformly distributed amongst the remaining 255 patches (60_1).

3. If energy difference was more than 10% of the camera-based global horizontal illuminance, then 100% of the difference was concentrated in one patch representing the circumsolar region (100_1).
4. If energy difference was more than 10% of the camera-based global horizontal illuminance, then 100% of the difference was concentrated in the extended circumsolar region – one patch representing sun plus four adjacent patches (100_5).

Indoor illuminance prediction

To predict illuminance levels in the scale model we used the simulation program RADIANCE (Ward Larson and Shakespeare 2003). The 1:5 scale model represented a rectangular space (length: 5m, width: 3 m, height: 2.85 m) with a 3m by 1.5m window.

RESULTS

Figure 1 shows the relationship between photometrically obtained and non-calibrated camera-based illuminances due to the 12 aforementioned sky sectors.

Figures 2 to 5 show the relationship between photometrically obtained and calibrated camera-based illuminances (using the previously described calibration procedures).

Figures 6 to 8 show the comparison of measured versus simulated illuminance levels in the scale model. Simulation results in Figure 6 were derived using CIE standard skies (overcast, intermediate, clear), whereby the selection of the proper sky for each instance was based on the visual inspection of the corresponding sky image. The underlying sky model for Figure 7 was Perez All-weather model for sky luminance distribution. Finally, Figure 8 is based on calibrated digital photography, whereby the previously mentioned 100_5 calibration procedure was applied.

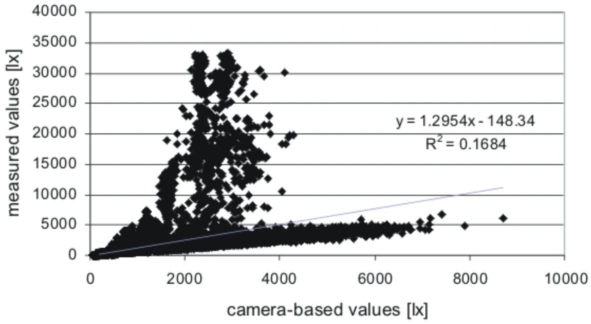

Figure 1 Measured versus initial (non-calibrated) camera-based illuminance values

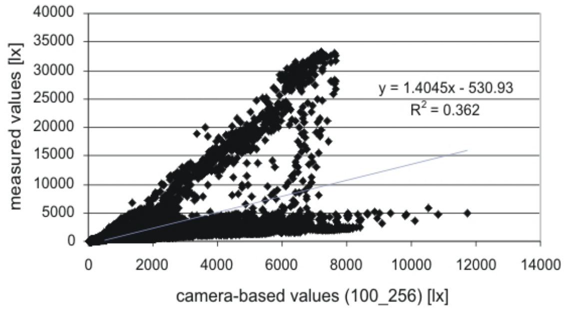

Figure 2 Measured versus calibrated camera-based illuminance values (100_256)

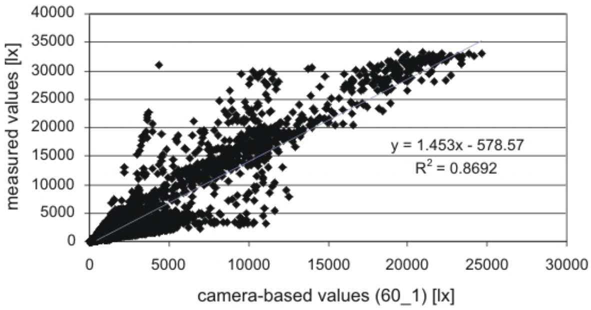

Figure 3 Measured versus calibrated camera-based illuminance values (60_1)

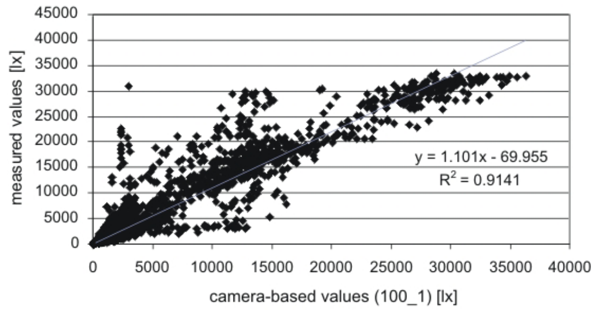

Figure 4 Measured versus calibrated camera-based illuminance values (100_1)

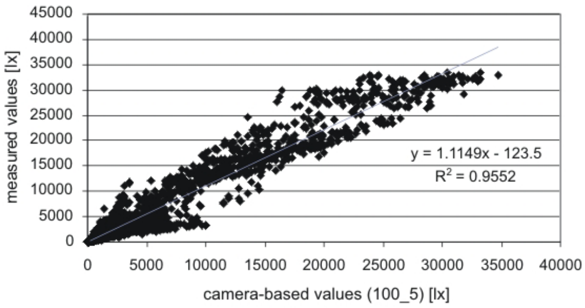

Figure 5 Measured versus calibrated camera-based illuminance values (100_5)

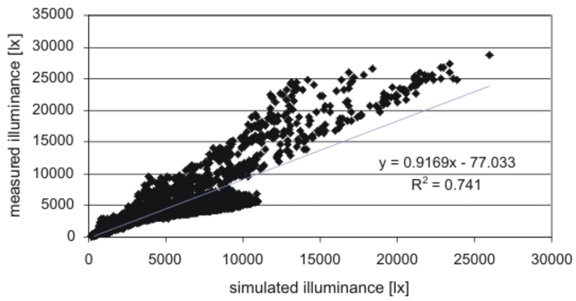

Figure 6 Simulated versus measured indoor illuminance values (sky luminance data based on CIE Standard Skies)

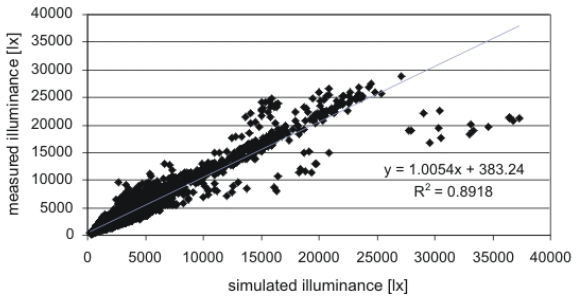

Figure 7 Simulated versus measured indoor illuminance values (sky luminance data based on Perez all-weather sky)

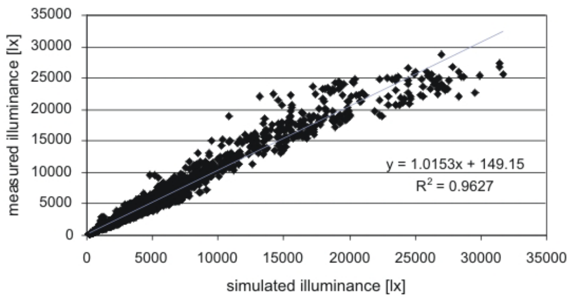

Figure 8 Simulated versus measured indoor illuminance values (sky luminance data based on digital imaging)

DISCUSSION

Illuminance levels obtained from non-calibrated and uniformly calibrated digital images display a poor correlation with photometric measurements (see Figure 1). Differential calibration provides significant improvements (see Figures 2 to 5). Specifically, our study suggest that a good approximation of photometric measurements can be achieved using the 100_5 calibration procedure (see Figure 5). Moreover, as figures 6-8 demonstrate, sky models that are calibrated based on this latter procedure lead to the most accurate prediction of indoor illuminance levels in the scale model.

CONCLUSION

The results of the research presented in this paper imply that digital sky imaging calibrated with parallel measurements of overall horizontal illuminance levels, can provide an efficient basis for the generation of detailed sky luminance models. The application of such sky luminance models increases the predictive accuracy of the computational daylight prediction tools. Thus, the reliability of daylight simulation can be increased toward supporting the design and operation of daylighting systems in buildings.

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