EVALUATION OF DAYLIGHT AVAILABILITY CONVERSION MODELS AT THE ALBANY IDMP STATION

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ABSTRACT

We present the results of the evaluation of daylight availability conversion models against experimental data recorded in Albany over a two-year period, in the context of the International Daylight Measurement Program (IDMP). The daylight availability conversion models include global, direct and diffuse luminous efficacy models (Olseth & Skartveit, 1989 and Perez et al., 1990) as well as models to compute the sky's zenith luminance and diffuse illuminance on arbitrary tilted surfaces (Perez et al., 1990). The performance of both models tested against independent data is found to be acceptable and fully consistent with previous investigations undertaken with partially dependent data.

1. INTRODUCTION

A major impediment to the utilization of today's versatile daylight simulation tools is the lack adequate site-specific input data. Daylight availability measurements have been routinely performed only in a handful of locations worldwide. However sophisticated, calculations that cannot access site/time specific daylight availability data must rely on generic data and may be greatly underutilized. A way around the scarcity of daylight availability data is to model illuminances and luminances from irradiances that are more widely available -- e.g., from irradiance networks, satellite remote sensing [e.g., see Zelenka et al., 1992] or from national archives [e.g., see Maxwell et al. 1992]. The evaluation of such transposition models is the subject of this paper. We focus our attention here on models that generate global, direct, diffuse and tilted illuminance as well as zenith luminance. Sky luminance distribution models are treated in other papers by the authors and their colleagues [see Perez et al., 1993 and Ineichen et al., 1994].

2. EXPERIMENTAL DATA

The data used to validate the models were recorded in Albany, New York, as part of the IDMP over a 21 months period from October 1991 to June 1993.

The International Illumination Commission (CIE) and the World Meteorological Organization (WMO) initiated the IDMP with the goal of generating a worldwide daylight availability dataset that could be used, among other applications, to validate conversion models. As part of the IDMP, participating teams throughout the world would measure irradiance and daylight components under a common set of guidelines [Perez et al., 1987-1994]. Two types of measurement stations were specified: *Research Class Stations* where measurements should include at least global direct and diffuse irradiance and illuminance, illuminance in four vertical azimuths, zenith luminance, sky luminance distribution and cloud cover, and *General Class Stations* including at least global and diffuse irradiance and illuminance, plus four vertical illuminances.

The Albany IDMP station is an "upgraded" General Class station where direct irradiance, direct illuminance and zenith luminance are measured besides the basic General Class quantities. In addition, auxiliary measurements of global, direct and diffuse irradiance, global illuminance, and zenith luminance are performed, which greatly enhance our ability to quality control the data (both automatically and visually), beyond the recommended IDMP quality control (Molineaux et al., 1994). All data are acquired and archived on a one-minute basis. However, the data used in this paper are hourly averages.

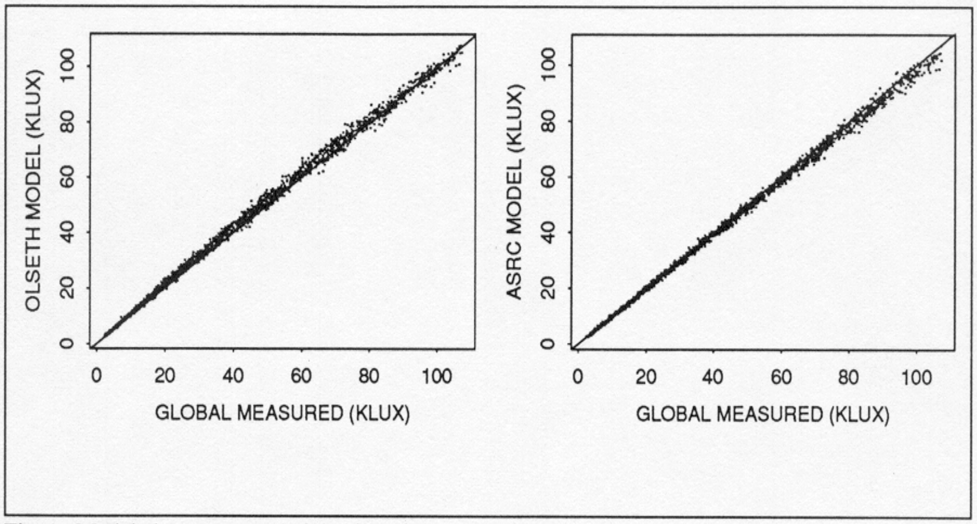

Fig. 1: Modeled vs. measured global illuminance

3. <u>THE MODELS</u>

Luminous efficacy models: We tested two algorithms for modeling global, direct and diffuse illuminance [Olseth & Skartveit, 1989 and Perez et al., 1990].

The first model is based on an all-weather spectral model obtained by interpolation of the simple clear day spectral radiative transfer model SPECTRAL2 [Bird and Riordan, 1986] and a cloud transmittance model [Stephens et al., 1984]. Luminous efficacy is obtained via integration of the all-weather spectrum normalized to the CIE photopic curve. A simple function for beam efficacy and three functions for diffuse luminous efficacies are generated, corresponding to "blue sky", bright cloud" and "dark cloud" conditions. One sets the functions and interpolates as a function of insolation conditions determined from the model inputs, that is, global and diffuse irradiance (note that diffuse may be modeled from global if it is not available). Minor tuning of this model was done to account for observed data, independently from the current dataset.

The second model is an empirical fit of observations from several sites, to insolation conditions parameterized in terms of sky clearness, sky brightness and solar geometry. The input to this model consists, as above, of global and direct (or diffuse) irradiance that may be modeled from global if not available. This model was recently used in the preparation of the new ASHRAE Weather Year for Energy Calculation (WYEC2) data sets (ASHRAE, 1994).

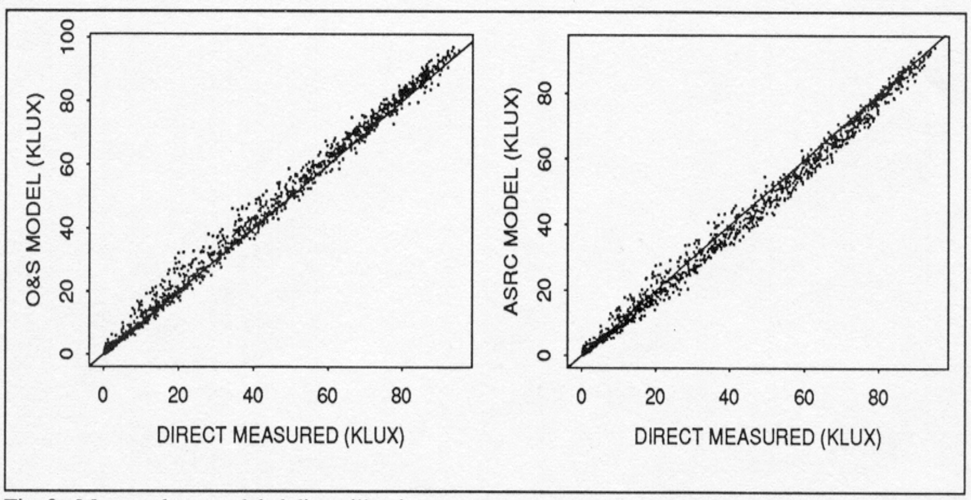

Fig. 2: Measured vs. modeled direct illuminance

Zenith Luminance Model: Zenith luminance is a parameter which is mostly useful for simplified calculations involving top-lighting. Zenith luminance has also been used historically as an input to sky luminance distribution models [e.g., CIE, 1973]; however, it is now considered more effective to normalize sky luminance to diffuse illuminance. The model tested here is that proposed by Perez et al., [1990]. In this model, the ratio of zenith luminance to diffuse irradiance is treated as a "pseudo-luminous efficacy". Its variations were fitted to a set of multi-climatic data based on the clearness-brightness-geometry parameterization discussed above.

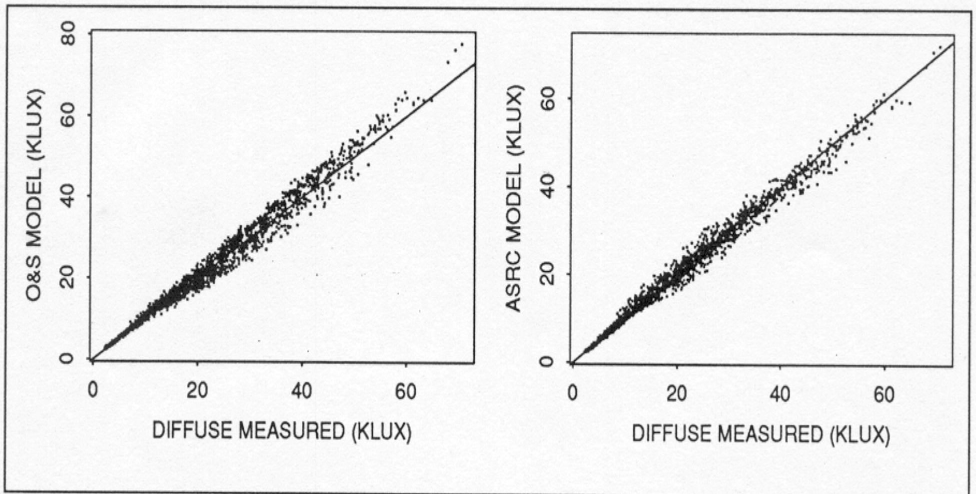

Fig. 3: Modeled vs. measured diffuse illuminance

Tilted Illuminance Model: Diffuse illuminance on a tilted surface is used primarily for simplified daylighting calculations involving side lighting (more sophisticated calculations would require sky luminance as an input). The model tested here is based on the *tilted irradiance* model developed by the authors [see Perez et al., 1990]. This model features a simple geometric representation of the sky's hemisphere that accounts for the prevailing anisotropic features of the sky (i.e., horizon/zenith gradient and circumsolar enhancement). A set of coefficients modulate this framework as a function of insolation conditions. These coefficients were obtained as above, via fitting to a multi-site data set.

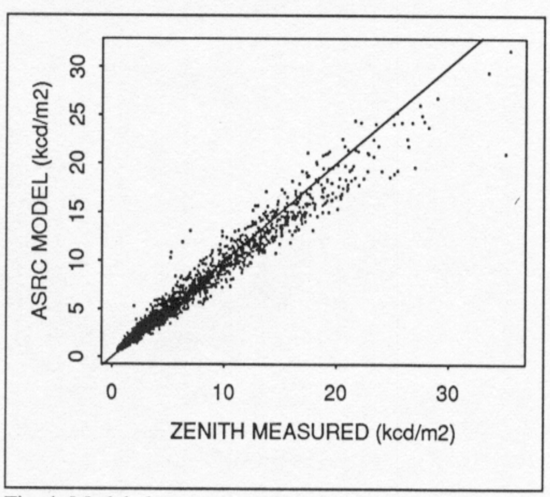

Fig. 4: Modeled vs. measured zenith luminance

The model is tested here in its "operational mode" using only irradiance data as input: diffuse irradiance is first converted into diffuse illuminance that is, in turn, converted into tilted diffuse illuminance. Modeled direct illuminance is further added to modeled tilted diffuse illuminance before comparison against measured tilted illuminance.

4. RESULTS

Model performance is summarized in Table 3 in terms of root mean square (RMSE) and mean bias error (MBE).

In order to put some of these result in a practical perspective, we compared the precision of the luminous efficacy models to measurement precision representative of general class stations:

- For global illuminance, we compared the precision of the models to the difference between our two global photometers that operated sided-by-side.
- For direct and diffuse we compared model precision to the measurement precision achieved when relying on a fixed shadowband photometer rather than a photoheliometer (note (1) that a fixed shadowband is the standard practice for IDMP general class stations and (2) that we used the difference between global and direct illuminance as a reference for diffuse illuminance).

TABLE 1

Root Mean Square and Mean Bias Errors

mod 1: Olseth &Skartveit, mod2: Perez et al. (ASRC)
sensor: auxilliary/alternative measurement
prev.: comparison against partially dependant data [Perez et al., 1990]

	Mean measured value (lux)	Root mean square error (%)				Mean bias error (%)			
		mod 1	mod 2	other sensor	prev.	mod 1	mod 2	other sensor	prev
Global illuminance	28,195	6.2%	4.3%	2.4%	4.2%	3.7%	-0.8%	0.6%	0.4%
Direct illuminance	20,321	14.1%	10.8%	14.1%	8.7%	6.5%	-1.9%	8.5%	0.9%
Diffuse illuminance	16,321	9.9%	7.5%	10.9%	10.4%	2.2%	-1.9%	-4.6%	0.8%
Zenith luminance (cd/sq.m)	4,724		18.4%		26.6%		-3.2%		0.6%
Verical illuminance									
North	6,274		16.0%		17.6%		1.5%		2.8%
East	13,074		11.7%		13.8%		1.6%		-0.6%
South	19,368		9.7%		9.9%		0.1%		-0.7%
West	14,318		10.8%		12.6%		-0.9%		-1.7%

We also compared, in the case of the models by Perez et al., the performance obtained with the current set of data, to that previously reported against a set of partially dependent data that had been used for its development.

The modeled vs. measured scatter plots in Figures 1 through 5, graphically illustrate the behavior of the global, direct, diffuse luminous efficacy, zenith luminance and tilted illuminance models respectively.

5. DISCUSSION

The performance of all considered model is found to be acceptable and, as a general rule, in agreement with previous studies. For global, both models approach instrument precision. For direct and diffuse, the models perform better than measurements using an (isotropically corrected) fixed shadowband for diffuse. This may have substantial implications when validating models against data from General Class stations where direct irradiance and illuminance are not measured.

The root mean square error of the zenith luminance model is understandably larger than that of the illuminance models, because of the small portion of the sky considered that is more sensitive to random cloud variations than the whole hemisphere (see discussions by Perez et al., 1993).

It is interesting to note that the RMSEs of zenith luminance and diffuse and tilted illuminances are slightly smaller than in the original comparison against the dependent data set. This may be a result of improved data quality (hence reduced measurement error noise). For direct, this trend is reversed, the model by Perez et al. shows a small but noticeable bias, that may be the result of a small calibration bias in the original set of data.

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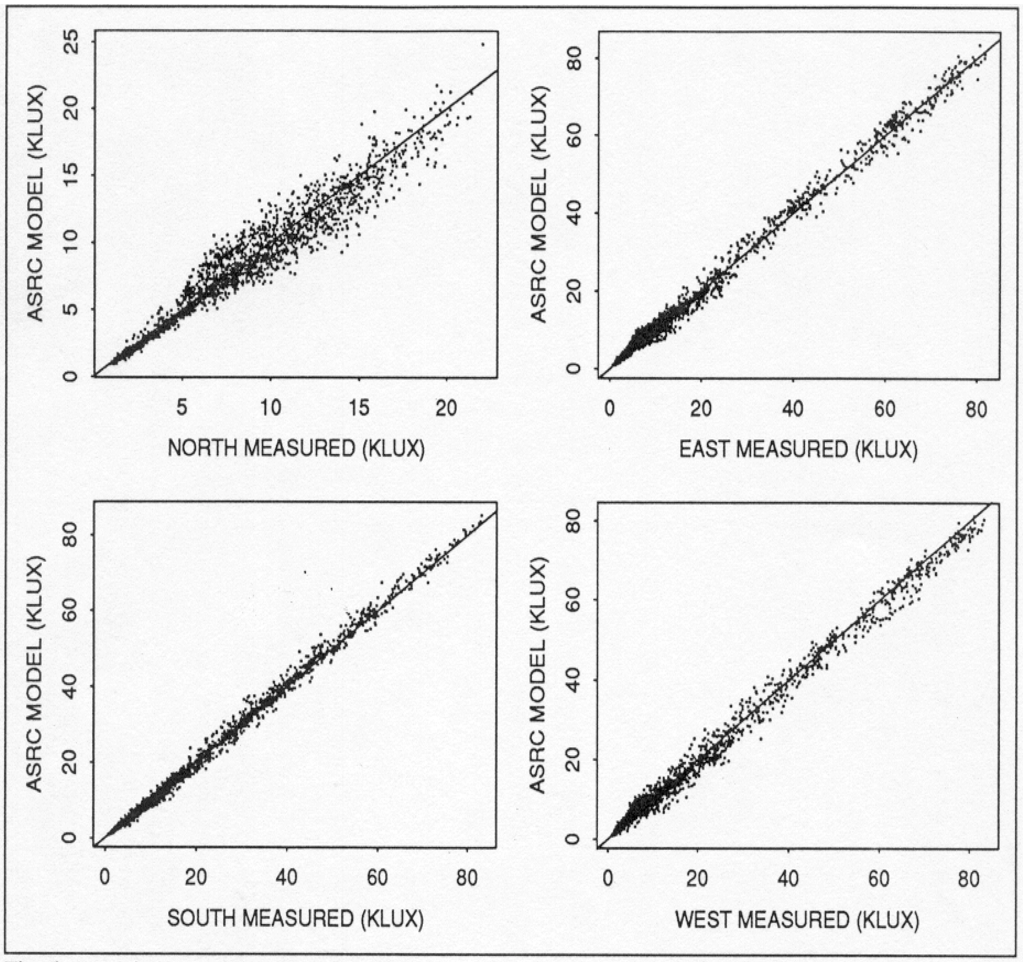

Fig. 5: Modeled vs. measured vertical illuminances

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