SIMULATION INPUT INFORMATION ON SKY RADIANCE: AN IRRADIANCE COEFFICIENT APPROACH

Ardeshir Mahdavi[1] and Sokol Dervishi[1,2]
[1]Department of Building Physics and Building Ecology, Vienna University of Technology
Vienna, Austria
[2]Department of Architecture, EPOKA University, Tirana, Albania

ABSTRACT

This paper explores the development of high-resolution sky radiance models based on the concept of Irradiance Coefficient (IC). To develop and test such a model, detailed empirical information from a location in Vienna (Austria) was deployed. A first approximation of the model involved mean values of IC for discrete sky patches. Calculations based on this first model implementation were compared with measured data.

INTRODUCTION

Sky radiance models are of essential importance in a host of scientific and engineering applications. An especially relevant class of such applications pertains to the deployment of computational performance simulation tools towards supporting the design and operation of energy-efficient and sustainable buildings and their systems (e.g., solar-thermal collectors, photovoltaic elements).

Previous studies have addressed the comparison of a number of models for the computation of sky radiance distribution (see, for example, Liu and Jordan 1960, Klucher 1979, Hay and Davies 1980, Harrison and Coombes 1988, Skartveit and Olseth 1986, Brunger and Hooper 1993). Kittler at al. 1997 classified all sky conditions into 15 categories and prposed numerical equations to show the sky radiance distribution. CIE (2003) recommended this model as CIE Standard General Sky. Notton et al. 2006 predicted hourly solar irradiation on inclined surfaces based on the horizontal measurements using mathematical models. Vartiainen 2000, Eseev and Kudish 2009, Guemard 2009, Padovan and Del Col 2008, compared different models to predict the global solar radiation on titled surfaces in different places. The present paper further explores the possibility of developing high-resolution sky radiance models. Toward this end, we introduce the concept of Irradiance Coefficient (IC). IC denotes, for a specific location, the contribution of a discrete sky patch to the overall horizontal diffuse irradiance. IC can be formulated in terms of a probabilistic function of a number of salient variables pertinent to location and microclimatic conditions.

The present study is focused on a first exploratory and highly simplified implementation of an IC-based sky radiance model. To develop and test such a model, we deployed detailed empirical information collected at the microclimatic monitoring station of the Department of Building Physics and Building Ecology of the Vienna University of Technology, Austria. The collected information contains both typical weather station data and additional information concerning the diffuse component of the global horizontal irradiance as well as detailed sky radiance distribution.

APPROACH

Model requirement

The present research intends to contribute to the development of high-resolution sky radiance models. Such a model is expected to generate a detailed (multi-patch) sky radiance distribution map based on a limited set of input data that could be obtained from a typical weather station (e.g., air temperature and humidity, global horizontal irradiance).

The empirical basis

The empirical basis of the model development effort are primarily long term sky patch radiance values measured at the microclimatic monitoring station of the Department of Building Physics and Building Ecology (Vienna, Austria). Using a sky scanner, radiance is measured regularly (every 15 minutes) for 145 sky patches. The measurement period relevant for the purposes of the present paper was from 01.08.2010 to 30.07.2011. Two separate subsets of measurements were used for model development (3580 data points) and model test (3450 data points) purposes respectively.

The modeling principle

To generate the sky radiance model, the concept of Irradiance Coefficient (IC) was applied. Irradiance Coefficient is defined here as the ratio of irradiance due to the sky patch *i*(E_i) divided by the horizontal diffuse irradiance (E_{diff}) at a certain point (see equation 1). Note that the resulting sky radiance model accounts for the diffuse portion of the global horizontal irradiance. The direct contribution of solar radiation can be computed separately based on available algorithms.

$$IC_i = E_i \cdot E_{diff}^{-1} \qquad (1)$$

The ultimate objective of the model development effort is to derive the time and location dependent values of IC_i as a general probabilistic function of a number of relevant variables pertinent to both location information and microclimatic data. For the purposes of the present paper, a first highly simplified approximation of the IC_i is defined in terms of a set of patch-dependent constant values. Specifically, the collected empirical data (model development period) was used to derive constant terms (mean values) for 145 sky patches. Given a known value of the diffuse irradiance at a certain time interval *j* ($E_{diff,j}$), specific irradiance contribution of a sky patch *i* at time interval *j* ($E_{i,j}$) can be estimated based on the IC value of the respective patch (IC_i):

$$E_{i,j} = E_{diff,j} \cdot IC_i \quad (2)$$

Model evaluation

To evaluate the performance of this initial implementation of an IC-based sky radiance model, the estimated irradiance contributions of each patch were compared with the respective measured values (from the model test period).

RESULTS AND DISCUSSION

To illustrate the relationship between calculation-based and measurement-based irradiance values, Figure 1 includes data for all sky patches with an altitude of 78 degrees. Note that this Figure is based on the data collected for the test period and includes a variety of sky conditions (sunny, intermediate, cloudy).

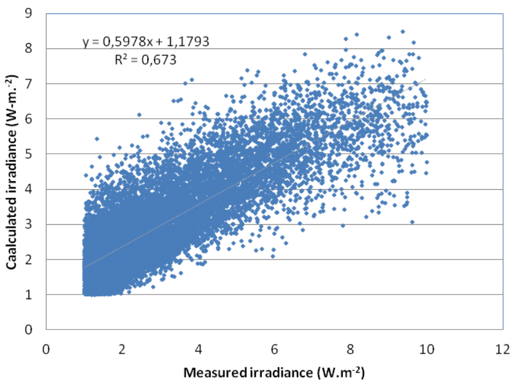

Figure 1 Measured versus calculated irradiance values for sky patches with an altitude of 78 degrees (all sky conditions)

To provide a general overview of this relationship for the entire dataset (patch altitudes from 18 to 78 degrees), two statistical indicators were applied, namely Mean Bias Difference (MBD) and Root Mean Square Deviation (RMSD) as per equations 3 and 4.The results are summarized in Table 1. Note that in this Table each altitude category includes patches with different azimuth angles that share the same altitude angle.

$$MBD = \frac{\sum_{i=1}^{n} (\frac{M_i - C_i}{M_i})}{n} \cdot 100(\%) \quad (3)$$

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n} (\frac{M_i - C_i}{M_i})}{n}} \cdot 100(\%) \quad (4)$$

Table 1
MBD and RMSD results for measured and calculated irradiance values due to all patches and all sky conditions

ALTITUDE	MBD [%]	RMSD [%]
18°	-13.3	41.8
30°	-17.1	51.1
42°	-17.6	49.7
54°	-16.3	47.9
66°	-13.7	50.6
78°	-11.5	47.2

As Figure 1 and Table 1 show, the performance of the simplified IC-based sky radiance model (using constant – mean – values) is rather modest. As it could be expected, the variance of sky patch radiance values could be quite high, leading to significant differences between calculations and measurements. One way to improve the model's predictive performance would be to filter the data in view of the relevant sky conditions. To explore this possibility, we repeated the above analysis for cloudy sky conditions only. Toward this end, the Clearness Index k_t was used as an indicator (Reindl et al. 1990). As the illustrative example of Figure 2 and the summary results in Table 2 show, categorization of the result based on the applicable sky conditions leads to a major improvement in the performance of the IC-based sky radiance model.

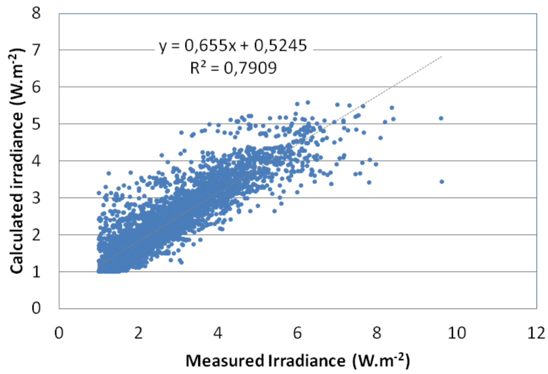

Figure 2 Measured versus calculated irradiance values for sky patches with an altitude of 78 degrees (cloudy sky conditions)

Table2
MBD and RMSD results for measured and calculated irradiance values due to all patches and cloudy sky conditions

ALTITUDE	MBD [%]	RMSD [%]
18°	-5.9	27.2
30°	-5.1	29.2
42°	-13.1	32.0
54°	-0.6	24.2
66°	4.0	23.4
78°	9.2	25.6

We expect that the performance of IC-based sky radiance models could be further improved if, as it was stated before, a more detailed probabilistic version of the concept is implemented, instead of the current matrix of averaged Irradiance Coefficients. To illustrate this point, the frequency distribution of the Irradiance Coefficient of a single patch is depicted in Figure 3.

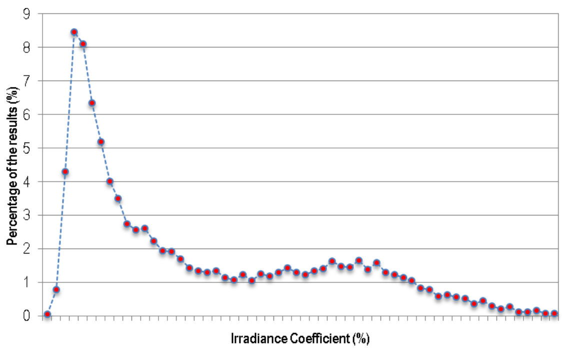

Figure 3 Frequency distribution of the Irradiance Coefficient of a single sky patch (altitude = 78 degrees, azimuth = 0 degrees) for the entire data base

Given the broad range of values involved, it is to be expected that a reduction to a single value for IC would introduce a considerable error range in the calculations.

CONCLUSION

Detailed energy-related building performance simulation use cases require detailed information on sky conditions. As detailed sky radiance maps are available only for a limited number of locations, methods and models are needed to drive such detailed sky radiance maps computationally from more readily available irradiance data. In this context, the present paper introduced an approach to generation of detailed sky radiance models based on the Irradiance Coefficient concept. The initial highly simplified application of this formalism in terms of constant IC values for discrete sky patches provided a modest performance of the entire evaluation database. The model performance improved, however, once only cloudy sky conditions were considered. Future research will explore a more detailed realization of the concept not in terms of constant values, but in terms of probabilistic functions of relevant location-dependent and microclimatic variables.

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