

COMPUTATIONAL DERIVATION OF INCIDENT IRRADIANCE ON BUILDING FACADES BASED ON MEASURED GLOBAL HORIZONTAL IRRADIANCE DATA

Ardeshir Mahdavi, Sokol Dervishi, and Bojana Spasojevic
Department of Building Physics and Building Ecology
Vienna University of Technology, Vienna, Austria

ABSTRACT

Reliable simulation of buildings' energy performance requires, amongst other things, the availability of detailed information on the magnitudes of incident solar radiation on building facades. In this paper we compare three methods to compute incident vertical irradiance values based on measured global horizontal irradiance values.

INTRODUCTION

Availability of reliable information on the magnitudes of incident solar radiation on building facades is required for a number of applications. For example, such information is important in view of: *i*) dependable simulation of the energy performance of buildings in general and solar gains in particular; *ii*) the design of exterior and interior shading devices; *iii*) effective real-time control of shading devices without the need for intricate measurement devices. However, only for relatively few locations detailed measured data concerning incident solar radiation on vertical (or otherwise inclined) surfaces are available. Concurrent measurements of horizontal global and horizontal diffuse (or direct normal) irradiance data are likewise available only for a limited number of locations. In contrast, the measurement of global horizontal irradiance is rather simple and cost-effective. It can be, conceivably, an integral part of the sensory equipment of every building. The question is, then, if incident irradiance values on vertical (or otherwise inclined) building surfaces can be computationally derived from measured global irradiance levels in a manner both reliable and convenient. Given this context, we applied three methods to compute incident vertical irradiance values based on measured global horizontal irradiance values. We then compared these computationally derived values with corresponding measurements to rank the methods' performance.

APPROACH

The research design involved the following steps:

1. To computationally derive vertical irradiance values from measured global horizontal irradiance values, three methods were considered. The first method (referred to here as "H&K") is based on a procedure suggested by Heindl and

Koch 1976. It allows for the calculation of incident solar radiation on arbitrary surfaces based on input data including date, time, location, orientation of the receiving surfaces as well as a number of meteorological parameters. The second method (referred to here as "RAD") involves the use of the simulation application RADIANCE (Ward Larson and Shakespeare 2003). In this case, the sky model for simulation of the incident radiation on vertical surfaces was the Perez All-weather model (Perez et al. 1993). As this model requires the input of both direct normal and diffuse radiation, an algorithm suggested by Reindl (Reindl et al. 1990) was used. This algorithm allows deriving from measured global horizontal irradiance values the corresponding diffuse components. Based on the resulting direct horizontal irradiance values the direct normal values can be calculated using standard trigonometric functions. The third method (referred here to as "MET") involved the use of the application METEONORM (2005). This application allows, amongst other things, for the estimation of radiation incident on arbitrarily oriented surfaces based on available measured global horizontal irradiance and outdoor air temperature values.

2. Over a period of 16 days global horizontal irradiance and illuminance levels as well as vertical illuminance levels on four vertical surfaces (south, west, north, and east) were measured on an unobstructed roof area or our university building. Measurements were taken every 15 minutes. From these measured illuminance levels corresponding irradiance levels were derived using the simultaneously determined luminous efficacy values.
3. Calculated and measured irradiance values on these four vertical surfaces were compared.

RESULTS

Figures 1 to 15 illustrate the relationship between measured irradiance levels and the corresponding calculations based on the three above-mentioned methods (Figures 1 to 5: H&K; Figures 6 to 10: MET; Figure 11 to 15: RAD). Figure 16 illustrates the cumulative relative error values for all three methods.

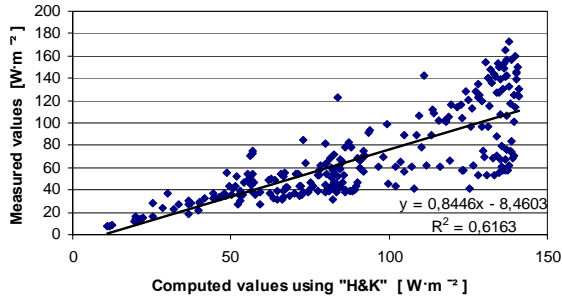


Figure 1 Comparison for H&K; Orientation: North

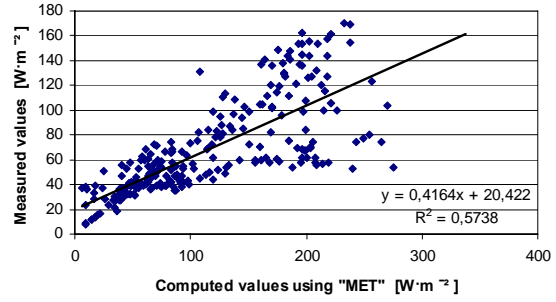


Figure 6 Comparison for MET; Orientation: North

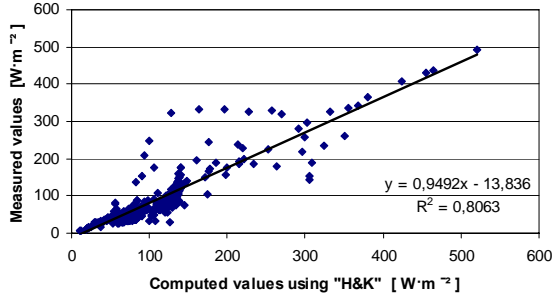


Figure 2 Comparison for H&K; Orientation: East

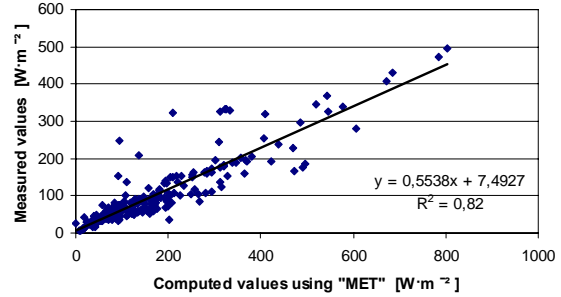


Figure 7 Comparison for MET; Orientation: East

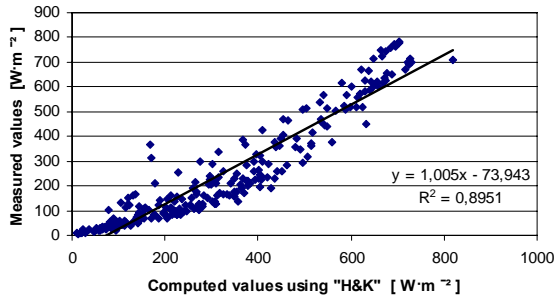


Figure 3 Comparison for H&K; Orientation: South

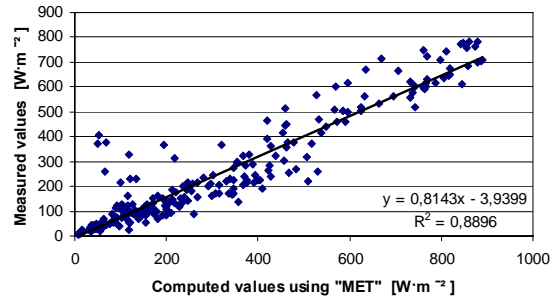


Figure 8 Comparison for MET; Orientation: South

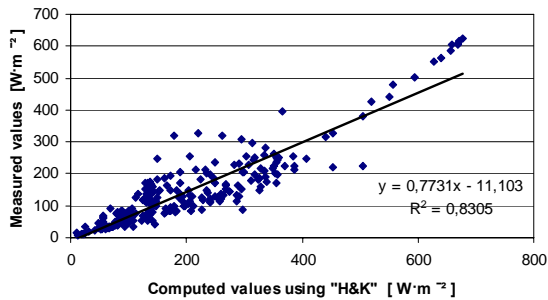


Figure 4 Comparison for H&K; Orientation: West

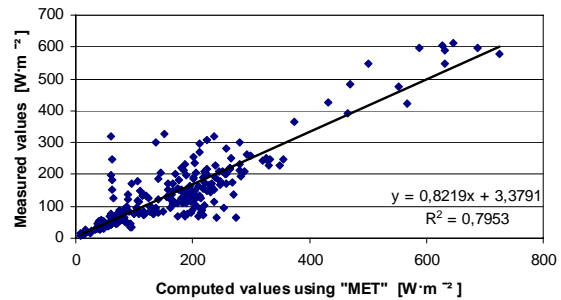


Figure 9 Comparison for MET; Orientation: West

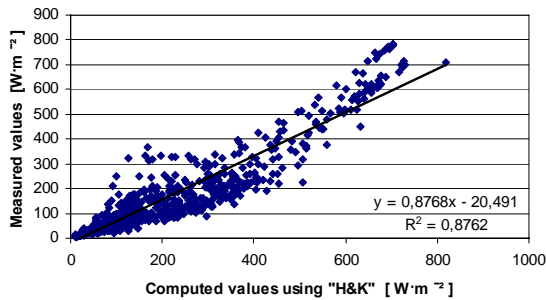


Figure 5 Comparison for H&K; All orientations

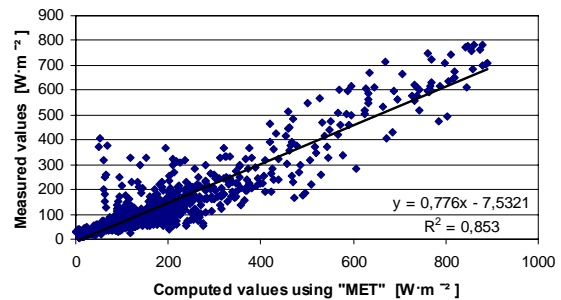


Figure 10 Comparison for MET; All orientations

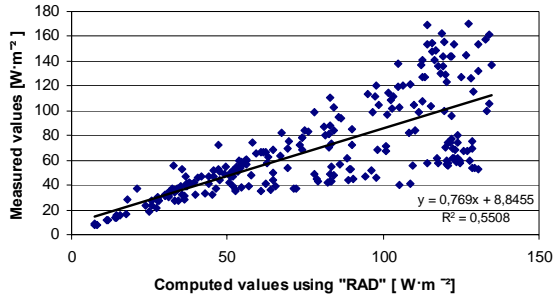


Figure 11 Comparison for RAD; Orientation: North

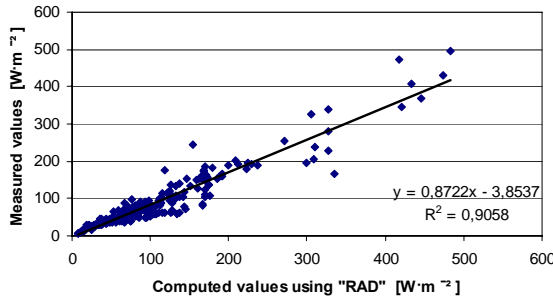


Figure 12 Comparison for RAD; Orientation: East

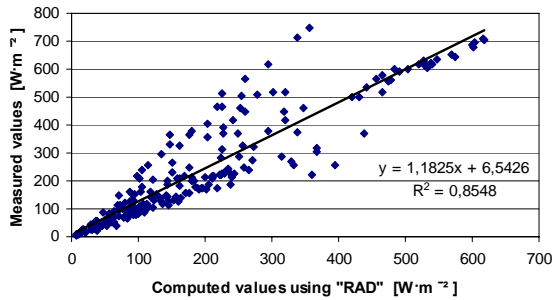


Figure 13 Comparison for RAD; Orientation: South

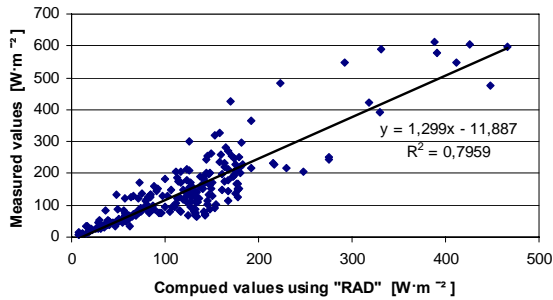


Figure 14 Comparison for RAD; Orientation: West

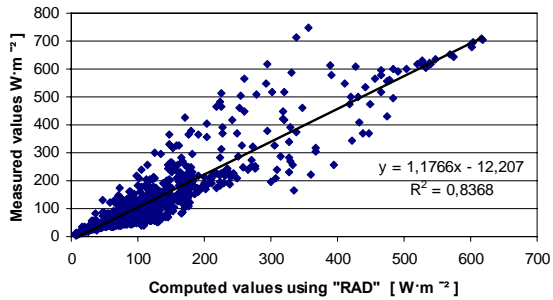


Figure 15 Comparison for RAD; All orientations

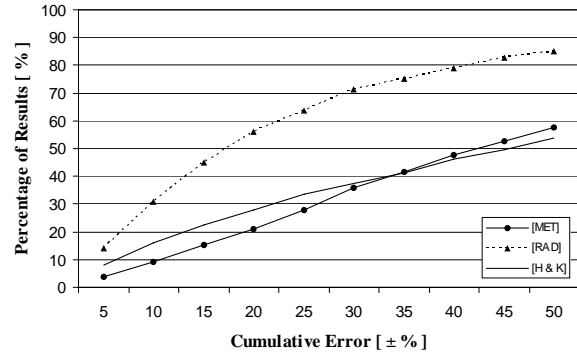


Figure 16 Comparison of Relative errors of computed vertical irradiance values for the three methods (Met, RAD, H&K) and all orientations

DISCUSSION

As Figure 16 implies, RAD (computation using RADIANCE and the Reindl algorithm) works best amongst the three methods considered in this paper. Some 55% of data (measurement-calculation comparisons for all four directions) show a relative error less than 20%. Some 85% of data show a relative error of less than 50%.

CONCLUSION

Vertical irradiance levels can be conveniently derived from measurements of global horizontal irradiance. Thereby, the degree of achievable accuracy varies considerably. The best performing method out of the three considered here may provide acceptable results for applications that are content with rough estimations.

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REFERENCES

- Meteonorm 2005. Global meteorological database. Version 5.1. URL: www.meteonorm.com.
- Perez, R., Seals, R., Michalsky, J. 1993. All-weather model for sky luminance distribution - preliminary configuration and validation. Solar Energy Vol. 50, No. 3, pp. 235-245.
- Reindl, D.T., Beckman, W.A., Duffie, J.A. 1990. Diffuse fraction correlations. Solar Energy Vol. 45, No. 1, pp. 1-7.
- Ward Larson, G., Shakespeare, R. 2003. Rendering with Radiance: The Art and Science of Lighting Visualisation. Revised Edition. Space and Davis, CA, USA.