Satellight
Commission of the European Communities

DNMI
Det norske meteorologiske institutt

Third SATELLIGHT meeting, Les Marecottes January 16/17 1997

TEST OF A LUMINOUS EFFICACY MODEL ON ILLUMINANCE/IRRADIANCE DATA FROM 4 EUROPEAN IDMP STATIONS

by

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SATELLIGHT Programme JOR3-CT950041
First draft, November 1996

1. INTRODUCTION

Most radiation-driven processes are spectrally selective, like the photosynthesis or the erythemal response of human skin to ultraviolet radiation. Equally well-known is the concept of daylight, i.e. solar radiation evaluated in proportion to its capability of stimulating the human eye. Even though daylight data are in great demand, they frequently have to be estimated from prescribed luminous efficacies and observed or estimated beam and diffuse irradiance.

The present note deals with observed and modelled relationships between irradiance and illuminance measured on horizontal surfaces.

2. DATA

Data from the European General class IDMP stations at Lisboa (38°46'N, 9°08'W, 106 m above m.s.l.; year 1993 + January-June 1994), Lyon (Vaulx-en-Valin, 45°47'N, 4°56'E, 170 m above m.s.l.; year 1994), and the Research class station at Garston (51°43'N, 0°22'W, 80 m above m.s.l.; year 1992) were gratefully received from D. Dumortier at ENTPE, Lyon. Besides, data from the Swedish General class IDMP station Gävle-Brynäs (60°40'N, 17°10'E, 16 m above m.s.l.; year 1995) were gratefully received from H. A. Löfberg at the Royal Institute of Technology, Department of Built Environment. Global and diffuse horizontal irradiances are measured by Kipp&Zonen CM6 pyranometers at Lisboa and Lyon, and by Kipp&Zonen CM11 pyranometers at Garston and Gävle, while the similar illuminances are measured by Licor LI-210 SA sensors at Lisboa, by Licor LI-210 SZ sensors at Gävle, and by LMT BAP 30FCT sensors at Lyon and Garston. The sensors for diffuse irradiance/illuminance are shaded with shadow rings in Lisboa (7.7 cm width, 31.5 cm radius), Lyon (irradiance: 5 cm width, 17.8 cm radius, and illuminance: 5.4 cm width, 27.5 cm radius), and Garston (5.0 cm width, 25.4 cm radius), and with sun tracking shading disks in Gävle (7 cm radius, 70 cm distance). In Garston, normal beam irradiance/illuminance is also recorded, using Eppley solar trackers. For Lisboa, Lyon, and Garston our model is run with their climatological average monthly water vapour amounts [1]. Since Gävle and Bergen are at the same latitude, the model is run with the same monthly water vapour amounts as those estimated for Bergen (0.8-1.9 cm).

3. THE LUMINOUS EFFICACY MODEL

The luminous efficacy model [2] is based on the CIE curve for photopic vision and spectral irradiances obtained by an interpolation between transmittance models for, respectively, cloudless sky [3] and unbroken cloud cover [4]. This interpolation decomposes the diffuse irradiance into "blue sky", "dark cloud", and "bright cloud" irradiance. For partly cloudy cases, the model was slightly tuned to hourly global illuminance and irradiance from Bergen. The parameterized version of the model requires solar elevation, day of year, and diffuse and beam clearness indices as input. In the case of beam irradiation, the model is slightly modified here to explicitly account for variation in column amount of water vapour, under the assumption that water vapour extinction takes place solely at visible wavelengths. Moreover, in the case of diffuse irradiation the model is tuned to data from Albany, NY [5] by multiplying the difference between "dark cloud" efficacy and extraterrestrial efficacy by a factor 0.7.

4. MODELLED VERSUS OBSERVED ILLUMINANCE.

"Modelled" diffuse/beam illuminance is obtained by transforming observed horizontal diffuse/beam irradiance into illuminance by the luminous efficacy model [2].

At Garston, the beam irradiance/illuminance is measured directly by a tracking sensor or differentially as the difference between measured global and measured (shadow ring) diffuse. Similarly, the diffuse irradiance/illuminance is measured directly by the use of shadow ring, or differentially as the difference between measured global and measured (tracker) beam. Apart from a few outliers, most probably due to alignment problems, the conformity between directly and differentially measured fluxes is nice over the entire solar elevation range (Fig. 1).

The degree of conformity between directly and differentially measured fluxes varies, however, slightly between irradiances (Fig. 1a-b) and illumiances (Fig. 1c-d). This makes luminous efficacy calculated from observed fluxes sensitive to the choice between directly and differentially measured fluxes. Not unexpectedly, it turns out that this sensitivity is most pronounced in cases when the differentially observed flux is a small difference between two comparatively large numbers. That is, for beam efficacy the sensitivity is most pronounced in the "low beam" case while it for diffuse efficacy is most pronounced in the "high beam" case and in the case of low solar elevation (< 10°, Fig 2a). Moreover, diffuse efficacies calculated from directly observed fluxes conform better with our model than do diffuse efficacies calculated from differentially observed fluxes (Fig. 2c). It is not equally obvious wether beam efficacies calculated from directly observed fluxes or efficacies calculated from differentially observed fluxes conform best with our model (Fig. 2b-c). The conformity (Fig. 2a) between modelled efficacies and efficacies calculated from directly observed fluxes demonstrates that our model nicely reproduces how beam efficacy as well as diffuse luminous efficacy on the average depend on cloudiness and solar elevation.

For each of the stations separately and for all four stations collectively, Figs. 3-4 show distributions of hourly observed illuminances/luminous efficacies along with distributions of "deviations" (= differences between observed and modelled values). The individual deviations cover a quite narrow range in the case of illuminances, while the corresponding range is more significant in the case of luminous efficacy (Figs. 3-4). Fig. 5 shows corresponding median values of observed and modelled illuminances/luminous efficacies along with median deviations of illuminances/luminous efficacies. It is seen that the median illuminance deviations are small compared both to the differences between the four stations and to the differences between global, diffuse and beam illuminances (Fig. 5, left). The same applies to a somewhat lesser extent to luminous efficacies, except for some differences between stations with respect to beam luminous efficacy. For both illuminances and luminous efficacies the smallest deviations are seen at the Research Class station Garston and for the four stations collectively (Figs. 3-5). It is also seen that the deviation in global luminous efficacy varies less than does the deviation in both diffuse and beam luminous efficacies, both at each station separately (Fig. 3) and between the four stations (Fig. 5, right).

5. CONCLUDING REMARKS

Luminous efficacy calculated from observed fluxes is sensitive to the choice between directly and differentially observed fluxes, and most so in the case of low solar elevation and in cases where the differentially observed flux is a small difference between two comparatively large numbers.

The conformity between modelled efficacies and efficacies calculated from directly observed fluxes (Garston) demonstrates that our luminous efficacy model nicely reproduces how beam as well as diffuse luminous efficacy on the average depend on cloudiness and solar elevation.

Among 1 Research and 3 General class European IDMP stations, the median half-hourly deviations (observed - modelled) are small compared both to differences between stations and to differences between global, beam and diffuse illuminances/efficacies. Moreover, these deviations are smallest at the Research class station (Garston).

6. REFERENCES

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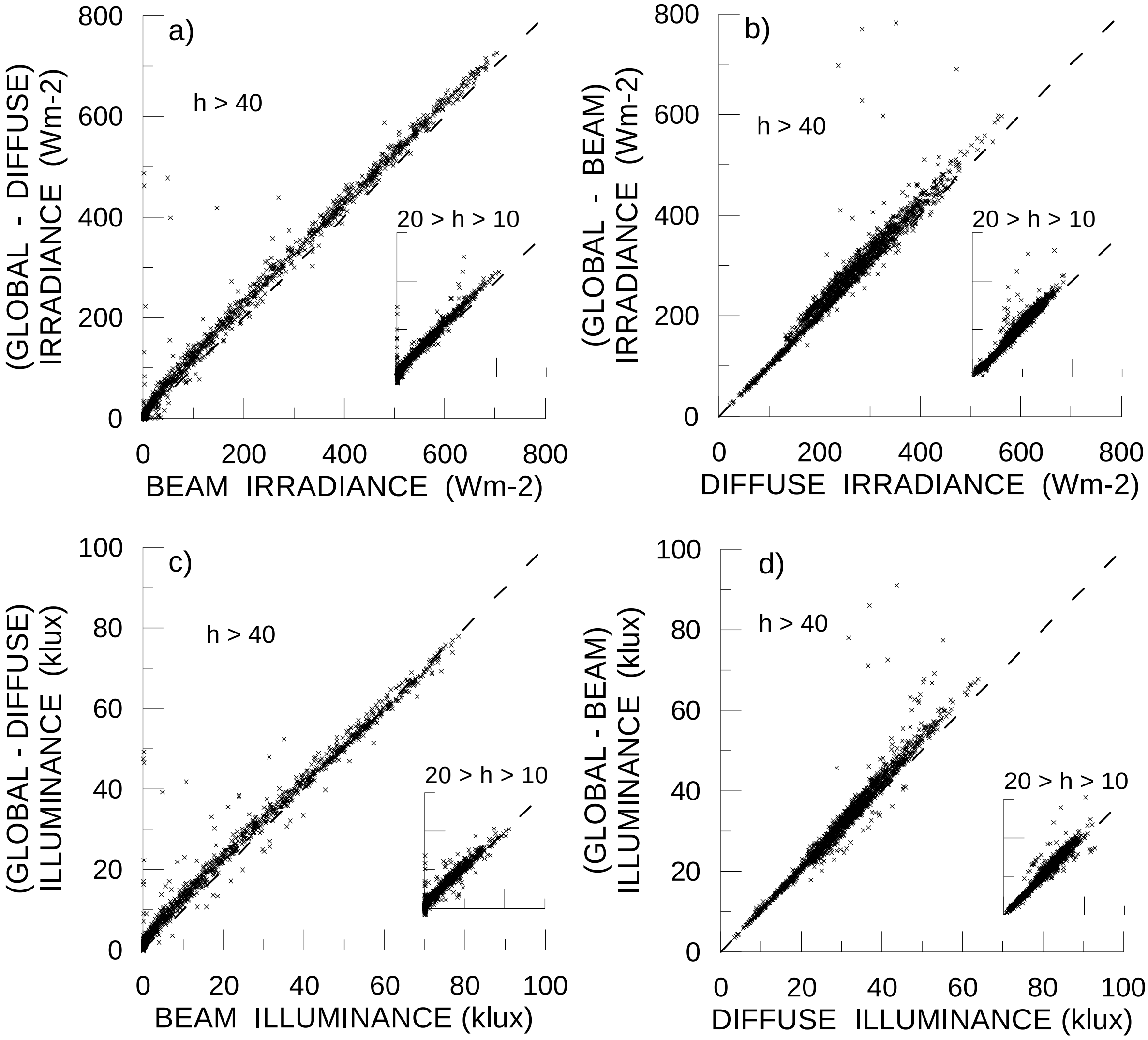

Fig. 1 Differentially observed beam/diffuse irradiance/illuminance plotted vs their directly observed counterparts on the abscissa (see text). One year of half-hourly data from Garston and 1:1 lines are plotted within two solar elevation ranges.

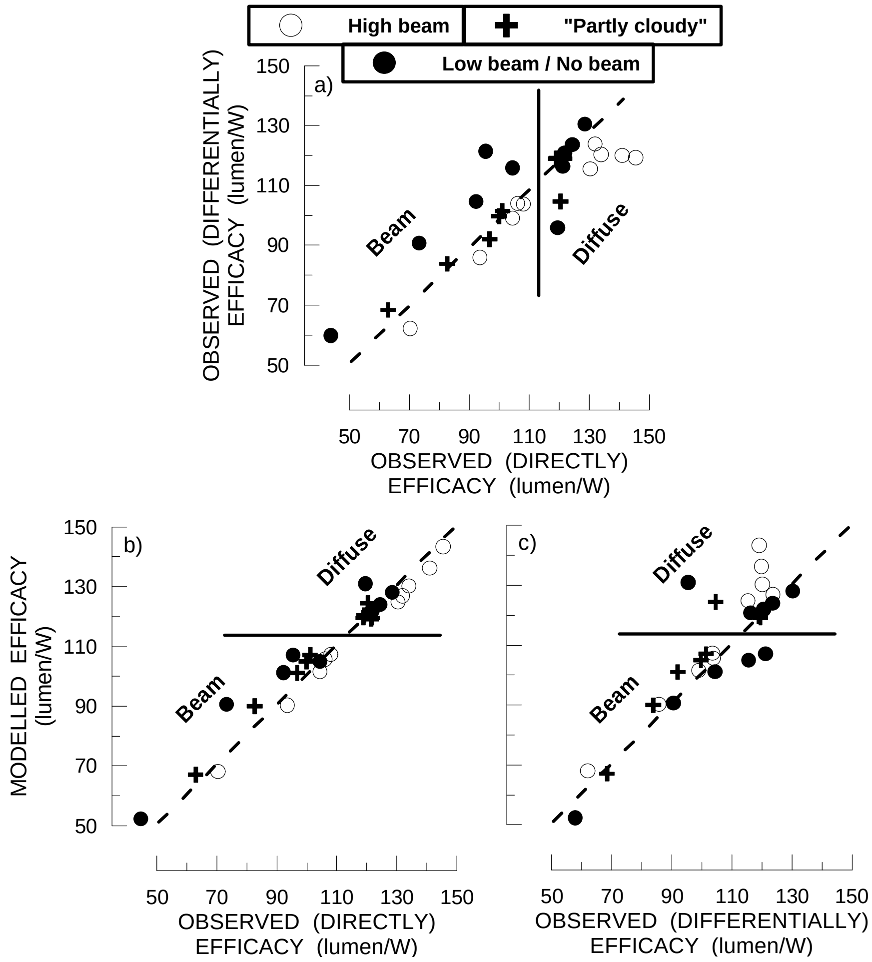

Fig. 2 One year of half-hourly Garston data divided into 5 solar solar elevation groups (<10°; 10-20°; 20-30°; 30-40°; >40°) and three normal incidence beam irradiance groups A - C (A: "High beam" > 90% of average cloudless value; B: 20 Wm^{-2} < "Low beam" < 120 Wm^{-2} or "No beam" = 0 Wm^{-2}; C: "Partly cloudy" - beam irradiance intermediate between "high beam" and "low/no beam"). Fully drawn lines separate group mean beam and diffuse efficacies, and 1:1 lines are drawn as broken lines:

a) Efficacies of differentially observed fluxes plotted vs efficacies of directly observed fluxes.

b) Modelled efficacies plotted vs efficacies of directly observed fluxes.

c) Modelled efficacies plotted vs efficacies of differentially observed fluxes.

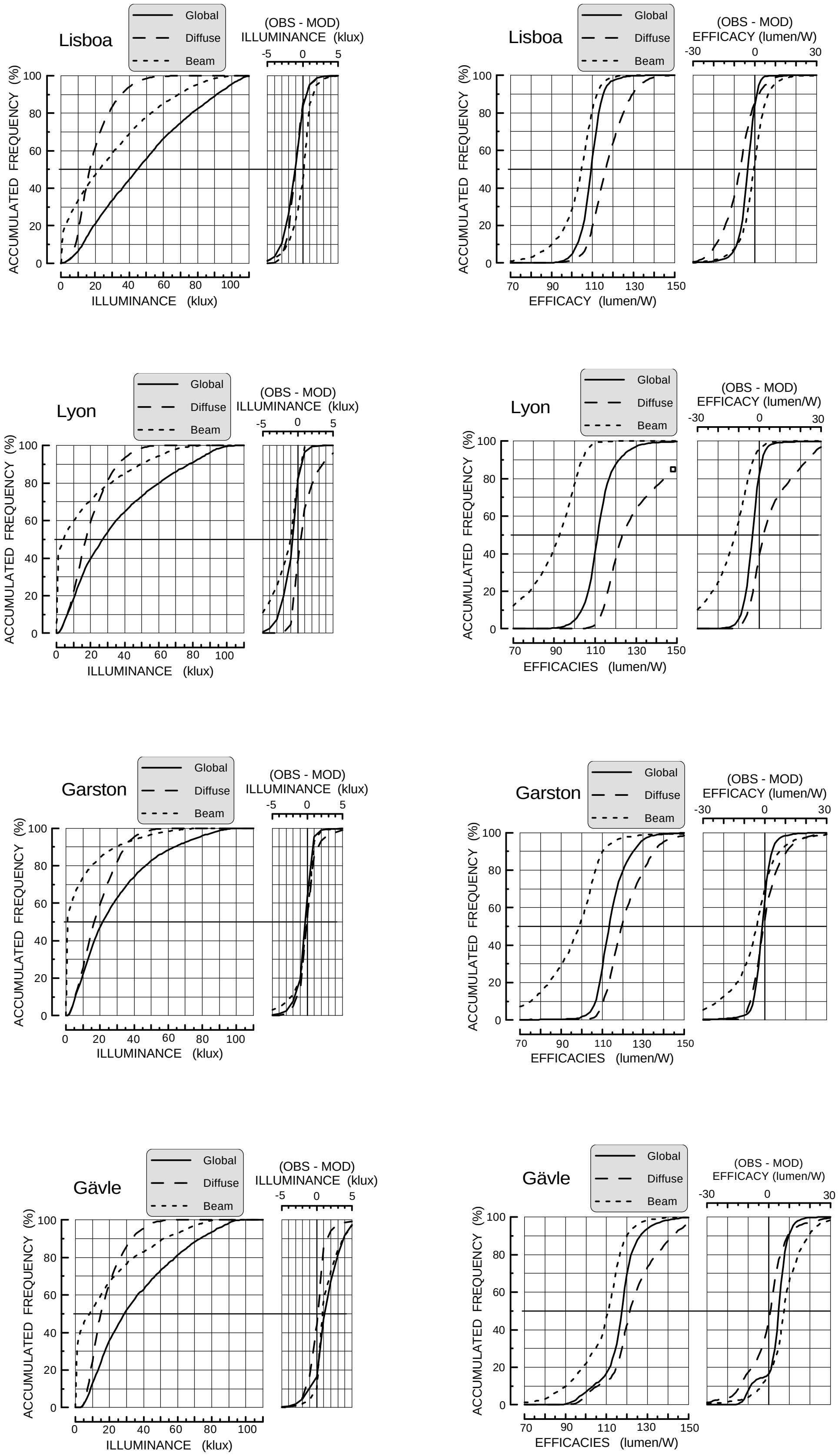

Fig. 3 Left: Accumulated frequency distribution of directly observed global and diffuse illuminances and differentially observed beam illuminance together with accumulated distribution of observed - modelled illuminances for Lisboa, Lyon, Garston, and Gävle. Solar elevations > 10^o.

Right: Corresponding distributions for luminous efficacies.

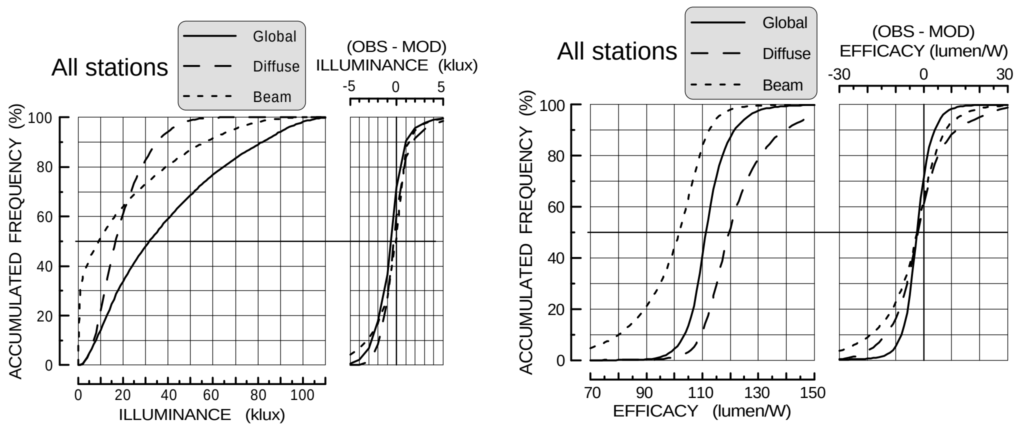

Fig. 4 Left: Accumulated frequency distribution of directly observed global and diffuse illuminances and differentially observed beamilluminance together with accumulated distribution of observed - modelled illuminances for all 4 stations in Fig. 3. Solar elevations $> 10^o$.
Right: Corresponding distributions for luminousefficacies

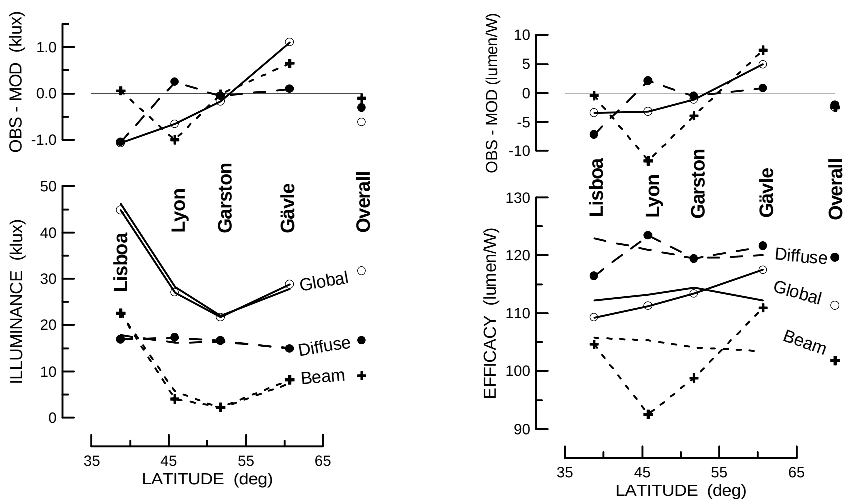

Fig. 5 Bottom: Median values of observed (curves with symbols) and modelled (curves without symbols) illuminances (left) and luminousefficacies (right).
Top: Median differences between observed and modelledilluminances (left) and luminous efficacies (right).