INTRODUCTION

The combination of the PowerWise shadow ring and a pyranometer offers a simple solution for the measurement of the diffuse solar radiation.

Specific advantages of this type of shadowing are that it is suitable for installation anywhere on earth (contrary to designs that require the specification of a particular latitude), that it can be combi- ned with a ventilation unit, and that it has a special U-profile ring which simplifies the mathematical correction for intercepted diffuse radiation.

The shadow ring will keep the pyranometer in the shade during the entire day, preventing the direct solar radiation to reach the sensor. As a result only the diffuse solar radiation is measured. A regular schedule of maintenance would require manual adjustment of the sliding bars (that are connected to the actual shadow ring) every two days. This adjustment is necessary because the elevation of the solar course changes slightly from day to day. For proper setting of the sliding bars, the table of “correction factors and the sliding bar setting” can be consulted.

The unit can be installed everywhere on earth. Normally the pyranometer will be in the horizontal position, alternatively it can be mounted in tilted positions along the north-south axis.

The ring itself is equipped with a special U-profile so that it has a nearly constant view angle during the year. A stable stand is guaranteed even at high winds.

Naturally, the shadow ring intercepts also a proportion of the diffuse sky radiation.
A correction factor for this effect is recommended to be used as a refinement of the measurement. A table of correction factors is combined with the table for sliding bar setting.

PowerWise Shadow Ring Technical info.

MEASUREMENT OF THE DIFFUSE SKY RADIATION

The shadow ring correction

A pyranometer equipped with a shadow ring is measuring the downward diffuse solar radiation as received by a horizontal surface from a solid angle of 2π with the exception of the solid angle subtended by the shadow ring.

To obtain an estimation of the radiation that would be received from the whole hemisphere if the ring were not present, a correction must be introduced. Such a correction factor is a function of the solid angle subtended by the ring part and the sliding bars of the PowerWise Shadow Ring and their altitude above the pyranometer horizon.

The special U-profile of the shadow ring offers the advantage that the intercepted circumsolar part of the sky is far more constant during the year compared to an I-profile (flat) shadow band.

The correction presented here is for the case of uniform sky radiation. The intercepted part can easily be calculated. A list with correction factors is supplied.
It is possible to use more refined models, assuming a more realistic distribution of the radiation across the sky, however it is difficult to indicate how much improvement can be attained doing this as these models tend to depend on empirically obtained data. A brief discussion concerning this problem is found on page 429 of the International Geophysical Year instruction manual 1958, Pergamon Press, London, Paris, New York.

The table is arranged so that the correction factors for particular latitude are in one row. The factors are computed for declinations of - 24^0 to + 24^0 with intervals of two degrees.
The declination and the date are related to each other. On the top and the bottom of the table there is a row with the corresponding date intervals, the upper row for increasing declination, the lower one for decreasing declination.

Diffuse sky radiation on a tilted plane

The correction factors are only valid for a pyranometer in the horizontal position.
However, for a pyranometer tilted T degrees to the south and on latitude B, the configuration of ring and pyranometer is the same as for a horizontal pyranometer at latitude (B - T) degrees.
You can derive a list of correction factors for a tilted pyranometer f taking into account that only part of the hemisphere is 'seen' by the pyranometer. However, this correction does not take the effect of ground-reflected radiation into account. The correction for this is very much dependant on local conditions and might vary throughout the day as a function of the solar position, and throughout the year as a function of ground properties. Therefore this is the responsi-bility of the customer.

MONTH		JAN			FEB					MAR						APR					MAY				JUN	
DAY OF MONTH		1	17	26	2	8	15	21	26	3	9	14	19	24	29	3	8	14	19	25	2	9	16	26	11	
	90	1	1	1	1	1	1	1	1	1	1	1	1	1	1.01	1.03	1.04	1.05	1.07	1.08	1.10	1.11	1.12	1.13	1.15	1.16
	85	1	1	1	1	1	1	1	1	1	1	1	1	1.01	1.02	1.03	1.04	1.05	1.07	1.08	1.09	1.11	1.12	1.13	1.15	1.16
	80	1	1	1	1	1	1	1	1	1	1.01	1.01	1.01	1.02	1.03	1.04	1.04	1.05	1.07	1.08	1.09	1.11	1.12	1.13	1.15	1.16
	75	1	1	1	1	1	1	1	1.01	1.01	1.01	1.02	1.03	1.03	1.04	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.12	1.13	1.14	1.15
	70	1	1	1	1	1	1.01	1.01	1.01	1.02	1.02	1.03	1.04	1.04	1.05	1.06	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.13	1.14	1.15
NORTHERN	65	1	1	1	1.01	1.01	1.01	1.02	1.02	1.03	1.03	1.04	1.05	1.05	1.06	1.07	1.07	1.08	1.09	1.10	1.10	1.11	1.12	1.13	1.13	1.14
LATITUDE	60	1.01	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.04	1.04	1.05	1.06	1.06	1.0	1.08	1.08	1.09	1.10	1.10	1.11	1.12	1.12	1.13	1.14	1.14
	55	1.01	1.02	1.02	1.02	1.03	1.03	1.04	1.04	1.05	1.05	1.06	1.07	1.07	1.08	1.08	1.09	1.10	1.10	1.11	1.12	1.12	1.13	1.13	1.14	1.14
	50	1.02	1.02	1.03	1.03	1.04	1.04	1.05	1.05	1.06	1.06	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.12	1.12	1.13	1.13	1.13	1.14	1.14
	45	1.03	1.03	1.04	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.13	1.13	1.13	1.14	1.14	1.14
	40	1.04	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.13	1.13	1.13	1.14	1.14	1.14	1.14
	35	1.05	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.14	114	1.14	1.14	1.14
	30	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.14	1.14	1.14	1.14	1.14
	25	1.07	1.07	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.14	1.14	1.14	1.14	1.14	1.14
	20	1.08	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.14	1.14	1.14	1.14	1.14	1.14	1.13
	15	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
	10	1.09	1.10	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12
	5	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.12	1.12
EQUATOR	0	1.11	1.11	1.12	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.12	1.11	1.11
	5	1.12	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.12	1.11	1.11	1.11	1.10
	10	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.11	1.11	1.11	1.10	1.10	1.09
	15	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.11	1.11	1.11	1.10	1.10	1.09	1.09	1.08
	20	1.13	1.13	1.13	1.14	1.14	1.14	1.14	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.11	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.08	1.08
	25	1.14	1.14	1.14	1.14	1.14	1,14	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.11	1.11	1.10	1.10	1.09	1.09	1.09	1.08	1.08	1.07	1.07
SOUTHERN	30	1.14	1.14	1.14	1.14	1.14	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.11	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.08	1.07	1.07	1.06	1.06
LATITUDE	35	1.14	1.14	1.14	1.14	1.14	1.13	1.13	1.13	1.12	1.12	1.12	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.08	1.08	1.07	1.07	1.06	1.05	1.05
	40	1.14	1.14	1.14	1.14	1.13	1.13	1.13	1.12	1.12	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.08	1.07	1.07	1.06	1.06	1.05	1.05	1.04	1.04
	45	1.14	1.14	1.14	1.13	1.13	1.13	1.12	1.12	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.07	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.03	1.03
	50	1.14	1.14	1.13	1.13	1.13	1.12	1.12	1.11	1.10	1.10	1.09	1.09	1.08	1.08	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.03	1.03	1.02	1.02
	55	1.14	1.14	1.13	1.13	1.12	1.12	1.11	1.10	1.10	1.09	1.08	1.08	1.07	1.07	1.06	1.05	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.01
	60	1.14	1.14	1.13	1.12	1.12	1.11	1.10	1.10	1.09	1.08	1.08	1.07	1.06	1.06	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.01	1.01	1.01
	65	1.14	1.13	1.13	1.12	1.11	1.10	1.10	1.09	1.08	1.07	1.07	1.06	1.05	1.05	1.04	1.03	1.03	1.02	1.02	1.01	1.01	1.01	1	1	1
	70	1.15	1.14	1.13	1.13	1.11	1.10	1.09	1.08	1.07	1.06	1.06	1.05	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.01	1	1	1	1	1
	75	1.15	1.14	1.13	1.12	1.10	1.09	1.08	1.07	1.06	1.05	1.05	1.04	1.03	1.03	1.02	1.01	1.01	1.01	1	1	1	1	1	1	1
	80	1.16	1.14	1.13	1.12	1.11	1.09	1.08	1.07	1.05	1.04	1.04	1.03	1.02	1.01	1.01	1.01	1	1	1	1	1	1	1	1	1
	85	1.16	1.15	1.13	1.12	1.11	1.09	1.08	1.07	1.05	1.04	1.03	1.02	1.01	1	1	1	1	1	1	1	1	1	1	1	1
	90	1.16	1.15	1.13	1.12	1.11	1.10	1.08	1.07	1.05	1.04	1.03	1.01	1	1	1	1	1	1	1	1	1	1	1	1	1
DAY OF MONTH		12	27	18	10	4	29	23	17	12	7	1	26	21	16	11	5	31	25	19	13	6	29	19	3	
MONTH		DEC	NOV				OCT					SEPT						AUG					JUL			
SOLAR DECLINATION		-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22	24
SLIDING BAR SETTING		132	120	108	97	85	74	63	52	42	31	21	10	0	10	21	31	42	52	63	74	85	97	108	120	132

table 1 correction factors and sliding bar setting

please note *That the correction factors are based on the assumption horizontal pyranometer installation and on uniform diffuse sky irradiance.*

please note *That the sliding bar has two scales; a higher and alower one. At positive solar declinations (between 21 march and 23 sept) the part of the scale that is oriented south must be read. In the northern hemisphere this is the lower part.*

APPENDIX

Theoretical derivation of the correction factor, for uniform sky radiation

The relation between the correction factor C and the intercepted part S of the downward component of the sky radiation is

$$C = 1 / (1 - S)$$

S can be expressed in the view angle V of the ring, the sun's declination D and the latitude B of the observation site.
Let U_0 be the angle between the sun at sunrise (or at sunset) and the sun at true noon in the plane of the ring.
U_0 is computed with the formula:

$$\cos U_0 = - \tan B \,.\, \tan D$$

Let us consider a part of the ring subtending a solid angle V.dU as seen from point M, the center of the ring, and as seen from the pyranometer of

$$V \,.\, \cos D \,.\, dU$$

V is assumed to be constant within the range of D, due to the special U-profile shadow ring.
Not every part of the ring equally affects the total downward component of the sky. This is because this component is proportional with the cosine of its zenith angle Z. Radiation with a zenith angle Z within this solid angle causes a downward component

$$L \,.\, V \,.\, \cos D \,.\, \cos Z \,.\, dU$$

L is the radiance (= brightness) of the sky in W/m2 sr. L is assumed to be uniform over the complete sky. So the complete ring part above the horizon intercepts a downward corn-ponent

$$2L \,.\, V \,.\, \cos D \,.\, \int_0^{U_0} \cos Z \,.\, dU$$

Z can be expressed in the declination D, latitude B and time (by the hour angle U) with the formula

$$\cos Z = \sin B \,.\, \sin D + \cos B \,.\, \cos D \,.\, \cos U$$

After integrating we find the total intercepted downward radiation to be

$$2L \,.\, V \,.\, \cos D \,.\, (U_0 \,.\, \sin B \,.\, \sin D + \sin U_0 \,.\, \cos B \,.\, \cos D)$$

The total irradiance of a horizontal surface by a sky with radiance L (W/m2 sr) is L (W/m2).
The intercepted part S of the sky radiation therefore is

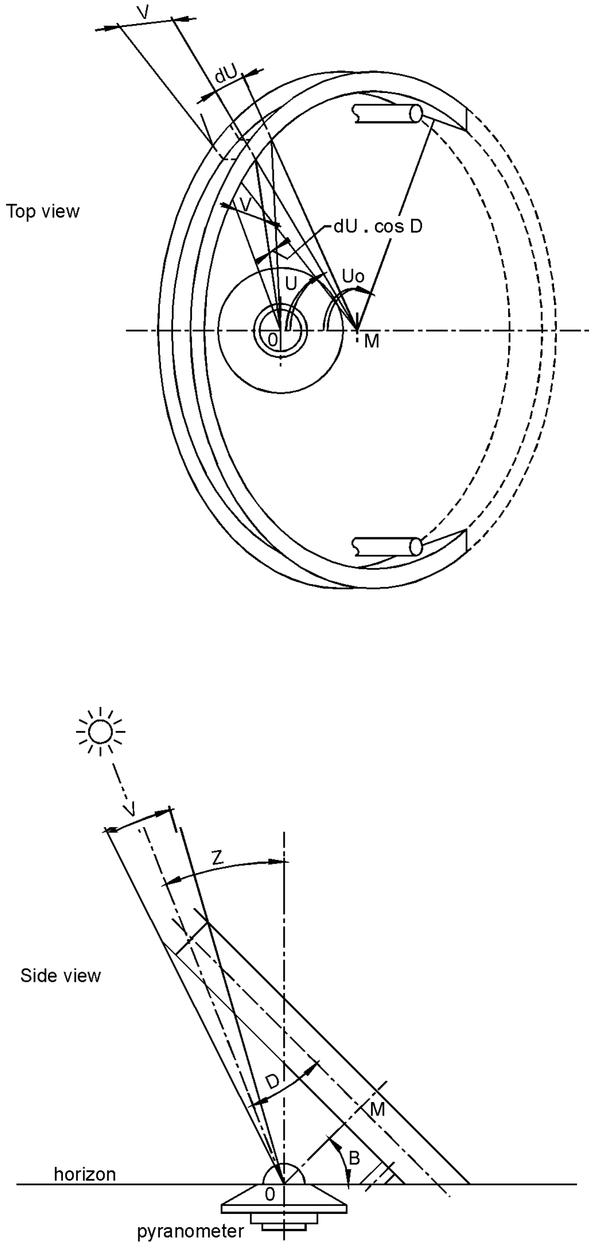
$$S = 2V \,.\, \cos D \,.\, (U_0 \,.\, \sin B \,.\, \sin D + \sin U_0 \,.\, \cos B \,.\, \cos D) / \pi$$

From this formula the list of correction factors is computed taking into account formula and V = 0.185 rad. Mind that U_0 is in radians.
Actually V varies within 2% in dependence of the declination D but this gives only rise to an error less than ± 0.5% in the calculated correction factors.

The influence of the sliding bar parts rising above the horizon is neglected.
To compare: the formula for a flat shadow band is

$$S = 2W \,.\, \cos3 \,.\, D \,.\, (U_0 \,.\, \sin B \,.\, \sin D + \sin U_0 \,.\, \cos B \,.\, \cos D) \,/\, \pi.\, R$$

W is the ring width and R is the ring radius.



the view angle of the U-profile shadow ring as a function of the solar declination, in comparison to a conventional flat shadow band. It is shown that the Shadow Ring has superior performance, as a result less seasonally variation of errors.

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