TECHNICAL PAPERS SUPPORTING SAP 2012

SAP

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Calculation of solar radiation in SAP 2012 (revised version June 2014)

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Summary

This paper describes the method used in SAP 2012 to calculate solar radiation on vertical or inclined surfaces at different orientations.

SAP 2009's capability to deal with solar panels was limited by the use of lookup tables as the source of the solar radiation figure. It was therefore desirable to develop a new calculation procedure to estimate solar radiation data for a panel pointing in any direction, and in any region of the UK.

Data for a number of sites was analysed and trends in its variation noted. Equations approximating the observed solar radiation levels were derived. The method developed was tested against the source data and sense checked by the use of further examples to ensure it gave reliable and reasonable figures in all cases.

The procedure developed provides a simple, reliable and considerably more flexible way of calculating monthly solar radiation figures for use in SAP.

The original version of STP11/SR01 was published on the SAP 2012 website in connection with the consultation on SAP 2012 undertaken during Spring 2012. This paper is a revised version taking account of amendments to SAP 2012 following the consultation.

Contents

1 Introduction

SAP 2012 contains a table of data showing the average radiation incident on a horizontal surface during each month of the year, for each region. However, it is necessary to estimate from this the amount of solar radiation incident on windows (which are usually vertically inclined) and solar devices which are often inclined at the pitch of the roof.

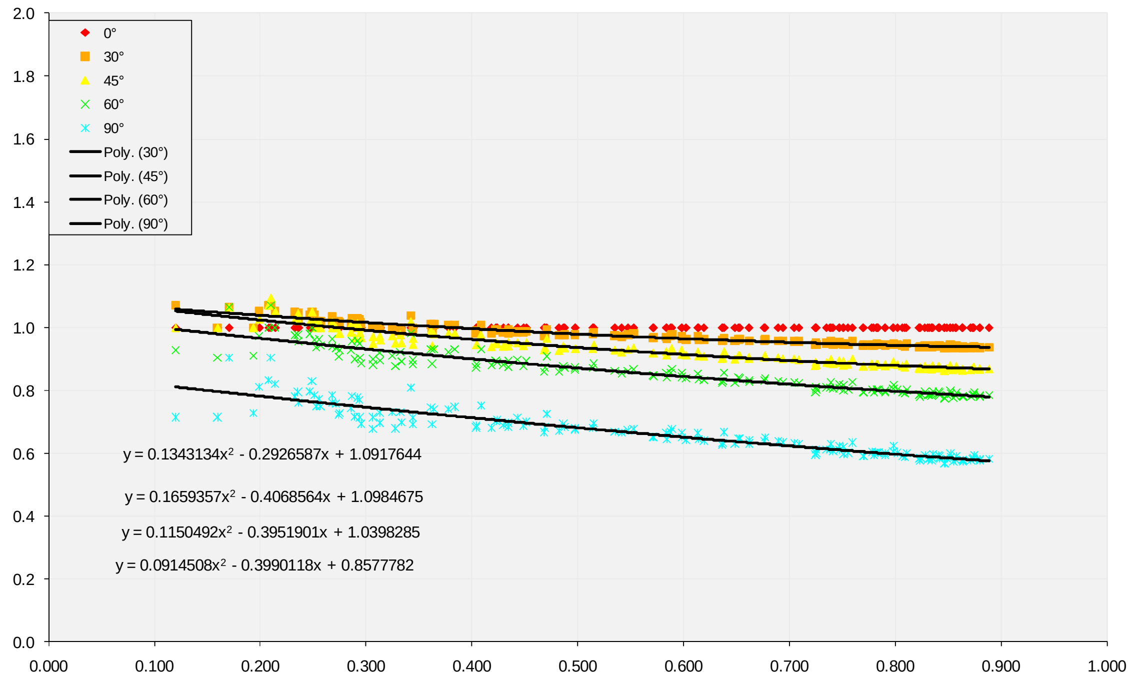
A method has been used in previous versions of SAP and BREDEM to calculate the radiation on vertical surfaces, specifically for use with windows. Separate tables of figures were used for solar devices at different angles of inclination derived from the data given in Page and Lebens[1]. However, as the number of possibilities we wish to be able to model has increased, it has become necessary to have a more general method capable of estimating the solar radiation incident on a surface facing in any direction at any steepness of pitch. The derivation of the method developed for this purpose is described in this document.

[1] Page J and Lebens R, *Climate in the United Kingdom*. Department of Energy. 1986.

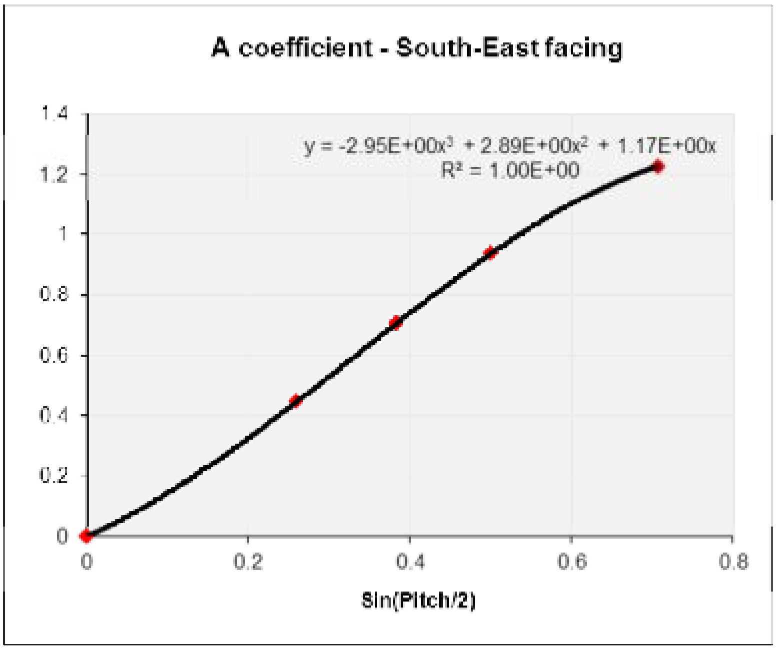
2 Derivation of new method

Monthly global solar radiation data for various locations around the UK, for various pitches and orientations, was taken from Page and Lebens. This data is now quite old (compiled in 1986) and has ceased to be the source of the SAP horizontal radiation data. However, it is of high quality and the purpose of this method is to calculate the ratio of the radiation on a horizontal surface to that on an inclined surface, so any changes in the absolute values should make very little difference.

The ratios of horizontal to inclined radiation were calculated for each orientation and inclination available. Data from all sites was plotted against the cosine of the latitude of the site minus the monthly solar declination (this is effectively a measure of solar height), showing a clear trend in each example, indicating that it should be possible to derive a useful mathematical approximation. An example graph is shown below (east facing, 5 pitches). Data to the far left of the graph is for the most southerly regions in summer months, whilst data to the far right is for the most northerly locations in winter.



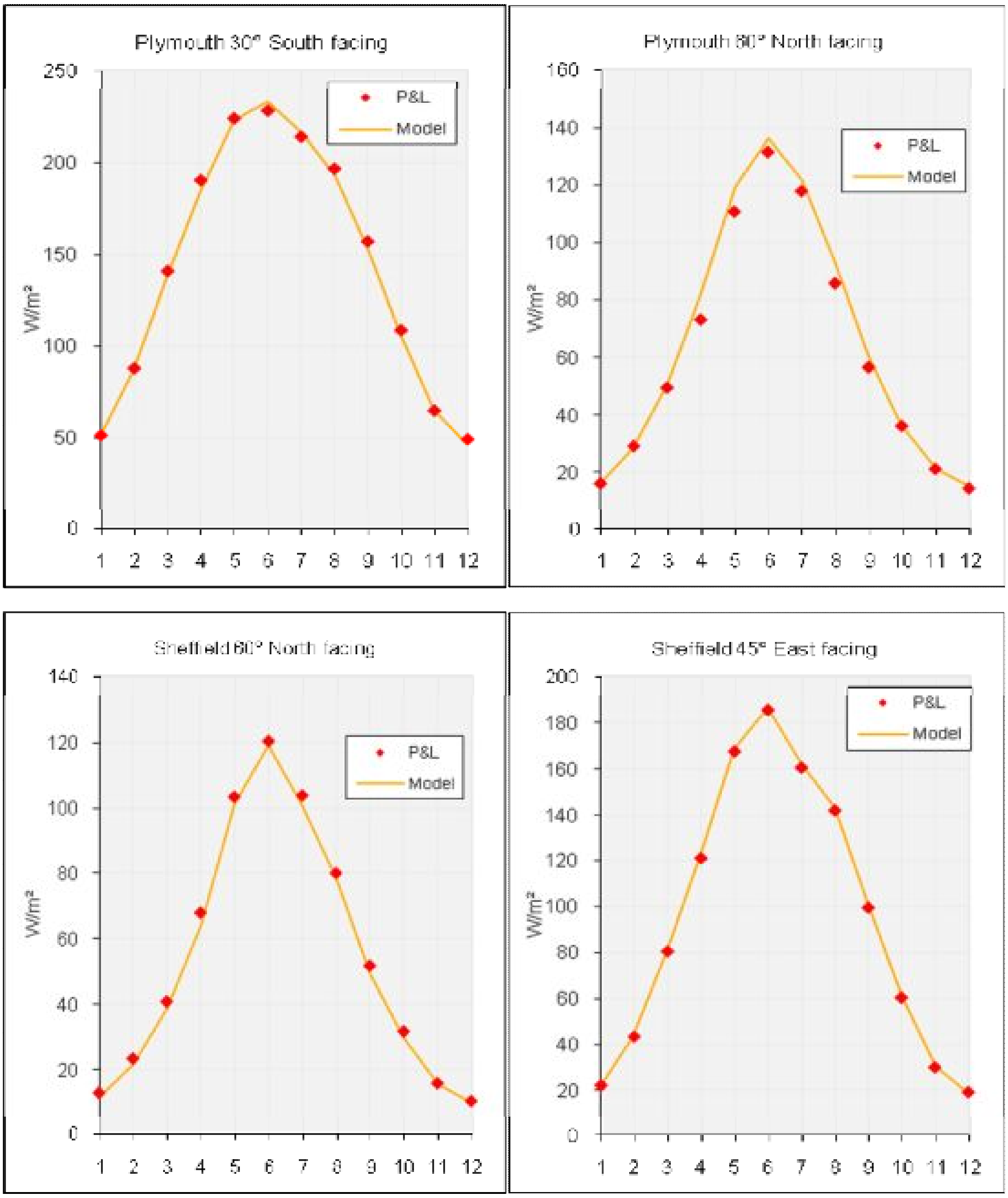
2nd order polynomials of the form Ax^2+Bx+C were found to give a good fit to the data. It was also found that coefficients of the polynomial equations varied in a predictable way with the sine of the pitch of the panel for each orientation (see example below for the 'A' coefficient, South-East facing), also using polynomials. Using equations allows the calculation to be performed for any pitch from 0 to 90°, not just at the specific angles for which we have weather data.



A two stage process was therefore adopted. The first is to generate the A, B and C coefficients for the polynomial equations. The second is to use those equations to generate the ratio of the horizontal to pitched solar radiation. Graphs like the one above were used to derive the following table of 'k' constants necessary for this method.

Orientation	A			B			C		
	k1	k2	k3	k4	k5	k6	k7	k8	k9
North	26.3	-38.5	14.8	-16.5	27.3	-11.9	-1.060	0.087	-0.191
NNE/NNW	13.2	-21.1	8.90	-5.06	11.4	-6.15	-2.72	2.49	-1.09
NE/NW	0.165	-3.68	3.00	6.38	-4.53	-0.41	-4.38	4.89	-1.99
ENE/WNW	0.803	-3.02	2.04	2.93	-1.32	-1.02	-2.46	2.07	-0.693
East/West	1.44	-2.36	1.07	-0.514	1.89	-1.64	-0.542	-0.757	0.604
ESE/WSW	-0.755	0.265	1.12	2.58	-0.825	-2.96	-1.63	-0.504	1.84
SE/SW	-2.95	2.89	1.17	5.67	-3.54	-4.28	-2.72	-0.250	3.07
SSE/SSW	-1.81	1.39	2.05	4.65	-1.96	-5.84	-2.72	-0.621	3.83
South	-0.660	-0.106	2.93	3.63	-0.374	-7.40	-2.71	-0.991	4.59

The method was then tested for various pitches, orientations and regions and found to give a good approximation to the original data it is based on. Four examples are given below, in which the horizontal axis is the month number and the vertical axis is the predicted solar radiation at the stated angle and inclination. The red points are the reference data.


Plymouth 30° South facing
P&L
Model
W/m²
Plymouth 60° North facing
Sheffield 60° North facing
Sheffield 45° East facing

3 Description of method

Step 1 - Work out the ABC constants for the appropriate orientation:

$A = k1 \times \sin^3(p/2) + k2 \times \sin^2(p/2) + k3 \times \sin(p/2)$

$B = k4 \times \sin^3(p/2) + k5 \times \sin^2(p/2) + k6 \times \sin(p/2)$

$C = k7 \times \sin^3(p/2) + k8 \times \sin^2(p/2) + k9 \times \sin(p/2) + 1$

where p is the pitch of the panel in degrees (e.g. horizontal=0°, vertical =90°) and the k constants are taken from the following table:

Orientation	A			B			C		
	k1	k2	k3	k4	k5	k6	k7	k8	k9
North	26.3	-38.5	14.8	-16.5	27.3	-11.9	-1.060	0.087	-0.191
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South	-0.660	-0.106	2.93	3.63	-0.374	-7.40	-2.71	-0.991	4.59

Step 2 - For each month work out the ratio of inclined to horizontal radiation

$R_{h\text{-}inc} = A \times \cos^2(\phi - \delta) + B \times \cos(\phi - \delta) + C$

Where ϕ is the latitude of the site (°) and δ is the solar declination for the month (°), both taken from the existing SAP lookup tables.

Step 3 - Multiply the factors for each month by the horizontal radiation for that month and region

$Fx(m) = S_h \times R_{h\text{-}inc}$

Where Fx(m) is the solar radiation at the chosen orientation and pitch, S_h is the solar radiation on a horizontal surface (from SAP 2012 Appendix U).

4 Conclusion

The method derived reliably predicts the monthly solar radiation on inclined surfaces. It is an improvement on what has been used in SAP before because it is able to provide data for any pitch, orientation and region. This simplifies the SAP methodology by avoiding the need to include a large number of lookup tables for the many possible combinations of pitch, orientation and region.