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SAP calculation of electricity generated by solar PV systems

Issue 1.0

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1. INTRODUCTION

This paper explores the potential for improving the calculation of solar photovoltaic system (PV) annual energy yield within the next revision of SAP in 2016. The challenge is to improve calculation accuracy and repeatability without unduly adding to the workload of the SAP assessor and without assuming an in-depth technical knowledge.

The annual energy yield of PV systems (normally called 'annual yield') can vary considerably with factors such as annual solar irradiance, latitude, ambient temperature, panel ventilation, reflectance of surrounding surfaces and terrain, orientation and pitch of modules, soiling, technology type, system design (including inverter type and matching, cabling, etc.) and shading (called 'overshading' in SAP). Therefore, accurate calculations are normally only attempted with complex simulation programs, using local historical met data, local environmental data and key system design parameters.

Fortunately, the calculations are more sensitive to certain factors than others, allowing the possibility of first approximation calculations. As a minimum, any estimation method must take into account the following factors:

a) annual solar radiation on the horizontal plane at the location
b) latitude of system
c) orientation and pitch of modules
d) installed electrical capacity of the PV system
e) shading

Further information on the factors affecting PV performance and their relative sensitivities can be found in the reference [1].

Factors (a) – (d) above are relatively easily obtained from knowledge of the location, look-up tables and the basic system design parameters.

However, the various solar shading scenarios (factor (e)) are by their nature quite complex to assess without recourse to 3-D modelling of the building and its surroundings. The main focus of this paper is therefore upon the assessment of shading.

Before addressing the shading, it is instructive to compare the existing SAP 2012 and Microgeneration Certification Scheme (MCS) methodologies, since many of the same problems have been addressed.

2. COMPARISON BETWEEN SAP AND MCS METHODOLOGIES

The topic of how best to simplify calculations of PV annual energy output has been a source of much discussion within the PV MCS Working Group. This working group is responsible for writing the product and installation standards for PV technologies.

The MCS remit was similar to that of SAP in that it was desirable to produce an estimation method that did not require a large number of input parameters and was relatively simple to use, yet gave repeatable results of a reasonable accuracy.

MCS requires a calculation that can be done fairly easily on paper, without recourse to a computer or third party software. The MCS method could assume a more in-depth technical knowledge than would be usual for a SAP assessor, since the MCS assessor would normally be a professional PV installer.

After some research, comparison of methods and discussion, the MCS working group settled on a simple equation:

$$\text{Annual AC output (kWh)} = \text{kWp x Kk x SF} \qquad (1)$$

where:

kWp = rated electrical capacity of the PV system

Kk = annual *normalised* solar radiation (kWh/kWp), taking into account the location (based on SAP region), orientation and tilt of panels and an overall performance ratio figure of 0.8[i].

SF is a shading factor, for which an estimation procedure is defined

The equivalent SAP equation[ii] is:

$$\text{Annual AC output (kWh)} = 0.8 \text{ x kWp x S x Zpv} \qquad (2)$$

where:

0.8 = an assumed performance ratio of the system

kWp = rated electrical capacity of system

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[i] This figure is an estimate of the mean efficiency figure of the system (excluding panel efficiency) for the given parameters of the site and system design.

[ii] Equation 2 must be divided by $1kW/m^2$ in order to obtain the correct units

S = annual solar radiation (kWh/m²) from U3.3 in Appendix U for the applicable climate (based on SAP region) and orientation and tilt of the PV
Zpv is a shading factor, which is determined from SAP Table H2

Therefore, equations 1 and 2 are essentially identical.

MCS uses SAP climate regions for calculating incident energy, so there should be a close correlation between the two data sets.

However, the data inputs for annual solar radiation (S) and latitude in SAP vary depending upon the purpose of the calculation. SAP Appendix U states that *"Calculations for fabric energy efficiency (FEE), regulation compliance (TER and DER) and for ratings (SAP rating and environmental impact rating) are done with UK average weather. Other calculations (such as for energy use and costs on EPCs) are done using local weather".*

Therefore, the MCS and SAP methods (when calculating operating costs) are aligned.

The MCS 'Kk' factor provides kWh/kWp data, corrected for location, orientation and pitch. Also, the assumed performance ratio (0.8) is incorporated into the factor. SAP provides data for solar irradiance on a horizontal surface, which is then modified by look-ups and calculation for the relevant orientation and pitch; the performance ratio is then stated explicitly in equation 2. So, the two methods are very similar.

Both methods also have a shading factor and this is where the main differences appear. The SAP method uses a simple lookup table (H2) to estimate a shading factor, whereas MCS uses a sun path diagram to estimate the effects of both near field and far field shading.

The full MCS methodology can be found in the MCS "*Guide to the installation of photovoltaic systems"* [2].

3. FACTORS CONSIDERED

The factors in equation 2 are considered in order below:

3.1 Performance Ratio (PR)

The assumed typical Performance Ratio (PR) figure of 0.8 is widely seen within the industry as representative of a well-designed and installed system. Whilst PRs higher than 0.8 are possible, there is little published literature pertaining to the UK that would support the use of a higher value.

Clearly, whilst not a determining factor, alignment with the MCS PR figure (also 0.8) is helpful in avoiding confusion or the possibility of installers presenting the most favourable figures to potential buyers of systems.

We would therefore recommend leaving the PR figure at the existing value of 0.8.

3.2 Installed rated power (kWp)

For SAP assessors, the method of determining the rated power (kWp) relies on reading the PV system documentation, or by estimating the solar panel area and making an assumption about the panel technology and its efficiency.

Whilst this is not entirely satisfactory (there will some installations for which, for a variety of reasons, the relevant documents are not available), the only alternative would be to read the rated power (Wp) on the manufacturer's label on the back of a representative panel, which could mean removing panels at roof level – clearly not feasible during a SAP assessment – and then counting up the total number of panels. There is also some uncertainty in the manufacturer's stated panel rating, since different manufacturers tend to use slightly different tolerances when quoting the panel's rated power. Nevertheless, without a laboratory test, the SAP assessor can only rely upon the available documentation, or use the SAP default method (S11.1) where documentation is not available. **No change is recommended for determining rated power.**

3.3 Annual solar radiation (S)

SAP provides data for mean monthly solar irradiance on a horizontal surface in the region of interest, as well as UK average values, which are then modified by further look-ups and calculation to arrive at the solar radiation on a plane with the relevant orientation and pitch. This appears to be a conventional methodology and **no modifications are recommended.**

3.4 Shading factor (Z_{pv})

The SAP method uses a simple table (H2) to estimate a shading factor, whereas MCS uses a sun path diagram to estimate the effects of both near field shading (e.g. chimneys or satellite dishes) and far field shading (e.g. hills, other buildings) [2].

The shading regime for any particular system can be critical to the annual performance. The most common types of panels, based on crystalline silicon, are particularly sensitive to shading, since all of the cells within a panel are wired in series. The “strings” of panels are also wired in series, so any cell that is shaded acts as a resistance in the circuit and tends to obstruct the flow of current throughout the whole string of panels. The relationship between the area shaded and the resulting energy loss is therefore highly non-linear.

All modern panels incorporate shading diodes that can route some of the current around a group of cells in which one or more cells have become resistive, thereby helping to mitigate the effects of shading. Figure 1 illustrates this functionality – the red cell is shaded and its associated by-pass diode has activated to re-route the current around the group of cells.

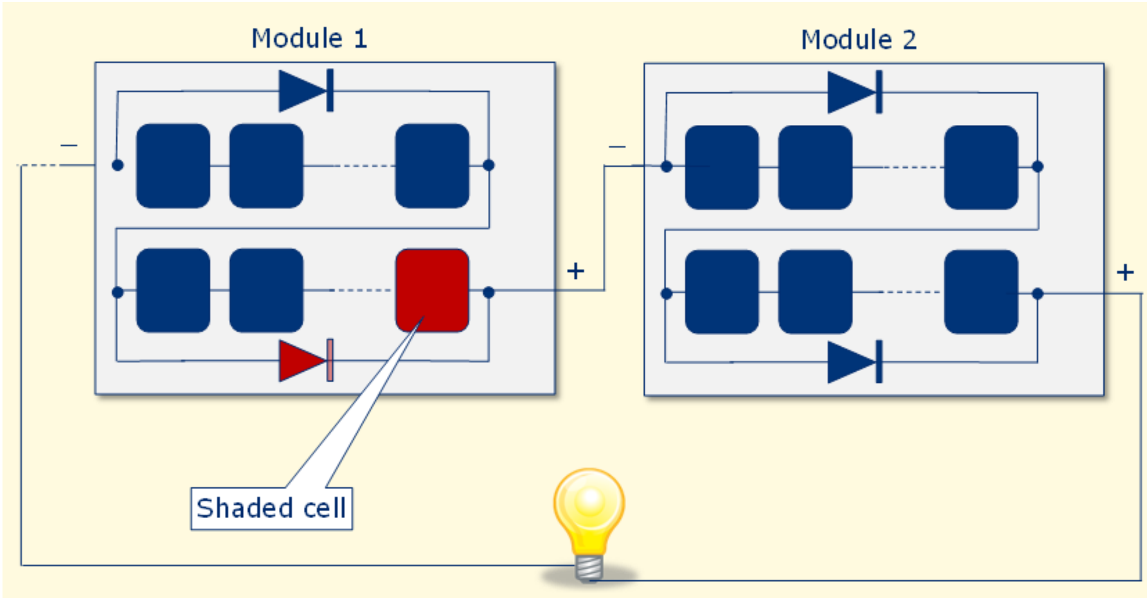


Figure 1: The action of a by-pass diode in a group of cells where one cell is shaded

However, there is still a considerable loss of power output when this re-routing occurs due to the resulting diversion of current around *all* cells protected by the diode (whether or not generating) and power losses within the diode itself. The magnitude of the losses is largely dictated by the level of irradiance and the area and shape of the shadow impinging on the array relative to the diode topology. Nearby objects cause sharper shadows than distant objects, resulting in stronger differential effects. Distant objects tend to lower the overall irradiance level, as seen by the array.

Table H2 from SAP 2012 for estimating the amount of shading on a surface is reproduced here:

Table H2 : Overshading factor

Overshading	**% of sky blocked by obstacles.**	**Overshading factor**
Heavy	> 80%	0.5
Significant	> 60% - 80%	0.65
Modest	20% - 60%	0.8
None or very little	< 20%	1.0

Note: Overshading must be assessed separately for solar panels, taking account of the tilt of the collector. Usually there is less overshading of a solar collector compared to overshading of windows for solar gain (Table 6d).

Table H2 is at present used in several places within the SAP methodology and is considered appropriate for situations where the effect of shading is more or less linear with the area shaded, e.g. for solar thermal systems.

However, due to the non-linear effect of shading on the output of PV it is proposed that **the same overshading factors used for solar thermal calculations should no longer be used to evaluate the performance of PV systems**. New PV-specific factors are therefore proposed later in this paper in order to arrive at more suitable values.

The MCS installer standard MIS 3002 [3] requires that energy yield estimates are made according to the method described within the MCS guide [2] and a standardised set of information is to be supplied to the system owner. Section 3.7.8 of the guide states that:

> *For systems under the MCS scheme, a performance estimate that determines the total annual a.c. energy output of a given system shall be communicated with the client before the point that the contract is awarded.*
>
> *Along with the performance estimate, the client shall be provided with the sun path diagram and the information used to calculate the performance estimate as illustrated in the following table.*

A. Installation data	
Installed capacity of PV system - kWp (stc)	kWp
Orientation of the PV system – degrees from South	°
Inclination of system – degrees from horizontal	°
Postcode region	
B. Calculations	
kWh/kWp (Kk) from table	kWh/kWp
Shade factor (SF)	
Estimated annual output (kWp x Kk x SF)	kWh

Thus, it can be seen that the shade factor (SF), and a sun path diagram, upon which SF is based, are *required* to be supplied to the system owner. Since this will have been calculated by a PV specialist making use of a more sophisticated assessment process this will be a more reliable figure than could be generated by a SAP assessor. Therefore, where available, **the MCS 'shade factor' should become the preferred source of the overshading factor for use in SAP assessments**. Since Feed-In-Tariff payments are conditional on an MCS accreditation, non-MCS installations are currently very rare, so the data should be available in nearly all recent installations. Unfortunately, experience shows that installers do not always leave the required documentation with the householder, or the householder may have lost it, so a table of default shading factors will still need to be provided in SAP for use where MCS data is unavailable.

3.5 Micro-inverters and DC optimisers

One further complication is that the use of micro-inverters and DC optimisers is now becoming more common. These devices convert electrical energy on a per-panel basis (traditional inverters convert all of the power from the array in one place), and so the effect of individual panels being shaded is mitigated. If documentation on site is available to show the use of such devices, and there is some shading of the array, an allowance could be made. However, arriving at a mechanism to calculate this allowance is a complex topic and will require further study. This should be considered as a possible future refinement to SAP, following research.

4. PROPOSED AMENDMENTS

4.1 Shading factor (Zpv)

Following the discussion in 3.4, it is recommended that some changes are made to the shading assessment methodology for PV systems within SAP, making use of the work done by the MCS PV Working Group, in order to arrive at a more accurate and repeatable Zpv factor.

There are two cases to consider, depending on whether or not MCS documentation is available for the particular installation.

4.1.1 MCS documentation is available

Where the correct MCS documentation exists (as stipulated in the MCS guide [2]), the value of **the shade factor, SF, should be used directly for the Zpv factor in SAP** appendix M.

4.1.2 MCS documentation is NOT available

If MCS documentation is not available:

1. assess the general level of overshading from distant objects (>10m), Zpv_{far}, using the existing Table H2 overshading categories (factors have been amended in this proposal)
2. apply a second (new) correction factor to correct for any near shading (<10m), Zpv_{near}.

The overall PV overshading factor (Zpv) is the product of Zpv_{far} and Zpv_{near}, limited to a minimum value of 0.2.

Overshading from distant obstructions >10m away			SAP 2012 Table H2 factor for comparison
Overshading description	**% of southern sky blocked by obstructions >10m away**	**Zpv_{far}**	
Heavy	> 80%	0.2	0.5
Significant	> 60% - 80%	0.35	0.65
Modest	20% - 60%	0.5	0.8
None or very little	<20%	1	1

Overshading from near objects <10m away	Zpv_{near}
None	1
Tall* obstruction to South or passing through array	0.2
Tall obstruction to SE/SW	0.45
Tall obstruction to E/W	0.65
Short** obstruction to South or passing through array	0.75
Short obstruction to SE/SW	0.75
Short obstruction to E/W	0.85

*Tall means the top of the obstruction is higher than the height of the top of the array.
**Short means the top of the obstruction is below the top of the array, but above the bottom.

Only one distant overshading factor can be applied, but potentially multiple near overshading factors could apply. Factors accumulate multiplicatively, as illustrated by the following example:

Modest distant object overshading: $Zpv_{far} = 0.5$

Tall obstruction to East: $Zpv_{near,1} = 0.65$

Short obstruction to W: $Zpv_{near,2} = 0.75$

$Zpv = 0.5 * 0.65 * 0.75 = 0.24$

The factors in the tables above were derived using the MCS sun-path diagram method for example obstructions - see appendix A.

4.1.3 Design stage SAP assessments

For new dwellings a SAP calculation is carried out twice: once at the design stage, and once when the dwelling is built, with the latter reflecting any changes compared to the design. At the design stage it is likely that details of the site and possibly of near-field obstructions will not be fully known. **It is therefore proposed that the maximum Zpv is limited to 0.85 for design stage SAP calculations.** As appropriate, a lower factor should still be determined and used to account for obstructions that can be anticipated.

5. IMPACT OF PROPOSED CHANGES

Enabling the use of shading factors provided in MCS certificates will improve the accuracy and consistency of SAP assessments and make them marginally easier for the assessor to undertake.

In cases where the householder has not been supplied with documentation, which is mandatory under MCS, the proposed amended method for estimating the shading factor (Zpv) should still lead to more realistic assessments with little or no extra burden for the assessor. In particular it acknowledges the importance of any obstructions near to the array.

5.1 Impact of changes

For sites where there is no significant shading (e.g. no ‘roof clutter’, such as satellite dishes, vents or chimneys, and no horizon shading from other buildings or hills), there is no effect on the existing SAP method and the shading factor remains set at 1, whether or not MCS data is available.

For situations where there is some shading of a PV array, the proposed shading factors are lower than those used in SAP 2012 because they recognise the non-linear impact of shading on PV output. Therefore, the predicted output of PV systems is generally lower than currently determined by SAP.

In many cases an MCS shading factor will be available and the revised Zpv tabulated values should not be used. The MCS figure could be lower or higher than the tabulated figure depending on the circumstances.

6. CONCLUSIONS AND RECOMMENDATIONS

An explanation of the main issues emerging for simplified assessments of energy yield from PV arrays has been presented. This is accompanied by a comparison with the MCS methodology, since many of the same problems have been addressed by the MCS PV Working Group.

An analysis of the main factors is presented, focussing on the shading factor, Zpv, since it is considered the most significant and variable factor.

An improved method of assessing Zpv is therefore offered, based on the MCS documentation that should be available on-site, but also proposing an alternative route if the documentation is not available. This should result in more accurate representation of PV systems in SAP.

7. SUGGESTED FURTHER WORK

Micro-inverters and DC optimisers are becoming more commonly used. These should reduce the sensitivity of arrays to partial shading. Assuming further research supports this conclusion, the benefits of such systems should be recognised in a future SAP update.

8. REFERENCES

[1] S. Pester and F. Crick, “Performance of Photovoltaic Systems on Non-Domestic Buildings,” IHS BRE Press, Bracknell, 2013.

[2] Microgeneration Certification Scheme, Guide to the installation of photovoltaic systems, London: Electrical Contractor's Association, 2012.

[3] Microgeneration Certification Scheme, *Microgeneration Installation Standard: MIS 3002,* London: Department of Energy and Climate Change, 2013.

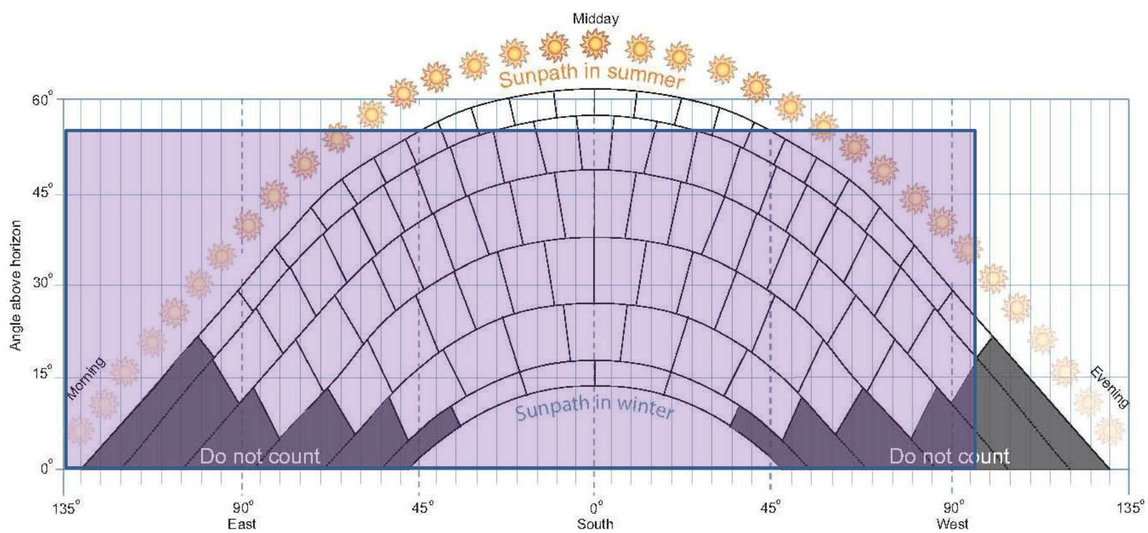
Appendix A - Examples used to derive tabulated values

MCS sun path diagrams were used to calculate overshading factor for a series of hypothetical example obstructions, as shown below. From these diagrams, the number of segments blocked by the obstacle is counted. Subtracting this from 100 and then dividing by 100 gives the overshading factor.

For near obstacles the object must have a semi-circle superimposed on it with radius equal to the height of the object.

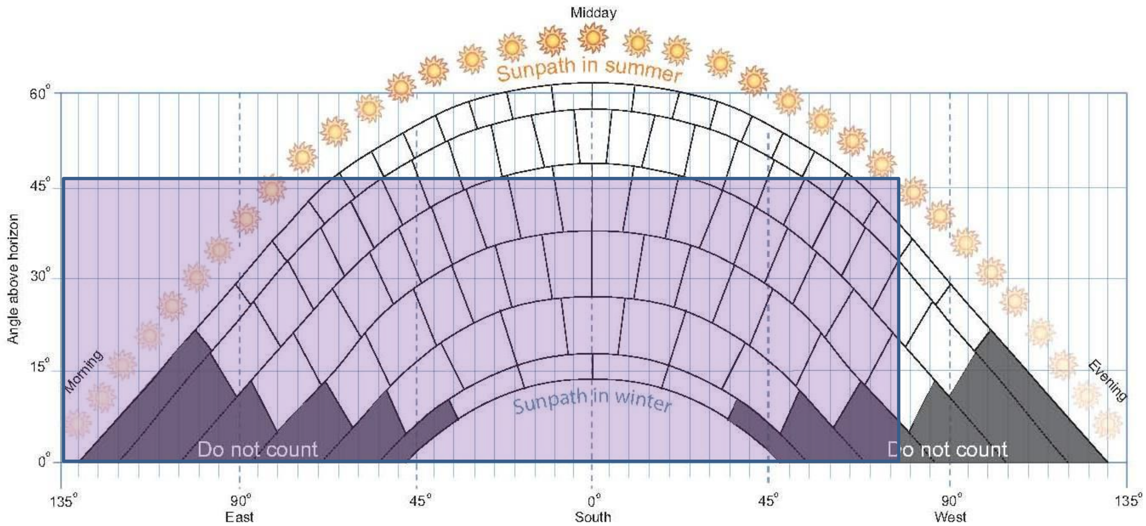
Heavy overshading (>80% southern sky blocked)

(80 segments blocked, Zpv,far = 0.2)



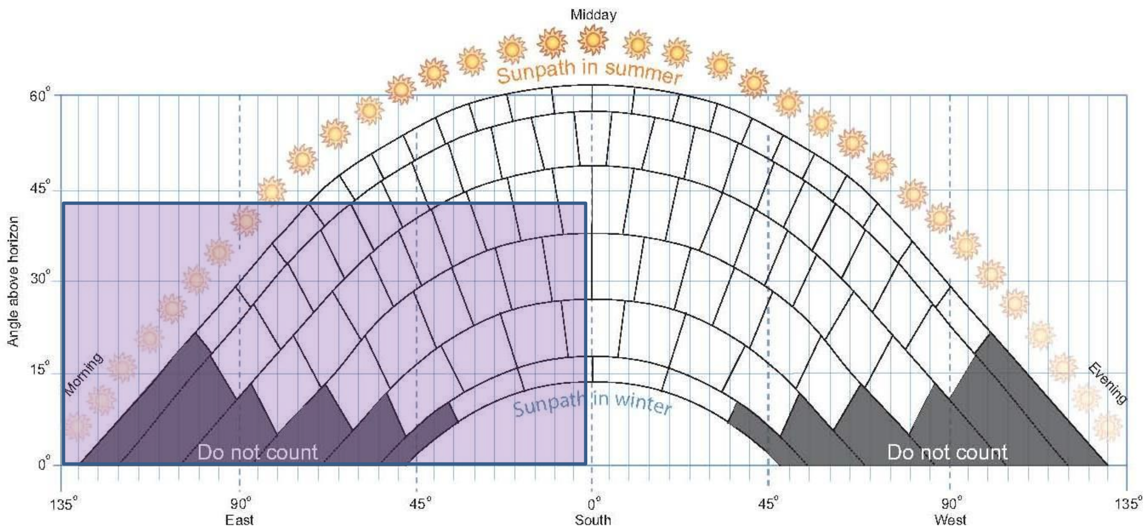
Significant overshading (60-80% southern sky blocked)

(64 segments blocked, Zpv,far = 0.46, rounded to 0.45)



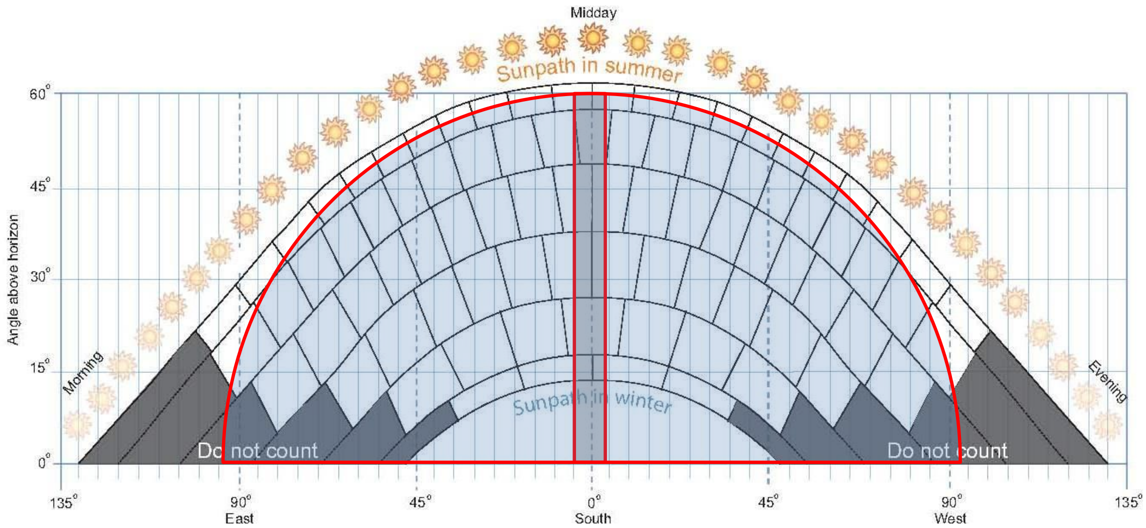
Modest overshading (20-60% southern sky blocked)

(52 segments blocked, Zpv,far = 0.48, rounded to 0.5)



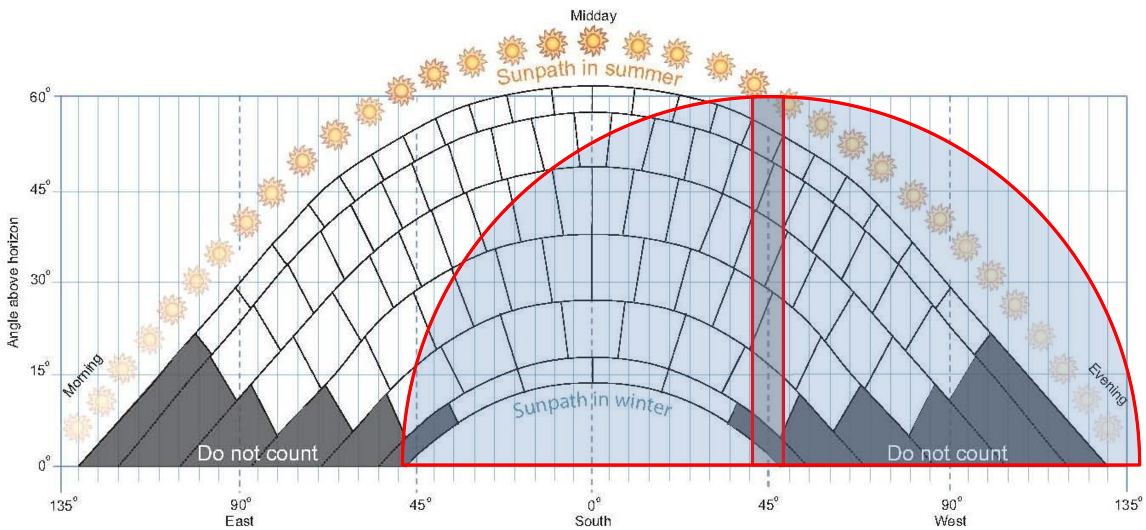
Near tall object to South

(82 segments blocked, Zpv,near = 0.18, rounded to 0.2)



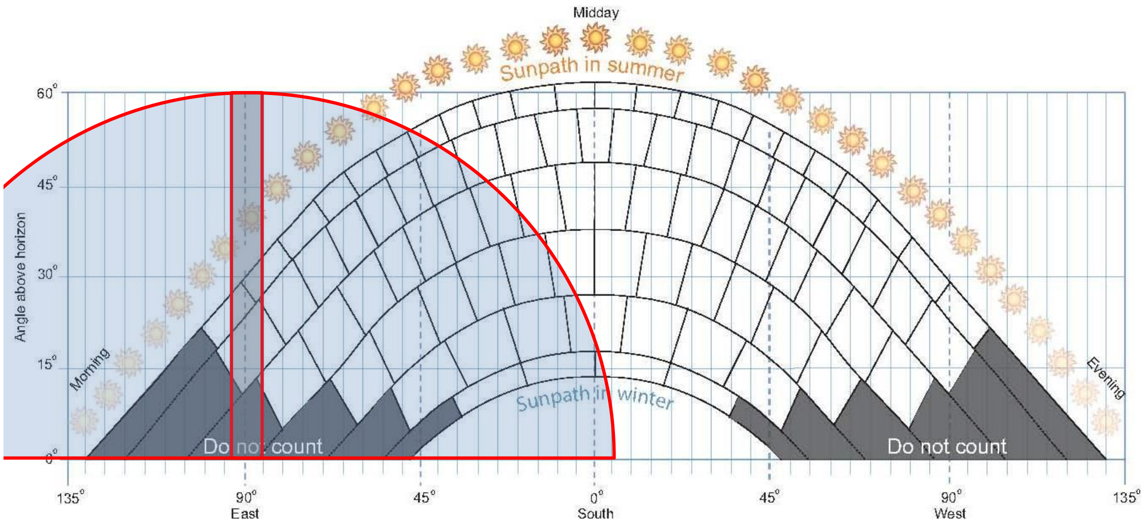
Near tall object to SE/SW

(57 segments blocked, Zpv,near = 0.43, rounded to 0.45)



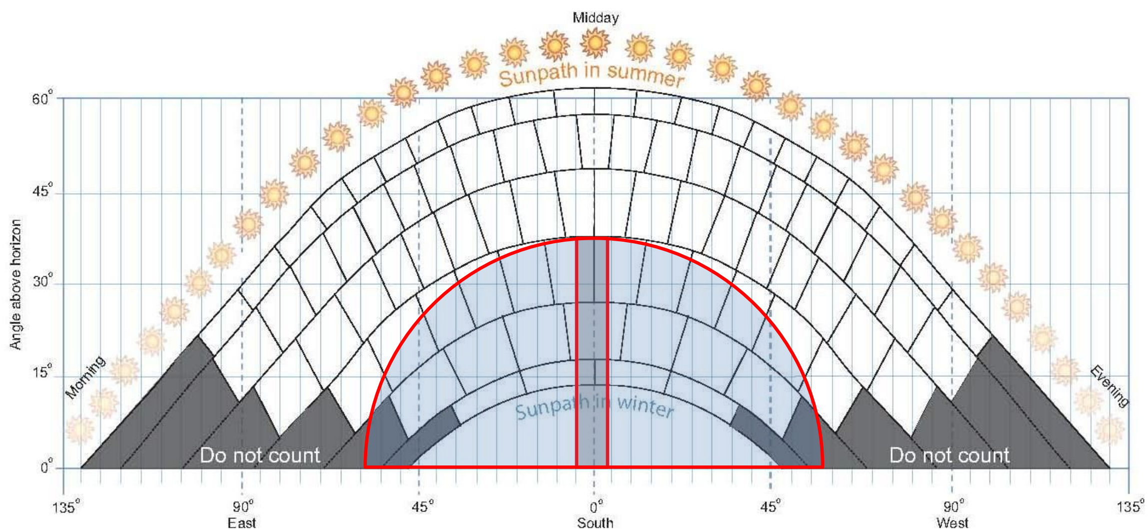
Near tall object to E/W

(35 segments blocked, Zpv,near = 0.65)



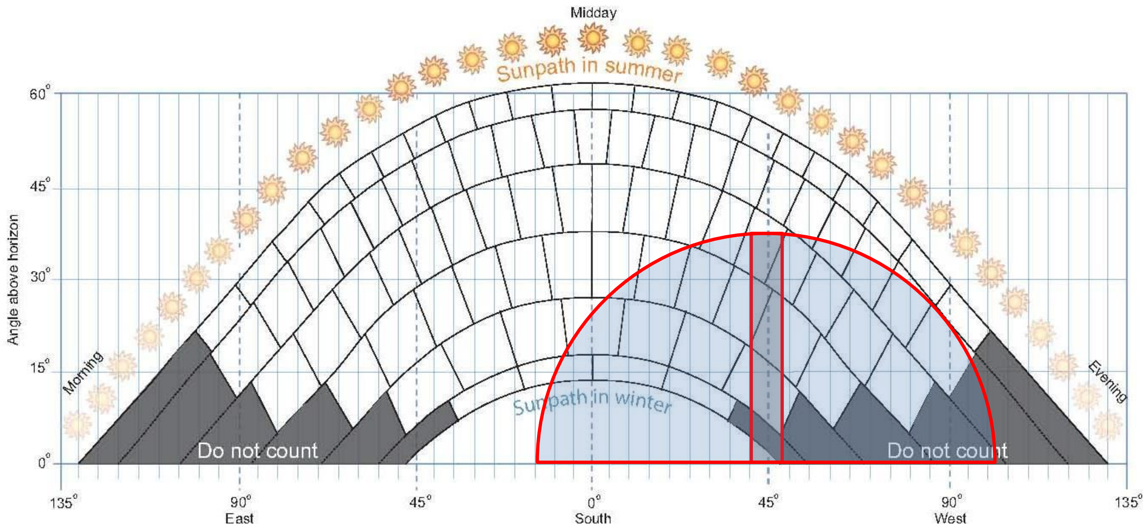
Near short object to South

(23 segments blocked, Zpv,near = 0.77, rounded to 0.75)



Near short object to SE/SW

(24 segments blocked, Zpv,near = 0.76, rounded to 0.75)



Near short object to E/W

(16 segments blocked, Zpv,near = 0.84, rounded to 0.85)