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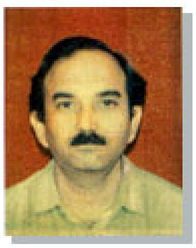
Effect of Solar Shading on Windows



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Solar heat gain from windows can be effectively reduced by the provision of indoor shading, such as venetian blinds, and horizontal projections, such as Chajjas and / or vertical fins. The horizontal projections and vertical fins function by shading a portion of the window, thereby reducing the solar heat gain, which is a major component of the heat gain estimate.

While it is true that the heat gain estimate (erroneously called heat load), is only an estimate, and can never be truly be called exact, however, the error in calculation by not considering shading on windows can be significant enough to cause substantial over- sizing of cooling equipment.

In fact, the lower floors of many buildings in densely - populated urban business districts are completely shaded throughout the year.

A real life example occurred recently, while I was checking a heat gain calculation done by an engineer. However, in this case I did not have to apply the equations to calculate the extent of shading of the West glass (which was extensive). The entire West glass was

shaded by an adjacent building throughout the day and in all seasons!
The reduction in the calculated cooling load was 7 tons, out of a total of 60 tons. Enough to say that determining window shading may prove essential at times.

The equations for calculating the shading effect of horizontal projections and vertical projections on windows, and thereby affecting the solar heat gain, are quite complex. These equations depend upon the angle that the sun makes with the horizontal, and the South orientation. These angles are in turn, dependent on the position of the Sun with respect to the reference point.

To simplify the calculation of the sunlit area of a window, without sacrificing accuracy, we have applied the equations using data commonly considered in calculating the peak heat gain, i.e., the peak heat gain calculation is done for the month of May, at 4 P.M., and that the mean latitude can be selected as 10° N, 20° N, & 30° N depending on the city for which the calculation is being made for. A brief list of the latitudes for cities is given below :

Ahmedabad 23.07 N	Hyderabad 17.45 N
Bangalore 12.97 N	Jaipur 26.82 N
Mumbai 19.12 N	Nagpur 21.10 N
Calcutta 22.65 N	New Delhi 28.58 N
Cuddalore 11.77 N	Sholapur 17.67 N
Panaji 15.48 N	Trivandrum 08.48 N
Chennai 13.00 N	Pune 18.53 N

As the Earth's rotational velocity is not uniform, and since the Earth's equatorial plane is tilted at an angle of 23° 45' to the orbital plane, the Solar Declination angle (the angle between the Earth- Sun line and the horizontal plane at the equator) varies throughout the year. Hence, a correction to the time, as kept by a watch has to be corrected, based on the time of year.

The time we read on a watch is incorrect, inasmuch that the time-by watch is not the solar time. This difference occurs since all watches and clocks have been manufactured to move at a uniform speed. (A solar sun- dial, however, would give the solar time accurately, as it uses the sun's rays directly for a read-out).

In addition, for any place which is not on the Equator, a correction has to be made for the Local Standard Time with respect to Greenwich Mean Time, at the equator. A further correction has to be made to the Local Standard Time, to account for the Local Time at the site. (For example, Indian Standard Time is located 82° 30' E, which is 5-1/2 hours ahead of GMT. Mumbai is 9° 36' W of the Local Standard Time Longitude, hence further correction of 2 minutes 24 seconds has to be made.

This variation is called the equation of time, and the declination angle varies for all months of the year. We shall concern ourselves with the month of May, as the peak load generally can be taken to occur in this month.

For 21st May, (May degree-day), the declination angle δ, is 20 degrees. (The degree day is the 21st day of each month and is taken to characterise the severity of the climate for that month.). Refer ASHRAE Fundamentals 1997, table 8, 29.14.

The position of the Sun is expressed in terms of solar altitude β (which is the angle the Earth - Sun line makes with the horizontal) and solar Azimuth Φ, (which is the angle of the Earth- Sun line with the South orientation.

The time of day based on the Apparent Solar Time and expressed as an Hour Angle H, and the latitude of the place, L is related to angles δ and β as:

$\sin \beta = \cos L \times \cos \delta \times \cos H + \sin L \times \sin \delta$

For simplification, we may calculate at fixed Latitudes (L) of 10, 20, and 30 8 N, which would cover the country. The Hour Angle (H), may be considered as 240 minutes of time after noon (i.e., 4 P.M.), which translates to an Hour Angle of 60 ° . (Based on an equivalence of 0.25 ° latitude for every minute of time difference between noon and the time in question, for which the sunlit area is being calculated).

The above equation then simplifies to:

$\sin \beta = 0.559$ for Latitude 20° N, Therefore, $\beta = 34°$

Similarly, for Latitude 10° N, $\beta = 31.47°$, and for Latitude 30° N, $\beta = 35.31°$

The Solar Azimuth angle, Φ is related to angles L and angles δ, as:

$\cos \Phi = (\sin \beta \times \sin L - \sin \delta) / (\cos \beta \times \cos L)$, which simplifies to:

$\cos \Phi = (-)\ 0.194$

Therefore $\Phi = 101.186°$ for Latitude 20° N.

Similarly, for Latitude 10° N, $\Phi = 107.41°$ and for Latitude 30° N, $\Phi = 94.3°$

Angle φ, (refer **figure 2**), which is the Surface Azimuth, is as per **table 1** for various orientations:

N	NE	E	SE	S	SW	W	NW
1808	(-)1358	(-)908	(-)458	08	458	908	1358

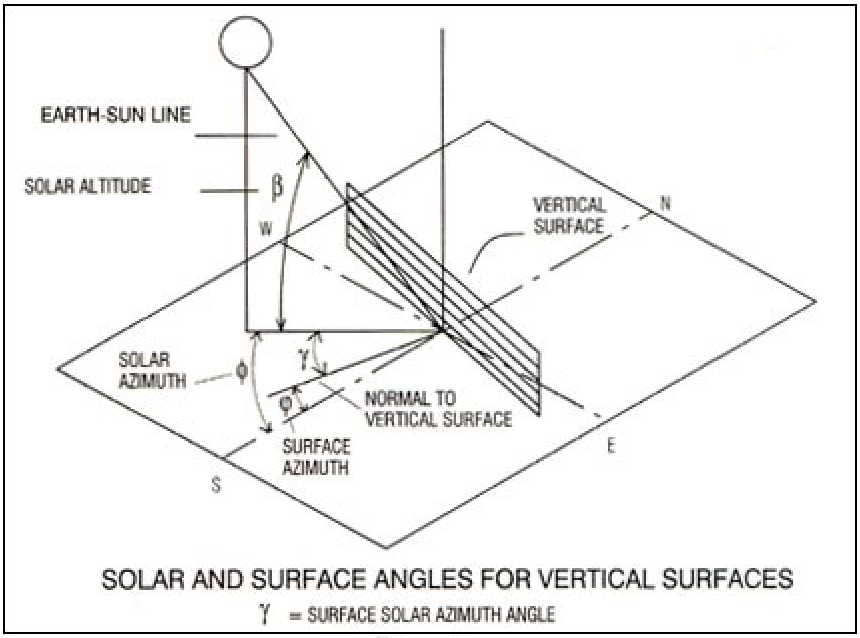

Figure 1

We now define angle γ, as the difference between angle Φ and angle φ. (See **figure 1**) or:

Angle γ = angle Φ - angle φ.

Angle γ = 101.186° - angle φ for Latitude 20° N.

Angle γ = 107.410° - angle φ for Latitude 10° N,

and angle γ = 94.300° - angle φ for Latitude 30° N.

Table 2 : This gives angle ? for the various orientations as below, for Latitude 20° N.

N	NE	E	SE	S	SW	W	NW
(-)78.88	236.28	191.28	146.28	101.28	56.28	11.28	(-)33.88

And tan| γ | works out as per **Table 4**,

Table 4

Latitude	N	NE	E	SE	S	SW	W	NW
10° N	3,189	1.914	0.314	(-) 0.523	(-) 3.189	1.914	0.314	0.523
20° N	5.057	1.493	0.198	(-) 0.670	(-) 5.057	1.493	0.198	0.67
30° N	13.30	1.163	0.075	(-) 0.860	(-) 3.30	1.163	0.075	0.860

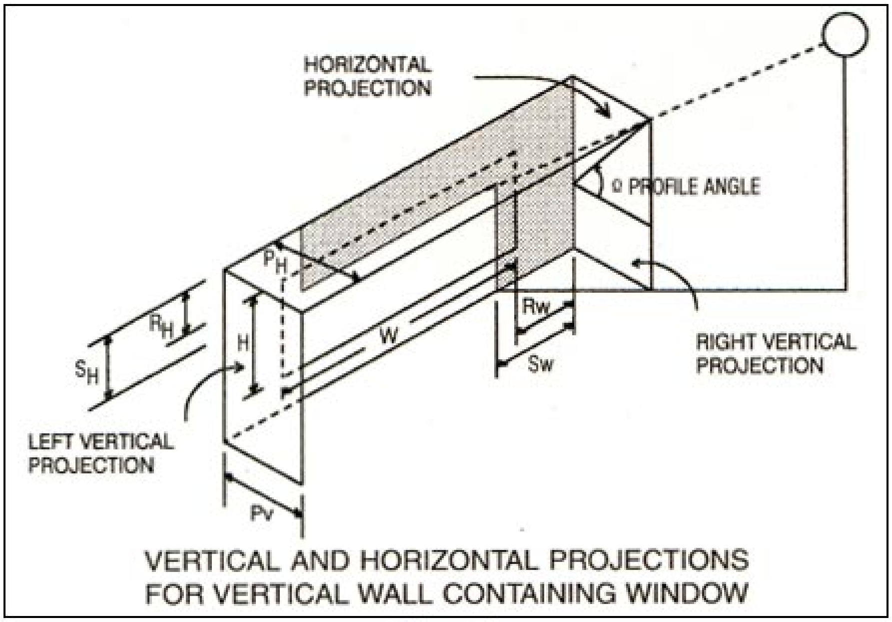

Figure 2

Since tan ω = tan β / cos γ, we have obtained tan ω for various orientations and latitudes as per **Table 5**.

Table 5 tan ω for Various Orientations and Latitudes

Latitude	N	NE	E	SE	S	SW	W	NW
10° N	2.047	(-) 1.322	(-)0.642	(-)0.691	(-)2.047	1.322	0.642	0.691
20° N	3.477	(-)1.211	(-)0.687	(-)0.812	(-)3.477	1.211	0.687	0.812
30° N	9.440	(-)1.086	(-)0.710	(-)0.934	(-)9.440	1.086	0.710	0.934

Referring now to **figure 2**:

If P_h be the horizontal projection

P_v be the vertical projection

Window dimensions are W wide x H high

R_h be the height of horizontal projection above the window.

R_w be the distance of the vertical projection from the window, then:

Shadow width, $S_w = P_v \times |\tan\gamma|$ and **... Equation (1)**

Shadow height, $S_h = P_h \times \tan\omega$. **... Equation (2)**

Let A_{sl} = Sunlit area,

$A_{sl} = [W - (S_w - R_w)] \times [H - (S_h - R_h)]$ **... Equation (3)**

And shaded area A_{sh} = Window area (W x H) - A_{sl}

Find values of S_w and S_h from Equations 1 and 2, based on the projection distances P_h and P_v. Read values of tan γ and | tan ω | from **Table 4 and 5**, based on the latitude and the orientation of the window, and substitute in Equation 3, using values of window width

W and height H, calculated shadow width and calculated shadow height, and height of horizontal projection R_h and distance away of vertical projection R_w from window.

The projection required for restaurant awnings to fully shade windows at 4 P.M. in summer can be determined by using the following Equations:

$S_{H(fs)} = H + R_h$ **... Equation (4)**

$S_{W(fs)} = W + R_w$ **... Equation (5)**

Then, the "projection" values required are:

$P_{h(fs)} = S_{H(fs)} \times \cot \omega$ **... Equation (6)**

$P_{v(fs)} = S_{W(fs)} \times | \cot \gamma |$ **... Equation (7)**

Note that in case only a horizontal projection exists, then the term $[W-(S_w-R_w)]$ will be equal to W.

Note also, that W, H, P_h, P_v, R_w, and R_h should all have the same units, i.e., mm, ft, etc.

The solar heat gains for the East and West orientations are considerably reduced all the year round by projections, while on Southerly orientations the benefit is more during Summer and Monsoon and less during the cooler months.

Also, you may observe from equation 3, that closer the horizontal or vertical projection is to the window, the greater is the shading. (R_w and R_h tend to zero)

Sample Calculation:

Window orientation: South-West (SW) ... given

Window width, W = 870 mm ... given

Window height, H = 1480 mm (vertical tall window) ... given

Horizontal projection: P_h = 200 mm ... given

Vertical projection: P_v = 150 mm ... given

Horizontal projection beyond window, R_h = 100 mm ... given

Vertical projection beyond window, R_w = 75 mm ... given

Tan| γ | for South-West orientation = 1.493 ... **Table 4**

$S_w = P_v | \tan \gamma |$ ... Eq. (1)

Therefore, $S_w = 150 \times 1.493 = 224$ mm

Tan ω for South-West orientation = 1.211 ... **Table 5**

$S_h = P_h \times \tan \omega$ ... Eq. (2)

Therefore, $S_h = 200 \times 1.211 = 242.2$ mm

Sunlit area is given by:

$A_{sl} = [W - (S_w - R_w)] \times [H - (S_h - R_h)]$ ... Eq. (3)

So, A_{sl} = [870 - (224 - 75)] x [1480 - (242.2 - 100)]

or 9,64,554 sqmm

The window area is W x H: = 870 x 1480 = 12,87,600 sqmm

The ratio of Sunlit window area to Total window area: 74.9%.

The above is a simplified procedure, assuming the month, time of day and the latitude as constants. Do take care to select values for the appropriate Latitude. As such, only the values from **Tables 4 and 5** are applied in equations 1, 2 and 3 to find the percentage of sunlit window.

Consideration of shaded area of windows is extremely important if accuracy of the heat gain estimate is desired, especially, in a tropical country, and will result in correctly sized equipment.

This calculation should prove sufficiently accurate for cooling load estimates, and may make a considerable difference to the calculated load, depending on the extent of shading.

For more accurate calculations for other degree days, time of day, and latitudes, use the basic equations with relevant input data.

Reference: *1997 ASHRAE Handbook, Fundamentals.*