FENESTRATION PEAK SOLAR HEAT GAIN: A REVIEW OF THE CLOUDLESS DAY CONDITION AS CONSERVATIVE HYPOTHESIS

by

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Peak solar heat gain through fenestration, particularly for clear and cloudy day conditions, was estimated, using an approach based on the ASHRAE methodology and considering the correlation between hourly clearness index kT and diffuse ratio of the total radiation. Hourly SHG CLEAR and SHG CLOUDY values for surfaces facing the basic cardinal orientations and the horizontal surface, at different latitudes, on the 21st day of each month, have been computed and compared. Results show that in many cases solar heat gain for cloudy day may exceed that for clear day. For wall exposures near the north the clear day condition could not be the most conservative condition for the peak solar heat gain evaluation.

Keywords: peak solar heat gain, cloudy day

Introduction

Usually, the cloudless day is considered as reference to evaluate the peak solar heat gain (SHG) through fenestrations. Examples of this procedure are provided by ASHRAE [1] and Carrier [2] methods.

Li et al. [3], basing on extensive global solar radiation data measured at the City University of Hong Kong, found that values of peak SHG for horizontal surfaces occurred in condition of cloudy day and were higher than those indicated by ASHRAE [1] for clear day. On the base of this climatic data, they developed an approach to evaluate peak SHG on subtropical regions.

Also for Mediterranean regions the hypothesis of clear day could not be the most conservative condition, as it has been observed by the authors while testing the performance of an heating, ventilation, and air conditioning plant in Rome for particular orientations of the building surfaces, although not for horizontal ones.

In general, the value of solar irradiance for a surface facing the sun can increase for the simultaneous presence of direct beam and diffuse radiation and it may occur when there are few clouds that leave large areas of clear sky, fig. (1).
But this situation is statistically rare, verifying only for particular locations and for a short time. Figure 2 shows the frequency of experimental SHG, extrapolated from measured data [3], compared to the SHG valued by ASHRAE for a clear day. Only for a 0.25% the former is higher than the latter.

Conversely, the situation that normal occurs is when the sky is overcast and the beam of radiant energy emerging from the clouds is more attenuated than on a clear day and largely spread in all directions, as indicated in fig. 1(b). However, as will be shown below, even in a cloudy day, for particular expositions, the total radiation reaching a surface can be greater than for a clear day.

Indeed, the total radiation $I_S$ reaching a surface can be expressed as [1]:

$$I_S = I_B \cos \Theta_S + I_D F_{SS} + \rho_G F_{SG} (I_B \cos \Theta_H + I_D)$$  

(1)

where $I_S$ is the total radiation, $I_B$ – the beam radiation, $I_D$ – the diffuse hourly radiation on a horizontal surface, $\rho_G$ – the ground reflecting coefficient, $\Theta_S$ – the angle of incidence respect the normal to the surface, $\Theta_H$ – the angle of incidence relative to the normal to the ground, $F_{SS}$ – the angle factor between sky and surface, and $F_{SG}$ – the angle factor between ground and surface.

In eq. (1), $\cos \Theta_S$ and $\cos \Theta_H$ are strongly dependent on the incoming solar rays direction; on the other hand the values of $F_{SS}$ and $F_{SG}$ are barely influenced by beam direction. Considering that on a cloudy day the total radiation decreases while the diffuse fraction increases, for small values of $\cos \Theta_S$ and $\cos \Theta_H$ the incremental variation of the diffuse component can prevail on the reduction of the beam component, carrying out an increase of the total radiation $I_S$.

Assumptions and preliminary analysis

An approximate analysis can be done using the available equations for the estimation of the diffuse fraction of total radiation.

Liu et al. [4] first found a correlation, not dependent from latitude and elevation, between the diffuse fraction $H_D/H_0$ of daily radiation and a “daily clearness index” $K_T$, defined as $K_T = H/H_0$, where $H$ is the daily radiation on a horizontal surface, $H_0$ – the daily extraterrestrial radiation on a horizontal surface, and $H_D$ – the diffuse daily radiation on a horizontal surface.
Other correlations were obtained by Orgill et al. [5] (data from Canadian measuring stations), Erbs et al. [6] (data from USA and Australia), and Reindl et al. [7] (data from USA and Europe) for hourly radiation. They found \( I_D/I_0 \) vs. \( k_T \) correlations, where \( k_T \) is the \( I/T_0 \) “hourly clearness index”, \( \Phi_D \) – the \( I_D/I_0 \) “diffuse ratio”, \( I \) – the hourly radiation on a horizontal surface, \( I_0 \) – the hourly extraterrestrial radiation on a horizontal surface, and \( I_D \) – the diffuse hourly radiation on a horizontal surface.

This three correlations are shown in fig. 3. They are substantially identical.

The Orgill and Hollands correlation, that has been widely used, is given by the following equations:

\[
\Phi_D(k_T) = \begin{cases} 
1 - 0.249k_T & \text{for } 0 \leq k_T \leq 0.35 \\
1.557 - 1.184k_T & \text{for } 0.35 \leq k_T \leq 0.75 \\
0.177 & \text{for } k_T > 0.75 
\end{cases} 
\]  

(2)

Using eq. (2) the total radiation reaching a surface is expressed as follows:

\[
I_S^{\text{cloudy}}(k_T) = I_{00}k_T \left\{1 - \Phi_D(k_T) \frac{\cos \theta_S}{\cos \theta_H} + \Phi_D(k_T)F_{SS} + \rho_G F_{SG}\right\} 
\]  

(3)

For vertical surfaces, with free sky view and flat surrounding ground, it is assumed that the angles factors are:

\[ F_{SS} \equiv 0.5 \quad \text{and} \quad F_{SG} \equiv 0.5 \]

Figure 4 shows the resulting plot of the ratio \( R_{CL} = I_S^{\text{cloudy}}(k_T)/I_S^{\text{clear}}(k_T) \) vs. \( k_T \) for several values of \( \cos \theta_S/\cos \theta_H \) and for \( \rho_G = 0 \) and 0.2.

Figure 4. Plot of the ratio \( R_{CL} = I_S^{\text{cloudy}}(k_T)/I_S^{\text{clear}}(k_T) \) vs. \( k_T \) for several values of \( \cos \theta_S/\cos \theta_H \) and for \( \rho_G = 0 \) and 0.2.
As illustrated in fig. 4, values of $R_{CL} > 1$ can occur for $k_T < 1$ when weather conditions may not represent a clear sky. This effect is considerable for low values of $\cos \theta_s/\cos \theta_H$ when, generally, the direct component of solar radiation on the given surface is far from the maximum value $I_B$. Furthermore, the maximum value of $R_{CL}$ goes up with the decrease of $\rho_C$. Note that if $k_T = 1$ (clear day) $R_{CL} = 1$ for any value of $\cos \theta_s/\cos \theta_H$.

To investigate in more detail this situation, in the following section has been calculated the hourly SHG through real fenestration, in relationship with the wall orientation, the day of the year and the hour in the day. The numerical calculation of SHG for clear and cloudy day have been made by using eqs. (1) and (3). All terms in the equations have been calculated strictly following the method and data given in [1] as better specified in the following section.

**Numerical calculation of SHG for clear and cloudy day**

All calculations have been made hourly (from 6 a.m. to 6 p.m.), on the 21st day of the month with the procedure reported in the appendix.

**Clear day**

Solar radiation data are given in tab. 1 from [1].

Table 1. Solar radiation data

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{SI}$ [Wm$^{-2}$]</td>
<td>1230</td>
<td>1215</td>
<td>1186</td>
<td>1136</td>
<td>1104</td>
<td>1088</td>
<td>1085</td>
<td>1107</td>
<td>1151</td>
<td>1192</td>
<td>1221</td>
<td>1233</td>
</tr>
<tr>
<td>$B_{air}$ mass-1</td>
<td>0.142</td>
<td>0.144</td>
<td>0.156</td>
<td>0.180</td>
<td>0.196</td>
<td>0.205</td>
<td>0.207</td>
<td>0.201</td>
<td>0.177</td>
<td>0.160</td>
<td>0.149</td>
<td>0.142</td>
</tr>
<tr>
<td>$C$, [-]</td>
<td>0.058</td>
<td>0.06</td>
<td>0.071</td>
<td>0.097</td>
<td>0.121</td>
<td>0.134</td>
<td>0.136</td>
<td>0.122</td>
<td>0.092</td>
<td>0.073</td>
<td>0.063</td>
<td>0.057</td>
</tr>
</tbody>
</table>

$A_{SI}$ is the apparent normal solar irradiation at air mass 0; $B$ the atmospheric extinction coefficient, and $C$ the diffuse radiance factor for clear day.

It has also, referring to fig. 5:
- solar declination $\delta$ vs. day of the year $n_D$:

$$\delta = 23.45 \sin \left[ \frac{360}{365} \left( \frac{284 + n_D}{365} \right) \right]$$

- hour angle $H_A$ vs. apparent solar time $A_{ST}$:

$$H_A = 15(A_{ST} - 12)$$

- direct normal irradiance $I_{DN}$ vs. solar altitude $\beta$:

$$I_{DN} = \frac{A_{SI}}{\sin \beta} \quad \text{if } \beta \leq \text{ then } I_{DN} = 0$$

- sun-wall azimuth $\gamma$ vs. wall azimuth $\psi$ and solar azimuth $\phi$ ( $\psi$ and $\phi$ from south, positive toward east):

$$\gamma = \psi - \phi$$

Figure 5. Solar angles
The following equations relate the solar altitude \( b \), the latitude \( L \), the declination \( d \), the hour angle \( H_A \), the solar azimuth \( \phi \), the angle of incidence of the beam radiation on the wall \( \Theta \), and the tilt angle on the wall \( \Sigma \) \[1\]:

\[
\sin b = \cos L \cos \delta \cos H_A + \sin L \sin \delta \quad (7b)
\]

\[
\sin \varphi = \frac{\cos \delta \sin H_A}{\cos \beta} \quad (7c)
\]

\[
\cos \Theta = \cos \beta \cos \gamma \sin \Sigma + \sin \beta \cos \Sigma \quad (7d)
\]

**Direct (beam) irradiance and diffuse irradiance**

Beam radiation on the wall \( I_B \):

- If \( \cos \Theta > 0 \) then \( I_B = I_{DN} \cos \Theta \); otherwise \( I_B = 0 \)
- Diffuse irradiance on the horizontal surface: \( I_{DH} = I_{DN} C \)
- Sky diffuse irradiance on vertical surface: \( I_{DSV} = I_{DN} CY \)
- Ground reflected diffuse irradiance on vertical surface:
  
  \[
  I_{DVG} = (I_{DH} + I_{DN} \cos \Theta_H) \rho_C F_{SG} = I_{DN} (C + \cos \Theta_H) \rho_C F_{SG} \quad (8)
  \]

It is assumed \( F_{SG} = 0.5 \) (ground horizontal, reflected radiation isotropic).

In the ASHRAE model, the total diffuse irradiance on vertical surface is given by:

\[
I_{DV} = I_{DSV} + I_{DVG} = I_{DN} [CY + (C + \cos \Theta_H) \rho_C F_{SG}] \quad (9)
\]

where \( Y \) is the ratio of sky diffuse irradiance on vertical surface to sky diffuse irradiance on horizontal surface and for clear day may be evaluated as:

If \( \cos \Theta > -0.2 \) then \( Y = 0.55 + 0.437 \cos \Theta + 0.313 \cos^2 \Theta \quad (10) \)

Otherwise \( Y = 0.45 \).

**Peak solar heat gain**

- Transmitted component:
  
  \[ SHG_T = I_B \tau(\Theta) + I_D \bar{\tau} \quad (11) \]

- Absorbed component:
  
  \[ SHG_A = I_B a(\Theta) + I_D \bar{a} \quad (12) \]

\( \tau(\Theta) \) and \( a(\Theta) \) are the transmission and absorption coefficients of the fenestration as a function of \( \Theta \); \( \bar{\tau} \) and \( \bar{a} \) are the average values: \( \tau(\Theta) \) and \( a(\Theta) \) may be expressed in polynomial form as \[1\]:

\[
\tau(\Theta) = \sum_{j=0}^{5} \alpha_j \Theta^j \quad \bar{\tau} = 2 \sum_{j=0}^{5} \frac{\alpha_j}{j+2} \quad (13)
\]

and

\[
a(\Theta) = \sum_{j=0}^{5} \alpha_j \Theta^j \quad \bar{a} = 2 \sum_{j=0}^{5} \frac{\alpha_j}{j+2} \quad (14)
\]
For an ASHRAE standard double glass the coefficients $t_j$ an $a_j$ for the polynomial expressions are given in tab. 2.

The SHG factor in clear day is finally given by:

$$SHG_{\text{CLEAR}} = SHG_T + NSHG_D$$  \hspace{1cm} (15)

where $N$ is the inward flowing fraction of the absorbed radiation. Here it has been assumed $N = 0.3$.

### Cloudy day

Equations (4)-(7) and the nomenclature given in section 3.1 remain the same. To calculate the beam and diffuse components the Orgill and Hollands correlation was used. It was slightly modified to obtain that in clear day condition $F_D(k_T)$ values in the Orgill and Hollands correlation were the same that in the ASHRAE model in the same month and hour.

For the ASHRAE model the hourly clearness index in clear day $k_T^{\text{clear}}(m,h)$ is given by:

$$k_T^{\text{clear}}(m,h) = \frac{I_{DN}(C + \cos \Theta_H)}{A \cos \Theta_H}$$ \hspace{1cm} (16)

and the corresponding $\Theta_D(k_T)$ value:

$$\Theta_D^{\text{clear}}(m,h) = \frac{I_{DN}C}{I_{DN}(C + \cos \Theta_H)}$$ \hspace{1cm} (17)

Using (16) and (17), the new correlation $\phi_D(k_T)$ can be expressed as:

$$\phi_D(k_T) = \begin{cases} 
1 - 0.249k_T & \text{for } 0 \leq k_T \leq 0.35 \text{ and } k_T^{\text{clear}} > 0.35 \\
0.913 + \frac{\phi_D^{\text{clear}} - 0.913}{k_T^{\text{clear}} - 0.35}(k_T - 0.35) & \text{for } 0.35 \leq k_T \leq 0.75 \text{ and } k_T^{\text{clear}} > 0.35 \\
\phi_D^{\text{clear}} & \text{for } k_T > 0.75 \text{ or } k_T \geq k_T^{\text{clear}}
\end{cases}$$ \hspace{1cm} (18)

The solar heat gain was then calculated with the procedure given in appendix A.

### Results

$SHG_{\text{CLOUDY}}$ values were calculated on the 21st day of each month, for latitudes between 35° and 55° north, for surfaces facing the eight cardinal orientations and the horizontal surface. For example, results for latitude of 48° north are given in tabs. 3 and 4. Data carried out from model were formatted in the same manner of that presented in [1] for each month, hour and orientation, for clear and cloudy conditions. Calculations were made for $\rho_G = 0.1$ (bituminous parking lot) and $\rho_G = 0.2$ (green grass) as suggested by Threlkeld [8].

The tables carry out the $SHG_{\text{CLOUDY}}$ values in relationship with different format.

Precisely:

- if $1 < SHG_{\text{CLOUDY}}/SHG_{\text{CLEAR}} \leq 1.25$ \hspace{1cm} underscored
- if $1.25 < SHG_{\text{CLOUDY}}/SHG_{\text{CLEAR}} \leq 1.5$ \hspace{1cm} italic
- if $1.5 < SHG_{\text{CLOUDY}}/SHG_{\text{CLEAR}}$ \hspace{1cm} bold italic

### Table 2. ASHRAE standard double glass coefficients for eqs. (13) and (14)

<table>
<thead>
<tr>
<th>$J$</th>
<th>$t_j$</th>
<th>$a_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.00885</td>
<td>0.01154</td>
</tr>
<tr>
<td>1</td>
<td>2.71235</td>
<td>0.77674</td>
</tr>
<tr>
<td>2</td>
<td>-0.62062</td>
<td>-3.94657</td>
</tr>
<tr>
<td>3</td>
<td>-7.07329</td>
<td>8.57881</td>
</tr>
<tr>
<td>4</td>
<td>9.75995</td>
<td>-8.38135</td>
</tr>
<tr>
<td>5</td>
<td>-3.89922</td>
<td>3.01188</td>
</tr>
</tbody>
</table>
The results reveal that:

- Comparisons between $\text{SHG}_{\text{CLOUDY}}$ and $\text{SHG}_{\text{CLEAR}}$ shown that the values of the former often exceed the latter, particularly for the smaller values of the ground albedo. The increment between respective hourly values was often a tenth percent but in some case was twice and more. Nevertheless, for all considered expositions, excluding north exposition, the maximum daily value occurs for clear condition so the clear day remains the conservative condition for computing the peak solar heat gain.

- For north exposure the behavior is different. Indeed $\text{SHG}_{\text{CLOUDY}}$ is never lower and in nearly every case, notably in peak condition, greater than $\text{SHG}_{\text{CLEAR}}$. Figure 6 shows the evolution of $\text{SHG}_{\text{CLOUDY}}$ and $\text{SHG}_{\text{CLEAR}}$ for the month of June, at different times of day. As it can be noted, for $\text{SHG}_{\text{CLOUDY}}$ the peak value occurs at noon while $\text{SHG}_{\text{CLEAR}}$ has the maximum values at early morning or in last hour of the evening, i.e. when the conditioning plant is off. For this reason the difference between the peak values occurring during the seasonal period of operation of the conditioning plant can reach 70-90 W/m$^2$. The time range shown in fig. 6 corresponds with the typical working time of an office building, from 08.00 to 17.00.

Therefore, for north exposition, if the value of fenestration heat gain is a valuable part of the total sensible heat gain, the assumption of clear day cannot be a conservative condition.

A better representation of the situation described above can be made plotting the values of the maximum difference between $\text{SGH}_{\text{CLOUDY}}$, $\text{SGH}_{\text{CLEAR}}$, $\text{SHG}_{\text{CLOUDY}}$, and $\text{SHG}_{\text{CLEAR}}$ as a function of the latitude and the exposition, as shown in the following figures.

Figure 7 describes $\text{SGH}_{\text{CLOUDY}}$, $\text{SGH}_{\text{CLEAR}}$, $\text{SHG}_{\text{CLOUDY}}$, and $\text{SHG}_{\text{CLEAR}}$, distributions for latitudes range between 0 and 60°, with exposition purely north. It is observed that this difference is small for low latitudes while is more pronounced for latitudes between 20° and 35°, decreasing gradually for high latitude values until to 60°.

In fig. 8 is presented the maximum deviation from north exposure so that the difference $\text{SGH}_{\text{CLEAR}}$ $\text{SGH}_{\text{CLOUDY}}$ is positive, for different latitudes. At low latitudes the difference $\text{SGH}_{\text{CLOUDY}}$, $\text{SHG}_{\text{CLOUDY}}$, and $\text{SGH}_{\text{CLEAR}}$ is small and only for exposure close to the north. At major latitudes, it is noted that this difference increases with the angular distance from north, until to 32° W or 13° E. The different behavior shown for west and east expositions is due to the choice of an asymmetric working time respect to the noon (fig. 6).
<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard Error</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.50</td>
<td>0.15</td>
<td>0.35</td>
<td>0.65</td>
<td>0.02</td>
<td>10</td>
</tr>
<tr>
<td>2011</td>
<td>0.52</td>
<td>0.17</td>
<td>0.38</td>
<td>0.68</td>
<td>0.02</td>
<td>12</td>
</tr>
<tr>
<td>2012</td>
<td>0.53</td>
<td>0.18</td>
<td>0.39</td>
<td>0.69</td>
<td>0.03</td>
<td>14</td>
</tr>
<tr>
<td>2013</td>
<td>0.54</td>
<td>0.19</td>
<td>0.40</td>
<td>0.70</td>
<td>0.03</td>
<td>16</td>
</tr>
<tr>
<td>2014</td>
<td>0.55</td>
<td>0.20</td>
<td>0.41</td>
<td>0.71</td>
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<td>18</td>
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<tr>
<td>2015</td>
<td>0.56</td>
<td>0.21</td>
<td>0.42</td>
<td>0.72</td>
<td>0.05</td>
<td>20</td>
</tr>
<tr>
<td>2016</td>
<td>0.57</td>
<td>0.22</td>
<td>0.43</td>
<td>0.73</td>
<td>0.06</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 1: Summary of Average Solar Heat Gains Over the Years.
Table 4

<table>
<thead>
<tr>
<th>Date</th>
<th>A.M.</th>
<th>Noon</th>
<th>1 P.M.</th>
<th>2 P.M.</th>
<th>3 P.M.</th>
<th>4 P.M.</th>
<th>5 P.M.</th>
<th>6 P.M.</th>
<th>7 P.M.</th>
<th>8 P.M.</th>
<th>9 P.M.</th>
<th>10 P.M.</th>
<th>11 P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 21</td>
<td>3</td>
<td>9.5</td>
<td>12.2</td>
<td>11.2</td>
<td>8.9</td>
<td>7.8</td>
<td>6.2</td>
<td>5.2</td>
<td>4.2</td>
<td>3.4</td>
<td>2.7</td>
<td>2.0</td>
<td>1.4</td>
</tr>
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<td>Feb 21</td>
<td>3</td>
<td>9.8</td>
<td>11.5</td>
<td>10.6</td>
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<td>7.5</td>
<td>6.1</td>
<td>5.2</td>
<td>4.3</td>
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<td>2.8</td>
<td>2.1</td>
<td>1.5</td>
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<td>7.2</td>
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<td>4.7</td>
<td>4.0</td>
<td>3.3</td>
<td>2.6</td>
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<td>11.8</td>
<td>10.3</td>
<td>9.5</td>
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<td>6.7</td>
<td>5.9</td>
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<td>12.3</td>
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<td>10.9</td>
<td>9.8</td>
<td>9.1</td>
<td>8.4</td>
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<td>7.0</td>
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<td>5.6</td>
</tr>
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<td>Jun 21</td>
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<td>11.8</td>
<td>13.7</td>
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<td>12.6</td>
<td>11.8</td>
<td>10.9</td>
<td>10.3</td>
<td>9.7</td>
<td>9.1</td>
<td>8.5</td>
<td>7.8</td>
<td>7.1</td>
</tr>
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<td>14.2</td>
<td>13.5</td>
<td>13.3</td>
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<td>11.3</td>
<td>10.7</td>
<td>10.1</td>
<td>9.5</td>
<td>8.9</td>
<td>8.2</td>
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<td>Aug 21</td>
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<td>14.7</td>
<td>13.9</td>
<td>14.8</td>
<td>14.1</td>
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<td>11.8</td>
<td>11.3</td>
<td>10.7</td>
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<tr>
<td>Sep 21</td>
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<td>15.7</td>
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Solar heat gain factors, W/m²

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Fontana, L., et al.: Fenestration Peak Solar Heat Gain: A Review of ...
THERMAL SCIENCE, Year 2011, Vol. 15, No. 1, pp. 223-234
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In Fig. 9 is plotted the evolution of $SGH_{\text{cloudy}}^{\text{max}} - SGH_{\text{clear}}^{\text{max}}$ varying the wall exposure from north to west, for different values of latitudes. The curves show a similar behavior in which there is a peak value that, increasing deviation from north exposure, decreases until to zero. This trend is more pronounced for high latitudes. In the latitudes between 15° and 35° the peak is in correspondence of an exposure deviation of about 4° from north. For major latitudes the peak disappears but, in a significant range of angles of exposure, the difference $SGH_{\text{cloudy}}^{\text{max}} - SGH_{\text{clear}}^{\text{max}}$ seems to stabilize on a constant positive value before to decrease to zero. So, also for wall exposure not strictly facing north, care must be taken for evaluating $SHG$ in clear day condition because, as described, could not be the most conservative condition for a correct calculation.

Note that the procedure search for the maximum value of $SHG_{\text{cloudy}}$ in the range $0 \leq k_T \leq 1$. For the extreme case $k_T = 1$, it is $SHG_{\text{cloudy}} \equiv SHG_{\text{clear}}$ (see fig. 4). This is why in tabs. 3 and 4 $SHG_{\text{cloudy}}$ appears never smaller then $SHG_{\text{clear}}$.

Nomenclature

- $A_{SI}$ – apparent normal solar irradiation at air mass = 0, [Wm$^{-2}$]
- $A_{ST}$ – apparent solar time [hours]
- $a(\theta)$ – absorption coefficient for beam component
- $a$ – absorption coefficient for diffuse component
- $B$ – atmospheric extinction coefficient, [air mass-1]
- $C$ – diffuse radiance factor (clear day), [-]
- $F_{SG}$ – angle factor between ground and surface, [-]
- $F_{SS}$ – angle factor between sky and surface, [-]
- $H$ – daily radiation on a horizontal surface [Wm$^{-2}$]
- $H_A$ – hour angle, [dec. degrees]
- $H_D$ – diffuse daily radiation on a horizontal surface, [Wm$^{-2}$]
References

APPENDIX

Calculation procedure for $SHG_{\text{max}}$.

- $I_{TH}$ = total irradiance on the horizontal plane;
- $I_{BH}$ = beam irradiance on the horizontal plane;
- $I_{DH}$ = diffuse irradiance on the horizontal plane.
- It is assumed $F_{SG} = 0.5$ (ground horizontal, reflected radiation isotropic).

$$I_{TH} = \text{total irradiance on the horizontal plane;}$$
$$I_{BH} = \text{beam irradiance on the horizontal plane;}$$
$$I_{DH} = \text{diffuse irradiance on the horizontal plane.}$$