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FOREWORD

This addendum adds a requirement to calculate the change to thermal comfort resulting from direct solar radiation impacting occupants. A calculation procedure is added in new Normative Appendix C, “Procedure for Calculating Comfort Impact of Solar Gain on Occupants.” The procedure in Appendix C results in an adjustment to mean radiant temperature (MRT) due to direct solar radiation so that the Standard 55 comfort zone calculation remains unchanged (i.e., the same six inputs are required). With this change, the Graphic Comfort Zone Method in Section 5.3.1 is restricted to conditions without direct solar radiation. When direct solar radiation is present and impacts a representative occupant, the Analytical Comfort Zone Method in Section 5.3.2 must be used. Section 5.3.2 provides prescriptive and performance compliance paths. Prescriptive tables in Section 5.3.2 cover many common applications and allow an MRT increase of 2.8°C (5°F) to be used if all criteria in Section 5.3.2.2.1(b) are met. The performance approach uses the calculation procedure in Section 5.3.2.2.1(a) and can be used for any application.

Normative Appendix C describes the calculation procedure and includes a computer code implementation. The CBE Thermal Comfort Tool (http://comfort.cbe.berkeley.edu) provides an online implementation of the method under the “SolarCal” button.

Note: In this addendum, changes to the current standard are indicated in the text by underlining (for additions) and strikethrough (for deletions) unless the instructions specifically mention some other means of indicating the changes.

Addendum g to Standard 55-2013

Revise Section 3 as shown. The remainder of Section 3 is unchanged.

3. DEFINITIONS

solar transmittance, total (T_{\text{sup}}): total solar radiation transmittance through a fenestration unit, including glazing unit and internal blinds or shades. See Normative Appendix C for acceptable calculation methods.

temperature, mean radiant (\textit{T}_r): the temperature of a uniform, black enclosure that exchanges the same amount of heat by radiation with the occupant as the actual enclosure surroundings. It is a single value for the entire body and accounts for both long-wave mean radiant temperature (T_{\text{rlw}}) and short-wave mean radiant temperature (T_{\text{rsw}}), expressed as a spatial average of the temperature of surfaces surrounding the occupant weighted by their view factors with respect to the occupant. (See Chapter 9 of ASHRAE Handbook—Fundamentals\textsuperscript{2} for a more complete description of mean radiant temperature.)

temperature, long-wave mean radiant (T_{\text{rlw}}): Radiant temperature from long-wave radiation from interior surfaces expressed as a spatial average of the temperature of surfaces surrounding the occupant, weighted by their view factors with respect to the occupant. (See ASHRAE Handbook—Fundamentals\textsuperscript{3}, Chapter 9).

temperature, short-wave mean radiant (T_{\text{rsw}}): Radiant temperature from short-wave direct and diffuse solar radiation expressed as an adjustment to long-wave mean radiant temperature (T_{\text{rlw}}) using the calculation procedure in Normative Appendix C of this standard.

shade openness factor: percentage of the area of a shade or blind material that is unobstructed. For woven shades, shade openness factor is the weave openness.

direct-beam solar radiation: solar radiation from the direction of the sun, expressed in W/m\textsuperscript{2} (Btu/ft\textsuperscript{2}). Does not include reflected or diffuse solar radiation. Also known as direct normal insolation (I_{\text{dni}}).

Revise Section 5.3.1 as shown. The remainder of Section 5.3.1 is unchanged.

5.3.1 Graphic Comfort Zone Method

5.3.1.1 Applicability. Use of this method shall be limited to representative occupants with metabolic rates between 1.0 and 1.3 met and clothing insulation (I_o) between 0.5 and 1.0 clo and who are not exposed to direct-beam solar radiation. Average air speed (\textit{V}_o) greater than 0.2 m/s (40 fpm) requires the use of Section 5.3.3.

The Graphic Comfort Zone is limited to a humidity ratio at or below 0.012 kg-H_2O/kg dry air (0.012 lb-H_2O/lb dry air), which corresponds to a water vapor pressure of 1.910 kPa (0.277 psi) at standard pressure or a dew-point temperature of 16.8°C (62.2°F).

Revise Section 5.3.2 as shown.

5.3.2 Analytical Comfort Zone Method

5.3.2.1 Applicability. It is permissible to apply the method in this section to all spaces within the scope of this standard where the occupants have activity levels that result in average metabolic rates between 1.0 and 2.0 met. Average air speeds (\textit{V}_o) greater than 0.20 m/s (40 fpm) require the use of Section 5.3.3.

5.3.2.2 Methodology. The computer code in Normative Appendix B is to be used with this standard.\textsuperscript{4} Compliance is achieved if −0.5 < \textit{PMV} < +0.5. Alternative methods are permitted. If any other method is used, it is the user’s responsibility to verify and document that the method used yields the same results. The ASHRAE Thermal Comfort Tool\textsuperscript{4} is permitted to be used to comply with this section.

5.3.2.2.1 When direct-beam solar radiation falls on a representative occupant, the mean radiant temperature (\textit{T}_r) shall account for long-wave mean radiant temperature (T_{\text{rlw}}).
and short-wave mean radiant temperature ($\overline{t_{rsw}}$) using one of the following options:

a. Full calculation of mean radiant temperature ($\overline{t_r}$) as follows:
   1. Step 1: Determine long-wave mean radiant temperature ($\overline{t_{lw}}$).
   2. Step 2: Determine short-wave mean radiant temperature ($\overline{t_{rsw}}$) using Normative Appendix C.
   3. Step 3: Mean radiant temperature ($\overline{t_r}$) is equal to ($\overline{t_{lw}}$ + $\overline{t_{rsw}}$), as determined in Steps 1 and 2.

b. Use a mean radiant temperature ($\overline{t_r}$) that is 2.8°C (5°F) higher than average air temperature ($t_a$) if all of the following conditions are met:
   1. The space has air temperature stratification less than Section 5.3.4.3.
   2. The space does not have active radiant surfaces.

   4. Outdoor air temperature is less than 43°C (110°F).
   5. Vertical fenestration has less than 9 ft (3 m) total height.
   6. No skylights are present.
   7. The space complies with all requirements in a single row of Tables 5.3.2.2.1A, B, C or D. Interpolation between values within a single table (5.3.2.2.1A, B, C, or D), but not between tables, is permissible. Solar absorptance properties for shade fabrics used in Tables 5.3.2.2.1A, B, C, or D shall use the most similar color from 5.3.2.2.1E unless more specific data are available from the manufacturer.

Tables 5.3.2.2.1A through D show criteria that allow use of mean radiant temperature ($\overline{t_r}$) that is 2.8°C (5°F) higher than average air temperature ($t_a$) for high-performance glazing units (Table 5.3.2.2.1A), clear low-performance glazing units (5.3.2.2.1B), tinted glazing units (5.3.2.2.1C), and electrochromic glazing units (5.3.2.2.1D). See Normative Appendix C Section C2(e) for a description of $f_{hes}$. 

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# TABLE 5.3.2.2.1A High-Performance (Low-e) Glazing Units

<table>
<thead>
<tr>
<th>Representative Occupant Distance from Interior Window or Shade Surface, ft (m)</th>
<th>Fraction of Body Exposed to Sun ( f_{\text{bes}} ), %</th>
<th>Glazing Unit Total Solar Transmission ( T_{\text{sol}} ), %</th>
<th>Glazing Unit Indirect SHGC ( \text{SHGC} - T_{\text{sol}} ), %</th>
<th>Interior Shade Openness Factor, %</th>
<th>Interior Shade Solar Absorptance of Window-Facing Side, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥3.3 (1)</td>
<td>≤50</td>
<td>≤15</td>
<td>≤4.5</td>
<td>≤9</td>
<td>≤65</td>
</tr>
<tr>
<td>≥3.3 (1)</td>
<td>≤100</td>
<td>≤15</td>
<td>≤4.5</td>
<td>≤5</td>
<td>≤65</td>
</tr>
</tbody>
</table>

# TABLE 5.3.2.2.1B Clear Low-Performance Glazing Units

<table>
<thead>
<tr>
<th>Representative Occupant Distance from Interior Window or Shade Surface, ft (m)</th>
<th>Fraction of Body Exposed to Sun ( f_{\text{bes}} ), %</th>
<th>Glazing Unit Total Solar Transmission ( T_{\text{sol}} ), %</th>
<th>Glazing Unit Indirect SHGC ( \text{SHGC} - T_{\text{sol}} ), %</th>
<th>Interior Shade Openness Factor, %</th>
<th>Interior Shade Solar Absorptance of Window-Facing Side, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥9.9 (3)</td>
<td>≤50</td>
<td>≤83</td>
<td>≤10</td>
<td>≤1</td>
<td>≤25</td>
</tr>
<tr>
<td>≥13.2 (4)</td>
<td>≤50</td>
<td>≤83</td>
<td>≤10</td>
<td>≤1</td>
<td>≤65</td>
</tr>
<tr>
<td>≥11.2 (3.4)</td>
<td>≤100</td>
<td>≤83</td>
<td>≤10</td>
<td>≤1</td>
<td>≤25</td>
</tr>
<tr>
<td>≥14.5 (4.4)</td>
<td>≤100</td>
<td>≤83</td>
<td>≤10</td>
<td>≤1</td>
<td>≤65</td>
</tr>
</tbody>
</table>

# TABLE 5.3.2.2.1C Tinted Glazing Units

<table>
<thead>
<tr>
<th>Representative Occupant Distance from Interior Window or Shade Surface, ft (m)</th>
<th>Fraction of Body Exposed to Sun ( f_{\text{bes}} ), %</th>
<th>Glazing Unit Total Solar Transmission ( T_{\text{sol}} ), %</th>
<th>Glazing Unit Indirect SHGC ( \text{SHGC} - T_{\text{sol}} ), %</th>
<th>Interior Shade Openness Factor, %</th>
<th>Interior Shade Solar Absorptance of Window-Facing Side, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥3.3 (1)</td>
<td>≤50</td>
<td>≤10</td>
<td>≤20</td>
<td>≤8</td>
<td>≤25</td>
</tr>
<tr>
<td>≥3.3 (1)</td>
<td>≤50</td>
<td>≤10</td>
<td>≤20</td>
<td>≤1</td>
<td>≤65</td>
</tr>
<tr>
<td>≥4 (1.2)</td>
<td>≤100</td>
<td>≤10</td>
<td>≤20</td>
<td>≤1</td>
<td>≤25</td>
</tr>
<tr>
<td>≥4.9 (1.5)</td>
<td>≤100</td>
<td>≤10</td>
<td>≤20</td>
<td>≤1</td>
<td>≤65</td>
</tr>
<tr>
<td>&gt;9.2 (2.8)</td>
<td>≤50</td>
<td>≤15</td>
<td>≤8</td>
<td>No shade</td>
<td>No shade</td>
</tr>
</tbody>
</table>

# TABLE 5.3.2.2.1D Dynamic Glazing Units (Increasing \( T_{\text{sol}} \) Represents Decreasing Tint)

<table>
<thead>
<tr>
<th>Representative Occupant Distance from Interior Window or Shade Surface, ft (m)</th>
<th>Fraction of Body Exposed to Sun ( f_{\text{bes}} ), %</th>
<th>Glazing Unit Total Solar Transmission ( T_{\text{sol}} ), %</th>
<th>Glazing Unit Indirect SHGC ( \text{SHGC} - T_{\text{sol}} ), %</th>
<th>Interior Shade Openness Factor, %</th>
<th>Interior Shade Solar Absorptance of Window-Facing Side, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥3.3 (1)</td>
<td>≤50</td>
<td>≤0.5</td>
<td>≤10</td>
<td>N/A</td>
<td>No shade</td>
</tr>
<tr>
<td>≥3.3 (1)</td>
<td>≤100</td>
<td>≤0.5</td>
<td>≤10</td>
<td>N/A</td>
<td>No shade</td>
</tr>
<tr>
<td>≥4.9 (1.5)</td>
<td>≤50</td>
<td>≤3</td>
<td>≤10</td>
<td>N/A</td>
<td>No shade</td>
</tr>
<tr>
<td>≥6.6 (2)</td>
<td>≤100</td>
<td>≤3</td>
<td>≤10</td>
<td>N/A</td>
<td>No shade</td>
</tr>
<tr>
<td>≥7.6 (2.3)</td>
<td>≤50</td>
<td>≤8</td>
<td>≤10</td>
<td>N/A</td>
<td>No shade</td>
</tr>
<tr>
<td>≥9.9 (3)</td>
<td>≤50</td>
<td>≤9</td>
<td>≤10</td>
<td>N/A</td>
<td>No shade</td>
</tr>
</tbody>
</table>

# TABLE 5.3.2.2.1E Interior Shade Solar Absorptance Based on Color Description of Window-Facing Side of Shade

<table>
<thead>
<tr>
<th>Solar Absorptance, %</th>
<th>0 to 15</th>
<th>15 to 25</th>
<th>25 to 65</th>
<th>&gt;65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color Description</td>
<td>White</td>
<td>Silver, cornsilk, wheat, oyster, beige, pearl</td>
<td>Beige, pewter, smoke, pebble, stone, pearl grey, light grey</td>
<td>Charcoal, graphite, chestnut</td>
</tr>
</tbody>
</table>
5.3.3 Elevated Air Speed Comfort Zone Method

5.3.3.1 Applicability. It is permissible to apply the method in this section to all spaces within the scope of this standard where the occupants have activity levels that result in average metabolic rates between 1.0 and 2.0 met, clothing insulation ($I_c$) between 0.0 and 1.5 clo, and average air speeds ($V_a$) greater than 0.20 m/s (40 fpm).

5.3.3.2 Methodology. The calculation method in Normative Appendix C is to be used with this method. This method uses the Analytical Comfort Zone Method in Section 5.3.2 combined with the Standard Effective Temperature (SET) method described in Normative Appendix D.

Figure 5.3.3A represents two particular cases of the Elevated Air Speed Comfort Zone Method and shall be permitted as a method of compliance for the conditions specified on the figure. It is permissible to determine the operative temperature range by linear interpolation between the limits found for each zone in Figure 5.3.3A.

Alternative methods are permitted. If any other method is used, the user shall verify and document that the method used yields the same results. The ASHRAE Thermal Comfort Tool (ASHRAE Handbook—Fundamentals, Chapter 9.24) is permitted to be used to comply with this section.

Informative Note: The flowchart in Figure 5.3.3B describes the steps for determining the limits to airspeed inputs in SET model.

When direct-beam solar radiation falls on a representative occupant, the mean radiant temperature ($\overline{t}_{\text{r}}$) shall account for long-wave mean radiant temperature ($\overline{t}_{\text{r,sw}}$) and short-wave mean radiant temperature ($\overline{t}_{\text{r,sw}}$) in accordance with Section 5.3.2.2.1.

Revise Section 5.3.4.2 as shown. Note that no changes are made here to Table 5.3.4.2.

5.3.4.2 Radiant Temperature Asymmetry. Radiant temperature asymmetry shall not exceed the values in Table 5.3.4.2. The radiant temperature asymmetry is quantified in its definition in Section 3.

When direct-beam solar radiation falls on a representative occupant, the radiant temperature asymmetry shall include the solar contribution as follows: The short-wave mean radiant temperature ($\overline{t}_{\text{r,sw}}$), as determined in Normative Appendix C, shall be multiplied by two and added to the plane radiant temperature ($\overline{t}_{\text{r}}$) for each horizontal or vertical direction in which the plane receives direct sunlight.

Insert the following text after item (g) in Section 6. The remainder of Section 6 is unchanged.

h. When direct-beam solar radiation falls on a representative occupant, documentation shall include solar design conditions (solar altitude, direct beam intensity), the method in Section 5.3.2.2.1 used for compliance, and the resultant mean radiant temperature ($\overline{t}_{\text{r}}$).
where \( f_{svv} \) is the fraction of sky vault in the occupant’s view (see Figure C1-1); \( I_{diff} \) is diffuse sky irradiance received on an upward-facing horizontal surface (W/m\(^2\) [Btuh/ft\(^2\)]); and \( T_{sol} \) is the total solar transmittance, the ratio of incident short-wave radiation to the total short-wave radiation passing through the glazing unit and shades of a window system.

The reflected radiation from natural and built surfaces protruding above the horizon is assumed to equal the \( I_{diff} \) they have blocked.

The total outdoor solar radiation on the horizontal is filtered by both \( T_{sol} \) and \( f_{svv} \) and multiplied by the reflectance of the floor and lower furnishings (\( R_{floor} \)).

\[
E_{refl} = 0.5 f_{svv} f_{bes} T_{sol} I_{diff} \tag{C-4}
\]

where \( I_{TH} \) is the total horizontal direct and diffuse irradiance outdoors (W/m\(^2\) [Btuh/ft\(^2\)]) and the floor reflectance (\( R_{floor} \)) is 0.6.

Direct radiation is incident only on the projected fraction of the body (\( f_p \)), which depends on solar altitude (\( \beta \)), the sun’s horizontal angle relative to the front of the person (SHARP), and posture (seated, standing). The \( f_p \) values are tabulated in the computer program in Section C4.

The direct radiation is also reduced by any shading of the body provided by the indoor surroundings, quantified by the body exposure fraction (\( f_{bes} \)) (see Figure C1-2).

\[
E_{dir} = f_p f_{svv} f_{bes} T_{sol} I_{dir} \tag{C-5}
\]

\( I_{dir} \) is the direct-beam (normal) solar radiation (W/m\(^2\) [Btuh/ft\(^2\)]). The meteorological radiation parameters are related as follows:

\[
I_{TH} = I_{dir} \sin \beta + I_{diff} \approx I_{diff} \text{ (approximated as (0.17 \( I_{dir} \) \( \sin \beta \))).}
\]

\( E_{refl} \) is therefore calculated from the following equation:

\[
E_{solar} = 0.5 f_{svv} (I_{diff} + 0.6 I_{TH}) + f_p f_{bes} I_{dir}
\times f_{svv} f_{bes} T_{sol} \alpha_{SW} / \alpha_{LW}
\times \tan (\frac{h}{2d}) \times \tan (\frac{w}{2d})
\]

To obtain \( E_{solar} \) with Equation C-6 and the fixed default values given above, the required inputs are \( f_{svv} \), \( I_{dir} \), \( f_{bes} \), \( T_{sol} \), \( \alpha_{SW} \), \( \alpha_{LW} \), \( \beta \), posture, and the sun’s horizontal angle relative to person (SHARP). These are described further in Section C2.

\( E_{solar} \) is converted to short-wave mean radiant temperature (\( T_{RMS} \)) using Equation C-1.

C2. INPUTS TO CALCULATION PROCEDURE

The calculation requires eight input values as listed in Table C2-1 and explained below.

a. Short-wave absorptivity (\( \alpha_{SW} \)). The short-wave absorptivity of the occupant will range widely depending on the color of the occupant’s skin as well as the color and amount of clothing covering the body. A value is 0.7 shall be used unless more specific information about the clothing or skin color of the occupants is available.

b. Sky-vault view fraction (\( f_{svv} \)). The sky-vault view fraction ranges between 0 and 1 as shown in Figure C1-2. It is calculated with Equation C-7 for windows to one side. This value depends on the dimensions of the window (width \( w \), height \( h \)) and the distance between the occupant and the window (\( d \)).

\[
f_{svv} = \frac{\tan^{-1} \left( \frac{h}{2d} \right) \tan^{-1} \left( \frac{w}{2d} \right)}{90 \times 180}
\]

where the \( \arctan \) function returns values in degrees. When calculating \( f_{svv} \) for multiple windows, the \( f_{svv} \) for each may be calculated and summed to obtain a total \( f_{svv} \). Exterior objects obstructing the sky vault shall not be considered because they have a similar diffuse reflectivity as the sky vault.

c. Total solar transmittance (\( T_{sol} \)). The total solar transmittance of window systems, including glazing unit, blinds, and other façade treatments, shall be determined using one of the following methods:

1. Glazing unit \( T_{sol} \) provided by manufacturer or from the National Fenestration Rating Council approved Lawrence Berkeley National Lab International Glazing Database.

2. Glazing unit plus interior fabric shade shall be calculated as the product of glazing unit \( T_{sol} \) (in item C2[a]) multiplied by the shade openness factor.

3. Glazing unit plus venetian blinds or other complex or unique shades shall be calculated using National Fenestration Rating Council approved software or Lawrence Berkeley National Lab Complex Glazing Database.

When direct solar radiation that falls on a representative occupant is transmitted through more than one window system with differing solar transmittances, the solar transmittance (\( T_{sol} \)) impinging on the occupant shall be calculated as the area-weighted average of the solar transmittance of each window system.

d. Direct-beam solar radiation (\( I_{dir} \)). Direct-beam solar radiation data for a standard cloudless atmosphere are presented in Table C2-3.

Informative Note to Section C2(d): \( I_{dir} \) is based on elevation above sea level up to 900 m (3000 ft). Above 900 m (3000 ft), increase these values 12%; above 1200 m (4000 ft) increase values 15%; above 1500 m (5000 ft), increase values 18%; and above 1800 m (6000 ft), increase values 21%.

e. Fraction of the body exposed to solar beam radiation (\( f_{bes} \)). The fraction of the body’s projected area factor (\( f_p \)) that is not shaded by the window frame, interior or exterior shading, or interior furniture. Refer to Figure C2-1.

f. Solar altitude (\( \beta \)). Solar altitude ranges from 0 degrees (horizon) to 90 degrees (zenith). Also called “solar elevation.” See Figure C2-2.
### TABLE C1-1 Symbols and Units

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERF</td>
<td>Effective radiant field</td>
<td>W/m²</td>
</tr>
<tr>
<td>$f_{ef}$</td>
<td>Fraction of body surface exchanging radiation with surroundings</td>
<td>—</td>
</tr>
<tr>
<td>$h_r$</td>
<td>Radiation heat transfer coefficient</td>
<td>W/m²·K</td>
</tr>
<tr>
<td>$t_a$</td>
<td>Air temperature</td>
<td>°C</td>
</tr>
<tr>
<td>$\alpha_{lw}$</td>
<td>Average long-wave radiation absorptivity of body (0.95)</td>
<td>—</td>
</tr>
<tr>
<td>$\alpha_{sw}$</td>
<td>Average short-wave radiation absorptivity of body</td>
<td>—</td>
</tr>
<tr>
<td>ERF_solar</td>
<td>Effective radiant field solar component</td>
<td>W/m²</td>
</tr>
<tr>
<td>$E_{solar}$</td>
<td>Total short-wave solar radiant flux</td>
<td>W/m²</td>
</tr>
<tr>
<td>$E_{dir}$</td>
<td>Direct-beam component of short-wave solar radiant flux</td>
<td>W/m²</td>
</tr>
<tr>
<td>$E_{diff}$</td>
<td>Diffuse component of short-wave solar radiant flux</td>
<td>W/m²</td>
</tr>
<tr>
<td>$E_{refl}$</td>
<td>Reflected component of short-wave solar radiant flux</td>
<td>W/m²</td>
</tr>
<tr>
<td>$f_{svv}$</td>
<td>Fraction of sky vault exposed to body</td>
<td>—</td>
</tr>
<tr>
<td>$T_{sol}$</td>
<td>Window system glazing unit plus shade solar transmittance</td>
<td>—</td>
</tr>
<tr>
<td>$I_{dir}$</td>
<td>Direct solar beam intensity</td>
<td>W/m²</td>
</tr>
<tr>
<td>$I_{diff}$</td>
<td>Diffuse solar intensity</td>
<td>W/m²</td>
</tr>
<tr>
<td>$I_{TH}$</td>
<td>Total horizontal solar intensity</td>
<td>W/m²</td>
</tr>
<tr>
<td>$f_p$</td>
<td>Projected area factor</td>
<td>—</td>
</tr>
<tr>
<td>$f_{bes}$</td>
<td>Fraction of possible body surface exposed to sun</td>
<td>—</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Solar altitude angle</td>
<td>deg</td>
</tr>
<tr>
<td>SHARP</td>
<td>Solar horizontal angle relative to front of person</td>
<td>deg</td>
</tr>
<tr>
<td>$R_{floor}$</td>
<td>Floor reflectance (fixed at 0.6)</td>
<td>—</td>
</tr>
<tr>
<td>Posture</td>
<td>Posture (seated, standing)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### TABLE C2-1 Input Variables and Ranges for Calculation Procedure

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
<th>Allowable default value</th>
<th>Range of Inputs Min to Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{sw}$</td>
<td>Short-wave radiation absorptivity</td>
<td>—</td>
<td>0.7</td>
<td>0.2 to 0.9</td>
</tr>
<tr>
<td>$f_{svv}$</td>
<td>Fraction of sky vault exposed to body</td>
<td>—</td>
<td>N/A</td>
<td>0 to 1</td>
</tr>
<tr>
<td>$T_{sol}$</td>
<td>Window system glazing unit plus shade solar transmittance</td>
<td>—</td>
<td>N/A</td>
<td>0 to 1</td>
</tr>
<tr>
<td>$I_{dir}$</td>
<td>Direct solar beam intensity</td>
<td>W/m²</td>
<td>900</td>
<td>200 to 1000</td>
</tr>
<tr>
<td>$f_{bes}$</td>
<td>Fraction of possible body surface exposed to sun</td>
<td>—</td>
<td>N/A</td>
<td>0 to 1</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Solar altitude angle</td>
<td>deg</td>
<td>N/A</td>
<td>0 to 90</td>
</tr>
<tr>
<td>SHARP</td>
<td>Solar horizontal angle relative to person</td>
<td>deg</td>
<td>N/A</td>
<td>0 to 180</td>
</tr>
<tr>
<td>Posture</td>
<td>Posture (seated, standing)</td>
<td>N/A</td>
<td></td>
<td>Seated/standing</td>
</tr>
</tbody>
</table>
Solar horizontal angle relative to the front of the person (SHARP). Solar horizontal angle relative to the front of the person ranges from 0 to 180 degrees and is symmetrical on either side. Zero (0) degrees represents direct beam radiation from the front, 90 degrees represents direct beam radiation from the side, and 180 degrees represent direct beam radiation from the back. SHARP is the angle between the sun and the person only. Orientation relative to compass or to room is not included in SHARP. See Figure C2-2.

h. Posture. Inputs are “seated” and “standing.”
FIGURE C1-1 Fraction of sky vault in occupant’s view ($f_{svv}$).

$\begin{array}{ccc}
\text{Fraction of entire sky vault viewed by occupant (~0.2)} \\
\end{array}$

FIGURE C2-1 Fraction of body exposed to sun ($f_{bes}$), not including the body's self shading. It is acceptable to simplify $f_{bes}$ to equal the fraction of the distance between head and toe exposed to direct sun, as shown. Informative Note: 1.0 is the greatest possible value for $f_{bes}$ because the body's self shading is not included in $f_{bes}$.

<table>
<thead>
<tr>
<th>$f_{bes} = 1$</th>
<th>$f_{bes} = 0.5$</th>
<th>$f_{bes} = 0.3$</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image 1" /></td>
<td><img src="image2.png" alt="Image 2" /></td>
<td><img src="image3.png" alt="Image 3" /></td>
</tr>
<tr>
<td><img src="image4.png" alt="Image 4" /></td>
<td><img src="image5.png" alt="Image 5" /></td>
<td><img src="image6.png" alt="Image 6" /></td>
</tr>
</tbody>
</table>
C3. COMPUTER PROGRAM FOR CALCULATING COMFORT IMPACT OF SOLAR GAIN ON OCCUPANTS

The following code is one implementation of the SET calculation using JavaScript in SI units.

```javascript
function find_span(arr, x){
    // for ordered array arr and value x, find the left index
    // of the closed interval that the value falls in.
    for (var i = 0; i < arr.length - 1; i++){
        if (x <= arr[i+1] && x >= arr[i]){  
            return i;
        }
    }
    return -1;
}

function get_fp(alt, sharp, posture){
    // This function calculates the projected sunlit fraction (fp)
    // given a seated or standing posture, a solar altitude, and a
    // solar horizontal angle relative to the person (SHARP). fp
    // values are taken from Thermal Comfort, Fanger 1970, Danish
    // Technical Press.

    // alt : altitude of sun in degrees [0, 90] (beta) Integer
    // sharp : sun’s horizontal angle relative to person
    // in degrees [0, 180] Integer
    var fp;
    var alt_range = [0, 15, 30, 45, 60, 75, 90];
    var sharp_range = [0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180];

    var alt_i = find_span(alt_range, alt);
    var sharp_i = find_span(sharp_range, sharp);
```

FIGURE C2-2  Solar horizontal angle relative to the front of the person (SHARP) and solar altitude ($\beta$).
if (posture == 'standing'){
  var fp_table = [[0.35, 0.35, 0.314, 0.258, 0.206, 0.144, 0.082],
                  [0.342, 0.342, 0.31, 0.252, 0.2, 0.14, 0.082],
                  [0.33, 0.33, 0.3, 0.244, 0.19, 0.132, 0.082],
                  [0.31, 0.31, 0.275, 0.228, 0.175, 0.124, 0.082],
                  [0.283, 0.283, 0.251, 0.208, 0.16, 0.114, 0.082],
                  [0.252, 0.252, 0.228, 0.188, 0.15, 0.108, 0.082],
                  [0.23, 0.23, 0.214, 0.18, 0.148, 0.108, 0.082],
                  [0.242, 0.242, 0.222, 0.18, 0.153, 0.112, 0.082],
                  [0.274, 0.274, 0.245, 0.203, 0.165, 0.116, 0.082],
                  [0.304, 0.304, 0.27, 0.22, 0.174, 0.121, 0.082],
                  [0.328, 0.328, 0.29, 0.234, 0.183, 0.125, 0.082],
                  [0.344, 0.344, 0.304, 0.244, 0.19, 0.128, 0.082],
                  [0.347, 0.347, 0.308, 0.246, 0.191, 0.128, 0.082]];
} else if (posture == 'seated'){
  var fp_table = [[0.29, 0.324, 0.305, 0.303, 0.262, 0.224, 0.177],
                  [0.292, 0.328, 0.294, 0.288, 0.268, 0.227, 0.177],
                  [0.288, 0.332, 0.298, 0.29, 0.264, 0.222, 0.177],
                  [0.274, 0.326, 0.294, 0.289, 0.252, 0.214, 0.177],
                  [0.254, 0.308, 0.28, 0.276, 0.241, 0.202, 0.177],
                  [0.23, 0.282, 0.262, 0.26, 0.233, 0.193, 0.177],
                  [0.216, 0.26, 0.248, 0.244, 0.22, 0.186, 0.177],
                  [0.234, 0.258, 0.236, 0.227, 0.208, 0.18, 0.177],
                  [0.262, 0.26, 0.224, 0.208, 0.196, 0.176, 0.177],
                  [0.28, 0.26, 0.21, 0.192, 0.184, 0.17, 0.177],
                  [0.298, 0.256, 0.194, 0.174, 0.168, 0.168, 0.177],
                  [0.306, 0.25, 0.18, 0.156, 0.156, 0.166, 0.177],
                  [0.3, 0.24, 0.168, 0.152, 0.152, 0.164, 0.177]];
}

var fp11 = fp_table[sharp_i][alt_i];  
var fp12 = fp_table[sharp_i][alt_i+1];
var fp21 = fp_table[sharp_i+1][alt_i];
var fp22 = fp_table[sharp_i+1][alt_i+1];

var sharp1 = sharp_range[sharp_i];
var sharp2 = sharp_range[sharp_i+1];
var alt1 = alt_range[alt_i];
var alt2 = alt_range[alt_i+1];

// bilinear interpolation
fp = fp11 * (sharp2 - sharp) * (alt2 - alt);
fp += fp21 * (sharp - sharp1) * (alt2 - alt);
fp += fp12 * (sharp2 - sharp) * (alt - alt1);
fp += fp22 * (sharp - sharp1) * (alt - alt1);
fp /= (sharp2 - sharp1) * (alt2 - alt1);

return fp;
}

function ERF(alt, sharp, posture, Idir, tsol, fsvv, fbes, asa){
  // ERF function to estimate the impact of solar radiation on occupant comfort
  // INPUTS:
  // alt : altitude of sun in degrees [0, 90]
  // sharp : sun's horizontal angle relative to person in degrees [0, 180]
  // posture: posture of occupant ('seated' or 'standing')
  // Idir : direct beam intensity (normal)
var DEG_TO_RAD = 0.0174532925;
var hr = 6;
var Idiff = 0.175 * Idir * Math.sin(alt * DEG_TO_RAD);

var fp = get_fp(alt, sharp, posture);

if (posture=='standing'){
    var feff = 0.725;
} else if (posture=='seated'){
    var feff = 0.696;
} else {
    console.log("Invalid posture (choose seated or seated"));
    return;
}

var sw_abs = asa;
var lw_abs = 0.95;

var E_diff = 0.5 * feff * fsvv * tsol * Idiff;
var E_direct = fp * feff * fbes * tsol * Idir;
var E_refl = 0.5 * feff * fsvv * tsol * (Idir * Math.sin(alt * DEG_TO_RAD) + Idiff) * 0.6;

var E_solar = E_diff + E_direct + E_refl;
var ERF = E_solar * (sw_abs / lw_abs);
var trsw = ERF / (hr * feff);

return {"ERF": ERF, "trsw": trsw};
### TABLE C4-1 Computer Code Validation Table

<table>
<thead>
<tr>
<th>alt</th>
<th>sharp</th>
<th>posture</th>
<th>Idir</th>
<th>tsol</th>
<th>fsvv</th>
<th>fbes</th>
<th>asa</th>
<th>ERF</th>
<th>trsw</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>120</td>
<td>Seated</td>
<td>800</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
<td>26.9</td>
<td>6.4</td>
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<td>800</td>
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<td>0.5</td>
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<td>0.7</td>
<td>59.2</td>
<td>14.2</td>
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<td>120</td>
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<td>0.7</td>
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<td>13.1</td>
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<td>0.1</td>
<td>0.7</td>
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<td>6.5</td>
</tr>
<tr>
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<td>800</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.7</td>
<td>36.4</td>
<td>8.7</td>
</tr>
<tr>
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<td>800</td>
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<td>0.5</td>
<td>0.7</td>
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<td>54.7</td>
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<td>0.7</td>
<td>45.5</td>
<td>10.9</td>
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</tbody>
</table>

Add the following new references to Informative Appendix L, “Bibliography and Informative References.”


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ASHRAE’s short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

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ASHRAE’s primary concern for environmental impact will be at the site where equipment within ASHRAE’s scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.
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