ADDENDA

ANSI/ASHRAE Addendum g to
ANSI/ASHRAE Standard 55-2013

Thermal Environmental Conditions for Human Occupancy

Approved by ASHRAE on September 30, 2016, and by the American National Standards Institute on October 1, 2016.

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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_{sol}): 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 ($\bar{t}_r$): 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 ($\overline{t_{rlw}}$) and short-wave mean radiant temperature ($\overline{t_{rsw}}$). ~~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*[3] for a more complete description of mean radiant temperature.)~~

temperature, long-wave mean radiant ($\overline{t_{rlw}}$): 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*[3], Chapter 9).

temperature, short-wave mean radiant ($\overline{t_{rsw}}$): Radiant temperature from short-wave direct and diffuse solar radiation expressed as an adjustment to long-wave mean radiant temperature ($\overline{t_{rlw}}$) 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^2 (Btuh/ft^2). Does not include reflected or diffuse solar radiation. Also known as direct normal insolation (I_{dir}).

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_{cl}) between 0.5 and 1.0 clo and who are not exposed to direct-beam solar radiation. Average air speed (V_a) 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 (V_a) greater tha~~t~~n 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.[4] Compliance is achieved if –0.5 < 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*[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 ($\bar{t}_r$) shall account for long-wave mean radiant temperature ($\overline{t_{rlw}}$)

and short-wave mean radiant temperature ($\overline{t_{rsw}}$) using one of the following options:

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

b. Use a mean radiant temperature ($\bar{t}_r$) 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.
   3. Building envelope opaque surfaces of the space (walls, floor, roof) meet U-factor prescriptive requirement of ASHRAE/IES Standard 90.1[7].
   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 ($\bar{t}_r$) 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_{bes}.

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

Representative Occupant Distance from Interior Window or Shade Surface, ft (m)	**Fraction of Body Exposed to Sun (f_{bes}), %**	**Glazing Unit Total Solar Transmission (T_{sol}), %**	**Glazing Unit Indirect SHGC (SHGC – T_{sol}), %**	**Interior Shade Openness Factor, %**	**Interior Shade Solar Absorptance of Window-Facing Side, %**
≥3.3 (1)	≤50	≤35	≤4.5	≤9	≤65
≥3.3 (1)	≤100	≤35	≤4.5	≤5	≤65

TABLE 5.3.2.2.1B Clear Low-Performance Glazing Units

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

TABLE 5.3.2.2.1C Tinted Glazing Units

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

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

Representative Occupant Distance from Interior Window or Shade Surface, ft (m)	**Fraction of Body Exposed to Sun (f_{bes}), %**	**Glazing Unit Total Solar Transmission (T_{sol}), %**	**Glazing Unit Indirect SHGC (SHGC – T_{sol}), %**	**Interior Shade Openness Factor, %**	**Interior Shade Solar Absorptance of Window-Facing Side, %**
≥3.3 (1)	≤50	≤0.5	≤10	N/A	No shade
≥3.3 (1)	≤100	≤0.5	≤10	N/A	No shade
≥4.9 (1.5)	≤50	≤3	≤10	N/A	No shade
≥6.6 (2)	≤100	≤3	≤10	N/A	No shade
≥7.6 (2.3)	≤50	≤6	≤10	N/A	No shade
≥9.9 (3)	≤50	≤9	≤10	N/A	No shade

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

Solar Absorptance, %	<15	15 to 25	25 to 65	>65
Color Description	White	Silver, cornsilk, wheat, oyster, beige, pearl	Beige, pewter, smoke, pebble, stone, pearl grey, light grey	Charcoal, graphite, chestnut

Revise Section 5.3.3 as shown. The Remainder of Section 5.3.3 is unchanged. Note that Addendum b to Standard 55-2013 made changes to Section 5.3.3. Addenda are available for free at https://www.ashrae.org/standards-research--technology/standards-addenda.

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_{cl}) 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~~D 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 ~~C~~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*[4] 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 ($\overline{t_r}$) shall account for long-wave mean radiant temperature ($\overline{t_{rlw}}$) and short-wave mean radiant temperature ($\overline{t_{rsw}}$) 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 ($\overline{t_{rsw}}$), as determined in Normative Appendix C. shall be multiplied by two and added to the plane radiant temperature (t_{pr}) 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 condition (solar altitude, direct beam intensity), the method in Section 5.3.2.2.1 used for compliance, and the resultant mean radiant temperature ($\overline{t_r}$).

Revise Section 8 as shown. The remainder of Section 8 is unchanged.

7. ANSI/ASHRAE/IES Standard 90.1-~~2010~~2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings.*

XX 2013 *ASHRAE Handbook—Fundamentals.*

Add a new Normative Appendix C. Reletter current Normative Appendix C and remaining appendices. All of this text is new; it is not underlined below merely to facilitate ease of reading. Note that the current Normative Appendix C and subsequent appendices were relettered in Addendum b to Standard 55-2013. Addenda are available for free at https://www.ashrae.org/standards-research--technology/standards-addenda.

(This is a normative appendix and is part of this standard.)

NORMATIVE APPENDIX C PROCEDURE FOR CALCULATING COMFORT IMPACT OF SOLAR GAIN ON OCCUPANTS

C1. CALCULATION PROCEDURE

Solar gain to the human body is calculated using the effective radiant field (ERF), a measure of the net radiant energy flux to or from the human body (*ASHRAE Handbook of Fundamentals*[XX], Chapter 9.24). ERF is expressed in W/m^2 (Btuh/ft^2), where "area" refers to body surface area. The surrounding surface temperatures of a space are expressed as mean radiant temperature ($\overline{t_r}$), which equals long-wave mean radiant temperature ($\overline{t_{rlw}}$) when no solar radiation is present. The ERF on the human body from long-wave exchange with surfaces is related to $\overline{t_{rlw}}$ by

$$\mathrm{ERF} = f_{eff} h_r (\overline{t_{rlw}} - t_a) \tag{C-1}$$

where f_{eff} is the fraction of the body surface exposed to radiation from the environment (= 0.696 for a seated person and 0.725 for a standing person), h_r is the radiation heat transfer coefficient (W/m^2·K [Btuh/ft^2·°F]), and T_a is the air temperature (°C [°F]).

The energy flux actually absorbed by the body is ERF times the long-wave absorptivity (α_{LW}) of skin and clothing (0.95 is the default value for skin and clothing).

Solar radiation absorbed on the body's surface can be equated to an additional amount of long-wave flux, ERF$_{solar}$:

$$\alpha_{LW}\mathrm{ERF}_{solar} = \alpha_{SW} E_{solar} \tag{C-2}$$

where E_{solar} is the short-wave solar radiant flux on the body surface (W/m^2 [Btuh/ft^2]) and α_{SW} is short-wave absorptivity.

E_{solar} is the sum of three fluxes that have been filtered by fenestration properties and geometry and are distributed on the occupant body surface: diffuse solar energy coming from the sky vault (E_{diff}), solar energy reflected upward from the floor (E_{refl}), and direct-beam solar energy coming directly from the sun (E_{dir}). These fluxes are defined below.

$$E_{diff} = 0.5 f_{eff} f_{svv} T_{sol} I_{diff} \tag{C-3}$$

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}).

$$E_{refl} = 0.5 f_{eff} f_{svv} T_{sol} I_{TH} R_{floor} \tag{C-4}$$

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 (β), 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).

$$E_{dir} = f_p f_{eff} f_{bes} T_{sol} I_{dir} \tag{C-5}$$

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

$I_{TH} = I_{dir}\sin\beta + I_{diff} \times I_{diff}$ is approximated as (0.17 I_{dir} sinβ).

ERF$_{solar}$ is therefore calculated from the following equation:

$$\mathrm{ERF}_{solar} = [0.5 f_{svv}(I_{diff} + 0.6 I_{TH}) + f_p f_{bes} I_{dir} \times f_{eff} T_{sol}[\alpha_{SW}/\alpha_{LW}] \tag{C-6}$$

To obtain ERF$_{solar}$ with Equation C-6 and the fixed default values given above, the required inputs are f_{svv}, I_{dir}, f_{bes}, T_{sol}, α_{SW}, β, posture, and the sun's horizontal angle relative to person (SHARP). These are described further in Section C2.

ERF$_{solar}$ is converted to short-wave mean radiant temperature ($\overline{t_{rsw}}$) 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 (α_{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.

Informative Note: Short-wave absorptivity typically ranges from 0.57 to 0.84, depending on skin and clothing color. More information is available in Blum (1945).

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).

$$f_{svv} = \frac{\tan^{-1}\left(\frac{h}{2d}\right)\tan^{-1}\left(\frac{w}{2d}\right)}{90 \times 180} \tag{C-7}$$

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 (β).** 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

Symbol	Description	Unit
ERF	Effective radiant field	W/m^2
f_{eff}	Fraction of body surface exchanging radiation with surroundings	—
h_r	Radiation heat transfer coefficient	$W/m^2 \cdot K$
t_a	Air temperature	°C
α_{LW}	Average long-wave radiation absorptivity of body (0.95)	—
α_{SW}	Average short-wave radiation absorptivity of body	—
ERF_{solar}	Effective radiant field solar component	W/m^2
E_{solar}	Total short-wave solar radiant flux	W/m^2
E_{dir}	Direct-beam component of short-wave solar radiant flux	W/m^2
E_{diff}	Diffuse component of short-wave solar radiant flux	W/m^2
E_{refl}	Reflected component of short-wave solar radiant flux	W/m^2
f_{svv}	Fraction of sky vault exposed to body	—
T_{sol}	Window system glazing unit plus shade solar transmittance	—
I_{dir}	Direct solar beam intensity	W/m^2
I_{diff}	Diffuse solar intensity	W/m^2
I_{TH}	Total horizontal solar intensity	W/m^2
f_p	Projected area factor	—
f_{bes}	Fraction of body surface exposed to sun	—
β	Solar altitude angle	deg
SHARP	Solar horizontal angle relative to front of person	deg
R_{floor}	Floor reflectance (fixed at 0.6)	—
	Posture (seated, standing)	

TABLE C2-1 Input Variables and Ranges for Calculation Procedure

Symbol	Description	Unit	Allowable default value	Range of Inputs Min to Max
α_{SW}	Short-wave radiation absorptivity	—	0.7	0.2 to 0.9
f_{svv}	Fraction of sky vault exposed to body	—	N/A	0 to 1
T_{sol}	Window system glazing unit plus shade solar transmittance	—	N/A	0 to 1
I_{dir}	Direct solar beam intensity	W/m^2	900	200 to 1000
f_{bes}	Fraction of the possible body surface exposed to sun	—	N/A	0 to 1
β	Solar altitude angle	deg	N/A	0 to 90
SHARP	Solar horizontal angle relative to person	deg	N/A	0 to 180
	Posture (seated, standing)		N/A	Seated/standing

TABLE C2-2 Sky Vault View Fraction (f_{svv}) for Single-Sided Window Geometry and Occupant Location

Window Width, ft (m)	30 (9.1)	150 (45.5)	30 (9.1)	150 (45.5)	30 (9.1)	150 (45.5)	30 (9.1)	150 (45.5)	6 (1.8)	6 (1.8)	6 (1.8)	4 (1.2)	4 (1.2)
Window Height, ft (m)	10 (3)	10 (3)	6 (1.8)	6 (1.8)	10 (3)	10 (3)	6 (1.8)	6 (1.8)	9 (2.7)	6 (1.8)	6 (1.8)	4 (1.2)	4 (1.2)
Distance from Window to Occupant, ft (m)	3.3 (1)	3.3 (1)	3.3 (1)	3.3 (1)	6 (1.8)	6 (1.8)	6 (1.8)	6 (1.8)	3.3 (1)	3.3 (1)	6 (1.8)	3.3 (1)	6 (1.8)
F_{svv}	27%	31%	20%	23%	17%	21%	11%	14%	14%	11%	4%	6%	2%

TABLE C2-3 Direct-Beam Solar Radiation Values for a Standard Cloudless Atmosphere, by Solar Altitude

Solar Altitude Angle (β), deg	5	10	20	30	40	50	60	70	80	90
Direct-Beam Solar Radiation (I_{dir}), W/m^2	210	390	620	740	810	860	890	910	920	925

g. **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."

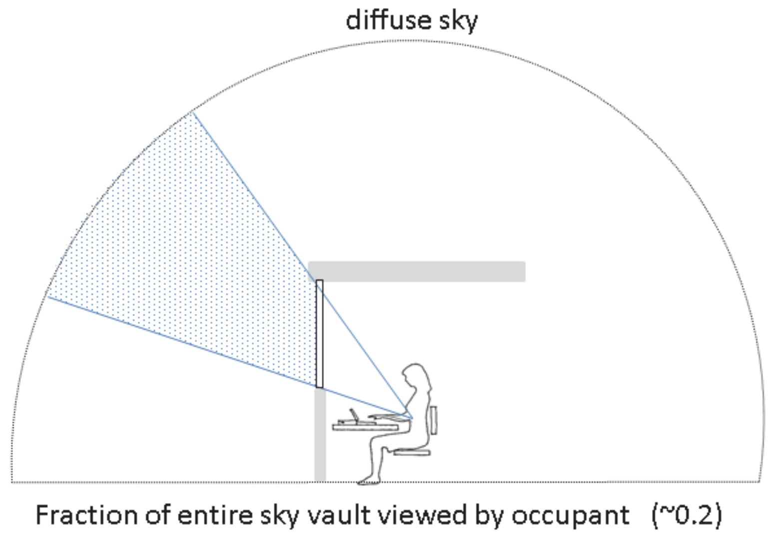

FIGURE C1-1 Fraction of sky vault in occupant's view (f_{svv}).

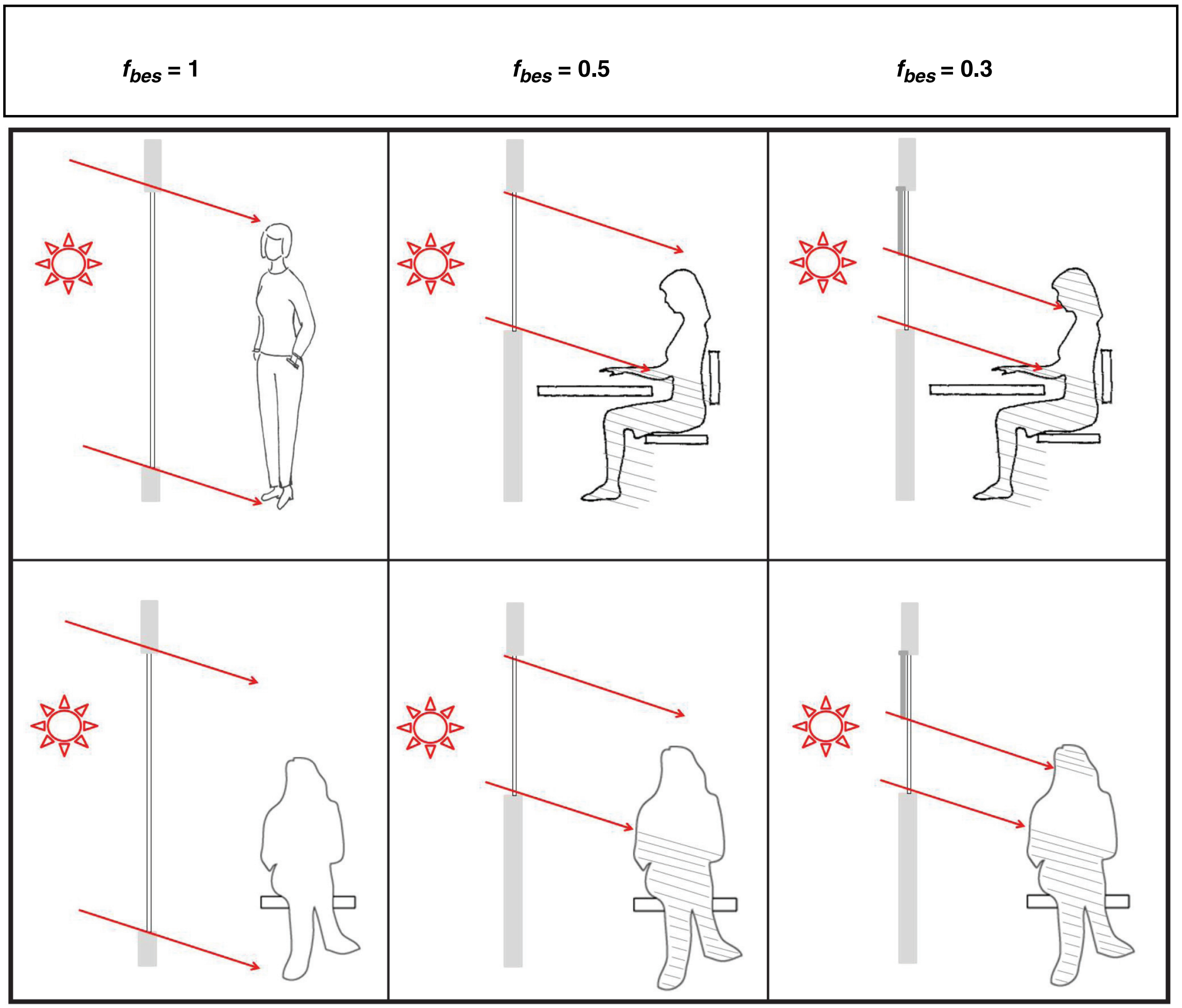

FIGURE C2-1 Fraction of body exposed to sun (f_{bes}), not including the body's self shading. It is acceptable to simplify f_{bes} to equal the fraction of the distance between head and toe exposed to direct sun, as shown. *Informative Note:* 1.0 is the greatest possible value for fbes because the body's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

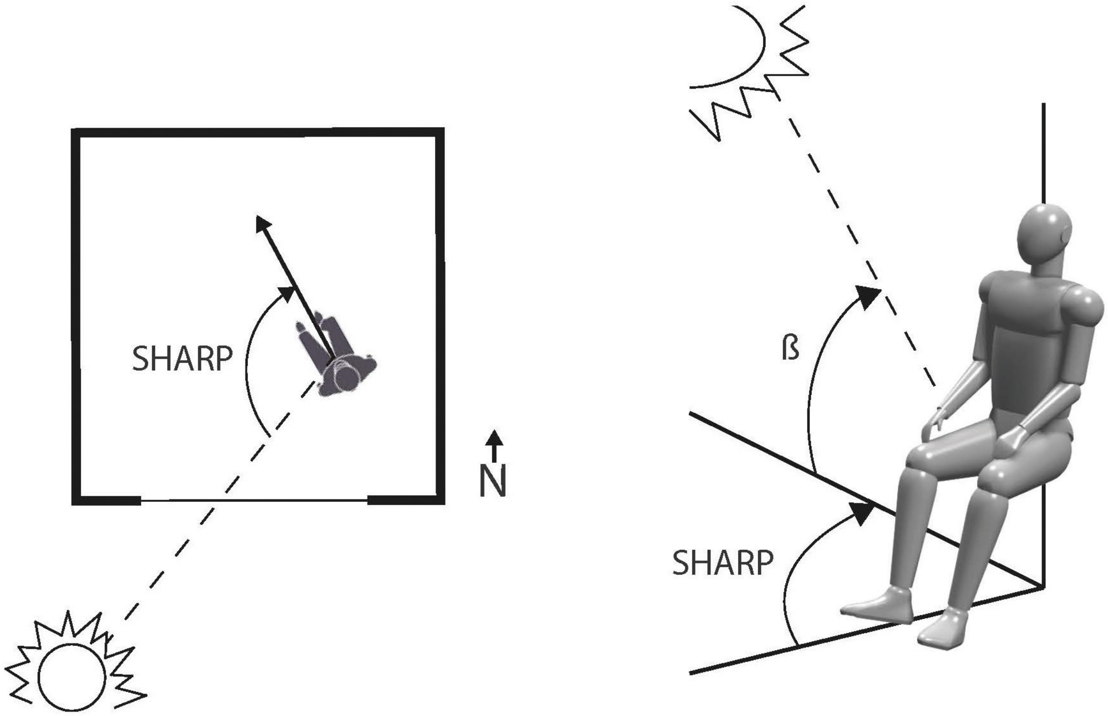

FIGURE C2-2 Solar horizontal angle relative to the front of the person (SHARP) and solar altitude (β).

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.

```
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);
```

```
    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)
```

```
    //  tsol: total solar transmittance (SC * 0.87)
    //  fsvv : sky vault view fraction : fraction of sky vault
    //    in occupant's view [0, 1]
    //  fbes : fraction body exposed to sun [0, 1]
    //  asa : average shortwave
    //    absorptivity of body [0, 1] (alpha_sw)

    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};
}
```

C4. COMPUTER CODE VALIDATION TABLE

TABLE C4-1 Computer Code Validation Table

alt	sharp	posture	Idir	tsol	fsvv	fbes	asa	ERF	trsw
0	120	Seated	800	0.5	0.5	0.5	0.7	26.9	6.4
60	120	Seated	800	0.5	0.5	0.5	0.7	59.2	14.2
90	120	Seated	800	0.5	0.5	0.5	0.7	63.3	15.2
30	0	Seated	800	0.5	0.5	0.5	0.7	53.8	12.9
30	30	Seated	800	0.5	0.5	0.5	0.7	53.1	12.7
30	60	Seated	800	0.5	0.5	0.5	0.7	51.3	12.3
30	90	Seated	800	0.5	0.5	0.5	0.7	48	11.5
30	150	Seated	800	0.5	0.5	0.5	0.7	42.5	10.2
30	180	Seated	800	0.5	0.5	0.5	0.7	39.8	9.5
30	120	Standing	800	0.5	0.5	0.5	0.7	49.7	11.4
30	120	Seated	400	0.5	0.5	0.5	0.7	22.8	5.5
30	120	Seated	600	0.5	0.5	0.5	0.7	34.2	8.2
30	120	Seated	1000	0.5	0.5	0.5	0.7	56.9	13.6
30	120	Seated	800	0.1	0.5	0.5	0.7	9.1	2.2
30	120	Seated	800	0.3	0.5	0.5	0.7	27.3	6.5
30	120	Seated	800	0.7	0.5	0.5	0.7	63.8	15.3
30	120	Seated	800	0.5	0.1	0.5	0.7	27.5	6.6
30	120	Seated	800	0.5	0.3	0.5	0.7	36.5	8.7
30	120	Seated	800	0.5	0.7	0.5	0.7	54.6	13.1
30	120	Seated	800	0.5	0.5	0.1	0.7	27.2	6.5
30	120	Seated	800	0.5	0.5	0.3	0.7	36.4	8.7
30	120	Seated	800	0.5	0.5	0.7	0.7	54.7	13.1
30	120	Seated	800	0.5	0.5	0.5	0.3	19.5	4.7
30	120	Seated	800	0.5	0.5	0.5	0.5	32.5	7.8
30	120	Seated	800	0.5	0.5	0.5	0.9	58.6	14
30	120	Seated	800	0.5	0.5	0.5	0.7	45.5	10.9

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

Arens, E., T. Hoyt, X. Zhou, L. Huang, H. Zhang, and S. Schiavon. 2015. Modeling the comfort effects of short-wave solar radiation indoors. *Building and Environment* 88:3–9.

Blum, H.F. 1945. Solar heat load, its relationship to the total heat load, and its relative importance in the design of clothing. *Journal of Clinical Investigation* 24:712–21.

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