BSR/ASHRAE Addendum e
to ANSI/ASHRAE Standard 55-2017

Public Review Draft

Proposed Addendum e to Standard 55-2017, Thermal Environmental Conditions for Human Occupancy

First Public Review (July 2020)
(Draft shows Proposed Changes to Current Standard)

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FOREWORD

This proposed addendum includes a bug fix to the shortwave solar calculation method explained in Section C1 and the corresponding consequential edits to the prescriptive tables in Section 5.3.2.2.1. The previous method discounted the contribution of diffuse solar radiation by using an incorrect formula for attributing horizontal diffuse radiation. At low angles of solar altitude, this change will increase the shortwave mean radiant temperature compared to the previous version.

[Note to Reviewers: This addendum makes proposed changes to the current standard. These changes are indicated in the text by underlining (for additions) and ~~strikethrough~~ (for deletions) except where the reviewer instructions specifically describe some other means of showing the changes. Only these changes to the current standard are open for review and comment at this time. Additional material is provided for context only and is not open for comment except as it relates to the proposed changes.]

Addendum e to 55-2017

Modify Tables 5.3.2.2.1A, 5.3.2.2.1B, 5.3.2.2.1C and 5.3.2.2.1D in Section 5.3.2.2.1 as follows.

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, %
≥ 4.8~~3.3~~ (1.5)	≤ 50	≤ 35	≤ 4.5	≤ 9	≤ 65
≥ 5.1~~3.3~~ (1.6)	≤ 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, %
≥ 11~~9.9~~ (3.3)	≤ 50	≤ 83	≤ 10	≤ 1	≤ 25
≥ 14.5~~13.2~~ (4.4)	≤ 50	≤ 83	≤ 10	≤ 1	≤ 65
≥ 12.2~~11.2~~ (3.7~~3.4~~)	≤ 100	≤ 83	≤ 10	≤ 1	≤ 25

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, %
≥ 15.9~~14.5~~ (4.9~~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, %
≥ 5.3~~3.3~~ (1.6)	≤ 50	≤ 10	≤ 20	≤ 8	≤ 25
≥ 6.1~~3.3~~ (1.9)	≤ 50	≤ 10	≤ 20	≤ 1	≤ 65
≥ 5.94 (1.8~~1.2~~)	≤ 100	≤ 10	≤ 20	≤ 1	≤ 25
≥ 7.4~~4.9~~ (2.3~~1.5~~)	≤ 100	≤ 10	≤ 20	≤ 1	≤ 65
> 7.3~~9.2~~ (2.2~~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, %
≥ 6.1~~3.3~~ (1.9)	≤ 50	≤ 0.5	≤ 10	n/a	no shade
≥ 6.1~~3.3~~ (1.9)	≤ 100	≤ 0.5	≤ 10	n/a	no shade
≥ 7.9~~4.9~~ (2.4~~1.5~~)	≤ 50	≤ 3	≤ 10	n/a	no shade
≥ 9.5~~6.6~~ (2.9)	≤ 100	≤ 3	≤ 10	n/a	no shade
≥ 9.8~~7.6~~ (3~~2.3~~)	≤ 50	≤ 6	≤ 10	n/a	no shade
≥ 10.3~~9.9~~ (3.1)	≤ 50	≤ 9	≤ 10	n/a	no shade

Modify Section C1 as follows. Changes are highlighted in yellow to make them more visible.

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 [2013 *ASHRAE Handbook – Fundamentals*[5], 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 longwave exchange with surfaces is related to $\overline{t_{rlw}}$ by

$$ERF = f_{eff}\, h_r\, (\overline{t_{rlw}} - t_a) \qquad \text{(C-1)}$$

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]), and T_a is the air temperature (ºC [ºF]).

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}:

$$\alpha_{LW}\, ERF_{solar} = \alpha_{SW}\, E_{solar} \qquad \text{(C-2)}$$

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.

$$E_{diff} = 0.5\, f_{eff}\, f_{svv}\, T_{sol}\, I_{diff} \qquad \text{(C-3)}$$

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 shortwave 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}.

$$E_{refl} = 0.5\, f_{eff}\, f_{svv}\, T_{sol}\, I_{TH}\, R_{floor} \qquad \text{(C-4)}$$

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).

$$E_{dir} = f_p f_{eff} f_{bes} T_{sol} I_{dir} \qquad \text{(C-5)}$$

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

$I_{TH} = I_{dir} \sin\beta + I_{diff}$. I_{diff} is approximated as (0.2~~17~~ I_{dir}~~sinβ~~).

ERF_{solar} is therefore calculated from the following equation:

$$ERF_{solar} = (0.5 f_{svv} (I_{diff} + 0.6 I_{TH}) + f_p f_{bes} I_{dir}) \times f_{eff} T_{sol} (\alpha_{SW}/\alpha_{LW}) \qquad \text{(C-6)}$$

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.

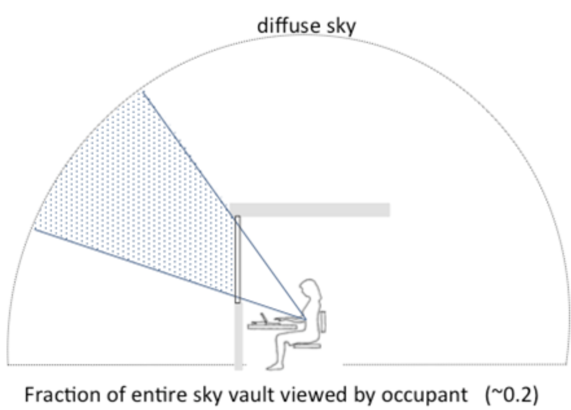

Figure C1-1 Fraction of sky vault in occupant's view (f_{svv})

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-K
t_a	Air temperature	°C
α_{LW}	Average longwave radiation absorptivity of body (0.95)	-
α_{SW}	Average shortwave radiation absorptivity of body	-
ERF_{solar}	Effective radiant field solar component	W/m^2
E_{solar}	Total shortwave solar radiant flux	W/m^2
E_{dir}	Direct beam component of shortwave solar radiant flux	W/m^2
E_{diff}	Diffuse component of shortwave solar radiant flux	W/m^2
E_{refl}	Reflected component of shortwave 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)	

Modify Section C3 as follows. Changes are highlighted in yellow to make them more visible.

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~~ 2 * 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};
}
```

Modify Section C4 as follows.

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~~ 42.9	~~6.4~~ 10.3
60	120	seated	800	0.5	0.5	0.5	0.7	~~59.2~~ 63.7	~~14.2~~ 15.3
90	120	seated	800	0.5	0.5	0.5	0.7	~~63.3~~ 64.9	~~15.2~~ 15.5
30	0	seated	800	0.5	0.5	0.5	0.7	~~53.8~~ 62.7	~~12.9~~ 15.0
30	30	seated	800	0.5	0.5	0.5	0.7	~~53.1~~ 62.7	~~12.7~~ 15.0
30	60	seated	800	0.5	0.5	0.5	0.7	~~51.3~~ 59.8	~~12.3~~ 14.3

30	90	seated	800	0.5	0.5	0.5	0.7	~~48~~ 56.8	~~11.5~~ 13.6
30	150	seated	800	0.5	0.5	0.5	0.7	~~42.5~~ 52.4	~~10.2~~ 12.6
30	180	seated	800	0.5	0.5	0.5	0.7	~~39.8~~ 49.5	~~9.5~~ 11.8
30	120	standing	800	0.5	0.5	0.5	0.7	~~49.7~~ 59.6	~~11.4~~ 13.7
30	120	seated	400	0.5	0.5	0.5	0.7	~~22.8~~ 27.7	~~5.5~~ 6.6
30	120	seated	600	0.5	0.5	0.5	0.7	~~34.2~~ 41.5	~~8.2~~ 9.9
30	120	seated	1000	0.5	0.5	0.5	0.7	~~56.9~~ 69.2	~~13.6~~ 16.6
30	120	seated	800	0.1	0.5	0.5	0.7	~~9.1~~ 11.1	~~2.2~~ 2.7
30	120	seated	800	0.3	0.5	0.5	0.7	~~27.3~~ 33.2	~~6.5~~ 8.0
30	120	seated	800	0.7	0.5	0.5	0.7	~~63.8~~ 77.5	~~15.3~~ 18.6
30	120	seated	800	0.5	0.1	0.5	0.7	~~27.5~~ 29.9	~~6.6~~ 7.2
30	120	seated	800	0.5	0.3	0.5	0.7	~~36.5~~ 42.7	~~8.7~~ 10.2
30	120	seated	800	0.5	0.7	0.5	0.7	~~54.6~~ 68.1	~~13.1~~ 16.3
30	120	seated	800	0.5	0.5	0.1	0.7	~~27.2~~ 36.5	~~6.5~~ 8.7
30	120	seated	800	0.5	0.5	0.3	0.7	~~36.4~~ 45.9	~~8.7~~ 11.0
30	120	seated	800	0.5	0.5	0.7	0.7	~~54.7~~ 64.8	~~13.1~~ 15.5
30	120	seated	800	0.5	0.5	0.5	0.3	~~19.5~~ 23.7	~~4.7~~ 5.7
30	120	seated	800	0.5	0.5	0.5	0.5	~~32.5~~ 39.6	~~7.8~~ 9.5
30	120	seated	800	0.5	0.5	0.5	0.9	~~58.6~~ 71.2	~~14~~ 17.0
30	120	seated	800	0.5	0.5	0.5	0.7	~~45.5~~ 55.4	~~10.9~~ 13.3