STANDARD

ANSI/ASHRAE Standard 55-2017
(Supersedes ANSI/ASHRAE Standard 55-2013)
Includes ANSI/ASHRAE addenda listed in Appendix N

Thermal Environmental Conditions for Human Occupancy

See Appendix N for approval dates.

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b. participation in the next review of the Standard,
c. offering constructive criticism for improving the Standard, or
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NOTE

Approved addenda, errata, or interpretations for this standard can be downloaded free of charge from the ASHRAE website at www.ashrae.org/technology.

(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process.)

FOREWORD

ANSI/ASHRAE Standard 55-2017 is the latest edition of Standard 55. It incorporates seven addenda to the 2013 edition that were written with a renewed focus on application of the standard by practitioners and use of clear, enforceable language.

The core of the standard in Sections 4 and 5 specifies methods to determine thermal environmental conditions (temperature, humidity, air speed, and radiant effects) in buildings and other spaces that a significant proportion of the occupants will find acceptable at a certain metabolic rate and clothing level. The comprehensive analytical method to determine these conditions uses calculation algorithms included in the standard and appendices, all of which are implemented in the ASHRAE Thermal Comfort Tool.

The standard contains a graphical method of compliance, which is familiar to many users, yet is permitted to be used only in limited circumstances. Given the widespread and easy accessibility of computing power, along with third-party implementations of the analytical method, it is expected that more users will favor the comprehensive analytical methods over the graphical method.

Section 6 contains requirements for demonstrating that a design of an occupied space or building meets the comfort requirements in Sections 4 and 5. Section 7 includes requirements for the measurement and evaluation of existing thermal environments and is also applicable to commissioning.

Because the two personal characteristics of occupants (metabolic rate and clothing level) vary, operating set points for buildings are not mandated by this standard.

Standard 55 was first published in 1966 and republished in 1974, 1981, and 1992. Beginning in 2004, it is now updated using ASHRAE's continuous maintenance procedures. According to these procedures, Standard 55 is continuously revised by addenda that are publicly reviewed, approved by ASHRAE and ANSI, and published and posted for free on the ASHRAE website.

The seven addenda published since 2013 are summarized in detail in Informative Appendix N. The most noteworthy changes are as follows:

a. *Clarification of the three comfort calculation approaches in Section 5.3.3, "Elevated Air Speed," including a new applicability table and a reorganization of Section 5.3.3 to address an Elevated Air Speed Comfort Zone Method.*
b. *Simplification of Normative Appendix A, "Methods for Determining Operative Temperature," to a single procedure for calculating operative temperature.*
c. *Removal of permissive language found throughout the standard (excluding the title; Sections 1, 2, 3, and 7; and all Informative Appendices).*
d. *Modification of Section 2, "Scope," to ensure the standard is not used to override any safety, health, or critical process requirements.*
e. *Addition of a new 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."*

1. PURPOSE

The purpose of this standard is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space.

2. SCOPE

2.1 The environmental factors addressed in this standard are temperature, thermal radiation, humidity, and air speed; the personal factors are those of activity and clothing.

2.2 It is intended that all of the criteria in this standard be applied together, as comfort in the indoor environment is complex and responds to the interaction of all of the factors that are addressed herein.

2.3 This standard specifies thermal environmental conditions acceptable for healthy adults at atmospheric pressure equivalent to altitudes up to 3000 m (10,000 ft) in indoor spaces designed for human occupancy for periods not less than 15 minutes.

2.4 This standard does not address such nonthermal environmental factors as air quality, acoustics, and illumination or other physical, chemical, or biological space contaminants that may affect comfort or health.

2.5 This standard shall not be used to override any safety, health, or critical process requirements.

3. DEFINITIONS

adaptive model: a model that relates indoor design temperatures or acceptable temperature ranges to outdoor meteorological or climatological parameters. ***Informative Note:*** *Adaptive model* is another name for the method described in Section 5.4, "Determining Acceptable Thermal Conditions in Occupant-Controlled Naturally Conditioned Spaces.")

air speed: the rate of air movement at a point, without regard to direction.

air speed, average (V_a): the average air speed surrounding a representative occupant. The average is with respect to location and time. The spatial average is for three heights as defined for average air temperature t_a. The air speed is averaged over an interval not less than one and not more than three minutes. Variations that occur over a period greater than three minutes shall be treated as multiple different air speeds.

climate data: hourly, site-specific values of representative meteorological data, such as temperature, wind, speed, solar radiation, and relative humidity. For cities or urban regions with several climate data entries, and for locations where climate data are not available, the designer shall select available weather or meteorological data that best represents the climate at the building site. (See 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 14 for data sources.)

clo: a unit used to express the thermal insulation provided by garments and clothing ensembles; 1 clo = 0.155 $m^2 \cdot °C/W$ (0.88 $ft^2 \cdot h \cdot °F/Btu$).

comfort, thermal: that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

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}).

draft: the unwanted local cooling of the body caused by air movement.

environment, acceptable thermal: a thermal environment that a substantial majority (more than 80%) of the occupants find thermally acceptable.

environment, thermal: the thermal environmental conditions that affect a person's heat loss.

exceedance hours: the number of occupied hours within a defined time period in which the environmental conditions in an occupied space are outside of the comfort zone.

garment: a single piece of clothing.

generally accepted engineering standard: see ASHRAE/IES Standard 90.1 [2].

humidity: a general reference to the moisture content of the air. It is expressed in terms of several thermodynamic variables, including vapor pressure, dew-point temperature, wet-bulb temperature, humidity ratio, and relative humidity. It is spatially and temporally averaged in the same manner as air temperature. ***Informative Note:*** Any one of these humidity variables must be used in conjunction with dry-bulb temperature in order to describe a specific air condition.

insulation, clothing (I_{cl}): the resistance to sensible heat transfer provided by a clothing ensemble, expressed in units of clo. ***Informative Note:*** The definition of *clothing insulation* relates to heat transfer from the whole body and, thus, also includes the uncovered parts of the body, such as head and hands.

insulation, garment (I_{clu}): the increased resistance to sensible heat transfer obtained from adding an individual garment over the nude body, expressed in units of clo.

local thermal discomfort: the thermal discomfort caused by locally specific conditions such as a vertical air temperature difference between the feet and the head, by radiant temperature asymmetry, by local convective cooling (draft), or by contact with a hot or cold floor.

metabolic rate (met): the rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, per unit of skin surface area (expressed in units of met) equal to 58.2 W/m^2 (18.4 $Btu/h \cdot ft^2$), which is the energy produced per unit skin surface area of an average person seated at rest.

occupant, representative: an individual or composite or average of several individuals that is representative of the population occupying a space for 15 minutes or more.

occupant-controlled naturally conditioned spaces: those spaces where the thermal conditions of the space are regulated primarily by occupant-controlled openings in the envelope.

occupant-controlled openings: openings such as windows or vents that are directly controlled by the occupants of a space. Such openings may be manually controlled or controlled through the use of electrical or mechanical actuators under direct occupant control.

outdoor design condition: the local outdoor environmental conditions, represented by climate data, at which a heating or cooling system is designed to maintain the specified indoor thermal conditions.

predicted mean vote (PMV): an index that predicts the mean value of the thermal sensation votes (self-reported perceptions) of a large group of persons on a sensation scale expressed from –3 to +3 corresponding to the categories "cold," "cool," "slightly cool," "neutral," "slightly warm," "warm," and "hot."

predicted percentage of dissatisfied (PPD): an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV.

radiant temperature asymmetry: the difference between the plane radiant temperature t_{pr} in opposite directions. The vertical radiant temperature asymmetry is with plane radiant temperatures in the upward and downward directions. The horizontal radiant temperature asymmetry is the maximum radiant temperature asymmetry for all horizontal directions. The radiant temperature asymmetry is determined at waist level, 0.6 m (24 in.) for a seated occupant and 1.1 m (43 in.) for a standing occupant. (See 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 9 for a more complete description of plane radiant temperature and radiant asymmetry.)

sensation, thermal: a conscious subjective expression of an occupant's thermal perception of the environment, commonly expressed using the categories "cold," "cool," "slightly cool," "neutral," "slightly warm," "warm," and "hot."

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.

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, air: the temperature of the air at a point.

temperature, air average (t_a): the average air temperature surrounding a representative occupant. The average is with respect to location and time. The spatial average is the numerical average of the air temperature at the ankle level, the waist level, and the head level. These levels are 0.1, 0.6, and 1.1 m (4, 24, and 43 in.) for seated occupants and 0.1, 1.1, and 1.7 m (4, 43, and 67 in.) for standing occupants. Time averaging is over a period not less than three and not more than 15 minutes.

temperature, dew-point (t_{dp}): the air temperature at which the water vapor in air at a given barometric pressure will condense into a liquid.

temperature, floor (t_f): the surface temperature of the floor where it is in contact with the representative occupants' feet.

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 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 9.)

temperature, mean daily outdoor air ($\overline{t_{mda(out)}}$): any arithmetic mean for a 24-hour period permitted in Section 5.4 of the standard. Mean daily outdoor air temperature is used to calculate prevailing mean outdoor air temperature $\overline{t_{pma(out)}}$.

temperature, mean radiant ($\overline{t_r}$): the temperature of a uniform, black enclosure that exchanges the same amount of heat by radiation with the occupant as the actual 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 $\overline{t_{rsw}}$.

temperature, operative (t_o): the uniform temperature of an imaginary black enclosure, and the air within it, in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment; calculated in accordance with Normative Appendix A of this standard. (See 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 9, for further discussion of operative temperature.)

temperature, plane radiant (t_{pr}): the uniform temperature of an enclosure in which the incident radiant flux on one side of a small plane element is the same as in the existing environment.

temperature, prevailing mean outdoor air ($\overline{t_{pma(out)}}$): when used as an input variable in Figure 5.4.2 for the adaptive model, this temperature is based on the arithmetic average of the mean daily outdoor temperatures over some period of days as permitted in Section 5.4.2.1.

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.

temperature, standard effective (SET): the temperature of an imaginary environment at 50% rh, <0.1 m/s (20 fpm) average air speed V_a, and $\overline{t_r} = t_a$, in which the total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment with actual clothing and activity level.

zone, comfort: those combinations of air temperature, mean radiant temperature $\overline{t_r}$, and humidity that are predicted to be an acceptable thermal environment at particular values of air speed, metabolic rate, and clothing insulation I_{cl}.

zone, occupied: the region normally occupied by people within a space. In the absence of known occupant locations, the occupied zone is to be between the floor and 1.8 m (6 ft) above the floor and more than 1.0 m (3.3 ft) from outside walls/windows or fixed heating, ventilating, or air-conditioning equipment, and 0.3 m (1 ft) from internal walls.

4. GENERAL REQUIREMENTS

4.1 Where information is required to be identified in this standard, it shall be documented in accordance with and in addition to the requirements in Section 6.

4.2 Identify all of the space types to which the standard is being applied and any locations within a space to which it is not applied.

4.3 For each space type, at least one representative occupant shall be identified. If any known set of occupants is excluded from consideration then these excluded occupants shall be identified.

Informative Note: For example, the customers in a restaurant may have a metabolic rate near 1.0 met, while the servers may have a metabolic rate closer to 2.0 met. Per Section 5.2.1.1, each of these groups of occupants shall be considered separately in determining the conditions required for comfort. In some situations such as this, it will not be possible to provide an acceptable level or the same level of comfort to all disparate groups of occupants.

4.4 For each representative occupant, the metabolic rate M in mets and the insulation I in clo shall be determined.

4.5 The thermal environment required for comfort is determined in accordance with Section 5 of this standard.

5. CONDITIONS THAT PROVIDE THERMAL COMFORT

5.1 General Requirements. Section 5 of this standard shall be used to determine the acceptable thermal environment for each representative occupant of a space. Section 5.2 is used to determine representative occupant characteristics.

Section 5.3 in its entirety or Section 5.4 in its entirety shall be identified as the approach used in determining the acceptable thermal environment. Section 5.3 shall be permitted to be used in any space, and Section 5.4 shall be permitted to be used only in those spaces that meet the applicability criteria in Section 5.4.1. Determine operative temperature t_o in accordance with Normative Appendix A.

This section covers the determination of the following six factors in steady state. All six factors shall be addressed when defining conditions for acceptable thermal comfort:

a. Metabolic rate
b. Clothing insulation
c. Air temperature
d. Radiant temperature
e. Air speed
f. Humidity

Informative Notes:

1. It is possible for all six of these factors to vary with time. The first two are characteristics of the occupant and the remaining four are conditions of the thermal environment.

2. *Average air speed* and *average air temperature* have precise definitions in this standard. See Section 3 for all defined terms.

5.2 Method for Determining Occupant Characteristics

5.2.1 Metabolic Rate

5.2.1.1 Rate for Each Representative Occupant. For each representative occupant, determine the metabolic rate associated with the occupant's activities. Averaged metabolic rates shall not be used to represent multiple occupants whose metabolic rates differ by more than 0.1 met.

Informative Note: For example, in an office setting, when comparing an occupant who is seated and reading at 1.0 met with an occupant that is typing at 1.1 met, they can be grouped as a single representative occupant. If the same seated occupant is compared to an occupant who is seated and filing at 1.2 met, each shall be considered separately when determining the conditions required for thermal comfort.

5.2.1.2 Rate Determination. Use one or a combination of the following methods to determine metabolic rate:

a. Metabolic rates for typical occupant activity types given in Table 5.2.1.2 shall be used to describe the representative occupant. Where a range is given, select a single value within that range based on characteristics of the activity. If a proposed occupant activity type is not listed in Table 5.2.1.2, the most similar activity type based on characteristics of the activity shall be used.
b. Interpolate between or extrapolate from the values given in Table 5.2.1.2.
c. Use estimation and/or measurement methods described in 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 9.
d. Use other approved engineering or physiological methods.

5.2.1.3 Time-Weighted Averaging. Use a time-weighted average metabolic rate for individuals with activities that vary. Such averaging shall not be applied where an activity persists for more than one hour. In that case, two distinct metabolic rates shall be used.

Informative Note: For example, a person who spends 30 minutes out of each hour "lifting/packing," 15 minutes "filing, standing," and 15 minutes "walking about" has an average metabolic rate of $0.50 \times 2.1 + 0.25 \times 1.4 + 0.25 \times 1.7 = 1.8$ met. However, a person who is engaged in "lifting/packing" for more than one hour and then "filing, standing" for more than one hour shall be treated as having two distinct metabolic rates per Section 5.2.1.1.

5.2.1.4 High Metabolic Rates. This standard does not apply to occupants whose time-averaged metabolic rate exceeds 2.0 met.

5.2.2 Clothing Insulation

5.2.2.1 Insulation for Each Representative Occupant

5.2.2.1.1 For each representative occupant, determine the clothing insulation I_{cl} in clo.

5.2.2.1.2 Averaged clothing insulation I_{cl} shall not be used to represent multiple occupants whose clothing insulation differs by more than 0.15 clo.

Exception to 5.2.2.1.2: Where individuals are free to adjust clothing to account for individual differences in response to the thermal environment, it is permitted to use a single representative occupant with an average clothing insulation I_{cl} value to represent multiple individuals.

5.2.2.2 Insulation Determination. Use one or a combination of the following methods to determine clothing insulation I_{cl}:

a. Use the data presented in Table 5.2.2.2A for the expected ensemble of each representative occupant.
b. Add or subtract the insulation of individual garments in Table 5.2.2.2B from the ensembles in Table 5.2.2.2A to determine the insulation of ensembles not listed.
c. Determine a complete clothing ensemble using the sum of the individual values listed for each item of clothing in the ensemble in Table 5.2.2.2B.
d. It is permitted, but not required, to adjust any of the previous methods for seated occupants using Table 5.2.2.2C.
e. For moving occupants, it is permitted but not required to adjust any of the previous methods using the following formula:

$$I_{cl,\ active} = I_{cl} \times (0.6 + 0.4/M)$$
$$1.2 \text{ met} < M < 2.0 \text{ met}$$

where M is the metabolic rate in mets, and I_{cl} is the insulation without movement.

f. Interpolate between or extrapolate from the values given in Tables 5.2.2.2B and 5.2.2.2C.
g. Use Figure 5.2.2.2 to determine the clothing insulation I_{cl} of a representative occupant for a day as a function of outdoor air temperature at 06:00 a.m., $t_{a(out,6)}$.

   Clothing insulation I_{cl} determined in accordance with Figure 5.2.2.2 is permitted but not required to be adjusted to account for unique dress code or cultural norms using other methods in Section 5.2.2.2 or approved engineering methods.
h. Use measurement with thermal manikins or other approved engineering methods.

5.2.2.3 Limits of Applicability. This standard does not apply to occupants

a. whose clothing insulation exceeds 1.5 clo;
b. whose clothing is highly impermeable to moisture transport (e.g., chemical protective clothing or rain gear); or
c. who are sleeping, reclining in contact with bedding, or able to adjust blankets or bedding.

5.3 Method for Determining Acceptable Thermal Environment in Occupied Spaces. Section 5.3 is permitted to be used to determine the requirements for thermal comfort in all occupied spaces within the scope of this standard.

Acceptable thermal environments shall be determined using one of the three methods shown in Table 5.3.1 and any applicable requirements of Sections 5.3.4 and 5.3.5.

Informative Note: *Average air speed* and *average air temperature* have precise definitions in this standard. See Section 3 for all defined terms.

Table 5.2.1.2 Metabolic Rates for Typical Tasks

Activity	Metabolic Rate Met Units	W/m^2	$Btu/h \cdot ft^2$
Resting			
Sleeping	0.7	40	13
Reclining	0.8	45	15
Seated, quiet	1.0	60	18
Standing, relaxed	1.2	70	22
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	37
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	48
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	70
Office Activities			
Reading, seated	1.0	55	18
Writing	1.0	60	18
Typing	1.1	65	20
Filing, seated	1.2	70	22
Filing, standing	1.4	80	26
Walking about	1.7	100	31
Lifting/packing	2.1	120	39
Driving/Flying			
Automobile	1.0 to 2.0	60 to 115	18 to 37
Aircraft, routine	1.2	70	22
Aircraft, instrument landing	1.8	105	33
Aircraft, combat	2.4	140	44
Heavy vehicle	3.2	185	59
Miscellaneous Occupational Activities			
Cooking	1.6 to 2.0	95 to 115	29 to 37
House cleaning	2.0 to 3.4	115 to 200	37 to 63
Seated, heavy limb movement	2.2	130	41
Machine work			
sawing (table saw)	1.8	105	33
light (electrical industry)	2.0 to 2.4	115 to 140	37 to 44
heavy	4.0	235	74
Handling 50 kg (100 lb) bags	4.0	235	74
Pick and shovel work	4.0 to 4.8	235 to 280	74 to 88
Miscellaneous Leisure Activities			
Dancing, social	2.4 to 4.4	140 to 255	44 to 81
Calisthenics/exercise	3.0 to 4.0	175 to 235	55 to 74
Tennis, single	3.6 to 4.0	210 to 270	66 to 74
Basketball	5.0 to 7.6	290 to 440	90 to 140
Wrestling, competitive	7.0 to 8.7	410 to 505	130 to 160

Table 5.2.2.2A Clothing Insulation I_{cl} Values for Typical Ensembles

Clothing Description	Garments Included [a]	I_{cl}, clo
Trousers	(1) Trousers, short-sleeve shirt	0.57
	(2) Trousers, long-sleeve shirt	0.61
	(3) #2 plus suit jacket	0.96
	(4) #2 plus suit jacket, vest, t-shirt	1.14
	(5) #2 plus long-sleeve sweater, t-shirt	1.01
	(6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/dresses	(7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	(8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	(9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	(10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	(11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	(12) Walking shorts, short-sleeve shirt	0.36
Overalls/coveralls	(13) Long-sleeve coveralls, t-shirt	0.72
	(14) Overalls, long-sleeve shirt, t-shirt	0.89
	(15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	(16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	(17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

a. All clothing ensembles, except where otherwise indicated in parentheses, include shoes, socks, and briefs or panties. All skirt/dress clothing ensembles include pantyhose and no additional socks.

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 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 t_{dp} of 16.8°C (62.2°F).

5.3.1.2 Methodology. Figure 5.3.1 specifies the comfort zone for environments that meet the above criteria. Two zones are shown—one for 0.5 clo of clothing insulation I_{cl} and one for 1.0 clo of insulation.

Comfort zones for intermediate values of clothing insulation I_{cl} shall be determined by linear interpolation between the limits for 0.5 and 1.0 clo using the following relationships:

$$t_{min,\ Icl} = [(I_{cl} - 0.5 \text{ clo})\ t_{min,\ 1.0\ clo} + (1.0 \text{ clo} - I_{cl})\ t_{min,\ 0.5clo}]/0.5 \text{ clo}$$

$$t_{max,\ Icl} = [(I_{cl} - 0.5 \text{ clo})\ t_{max,\ 1.0\ clo} + (1.0 \text{ clo} - I_{cl})\ t_{max,\ 0.5clo}]/0.5 \text{ clo}$$

where

$t_{min,\ Icl}$ = lower operative temperature t_o limit for clothing insulation I_{cl}

$t_{max,\ Icl}$ = upper operative temperature t_o limit for clothing insulation I_{cl}

I_{cl} = thermal insulation of the clothing in question, clo

Average air speeds V_a greater than 0.2 m/s (40 fpm) increase the lower and upper operative temperature t_o limit for the comfort zone in accordance with Section 5.3.3.

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 than 0.20 m/s (40 fpm) require the use of Section 5.3.3.

5.3.2.2 Methodology. The computer code [3] in Normative Appendix B is to be used with this standard. 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 [3] is permitted to be used to comply with this section.

Informative Note: See Informative Appendix L for further explanation of predicted mean vote (PMV) and its relationship to predicted percentage dissatisfied (PPD).

Table 5.2.2.2B Garment Insulation I_{clu}

Garment Description [a]	I_{clu}, clo	Garment Description[a]	I_{clu}, clo
Underwear		Dress and Skirts[b]	
Bra	0.01	Skirt (thin) mm	0.14
Panties	0.03	Skirt (thick)	0.23
Men's briefs	0.04	Sleeveless, scoop neck (thin)	0.23
T-shirt	0.08	Sleeveless, scoop neck (thick), i.e., jumper	0.27
Half slip	0.14	Short-sleeve shirtdress (thin)	0.29
Long underwear bottoms	0.15	Long-sleeve shirtdress (thin)	0.33
Full slip	0.16	Long-sleeve shirtdress (thick)	0.47
Long underwear top	0.20	Sweaters	
Footwear		Sleeveless vest (thin)	0.13
Ankle-length athletic socks	0.02	Sleeveless vest (thick)	0.22
Panty hose/stockings	0.02	Long-sleeve (thin)	0.25
Sandals/thongs	0.02	Long-sleeve (thick)	0.36
Shoes	0.02	Suit Jackets and Vests[c]	
Slippers (quilted, pile lined)	0.03	Sleeveless vest (thin)	0.10
Calf-length socks	0.03	Sleeveless vest (thick)	0.17
Knee socks (thick)	0.06	Single-breasted (thin)	0.36
Boots	0.10	Single-breasted (thick)	0.44
Shirts and Blouses		Double-breasted (thin)	0.42
Sleeveless/scoop-neck blouse	0.12	Double-breasted (thick)	0.48
Short-sleeve knit sport shirt	0.17	Sleepwear and Robes	
Short-sleeve dress shirt	0.19	Sleeveless short gown (thin)	0.18
Long-sleeve dress shirt	0.25	Sleeveless long gown (thin)	0.20
Long-sleeve flannel shirt	0.34	Short-sleeve hospital gown	0.31
Long-sleeve sweatshirt	0.34	Short-sleeve short robe (thin)	0.34
Trousers and Coveralls		Short-sleeve pajamas (thin)	0.42
Short shorts	0.06	Long-sleeve long gown (thick)	0.46
Walking shorts	0.08	Long-sleeve short wrap robe (thick)	0.48
Straight trousers (thin)	0.15	Long-sleeve pajamas (thick)	0.57
Straight trousers (thick)	0.24	Long-sleeve long wrap robe (thick)	0.69
Sweatpants	0.28		
Overalls	0.30		
Coveralls	0.49		

a. "Thin" refers to garments made of lightweight, thin fabrics often worn in the summer; "thick" refers to garments made of heavyweight, thick fabrics often worn in the winter.
b. Knee-length dresses and skirts
c. Lined vests

Table 5.2.2.2C Added Insulation when Sitting on a Chair
(Applicable to Clothing Ensembles with Standing Insulation Values of 0.5 clo < I_{cl} < 1.2 clo)

Net chair [a]	0.00 clo
Metal chair	0.00 clo
Wooden side-arm chair [b]	0.00 clo
Wooden stool	+0.01 clo
Standard office chair	+0.10 clo
Executive chair	+0.15 clo

a. A chair constructed from thin, widely spaced cords that provide no thermal insulation.
b. ***Informative Note:*** This chair was used in most of the basic studies of thermal comfort that were used to establish the PMV-PPD index.

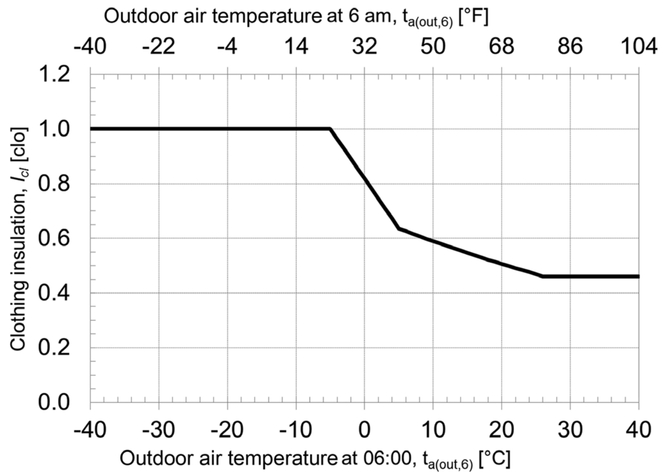


Figure 5.2.2.2 Representative clothing insulation I_{cl} as a function of outdoor air temperature at 06:00 a.m.

Table 5.3.1 Applicability of Methods for Determining Acceptable Thermal Environments in Occupied Spaces

Average Air Speed, m/s (fpm)	Humidity Ratio	Met	Clo	Comfort Zone Method
<0.20 (40)	<0.012 kg·H_2O/kg dry air	1.0 to 1.3	0.5 to 1.0	Section 5.3.1, "Graphic Comfort Zone Method"
<0.20 (40)	All	1.0 to 2.0	0 to 1.5	Section 5.3.2, "Analytical Comfort Zone Method"
>0.20 (40)	All	1.0 to 2.0	0 to 1.5	Section 5.3.3, "Elevated Air Speed Comfort Zone Method"

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 that meets the requirements of 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 [2].
   4. Outdoor air temperature is less than 43°C (110°F).
   5. Vertical fenestration has less than 9 ft (3 m) of 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 (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 Table 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 (Table 5.3.2.2.1B); tinted glazing units (Table 5.3.2.2.1C); and electrochromic glazing units (Table 5.3.2.2.1D). See Normative Appendix C, Section C2(e) for a description of f_{bes}.

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 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 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

(a)

(b)

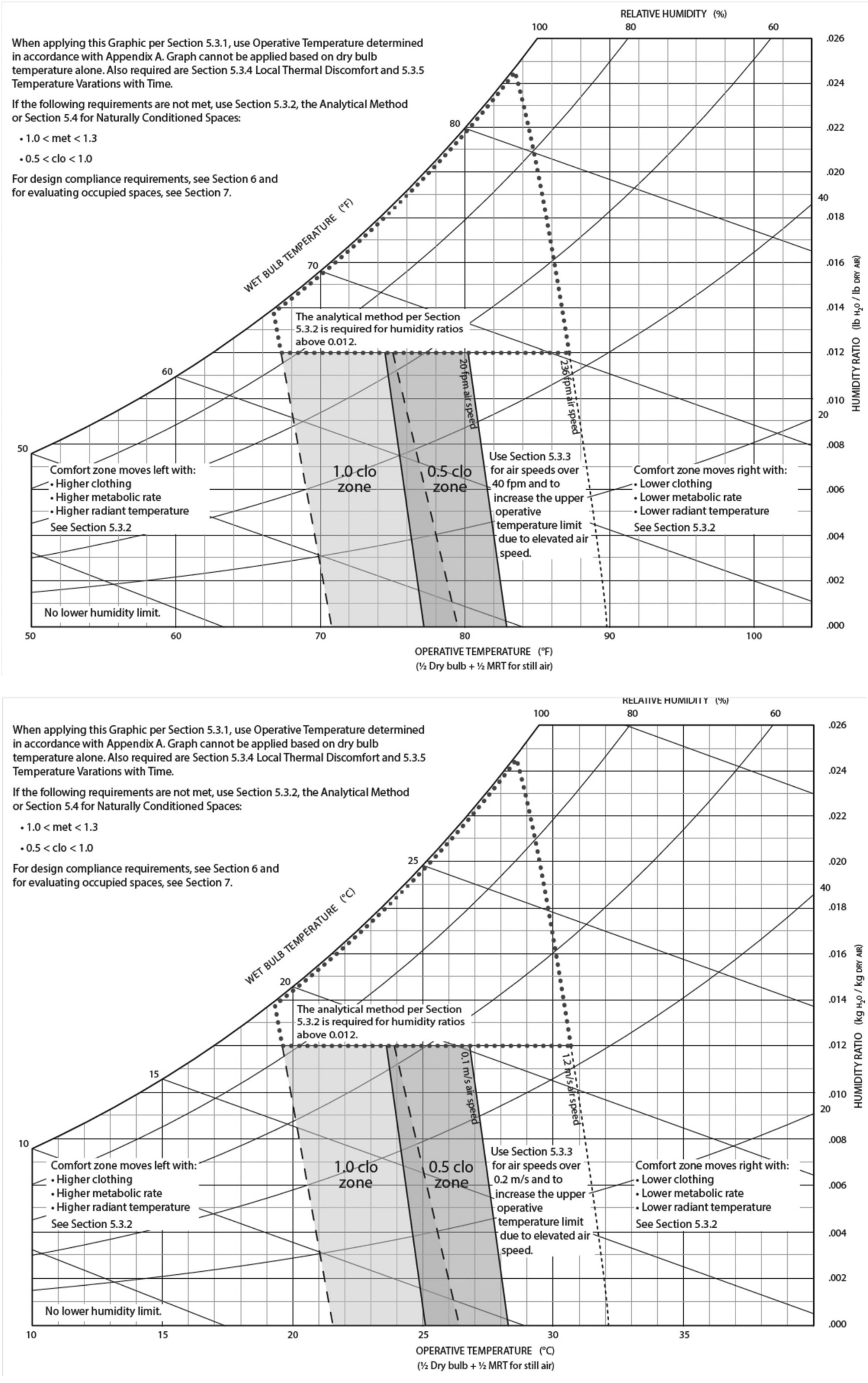


Figure 5.3.1 Graphic Comfort Zone Method: Acceptable range of operative temperature t_o and humidity for spaces that meet the criteria specified in Section 5.3.1 (1.0 ≤ met < 1.3; 0.5 < clo < 1.0)—(a) I-P and (b) SI.

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

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 [3] is permitted to be used to comply with this section.

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.

Figure 5.3.3B describes the steps for determining the limits to air speed inputs in SET model.

5.3.3.3 Average Air Speed V_a with Occupant Control. Section 5.3.3.4 does not apply when the occupants have control over average air speed V_a and one of the following criteria is met:

a. One means of control exists for every six occupants or fewer.
b. One means of control exists for every 84 m^2 (900 ft^2) or less.
c. In multioccupant spaces where groups gather for shared activities, such as classrooms and conference rooms, at least one control shall be provided for each space, regardless of size. Multioccupant spaces that are subdivided by movable walls shall have one control for each space subdivision.

5.3.3.4 Average Air Speed V_a without Occupant Control. If occupants do not have control over the local air speed, meeting the requirements of Section 5.3.3.3, the following limits apply to the SET model and to Figure 5.3.3A.

a. For operative temperatures t_o above 25.5°C (77.9°F), the upper limit to average air speed V_a shall be 0.8 m/s (160 fpm).
b. For operative temperatures t_o between 23.0°C and 25.5°C (73.4°F and 77.9°F), the upper limit to average air speed V_a shall follow an equal SET contour as described in Normative Appendix D. In Figure 5.3.3A, this curve is shown between the dark and light shaded areas. It is permitted to determine the curve in Figure 5.3.3A by using the following equation:

$$V_a = 50.49 - 4.4047(t_o) + 0.096425(t_o)^2 \qquad \text{(m/s, °C)}$$

$$V_a = 31375.7 - 857.295(t_o) + 5.86288(t_o)^2 \qquad \text{(fpm, °F)}$$

c. For operative temperatures t_o below 23.0°C (73.4°F), the limit to average air speed V_a shall be 0.2 m/s (40 fpm).

Exceptions 5.3.3.4(c):

1. Representative occupants with clothing insulation I_{cl} greater than 0.7 clo.
2. Representative occupants with metabolic rates above 1.3 met.

Informative Note: These limits are shown by the light gray area in Figure 5.3.3A.

5.3.4 Local Thermal Discomfort

5.3.4.1 Applicability. The requirements specified in this section are required to be met only when representative occupants meet both of the following criteria:

a. Have clothing insulation I_{cl} less than 0.7 clo
b. Are engaged in physical activity with metabolic rates below 1.3 met

For the purpose of compliance with this section, representative occupants' ankle level is 0.1 m (4 in.) above the floor, and head level is 1.1 m (43 in.) for seated occupants and 1.7 m (67 in.) for standing occupants.

Informative Note: The standard does not contain requirements for standing occupants when all the representative occupants are seated. Many standing occupants have met rates greater than 1.3 (see Section 5.2.1), and by criterion (b) above, the requirements of Section 5.3.4 do not apply to them.

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.

5.3.4.3 Vertical Air Temperature Difference. Air temperature difference between head level and ankle level shall not exceed 3°C (5.4°F) for seated occupants or 4°C (7.2°F) for standing occupants (see note in Section 5.3.4.1).

5.3.4.4 Floor Surface Temperature. When representative occupants are seated with feet in contact with the floor, floor surface temperatures within the occupied zone shall be 19°C to 29°C (66.2°F to 84.2°F).

5.3.5 Temperature Variations with Time

5.3.5.1 Applicability. The fluctuation requirements of this section shall be met when they are not under the direct control of the individual occupant.

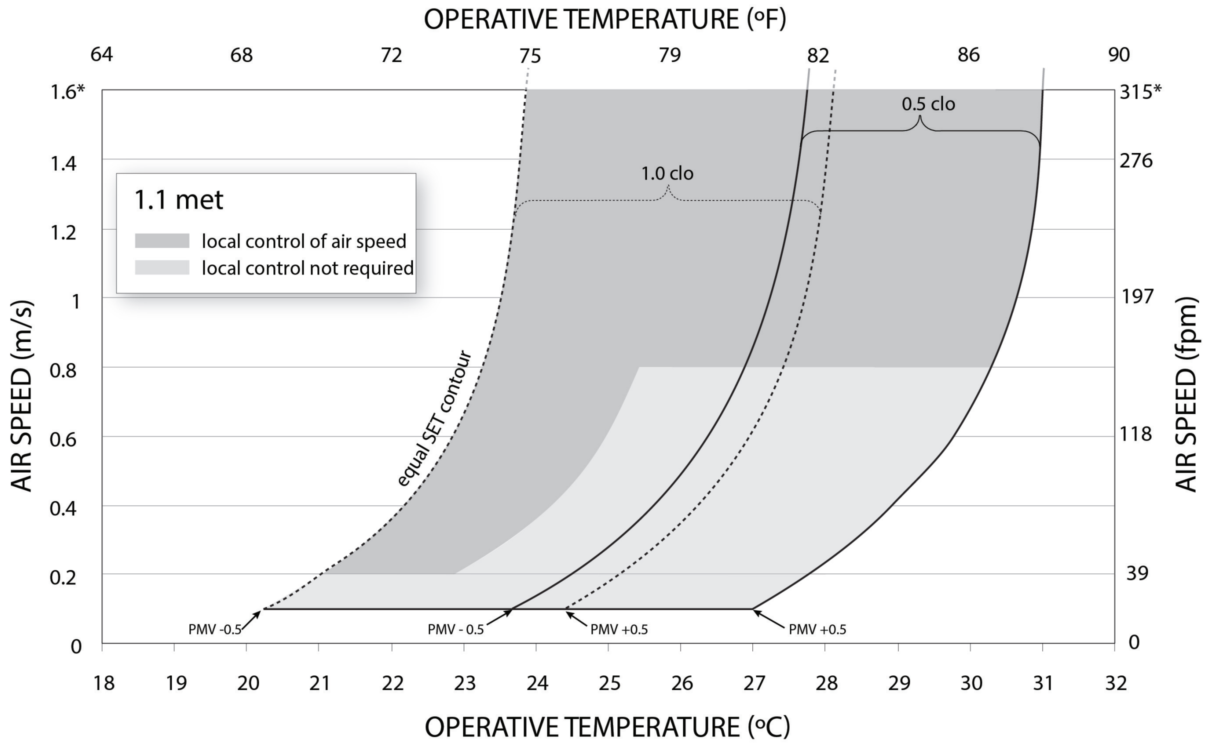
5.3.5.2 Cyclic Variations. Cyclic variations in operative temperature t_o that have a period not greater than 15 minutes shall have a peak-to-peak amplitude no greater than 1.1°C (2.0°F).

5.3.5.3 Drifts or Ramps. Monotonic, noncyclic changes in operative temperature t_o and cyclic variations with a period greater than 15 minutes shall not exceed the most restrictive requirements from Table 5.3.5.3.

Informative Note: For example, the operative temperature shall not change more than 2.2°C (4.0°F) during a 1.0 h period and more than 1.1°C (2.0°F) during any 0.25 h period within that 1.0 h period.

5.4 Determining Acceptable Thermal Conditions in Occupant-Controlled Naturally Conditioned Spaces

5.4.1 Applicability. This method defines acceptable thermal environments only for occupant-controlled naturally conditioned spaces that meet all of the following criteria:



* There is no upper limit to air speed when occupants have local control.

Figure 5.3.3A Acceptable ranges of operative temperature t_o and average air speed V_a for the 1.0 and 0.5 clo comfort zones presented in Figure 5.3.1 at humidity ratio 0.010.

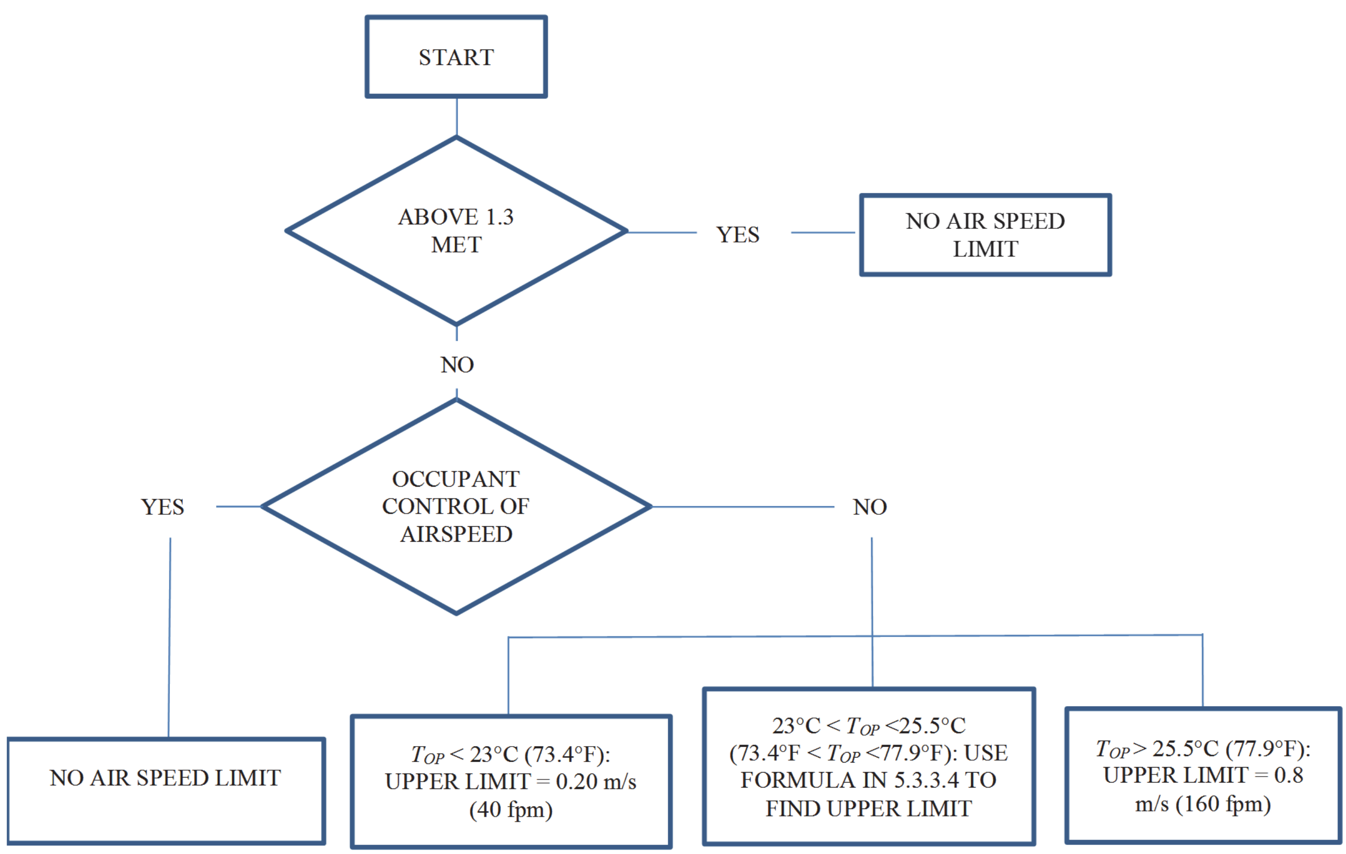


Figure 5.3.3B Flowchart for determining limits to air speed inputs in the Elevated Air Speed Comfort Zone Method.

Table 5.3.4.2 Allowable Radiant Temperature Asymmetry

Radiant Temperature Asymmetry °C (°F)			
Ceiling Warmer than Floor	**Ceiling Cooler than Floor**	**Wall Warmer than Air**	**Wall Cooler than Air**
<5 (9.0)	<14 (25.2)	<23 (41.4)	<10 (18.0)

Table 5.3.5.3 Limits on Temperature Drifts and Ramps

Time Period, h	0.25	0.5	1	2	4
Maximum Operative Temperature t_o Change Allowed, °C (°F)	1.1 (2.0)	1.7 (3.0)	2.2 (4.0)	2.8 (5.0)	3.3 (6.0)

a. There is no mechanical cooling system (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling) installed. No heating system is in operation.
b. Representative occupants have metabolic rates ranging from 1.0 to 1.3 met.
c. Representative occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5 to 1.0 clo.
d. The prevailing mean outdoor temperature is greater than 10°C (50°F) and less than 33.5°C (92.3°F).

5.4.2 Methodology. The allowable indoor operative temperatures t_o shall be determined from Figure 5.4.2 using the 80% acceptability limits or the equations in Section 5.4.2.2.

Informative Note: The 90% acceptability limits are included for information only. See Informative Appendix J for further guidance.

5.4.2.1 The prevailing mean outdoor air temperature $\overline{t_{pma(out)}}$ shall be determined in accordance with all of the following.

5.4.2.1.1 It shall be based on no fewer than seven and no more than 30 sequential days prior to the day in question.

5.4.2.1.2 It shall be a simple arithmetic mean of all of the mean daily outdoor air temperatures $\overline{t_{mda(out)}}$ of all the sequential days in Section 5.4.2.1.1.

Exception to 5.4.2.1.2: Weighting methods are permitted, provided that the weighting curve continually decreases toward the more distant days such that the weight applied to a day is between 0.6 and 0.9 of that applied to the subsequent day. For this option, the upper limit on the number of days in the sequence does not apply. (See Informative Appendix J for example calculation.)

Mean daily outdoor air temperature $\overline{t_{mda(out)}}$ for each of the sequential days in Section 5.4.2.1.1 shall be the simple arithmetic mean of all the outdoor dry-bulb temperature observations for the 24-hour day. The quantity of measurements shall be no less than two, and, in that case, shall be the minimum and maximum for the day. When using three or more measurements, the time periods shall be evenly spaced.

5.4.2.1.3 Observations in Section 5.4.2.1 shall be from the nearest approved meteorological station, public or private, or Typical Meteorological Year (TMY) weather file.

Exception to 5.4.2.1.3: When weather data to calculate the prevailing mean outdoor air temperature $\overline{t_{pma(out)}}$ are not available, it is permitted to use as the prevailing mean the published meteorological monthly means for each calendar month. It is permitted to interpolate between monthly means.

5.4.2.2 It shall be permitted to use the following equations, which correspond to the acceptable operative temperature t_o ranges in Figure 5.4.2:

$$\text{Upper 80\% acceptability limit (°C)} = 0.31\ \overline{t_{pma(out)}} + 21.3$$

$$\text{Upper 80\% acceptability limit (°F)} = 0.31\ \overline{t_{pma(out)}} + 60.5$$

$$\text{Lower 80\% acceptability limit (°C)} = 0.31\ \overline{t_{pma(out)}} + 14.3$$

$$\text{Lower 80\% acceptability limit (°F)} = 0.31\ \overline{t_{pma(out)}} + 47.9$$

5.4.2.3 The following effects are already accounted for in Figure 5.4.2 and the equations in Section 5.4.2.2, and therefore it is not required that they be separately evaluated: local thermal discomfort, clothing insulation I_{cl}, metabolic rate, humidity, and air speed.

5.4.2.4 If t_0 > 25°C (77°F), then it shall be permitted to increase the upper acceptability temperature limits in Figure 5.4.2 and the equations in Section 5.4.2.2 by the corresponding Δt_0 in Table 5.4.2.4.

6. DESIGN COMPLIANCE

6.1 Design. Building systems (i.e., combinations of mechanical systems, control systems, and thermal enclosures) shall be designed so that at outdoor and indoor design conditions they are able to maintain the occupied space or spaces at indoor thermal conditions specified by one of the methods in this standard.

The building systems shall be designed so that they are able to maintain the occupied space or spaces within the ranges specified for internal conditions in this standard, and within the range of expected operating conditions (indoor and outdoor).

6.2 Documentation. The method and design conditions appropriate for the intended use of the building shall be selected and documented as follows.

Informative Note: Some of the requirements in items (a) through (h) below are not applicable to naturally conditioned buildings.

a. The method of design compliance shall be stated for each space and/or system: Graphic Comfort Zone Method (Section 5.3.1), Analytical Comfort Zone Method (Section 5.3.2), Elevated Air Speed Comfort Zone Method (Section 5.3.3), or the use of Section 5.4 for occupant-controlled naturally conditioned spaces.
b. The design operative temperature t_o and humidity (including any tolerance or range), the design outdoor conditions (see 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 14), and total indoor loads shall be stated. The design exceedance hours (see Section 3, "Definitions") shall be documented based on the design conditions used.

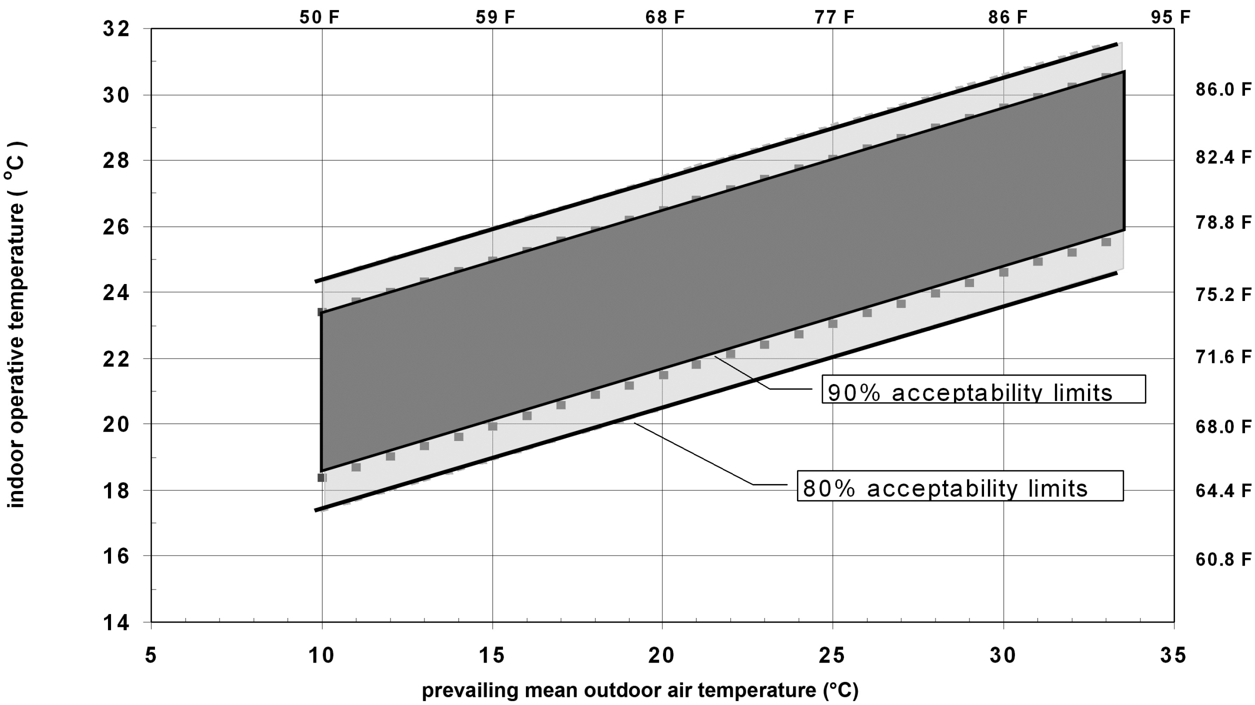


Figure 5.4.2 Acceptable operative temperature t_o ranges for naturally conditioned spaces.

Table 5.4.2.4 Increases in Acceptable Operative Temperature Limits (Δt_0) in Occupant-Controlled Naturally Conditioned Spaces (Figure 5.4.2) Resulting from Increasing Air Speed above 0.3 m/s (59 fpm)

Average Air Speed V_a 0.6 m/s (118 fpm)	Average Air Speed V_a 0.9 m/s (177 fpm)	Average Air Speed V_a 1.2 m/s (236 fpm)
1.2°C (2.2°F)	1.8°C (3.2°F)	2.2°C (4.0°F)

c. Values assumed for comfort parameters used in the calculation of thermal conditions, including operative temperature t_o, humidity, average air speed V_a, clothing insulation I_{cl}, and metabolic rate, shall be stated for heating and cooling design conditions. If an acceptable level of comfort is not being provided to any representative occupants, this shall be stated. Where Table 5.2.1.2 gives a range, the basis for selecting a single value within that range shall be stated. If the clothing insulation or metabolic rate parameters for a given space are outside the applicable bounds defined by the standard, or if the space is not regularly occupied as defined in Section 2.3, the space shall be clearly identified as not under the scope of the standard.

d. Local thermal discomfort shall be addressed, at a minimum, by a narrative explanation of why an effect is not likely to exceed Section 5 limits. Where calculations are used to determine the effect of local thermal discomfort in accordance with Section 5, the calculation inputs, methods, and results shall be stated.

e. System equipment capacity shall be provided for each space and/or system documenting performance meeting the design criteria stated. For each unique space, the design system or equipment heating and/or cooling capacity shall meet the thermal loads calculated under the heating and cooling design conditions stated for compliance with this standard.

f. Where elevated air speed with occupant control is employed to provide acceptable thermal conditions, documentation shall be provided to identify the method and equipment for occupant control.

g. Air speed, radiant temperature asymmetry, vertical air-temperature difference, surface temperatures, and temperature variations with time shall be determined in accordance with generally accepted engineering standards (e.g., *ASHRAE Handbook—HVAC Applications*, Chapter 57). The method used, and quantified selection criteria, characteristics, sizes, and indices that are applicable to the method, shall be stated.

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 $\bar{t}_r$.

Informative Note: See Informative Appendix K for sample compliance documentation.

7. EVALUATION OF COMFORT IN EXISTING BUILDINGS

7.1 Introduction. Evaluation of comfort in existing buildings is not a requirement of this standard. When such evaluation is otherwise required (e.g., by code or another standard) use one of the following methods:

7.1.1 Occupant surveys using Sections 7.2.1, 7.3.1, or 7.4.1.

7.1.2 Environmental measurement using Sections 7.2.2, 7.3.2, 7.3.3, 7.3.4, or 7.4.2.

7.1.3 When using the building automation system as an adjunct to Sections 7.1.1 or 7.1.2, it shall have the characteristics described in Section 7.3.5.

7.2 Criteria for Comfort in Existing Buildings

7.2.1 Comfort Determination from Occupant Surveys. Acceptability and satisfaction are directly determined from the responses of occupants using the scales and comfort limits described in Section 7.3.1.

7.2.2 Prediction of Comfort from Environmental Measurements

7.2.2.1 Mechanically Conditioned Spaces. Use Section 5.3.1.2 to determine the PMV-based comfort zone for the occupants' expected clothing and metabolic rate. The modeled clothing and activity levels of the occupants must be as observed or as expected for the use of the indoor space in question. Use Section 5.3.3 to adjust the comfort zone's lower and upper operative temperature limits for elevated air movement. Occupied zone conditions must also conform to requirements for avoiding local thermal discomfort (as specified in Section 5.3.4) and to limits to rate of temperature change over time, as specified in Section 5.3.5.

Parameters to be measured and/or recorded include the following:

a. Occupant metabolic rate (met) and clothing (clo) observations
b. Air temperature and humidity
c. Mean radiant temperature $\bar{t}_r$, unless it can be otherwise demonstrated that, within the space, $\bar{t}_r$ is within 1°C (2°F) of t_a
d. Air speed, unless it can be otherwise demonstrated that, within the space, average air speed V_a meets the requirements of Section 5.3.3

7.2.2.2 Naturally Conditioned Spaces. Section 5.4 prescribes the use of the adaptive model for determining the comfort zone boundaries. The air movement extensions to the comfort zone's lower and upper operative temperature limits (Table 5.4.2.4) shall be used when elevated air movement is present.

Parameters to be measured include the following:

a. Indoor air temperature and mean radiant temperature $\bar{t}_r$
b. Outdoor air temperature

7.3 Measurement Methods

7.3.1 Surveys of Occupant Responses to Environment. Surveys shall be solicited from the entire occupancy or a representative sample thereof. If more than 45 occupants are solicited, the response rate must exceed 35%. If solicited occupants number between 20 and 45, at least 15 must respond. For under 20 solicited occupants, 80% must respond.

7.3.1.1 Satisfaction Surveys

a. Thermal satisfaction shall be measured with a scale ending with the choices "very satisfied" and "very dissatisfied."
b. Thermal satisfaction surveys shall include diagnostic questions allowing causes of dissatisfaction to be identified.

7.3.1.2 Point-in-Time Surveys

a. Thermal acceptability questions shall include a continuous or seven-point scale ending with the choices "very unacceptable" and very acceptable."
b. Thermal sensation questions shall include the ASHRAE seven-point thermal sensation scale subdivided as follows: cold, cool, slightly cool, neutral, slightly warm, warm, hot.

Point-in-time surveys shall be solicited during times representative of the building's occupancy.

7.3.2 Physical Measurement Positions within the Building

a. **Floor plan.** Thermal environment measurements shall be made in the building at a representative sample of locations where the occupants are known to, or are expected to, spend their time. When performing evaluation of similar spaces in a building, it shall be permitted to select a representative sample of such spaces.

   If occupancy distribution cannot be observed or estimated, the measurement locations shall include both of the following:

   1. The center of the room or space
   2. 1.0 m (3.3 ft) inward from the center of each of the room's walls. In the case of exterior walls with windows, the measurement location shall be 1.0 m (3.3 ft) inward from the center of the largest window.

   Measurements shall also be taken in locations where the most extreme values of the thermal parameters are observed or estimated to occur (e.g., potentially occupied areas near windows, diffuser outlets, corners, and entries).

b. **Height above floor.** Air temperature and average air speed V_a shall be measured at the 0.1, 0.6, and 1.1 m (4, 24, and 43 in.) levels for seated occupants at the plan locations specified above. Measurements for standing occupants shall be made at the 0.1, 1.1, and 1.7 m (4, 43, and 67 in.) levels. Operative temperature t_o or PMV shall be measured or calculated at the 0.6 m (24 in.) level for seated occupants and the 1.1 m (43 in.) level for standing occupants. Floor temperature that may cause local discomfort shall be measured at the surface by contact thermometer or infrared thermometer (Section 5.3.4.5).

   Radiant temperature asymmetry that may cause local thermal discomfort (Sections 5.3.4.4) shall be measured in the affected occupants' locations, with the sensor oriented to capture the greatest surface temperature difference.

7.3.3 Timing of Physical Measurements. Measurement periods shall span two hours or more and, in addition, shall represent a sample of the total occupied hours in the period selected for evaluation (year, season, or typical day) or shall take place during periods directly determined to be the critical hours of anticipated occupancy.

Table 7.3.4 Instrumentation Measurement Range and Accuracy

Quantity	Measurement Range	Accuracy
Air temperature	10°C to 40°C (50°F to 104°F)	±0.2°C (0.4°F)
Mean radiant temperature	10°C to 40°C (50°F to 104°F)	±1°C (2°F)
Plane radiant temperature	0°C to 50°C (32°F to 122°F)	±0.5°C (1°F)
Surface temperature	0°C to 50°C (32°F to 122°F)	±1°C (2°F)
Humidity, relative	25% to 95% rh	±5% rh
Air speed	0.05 to 2 m/s (10 to 400 fpm)	±0.05 m/s (±10 fpm)
Directional radiation	–35 W/m^2 to +35 W/m^2 (–11 Btu/h·ft^2 to +11 Btu/h·ft^2)	±5 W/m^2 (±1.6 Btu/h·ft^2)

Measurement intervals for air temperature, mean radiant temperature $\bar{t}_r$, and humidity shall be five minutes or less, and for air speed shall be three minutes or less.

7.3.4 Physical Measurement Device Criteria. The measuring instrumentation used shall meet the requirements for measurement range and accuracy given in Table 7.3.4. Air temperature sensors shall be shielded from radiation exchange with the surroundings.

7.3.5 Measurements from Building Automation System (BAS)

7.3.5.1 Location. BAS space sensor locations shall be evaluated against the location criteria in Section 7.3.2.

7.3.5.2 Precision. BAS space temperature sensor accuracy shall be 0.5°C (1°F) or less, and space humidity sensor accuracy shall be ±5% rh.

7.3.5.3 Trending Capabilities. The BAS shall have the ability to trend space temperature data at intervals not exceeding 15 minutes over 30 days or longer.

7.3.5.4 Additional Concurrent Data. Data such as equipment status, supply and return air, and water temperatures shall be observed for time periods concurrent with the space temperature data.

7.4 Evaluation Methods

7.4.1 Evaluation Based on Survey Results

a. The probability of occupants satisfied shall be predicted from seven-point satisfaction survey scores by dividing the number of votes falling between –1 and +3, inclusive, by the total number of votes.

   Responses to diagnostic dissatisfaction questions shall be tallied by category.

b. For point-in-time surveys, comfort shall be evaluated using votes on the acceptability and/or thermal sensation scales. On the acceptability scale, votes between 0 (neutral) and +3 ("very acceptable"), inclusive, shall be divided by total votes to obtain the probability of comfort acceptability observed during the survey period. On the seven-point thermal sensation scale, votes between –1.5 and +1.5, inclusive, shall be divided by total votes to obtain the probability of comfort acceptability observed during the survey period.

7.4.2 Evaluation Based on Physical Measurements of the Thermal Environment. Use one of the following approaches in Section 7.4.2.1 or 7.4.2.2.

7.4.2.1 Approaches to Predicting whether a Thermal Environment is Acceptable at a Specific Instance in Time

a. Mechanically conditioned buildings:
   1. Occupied spaces shall be evaluated using the PMV and SET comfort zone as defined in Sections 5.3.1 and 5.3.3.
   2. Local thermal discomfort shall be evaluated using the limits to environmental asymmetry prescribed in Section 5.3.4.
b. Buildings with occupant-controlled operable windows:
   1. Occupied spaces shall be evaluated using the indoor operative temperature t_o contours of the adaptive model comfort zone in Section 5.4, including the contour extensions for average air speeds V_a above 0.3 m/s (59 fpm).

7.4.2.2 Approaches to Predicting whether a Thermal Environment is Acceptable over Time. Section 7.4.2.2.1 shall be used to quantify the number of hours in which environmental conditions are outside the comfort zone requirements during occupied hours in the time period of interest. Exceedance is measured by exceedance hours (EH) (see definition in Section 3). Section 7.4.2.2.2 is permitted but not required to be used with Section 7.4.2.2.1.

7.4.2.2.1 Exceedance hours are calculated for the PMV comfort zone and adaptive model comfort zone as follows:

Letting each sum be over occupied hours within the specified period, and comfort indices respective to that hour, for PMV comfort zone, EH = ΣH_{disc}, where H_{disc} is a discomfort hour; $H_{disc} = 1$ if $|PMV| - 0.5 > 0$ and 0 otherwise.

For adaptive model comfort zone, where $H_{>upper}$ and $H_{<lower}$ are discomfort hours outside of comfort zone boundaries t_{upper} and t_{lower}, EH = $\Sigma(H_{>upper} + H_{<lower})$, where $H_{>upper} = 1$ if $t_{op} > t_{upper}$ and 0 otherwise, and $H_{<lower} = 1$ if $t_{op} < t_{lower}$ and 0 otherwise.

Units are in hours. Exceedance hours can also be expressed as a probability by dividing EH by total occupied hours.

7.4.2.2.2 It is permissible to quantify the expected number of episodes of discomfort, rate-of-change exceedances, and local discomfort exceedances, within a time period of interest.

8. REFERENCES

1. ASHRAE. 2009. 2009 *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE.
2. ASHRAE. 2013. ANSI/ASHRAE/IES Standard 90.1-2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings.* Atlanta: ASHRAE.
3. ASHRAE. 2011. ASHRAE Thermal Comfort Tool CD, v2. Atlanta: ASHRAE.
4. ISO. 2005. ISO 7730, *Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*. Geneva, Switzerland: International Organization for Standardization.
5. ASHRAE. 2013. 2013 *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE.

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

NORMATIVE APPENDIX A METHODS FOR DETERMINING OPERATIVE TEMPERATURE

Determine operative temperature t_o using the following method or 2009 *ASHRAE Handbook—Fundamentals* [1], Chapter 9.

Informative Note: *Average air speed* and *average air temperature* have precise definitions in this standard. See Section 3 for all defined terms.

Operative temperature t_o is permitted to be calculated per the following formula:

$$t_o = At_a + (1 - A)\bar{t}_r$$

where

t_o = operative temperature

t_a = average air temperature

$\bar{t}_r$ = mean radiant temperature (For detailed calculation procedures, see the "Thermal Comfort" chapter of the most current edition of *ASHRAE Handbook—Fundamentals*.)

A can be selected from the following values as a function of the average air speed V_a.

V_a	<0.2 m/s (<40 fpm)	0.2 to 0.6 m/s (40 to 120 fpm)	0.6 to 1.0 m/s (120 to 200 fpm)
A	0.5	0.6	0.7

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

NORMATIVE APPENDIX B
COMPUTER PROGRAM FOR CALCULATION OF PMV-PPD

(Reference Annex D of ISO 7730 [4]. Used with permission of ISO. For additional technical information and an I-P version of the equations in this appendix, refer to the ASHRAE Thermal Comfort Tool [3] referenced in Section 8 of this standard. The Thermal Comfort Tool allows for I-P inputs and outputs, but the algorithm is implemented in SI units.)

```
10   REM     ' Computer program (BASIC) for calculation of
20   REM     ' Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD)
30   REM     ' in accordance with ISO 7730
40   CLS:    Print "Data Entry"                                    : 'data entry
50   INPUT   "  Clothing                        (clo)"             ; CLO
60   INPUT   "  Metabolic rate                  (met)"             ; MET
70   INPUT   "  External work, normally around 0 (met)"            ; WME
80   INPUT   "  Air Temperature                 (C)"               ; TA
90   INPUT   "  Mean radiant temperature        (C)"               ; TR
100  INPUT   "  Relative air velocity           (m/s)"             : VEL
110  PRINT   "  ENTER EITHER RH OR WATER VAPOR PRESSURE BUT NOT BOTH"
120  INPUT   "  Relative humidity               (%)"               ; RH
130  INPUT   "  Water vapor pressure            (Pa)"              ; PA
140  DEF  FNPS (T) = exp(16.6536-4030.183/(TA+235))                : ' saturated vapor pressure KPa
150  IF PA=0 THEN PA=RH*10*FNPS  (TA)                              : ' water vapor pressure, Pa
160  ICL = .155 * CLO                                              : ' thermal insulation of the clothing in m2K/W
170  M  =  MET * 58.15                                             : ' metabolic rate in W/m2
180  W  =  WME * 58.15                                             : ' external work in W/m2
190  MW  =  M – W                                                  : ' internal heat production in the human body
200  IF ICL < .078 THEN FCL = 1 + 1.29 * ICL ELSE FCL = 1.05+.645*ICL
205                                                                : ' clothing area factor
210  HCF = 12.1*SQR (VEL)                                          : ' heat transf. coefficient by forced convection
220  TAA =  TA + 273                                               : ' air temperature in Kelvin
230  TRA =  TR + 273                                               : ' mean radiant temperature in Kelvin
240  ' - - - - - - - - -  CACULATE SURFACE TEMPERATURE OF CLOTHING BY ITERATION - - - - - - - - - - - - - - -
250  TCLA =  TAA + (35.5-TA) / (3.5*(6.45*ICL+.1))
255  ' first guess for surface temperature of clothing
260  P1  =  ICL * FCL                                              : ' calculation term
270  P2  =  P1 * 3.96                                              : ' calculation term
280  P3  =  P1 * 100                                               : ' calculation term
290  P4  =  P1 * TAA                                               : ' calculation term
300  P5  =  308.7 – .028 * MW +P2 * (TRA/100) ^ 4                  : ' calculation term
310  XN  =  TCLA / 100
320  XF  =  XN
330  N =0                                                          : ' N: number of iterations
340  EPS = .00015                                                  : ' stop criteria in iteration
350  XF  =  (XF+XN) / 2
355  ' heat transf. coeff. by natural convection
360  HCN=2.38*ABS(100*XF-TAA)^.25
370  IF HCF>HCN THEN HC=HCF ELSE HC=HCN
380  XN=(P5+P4*HC-P2*XF^4) / (100+P3*HC)
390  N=N+1
400  IF N > 150 then goto 550
410  IF ABS(XN-XF) . EPS then goto 350
```

```
420    TCL=100*XN-273                                          :  ‘ surface temperature of the clothing
430    ‘ - - - - - - - - - - - - - - - - - - - HEAT LOSS COMPONENTS - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
435    “ heat loss diff. through skin
440    HL1 = 3.05*.001*(5733-6.99*MW-PA)
445    ‘ heat loss by sweating (comfort)
450    IF MW > 58.15 THEN HL2 = .42 * (MW-58.15)
       ELSE HL2 = 0!
455    ‘ latent respiration heat loss
460    HL3 = 1.7 * .00001 * M * (5867-PA)
465    ‘ dry respiration heat loss
470    HL4 = .0014 * M * (34-TA)
475    ‘ heat loss by radiation
480    HL5 = 3.96*FCL*(XN^4-(TRA/100)^4)
485    ‘ heat loss by convection
490    HL6 = FCL * HC * (TCL-TA)
500    ‘ - - - - - - - - - - - - - - - - - CALCULATE PMV AND PPD - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
505    ‘ thermal sensation trans. Coeff.
510    TS  =  .303 * EXP(-.036*M) + .028
515    ‘ predicted mean vote
520    PMV = TS * (MW-HL1-HL2-HL3-HL4-HL5-HL6)
525    ‘ predicted percentage dissat.
530    PPD=100-95*EXP(-.03353*PMV^4-.2179*PMV^2)
540    goto 570
550    PMV = 99999!
560    PPD-100
570    PRINT: PRINT “OUTPUT”
580    PRINT “ Predicted Mean Vote                          (PMV)            :  “
              ;: PRINT USING “###.###”; PMV
590    PRINT “ Predicted Percentage of Dissatisfied         (PPD)            :  “
              ;: PRINT USING ###.###”: PPD
600    PRINT: INPUT “NEXT RUN (Y/N) “  ;  R$
610    If (R$=”Y” or R$=”y”) THEN RUN
620    END
```

Example: Values used to generate the comfort envelope in Figure 5.3.1.

Run	Air Temp.		RH	Radiant Temp.		Air Speed					
#	°F	C	%	°F	C	FPM	m/s	Met	CLO	PMV	PPD %
1	67.3	19.6	86	67.3	19.6	20	0.10	1.1	1	–0.5	10
2	75.0	23.9	66	75.0	23.9	20	0.10	1.1	1	0.5	10
3	78.2	25.7	15	78.2	25.7	20	0.10	1.1	1	0.5	10
4	70.2	21.2	20	70.2	21.2	20	0.10	1.1	1	–0.5	10
5	74.5	23.6	67	74.5	23.6	20	0.10	1.1	0.5	–0.5	10
6	80.2	26.8	56	80.2	26.8	20	0.10	1.1	0.5	0.5	10
7	82.2	27.9	13	82.2	27.9	20	0.10	1.1	0.5	0.5	10
8	76.5	24.7	16	76.5	24.7	20	0.10	1.1	0.5	–0.5	10

(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 (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 long-wave exchange with surfaces is related to $\overline{t_{rlw}}$ by

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

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·°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$_{solar}$:

$$\alpha_{LW}\mathrm{ERF}_{solar} = \alpha_{SW}E_{solar} \quad \text{(C-2)}$$

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.

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

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 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}.

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

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).

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

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

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

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

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

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.

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 of 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 Table C2-2. 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 *d* between the occupant and the window.

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

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. See 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.

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."

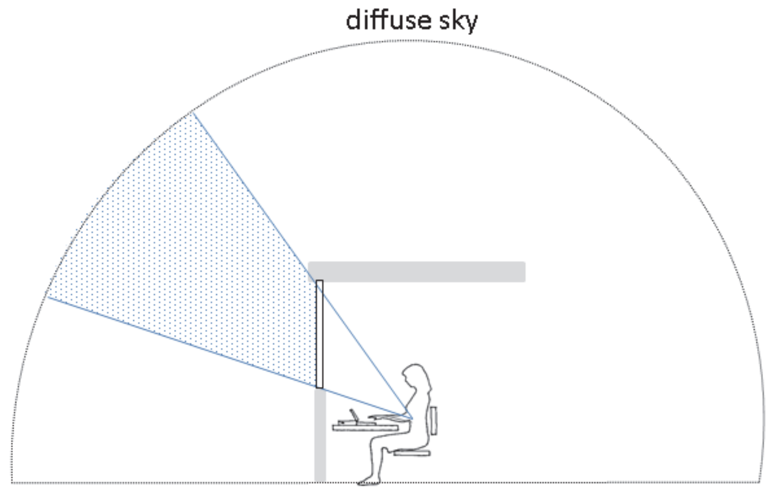


Figure C1-1 Fraction of sky vault in occupant's view (f_{svv}).

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 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)	

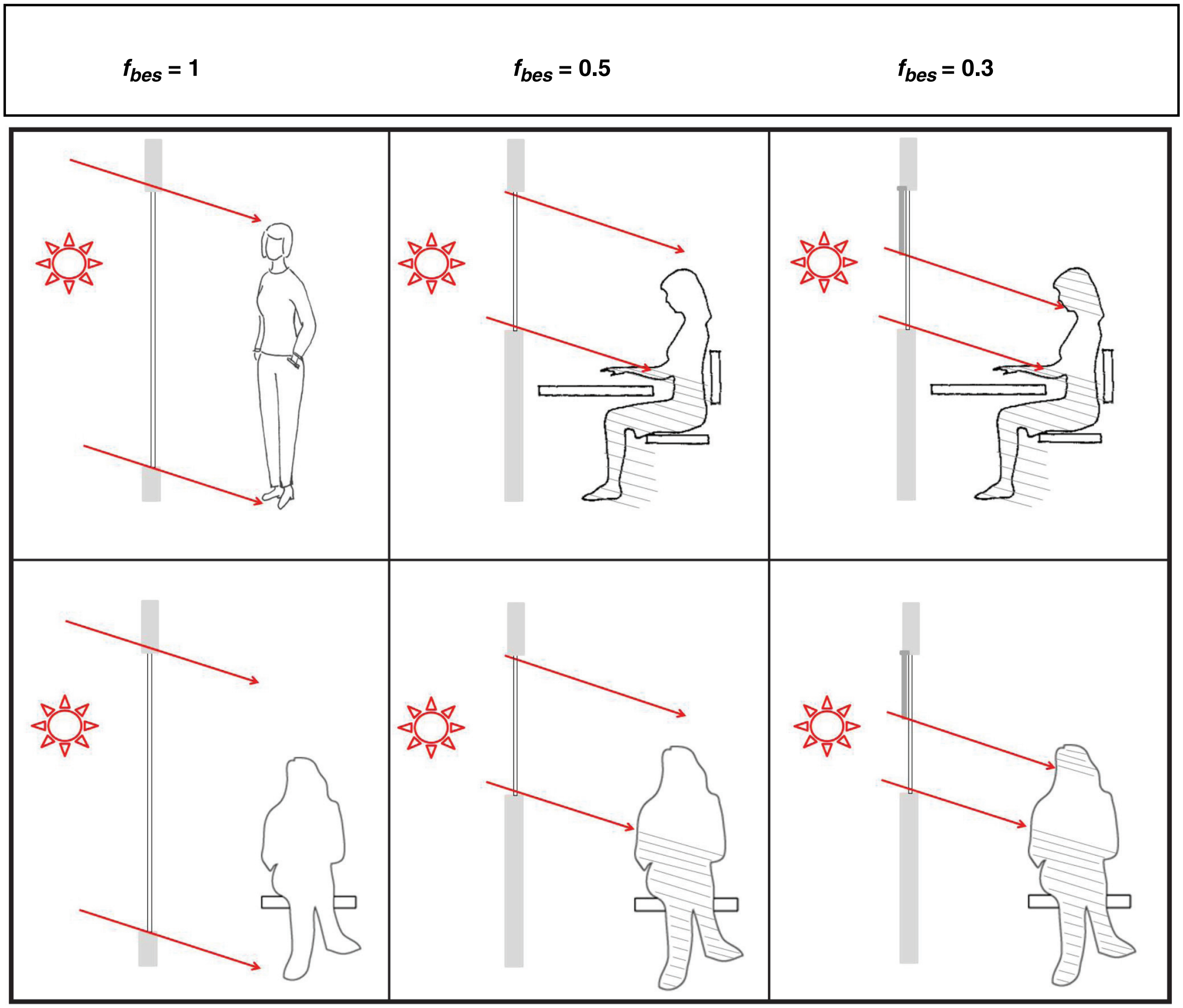


Figure C2-1 Fraction of body exposed to sun f_{bes}, not including the body's self shading. It is acceptable to simplify f_{bes} to equal the fraction of the distance between head and toe exposed to direct sun, as shown. *Informative Note:* 1.0 is the greatest possible value for f_{bes}, because the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

Table 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

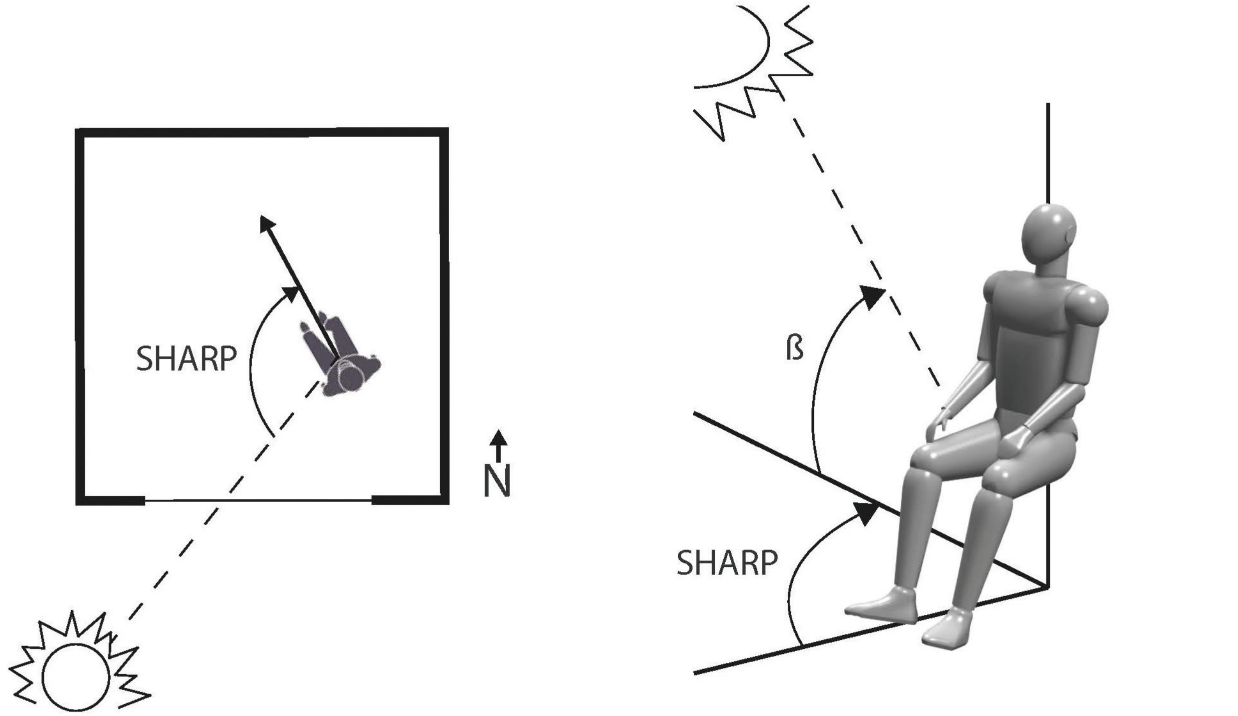


Figure C2-2 Solar horizontal angle relative to the front of the person (SHARP) and solar altitude β.

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

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

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

NORMATIVE APPENDIX D PROCEDURE FOR EVALUATING COOLING EFFECT OF ELEVATED AIR SPEED USING SET

D1. CALCULATION OVERVIEW

Section 5.3 requires that the Elevated Air Speed Comfort Zone Method be used when average air speed V_a is greater than 0.20 m/s (40 fpm). The SET model shall be used to account for the cooling effect of air speeds greater than the maximum allowed in the Graphic Comfort Zone or Analytical Comfort Zone methods. This appendix describes the calculation procedures for the Elevated Air Speed Comfort Zone Method.

For a given set of environmental and personal variables, including an elevated average air speed, an average air temperature t_a, and a mean radiant temperature $\bar{t}_r$, the SET is first calculated. Then the average air speed V_a is replaced by still air (0.1 m/s [20 fpm]), and the average air temperature and radiant temperature are adjusted according to the cooling effect (CE). The CE of the elevated air speed is the value that, when subtracted equally from both the average air temperature and the mean radiant temperature, yields the same SET under still air as in the first SET calculation under elevated air speed. The PMV adjusted for an environment with elevated average air speed is calculated using the adjusted average air temperature, the adjusted radiant temperature, and still air (0.1 m/s [20 fpm]).

a. Enter the average air temperature t_a, radiant temperature, relative humidity, clo value, and met rate.
b. Set the average air speed V_a.
c. Note the calculated value for SET in the output data.
d. Reduce the average air speed V_a to 0.1 m/s (20 fpm).
e. Reduce the average air temperature t_a and radiant temperature t_r equally in small increments until the SET is equal to the value noted in Step (c).
f. The CE is the quantity by which the average air temperature and radiant temperature have been reduced. The resulting air temperature value is the adjusted average air temperature, and the resulting radiant temperature is the adjusted mean radiant temperature.
g. The PMV adjusted for elevated average air speed is calculated using the following inputs:
   1. Adjusted average air temperature from Step (f)
   2. Adjusted mean radiant temperature from Step (f)
   3. Average air speed V_a of 0.1 m/s (20 fpm)
   4. Original relative humidity
   5. Original clo value
   6. Original met rate

D2. CALCULATION PROCEDURE

The following is a formal description of this process that can be automated.

Suppose t_a is the average air temperature and ν_{elev} is the elevated average air speed, such that ν_{elev} > 0.1 m/s (20 fpm). Let ν_{still} = 0.1 m/s (20 fpm). Consider functions PMV and SET, which take six parameters, which we will denote with the shorthand PMV(.,*) and SET (.,*). The variables of importance will be listed explicitly, while the parameters that are invariant will be denoted by "*". The variables we will refer to explicitly are the average air temperature t_a, mean radiant temperature ($\bar{t}_r$), average air speed (V_a), and relative humidity (RH).

To define the CE, we assert that it satisfies the following:

$$\mathrm{SET}(t_a, t_r, \nu_{elev}, *) = \mathrm{SET}(t_a - \mathrm{CE}, t_r - \mathrm{CE}, \nu_{still}, *) \quad \text{(D-1)}$$

That is, the adjusted average air temperature yields the same SET, given still air, as the actual air temperature does at elevated average air speed. In order to determine the cooling effect, an iterative root-finding method such as the bisection or secant method may be employed. The root of the parameterized function *f*(ce) is the CE:

$$f(\mathrm{ce}) = \mathrm{SET}(t_a, t_r, \nu_{elev}, *) - \mathrm{SET}(t_a - \mathrm{ce}, t_r - \mathrm{ce}, \nu_{still}, *) \quad \text{(D-2)}$$

The adjusted PMV is given by

$$\mathrm{PMV}_{adj} = \mathrm{PMV}(t_a - \mathrm{CE}, t_r - \mathrm{CE}, \nu_{still}, *) \quad \text{(D-3)}$$

Informative Note: For the use of SET in ASHRAE Standard 55, the function for self-generated air speed as a function of met rate has been removed.

D3. VALIDATION TABLE FOR SET CALCULATION

Software implementations and other methods of SET calculation shall be validated against Table D3.

Table D3 Validation Table for SET Computer Model

Temperature		MRT		Velocity		RH			SET	
°C	°F	°C	°F	m/s	fpm	%	Met	Clo	°C	°F
25	77	25	77	0.15	29.5	50	1	0.5	23.8	74.9
0	32	25	77	0.15	29.5	50	1	0.5	12.3	54.1
10	50	25	77	0.15	29.5	50	1	0.5	17.0	62.5
15	59	25	77	0.15	29.5	50	1	0.5	19.3	66.7
20	68	25	77	0.15	29.5	50	1	0.5	21.6	70.8
30	86	25	77	0.15	29.5	50	1	0.5	26.4	79.6
40	104	25	77	0.15	29.5	50	1	0.5	34.3	93.7
25	77	25	77	0.15	29.5	10	1	0.5	23.3	74.0
25	77	25	77	0.15	29.5	90	1	0.5	24.9	76.8
25	77	25	77	0.1	19.7	50	1	0.5	24.0	75.2
25	77	25	77	0.6	118.1	50	1	0.5	21.4	70.5
25	77	25	77	1.1	216.5	50	1	0.5	20.3	68.6
25	77	25	77	3	590.6	50	1	0.5	18.8	65.8
25	77	10	50	0.15	29.5	50	1	0.5	15.2	59.3
25	77	40	104	0.15	29.5	50	1	0.5	31.8	89.2
25	77	25	77	0.15	29.5	50	1	0.1	20.7	69.3
25	77	25	77	0.15	29.5	50	1	1	27.3	81.1
25	77	25	77	0.15	29.5	50	1	2	32.5	90.4
25	77	25	77	0.15	29.5	50	1	4	37.7	99.8
25	77	25	77	0.15	29.5	50	0.8	0.5	23.3	73.9
25	77	25	77	0.15	29.5	50	2	0.5	29.7	85.5
25	77	25	77	0.15	29.5	50	4	0.5	36.0	96.7

D4. COMPUTER PROGRAM FOR CALCULATION OF SET

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

```
    FindSaturatedVaporPressureTorr = function(T) {
    //Helper function for pierceSET calculates Saturated Vapor Pressure (Torr) at Temperature T (°C)
        return Math.exp(18.6686 - 4030.183/(T + 235.0));
}
pierceSET = function(TA, TR, VEL, RH, MET, CLO, WME, PATM) {
  //Input variables – TA (air temperature): °C, TR (mean radiant temperature): °C, VEL (air velocity): m/s,
  //RH (relative humidity): %, MET: met unit, CLO: clo unit, WME (external work): W/m2, PATM (atmospheric pressure): kPa
  var KCLO = 0.25;
  var BODYWEIGHT = 69.9;                                    //kg
  var BODYSURFACEAREA = 1.8258;                             //m2
  var METFACTOR = 58.2;                                     //W/m2
  var SBC = 0.000000056697;                                 //Stefan-Boltzmann constant (W/m2K4)
  var CSW = 170.0;
  var CDIL = 120.0;
  var CSTR = 0.5;
  var LTIME = 60.0;

  var VaporPressure = RH * FindSaturatedVaporPressureTorr(TA)/100.0;
  var AirVelocity = Math.max(VEL, 0.1);
  var TempSkinNeutral = 33.7;
  var TempCoreNeutral = 36.8;
  var TempBodyNeutral = 36.49;
  var SkinBloodFlowNeutral = 6.3;
  var TempSkin = TempSkinNeutral;                           //Initial values
  var TempCore = TempCoreNeutral;
  var SkinBloodFlow = SkinBloodFlowNeutral;
  var MSHIV = 0.0;
  var ALFA = 0.1;
  var ESK = 0.1 * MET;
  var PressureInAtmospheres = PATM * 0.009869;
  var RCL = 0.155 * CLO;
  var FACL = 1.0 + 0.15 * CLO;
  var LR = 2.2/PressureInAtmospheres;                       //Lewis Relation is 2.2 at sea level
  var RM = MET * METFACTOR;
  var M = MET * METFACTOR;
  if (CLO <= 0) {
    var WCRIT = 0.38 * Math.pow(AirVelocity, –0.29);
    var ICL = 1.0;
  } else {
    var WCRIT = 0.59 * Math.pow(AirVelocity, –0.08);
    var ICL = 0.45;
  }
    var CHC = 3.0 * Math.pow(PressureInAtmospheres, 0.53);
    var CHCV = 8.600001 * Math.pow((AirVelocity * PressureInAtmospheres), 0.53);
    var CHC = Math.max(CHC, CHCV);
    var CHR = 4.7;
    var CTC = CHR + CHC;
    var RA = 1.0/(FACL * CTC);                              //Resistance of air layer to dry heat transfer
    var TOP = (CHR * TR + CHC * TA)/CTC;
    var TCL = TOP + (TempSkin – TOP)/(CTC * (RA + RCL));
    //TCL and CHR are solved iteratively using: H(Tsk – TOP) = CTC(TCL – TOP),
    //where H = 1/(RA + RCL) and RA = 1/FACL*CTC
    var TCL_OLD = TCL;
    var flag = true;
    var DRY, HFCS, ERES, CRES, SCR, SSK, TCSK, TCCR, DTSK, DTCR, TB, SKSIG, WARMS, COLDS, CRSIG, WARMC,
        COLDC, BDSIG, WARMB, COLDB, REGSW, ERSW, REA, RECL, EMAX, PRSW, PWET, EDIF, ESK;
    for (var TIM = 1; TIM <= LTIME; TIM++) {                //Begin iteration
        do {
```

```
    if (flag) {
      TCL_OLD = TCL;
      CHR = 4.0 * SBC * Math.pow(((TCL + TR)/2.0 + 273.15), 3.0) * 0.72;
      CTC = CHR + CHC;
      RA = 1.0/(FACL * CTC);                      //Resistance of air layer to dry heat transfer
      TOP = (CHR * TR + CHC * TA)/CTC;
    }
    TCL = (RA * TempSkin + RCL * TOP)/(RA + RCL);
    flag = true;
  } while (Math.abs(TCL – TCL_OLD) > 0.01);
  flag = false;
  DRY = (TempSkin – TOP)/(RA + RCL);
  HFCS = (TempCore – TempSkin) * (5.28 + 1.163 * SkinBloodFlow);
  ERES = 0.0023 * M * (44.0 – VaporPressure);
  CRES = 0.0014 * M * (34.0 – TA);
  SCR = M – HFCS – ERES – CRES – WME;
  SSK = HFCS – DRY – ESK;
  TCSK = 0.97 * ALFA * BODYWEIGHT;
  TCCR = 0.97 * (1 – ALFA) * BODYWEIGHT;
  DTSK = (SSK * BODYSURFACEAREA)/(TCSK * 60.0);         //°C/min
  DTCR = SCR * BODYSURFACEAREA/(TCCR * 60.0);           //°C/min
  TempSkin = TempSkin + DTSK;
  TempCore = TempCore + DTCR;
  TB = ALFA * TempSkin + (1 – ALFA) * TempCore;
  SKSIG = TempSkin – TempSkinNeutral;
    if (SKSIG > 0) {
      WARMS = SKSIG;
      COLDS = 0.0;
  }
    else {
      WARMS = 0.0;
      COLDS = –1.0 * SKSIG;
  }
  CRSIG = (TempCore – TempCoreNeutral);
    if (CRSIG > 0) {
      WARMC = CRSIG;
      COLDC = 0.0;
  }
    else {
      WARMC = 0.0;
      COLDC = –1.0 * CRSIG;
  }
  BDSIG = TB – TempBodyNeutral;
  WARMB = (BDSIG > 0) * BDSIG;
  SkinBloodFlow = (SkinBloodFlowNeutral + CDIL * WARMC)/(1 + CSTR * COLDS);
  SkinBloodFlow = Math.max(0.5, Math.min(90.0, SkinBloodFlow));
  REGSW = CSW * WARMB * Math.exp(WARMS/10.7);
  REGSW = Math.min(REGSW, 500.0);
  var ERSW = 0.68 * REGSW;
  var REA = 1.0/(LR * FACL * CHC);                    //Evaporative resistance of air layer
  var RECL = RCL/(LR * ICL);                          //Evaporative resistance of clothing (icl=.45)
  var EMAX = (FindSaturatedVaporPressureTorr(TempSkin) – VaporPressure)/(REA + RECL);
  var PRSW = ERSW/EMAX;
  var PWET = 0.06 + 0.94 * PRSW;
  var EDIF = PWET * EMAX – ERSW;
  var ESK = ERSW + EDIF;
  if (PWET > WCRIT) {
    PWET = WCRIT;
    PRSW = WCRIT/0.94;
    ERSW = PRSW * EMAX;
```

```
            EDIF = 0.06 * (1.0 – PRSW) * EMAX;
            ESK = ERSW + EDIF;
        }
        if (EMAX < 0) {
            EDIF = 0;
            ERSW = 0;
            PWET = WCRIT;
            PRSW = WCRIT;
            ESK = EMAX;
        }
        ESK = ERSW + EDIF;
        MSHIV = 19.4 * COLDS * COLDC;
        M = RM + MSHIV;
        ALFA = 0.0417737 + 0.7451833/(SkinBloodFlow + 0.585417);
    }                                                           //End iteration

  var HSK = DRY + ESK;                                          //Total heat loss from skin
  var RN = M – WME;                                             //Net metabolic heat production
  var ECOMF = 0.42 * (RN – (1 * METFACTOR));
  if (ECOMF < 0.0) ECOMF = 0.0;                                 //From Fanger
  EMAX = EMAX * WCRIT;
  var W = PWET;
  var PSSK = FindSaturatedVaporPressureTorr(TempSkin);
  var CHRS = CHR;                                               //Definition of ASHRAE standard environment
                                                                //... denoted "S"
  if (MET < 0.85) {
  var CHCS = 3.0;
  } else {
        var CHCS = 5.66 * Math.pow(((MET – 0.85)), 0.39);
        CHCS = Math.max(CHCS, 3.0);
    }
  var CTCS = CHCS + CHRS;
  var RCLOS = 1.52/((MET – WME/METFACTOR) + 0.6944) – 0.1835;
  var RCLS = 0.155 * RCLOS;
  var FACLS = 1.0 + KCLO * RCLOS;
  var FCLS = 1.0/(1.0 + 0.155 * FACLS * CTCS * RCLOS);
  var IMS = 0.45;
  var ICLS = IMS * CHCS/CTCS * (1 – FCLS)/(CHCS/CTCS – FCLS * IMS);
  var RAS = 1.0/(FACLS * CTCS);
  var REAS = 1.0/(LR * FACLS * CHCS);
  var RECLS = RCLS/(LR * ICLS);
  var HD_S = 1.0/(RAS + RCLS);
  var HE_S = 1.0/(REAS + RECLS);

  //SET determined using Newton's iterative solution
  var DELTA = .0001;
  var dx = 100.0;
  var SET, ERR1, ERR2;
  var SET_OLD = TempSkin – HSK/HD_S;                            //Lower bound for SET
  while (Math.abs(dx) > .01) {
       ERR1 = (HSK – HD_S * (TempSkin – SET_OLD) – W * HE_S * (PSSK – 0.5 *
       FindSaturatedVaporPressureTorr(SET_OLD)));
       ERR2 = (HSK – HD_S * (TempSkin – (SET_OLD + DELTA)) – W * HE_S * (PSSK – 0.5 *
       FindSaturatedVaporPressureTorr((SET_OLD + DELTA))));
        SET = SET_OLD – DELTA * ERR1/(ERR2 – ERR1);
        dx = SET – SET_OLD;
        SET_OLD = SET;
    }
    return SET;
}
```

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX E
CONDITIONS THAT PROVIDE THERMAL COMFORT

E1. INTRODUCTION

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. Because there are large variations, physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space. The environmental conditions required for comfort are not the same for everyone. Extensive laboratory and field data have been collected that provide the necessary statistical information to define conditions that a specified percentage of occupants will find thermally comfortable.

The operative temperature t_o and humidity shown on the psychrometric chart in Figure 5.3.1 (graphical method) are for 80% occupant acceptability. This is based on a 10% dissatisfaction criterion for general (whole body) thermal comfort based on the PMV-PPD index, plus an additional 10% dissatisfaction that may occur on average from local (partial body) thermal discomfort (see below). Normative Appendix B provides a list of inputs and outputs used in the PMV/PPD computer program to generate these graphs.

E2. THERMAL COMFORT FACTORS

Six primary factors must be addressed when defining conditions for thermal comfort. A number of other, secondary factors affect comfort in some circumstances. The six primary factors are as follows:

1. Metabolic rate
2. Clothing insulation
3. Air temperature
4. Radiant temperature
5. Air speed
6. Humidity

The first two factors are characteristics of the occupants, and the remaining four factors are conditions of the thermal environment. Detailed descriptions of these factors are presented in Section 3 and Informative Appendices E, F, and G. These must be clearly understood in order to use the methods of Section 5 effectively.

E3. VARIATION AMONG OCCUPANTS

For each occupant, the activity level, represented as metabolic rate M in mets, and the clothing worn by the occupants, represented as insulation I in clo, must be considered in applying this standard. When there are substantial differences in physical activity and/or clothing for occupants of a space, these differences must be considered.

In some cases, it will not be possible to achieve an acceptable thermal environment for all occupants of a space due to individual differences, including activity and/or clothing. If the requirements are not met for some known set of occupants, then the standard requires that these occupants be identified.

E4. TEMPORAL VARIATION

It is possible for all six primary factors to vary with time. This standard only addresses thermal comfort in a steady state (with some limited specifications for temperature variations with time in Section 5.3.5).

As a result, people entering a space that meets the requirements of this standard may not immediately find the conditions comfortable if they have experienced different environmental conditions just prior to entering the space. The effect of prior exposure or activity may affect comfort perceptions for approximately one hour.

E5. LOCAL THERMAL DISCOMFORT

Nonuniformity is addressed in Section 5.3.4. Factors 1 through 6 may be nonuniform over an occupant's body, and this nonuniformity may be an important consideration in determining thermal comfort.

E6. VARIATION IN ACTIVITY LEVEL

The vast majority of the available thermal comfort data pertain to sedentary or near-sedentary physical activity levels typical of office work. This standard is intended primarily for these conditions. However, it is acceptable to use the standard to determine appropriate environmental conditions for moderately elevated activity. It does not apply to sleeping or bed rest. The body of available data does not contain significant information regarding the comfort requirements of children, the disabled, or the infirm. It is acceptable to apply the information in this standard to these types of occupants if it is applied judiciously to groups of occupants, such as those found in classroom situations.

E7. NATURALLY CONDITIONED SPACES

Section 5.3 contains the methodology that shall be used for most applications. The conditions required for thermal comfort in spaces that are naturally conditioned are not necessarily the same as those conditions required for other indoor spaces. Field experiments have shown that in naturally conditioned spaces, where occupants have control of operable windows, the subjective notion of comfort is different because of different thermal experiences, availability of control, and resulting shifts in occupant expectations. Section 5.4 specifies criteria required for a space to be considered naturally conditioned. The methods of Section 5.4 may, as an option, be applied to spaces that meet these criteria. The methods of Section 5.4 may not be applied to other spaces.

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INFORMATIVE APPENDIX F
USE OF METABOLIC RATE DATA

The data presented in Table 5.2.1.2 are reproduced from 2009 *ASHRAE Handbook—Fundamentals*, Chapter 9. The values in the table represent typical metabolic rates per unit of skin surface area for an average adult (DuBois area = 1.8 m^2 [19.6 ft^2]) for activities performed continuously. This Handbook chapter provides additional information for estimating and measuring activity levels. General guidelines for the use of these data follow.

Every activity that may be of interest is not included in this table. Users of this standard should use their judgment to match the activities being considered to comparable activities in the table. Some of the data in this table are reported as a range and some as a single value. The format for a given entry is based on the original data source and is not an indication of when a range of values should or should not be used. For all activities except sedentary activities, the metabolic rate for a given activity is likely to have a substantial range of variation that depends on the individual performing the task and the circumstances under which the task is performed.

It is permissible to use a time-weighted average metabolic rate for individuals with activities that vary over a period of one hour or less. For example, a person who typically spends 30 minutes out of each hour "lifting/packing," 15 minutes "filing, standing," and 15 minutes "walking about" has an average metabolic rate of $0.50 \times 2.1 + 0.25 \times 1.4 + 0.25 \times 1.7 = 1.8$ met. Such averaging should not be applied when the period of variation is greater than one hour. For example, a person who is engaged in "lifting/packing" for more than one hour and then "filing, standing" for more than one hour should be treated as having two distinct metabolic rates.

As metabolic rates increase above 1.0 met, the evaporation of sweat becomes an increasingly important factor for thermal comfort. The PMV method does not fully account for this factor, and this standard should not be applied to situations where the time-averaged metabolic rate is above 2.0 met.

Rest breaks (scheduled or hidden) or other operational factors (get parts, move products, etc.) combine to limit time-weighted metabolic rates to about 2.0 met in most applications.

Time averaging of metabolic rates only applies to an individual. The metabolic rates associated with the activities of various individuals in a space may not be averaged to find a single, average metabolic rate to be applied to that space. The range of activities of different individuals in the space, and the environmental conditions required for those activities, should be considered in applying this standard. For example, the customers in a restaurant may have a metabolic rate near 1.0 met, while the servers may have a metabolic rate closer to 2.0 met. Each of these groups of occupants should be considered separately in determining the conditions required for comfort. In some situations, it will not be possible to provide an acceptable level or the same level of comfort to all disparate groups of occupants (e.g., restaurant customers and servers).

The metabolic rates in Table 5.2.1.2 were determined when the subjects' thermal sensation was close to neutral. It is not yet known the extent to which people may modify their metabolic rate to decrease warm discomfort.

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INFORMATIVE APPENDIX G
CLOTHING INSULATION

The amount of thermal insulation worn by a person has a substantial impact on thermal comfort and is an important variable in applying this standard. Clothing insulation is expressed in a number of ways. In this standard, the clothing insulation I_{cl} of an ensemble expressed as a clo value is used. Users not familiar with clothing insulation terminology are referred to 2009 *ASHRAE Handbook—Fundamentals*, Chapter 9, for more information.

The insulation provided by clothing can be determined by a variety of means, and if accurate data are available from other sources, such as measurement with thermal manikins, these data are acceptable for use. When such information is not available, the tables in this standard may be used to estimate clothing insulation I_{cl} using one of the methods described below. Regardless of the source of the clothing insulation value, this standard is not intended for use with clothing ensembles with more than 1.5 clo of insulation, nor is it intended for use when occupants wear clothing that is highly impermeable to moisture transport (e.g., chemical protective clothing or rain gear).

Four methods for estimating clothing insulation I_{cl} are presented. Methods 1, 2, and 3 are listed in order of accuracy. The tables used in the standard are derived from 2009 *ASHRAE Handbook—Fundamentals*, Chapter 9.

- **Method 1:** Table 5.2.2.2A of this standard lists the insulation provided by a variety of common clothing ensembles. If the ensemble in question matches reasonably well with one of the ensembles in this table, then the indicated value of I_{cl} should be used.
- **Method 2:** Table 5.2.2.2B of this standard presents the thermal insulation of a variety of individual garments. It is acceptable to add or subtract these garments from the ensembles in Table 5.2.2.2A to estimate the insulation of ensembles that differ in garment composition from those in Table 5.2.2.2A. For example, if long underwear bottoms are added to Ensemble 5 in Table 5.2.2.2A, the insulation of the resulting ensemble is estimated as

$$I_{cl} = 1.01 + 0.15 = 1.16 \text{ clo}$$

- **Method 3:** It is acceptable to define a complete clothing ensemble using a combination of the garments listed in Table 5.2.2.2B of this standard. The insulation of the ensemble is estimated as the sum of the individual values listed in Table 5.2.2.2B. For example, the estimated insulation of an ensemble consisting of overalls worn with a flannel shirt, t-shirt, briefs, boots, and calf-length socks is

$$I_{cl} = 0.30 + 0.34 + 0.08 + 0.04 + 0.10 + 0.03 = 0.89 \text{ clo}$$

- **Method 4:** It is acceptable to determine the clothing insulation I_{cl} with Figure 5.2.2.2 in mechanically conditioned buildings. When people select their clothing as a function of outdoor and indoor climate variables, the most influential variable is outdoor air temperature. Figure 5.2.2.2 can be used to calculate the clothing insulation for each day of the year or for representative days. The curve in Figure 5.2.2.2 is an approximation for typical (or average) clothing. The model is based on field study and may not be appropriate for all cultures and occupancy types. The model represented in Figure 5.2.2.2 is suited to be implemented in building performance simulation software or building control systems. The model graphed in Figure 5.2.2.2 is described by the following equations:

For $t_{a(out,6)} < -5°C$	$I_{cl} = 1.00$
For $-5°C \le t_{a(out,6)} < 5°C$	$I_{cl} = 0.818 - 0.0364 \times t_{a(out,6)}$
For $5°C \le t_{a(out,6)} < 26°C$	$I_{cl} = 10^{(-0.1635 - 0.0066 \times ta(out,6))}$
or $t_{a(out,6)} \ge 26°C$	$I_{cl} = 0.46$
For $t_{a(out,6)} < 23°F$	$I_{cl} = 1.00$
For $23°F \le t_{a(out,6)} < 41°F$	$I_{cl} = 1.465 - 0.0202 \times t_{a(out,6)}$
For $41°F \le t_{a(out,6)} < 78.8°F$	$I_{cl} = 10^{(-0.0460 - 0.00367 \times ta(out,6))}$
or $t_{a(out,6)} \ge 78.8°F$	$I_{cl} = 0.46$

Tables 5.2.2.2A and 5.2.2.2B are for a standing person. A sitting posture results in a decreased thermal insulation due to compression of air layers in the clothing. This decrease can be offset by insulation provided by the chair. Table 5.2.2.2C shows the net effect on clothing insulation I_{cl} for typical indoor clothing ensembles that result from sitting in a chair. These data may be used to adjust clothing insulation calculated using any of the above methods. For example, the clothing insulation for a person wearing Ensemble 3 from Table 5.2.2.2A and sitting in an executive chair is 0.96 + 0.15 = 1.11 clo. For many chairs, the net effect of sitting is a minimal change in clothing insulation. For this reason, no adjustment to clothing insulation is needed if there is uncertainty as to the type of chair and/or if the activity for an individual includes both sitting and standing.

Tables 5.2.2.2A and 5.2.2.2B are for a person that is not moving. Body motion decreases the insulation of a clothing ensemble by pumping air through clothing openings and/or causing air motion within the clothing. This effect varies considerably, depending on the nature of the motion (e.g., walking versus lifting) and the nature of the clothing (stretchable and snug fitting versus stiff and loose fitting). Because of this variability, accurate estimates of clothing insulation I_{cl} for an active person are not available unless measurements are made for the specific clothing under the conditions in question (e.g., with a walking manikin). An approximation of the clothing insulation for an active person is

$$I_{cl,\ active} = I_{cl} \times (0.6 + 0.4/M)$$

$$1.2 \text{ met} < M < 2.0 \text{ met}$$

where M is the metabolic rate in met units and I_{cl} is the insulation without activity. For metabolic rates less than or equal to 1.2 met, no adjustment for motion is required.

When a person is sleeping or resting in a reclining posture, the bed and bedding provide considerable thermal insulation. It is not possible to determine the thermal insulation for most sleeping or resting situations unless the individual is immobile. Individuals adjust bedding to suit individual preferences. Provided adequate bedding materials are available, the thermal environmental conditions desired for sleeping and resting vary considerably from person to person and cannot be determined by the methods included in this standard.

Clothing variability among occupants in a space is an important consideration in applying this standard. This variability takes two forms. In the first form, different individuals wear different clothing due to factors unrelated to the thermal conditions. Examples include different clothing style preferences for men and women, and offices where managers are expected to wear suits while other staff members may work in shirtsleeves. In the second form, the variability results from adaptation to individual differences in response to the thermal environment. For example, some individuals wear sweaters while others wear short-sleeve shirts in the same environment if there are no constraints limiting what is worn. The first form of variability results in differences in the requirements for thermal comfort between the different occupants, and these differences should be addressed in applying this standard. In this situation, it is not correct to determine the average clothing insulation I_{cl} of various groups of occupants to determine the thermal environmental conditions needed for all occupants. Where the variability within a group of occupants is of the second form and is a result only of individuals freely making adjustments in clothing to suit their individual thermal preferences, it is correct to use a single representative average clothing insulation value for everyone in that group.

For near-sedentary activities where the metabolic rate is approximately 1.2 met, the effect of changing clothing insulation I_{cl} on the optimum operative temperature t_o is approximately 6°C (11°F) per clo.

For example, Table 5.2.2.2B indicates that adding a thin, long-sleeve sweater to a clothing ensemble increases clothing insulation I_{cl} by approximately 0.25 clo. Adding this insulation would lower the optimum operative temperature t_o by approximately 6°C/clo × 0.25 clo = 1.5°C (11°F/clo × 0.25 clo = 2.8°F).

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INFORMATIVE APPENDIX H
COMFORT ZONE METHODS

H1. DETERMINING ACCEPTABLE THERMAL CONDITIONS IN OCCUPIED SPACES

This standard recommends a specific percentage of occupants that constitutes acceptability and values of the thermal environment associated with this percentage.

For given values of humidity, air speed, metabolic rate, and clothing insulation, a comfort zone may be determined. The comfort zone is defined in terms of a range of operative temperatures t_o that provide acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature $\bar{t}_r$ that people find thermally acceptable.

This standard contains a simplified Graphical Comfort Zone Method for determining the comfort zone that is acceptable for use for many typical applications. A computer program based on a heat balance model will determine the comfort zone for a wider range of applications. For a given set of conditions, the results from the two methods are consistent, and either method is acceptable for use as long as the criteria outlined in the respective section are met.

See Normative Appendix A and 2009 *ASHRAE Handbook—Fundamentals*, Chapter 9, for procedures to calculate operative temperature t_o. Dry-bulb temperature is a proxy for operative temperature under certain conditions described in Normative Appendix A.

H2. GRAPHICAL COMFORT ZONE METHOD

Use of this method is limited to representative occupants with metabolic rates between 1.0 and 1.3 met and clothing insulation between 0.5 and 1.0 clo in spaces with air speeds less than 0.2 m/s (40 fpm). Spaces with air distribution systems that are engineered such that HVAC-system-supplied air streams do not enter the occupied zone will seldom have averaged air speeds that exceed 0.2 m/s (40 fpm). See 2009 *ASHRAE Handbook—Fundamentals*, Chapter 21, for guidance on selecting air distribution systems.

Figure 5.3.1 shows the comfort zone for environments that meet the above criteria. Two zones are shown—one for 0.5 clo of clothing insulation and one for 1.0 clo of insulation. These insulation levels are typical of clothing worn when the outdoor environment is warm and cool, respectively.

Comfort zones for intermediate values of clothing insulation are determined by linear interpolation between the limits for 0.5 and 1.0 clo, using the relationships shown in this standard.

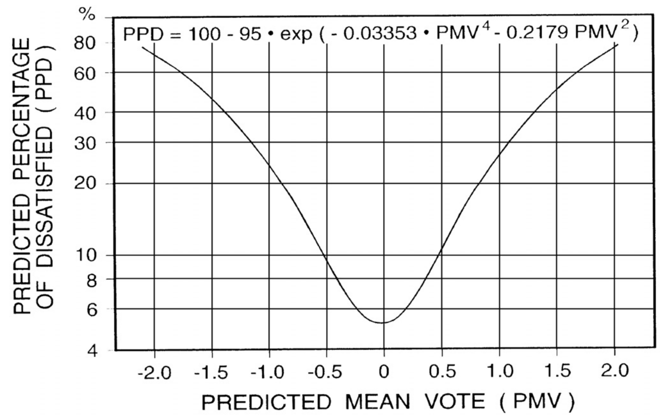

Figure H3 Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV).

Table H3 Acceptable Thermal Environment for General Comfort

PPD	PMV Range
<10	$-0.5 < PMV < +0.5$

Elevated air speeds increase the lower and upper operative temperature t_o limit for the comfort zone if the criteria in Section 5.3.3 are met.

H3. ANALYTICAL COMFORT ZONE METHOD

This method applies to spaces where the occupants have activity levels that result in average metabolic rates between 1.0 and 2.0 met and where clothing is worn that provides 1.5 clo or less of thermal insulation.

The ASHRAE thermal sensation scale, which was developed for use in quantifying people's thermal sensation, is defined as follows:

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
–1	Slightly cool
–2	Cool
–3	Cold

The predicted mean vote (PMV) model uses heat balance principles to relate the six key factors for thermal comfort to the average response of people on the above scale. The predicted percentage dissatisfied (PPD) index is related to the PMV as defined in Figure H3. It is based on the assumption that people voting +2, +3, –2, or –3 on the thermal sensation scale are dissatisfied and on the simplification that PPD is symmetric around a neutral PMV.

Table H3 defines the recommended PPD and PMV range for typical applications. This is the basis for the Graphical Comfort Zone Method in the standard.

The comfort zone is defined by the combinations of the six key factors for thermal comfort for which the PMV is within the recommended limits specified in Table H3. The PMV model is calculated with the air temperature and mean radiant temperature $\bar{t}_r$ in question, along with the applicable metabolic rate, clothing insulation, air speed, and humidity. If the resulting PMV value generated by the model is within the recommended range, the conditions are within the comfort zone.

Use of the PMV model in this standard is limited to air speeds below 0.20 m/s (40 fpm). When air speeds exceed 0.20 m/s (40 fpm), the comfort zone boundaries are adjusted based on the SET model described in the elevated air speed section and in Normative Appendix D.

Several computer codes are available that predict PMV-PPD. The computer code in Normative Appendix B was developed for use with this standard and is incorporated into ASHRAE Thermal Comfort Tool. If any other software is used, it is the user's responsibility to verify and document that the version used yields the same results as the code in Normative Appendix B or the ASHRAE Thermal Comfort Tool for the conditions for which it is applied.

H4. ELEVATED AIR SPEED COMFORT ZONE METHOD

The outer boundary curves in Figure 5.3.3A shift toward the left or right, depending on clo and met level. An increase of 0.1 clo or 0.1 met corresponds approximately to a 0.8°C (1.4°F) or 0.5°C (0.9°F) reduction in operative temperature t_0; a decrease of 0.1 clo or 0.1 met corresponds approximately to a 0.8°C (1.4°F) or 0.5°C (0.9°F) increase in operative temperature.

H5. HUMIDITY LIMITS

When the Graphical Comfort Zone Method is used, systems must be able to maintain a humidity ratio at or below 0.012, 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).

There are no established lower humidity limits for thermal comfort; consequently, this standard does not specify a minimum humidity level. Nonthermal comfort factors, such as skin drying, irritation of mucus membranes, dryness of the eyes, and static electricity generation, may place limits on the acceptability of very low humidity environments.

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INFORMATIVE APPENDIX I LOCAL DISCOMFORT AND VARIATIONS WITH TIME

I1. LOCAL THERMAL DISCOMFORT

Avoiding local thermal discomfort, whether caused by a vertical air temperature difference between the feet and the head, by an asymmetric radiant field, by local convective cooling (draft), or by contact with a hot or cold floor, is essential to providing acceptable thermal comfort.

The requirements specified in Section 5.3.4 of this standard apply directly to a lightly clothed person (with clothing insulation between 0.5 and 0.7 clo) engaged in near-sedentary physical activity (with metabolic rates between 1.0 and 1.3 met). With higher metabolic rates and/or with more clothing insulation, people are less thermally sensitive and, consequently, the risk of local discomfort is lower. Thus, it is acceptable to use the requirements of Section 5.3.4 for metabolic rates greater than 1.3 met and with clothing insulation greater than 0.7 clo, as they will be conservative. People are more sensitive to local discomfort when the whole body is cooler than neutral and less sensitive to local discomfort when the whole body is warmer than neutral. The requirements of Section 5.3.4 of this standard are based on environmental temperatures near the center of the comfort zone. These requirements apply to the entire comfort zone, but they may be conservative for conditions near the upper temperature limits of the comfort zone and may underestimate discomfort at the lower temperature limits of the comfort zone.

Table I1 shows the expected percent dissatisfied for each source of local thermal discomfort described in Sections 5.3.4.1 through 5.3.4.4. The criteria for all sources of local thermal discomfort should be met simultaneously at the levels specified for an environment to meet the requirements of Section 5.3 of this standard. The expected percent dissatisfied for each source of local thermal discomfort described in Sections 5.3.4.1 through 5.3.4.4 should be specified.

I2. RADIANT TEMPERATURE ASYMMETRY

The thermal radiation field about the body may be nonuniform due to hot and cold surfaces and direct sunlight. This asymmetry may cause local discomfort and reduce the thermal acceptability of the space. In general, people are more sensitive to asymmetric radiation caused by a warm ceiling than that caused by hot and cold vertical surfaces. Figure I2 gives the expected percentage of occupants dissatisfied due to radiant temperature asymmetry caused by a warm ceiling, a cool wall, a cool ceiling, or a warm wall.

Table I1 Expected Percent Dissatisfied Due to Sources of Local Discomfort

Draft	Vertical Air Temperature Difference	Warm or Cool Floors	Radiant Asymmetry
<20%	<5%	<10%	<5%

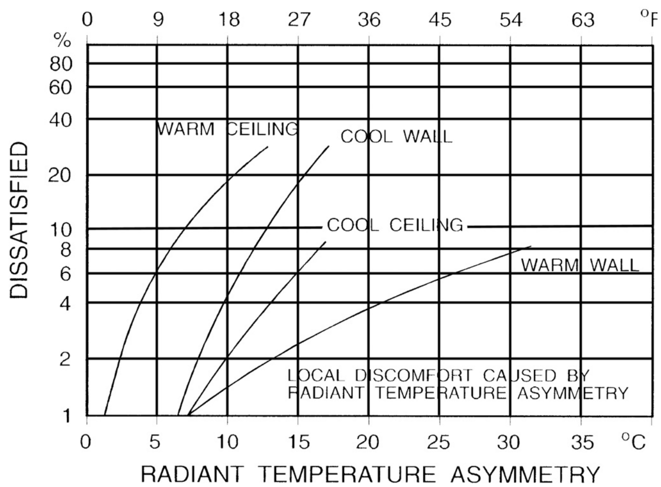

Figure I2 Local thermal discomfort caused by radiant asymmetry.

The allowable radiant asymmetry limits are based on Figure I2 and assume that a maximum of 5% of occupants are dissatisfied by radiant asymmetry.

I3. DRAFT

Draft is unwanted local cooling of the body caused by air movement. It is most prevalent when the whole-body thermal sensation is cool (below neutral). Draft sensation depends on air speed, air temperature, activity, and clothing. Sensitivity to draft is greatest where the skin is not covered by clothing, especially the head region comprising the head, neck, and shoulders and the leg region comprising the ankles, feet, and legs.

Use of elevated air speed to extend the thermal comfort range is appropriate when occupants are slightly warm, as set forth in Section 5.3.3. When occupants are neutral to slightly cool, such as under certain combinations of met rate and clo value with operative temperatures t_o below 23°C (73.4°F), average air speeds within the comfort envelope of ±0.5 PMV should not exceed 0.20 m/s (40 fpm). This draft limit applies to air movement caused by the building, its fenestration, and its HVAC system and not to air movement produced by office equipment or occupants. This standard allows average air speed to exceed this draft limit if it is under the occupants' local control and is within the elevated air speed comfort envelope described in Section 5.3.3.

I4. VERTICAL AIR TEMPERATURE DIFFERENCE

Thermal stratification that results in the air temperature at the head level being warmer than that at the ankle level may

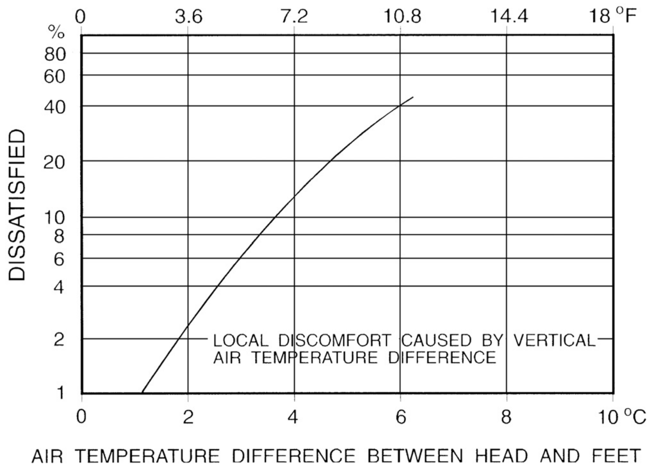

Figure I4 Local thermal discomfort caused by vertical temperature differences.

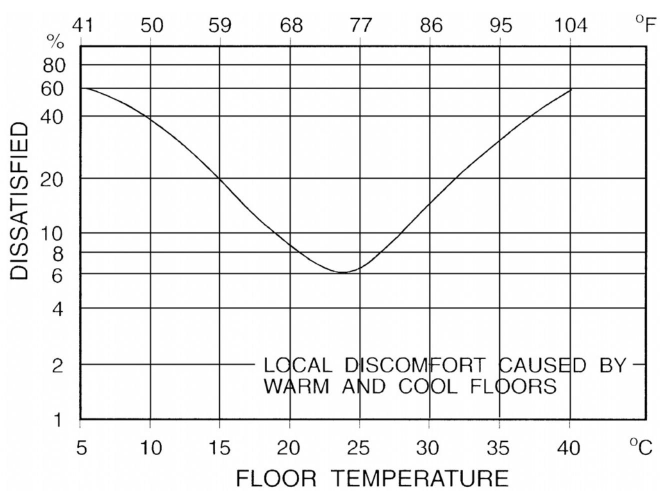

Figure I5 Local discomfort caused by warm and cool floors.

cause thermal discomfort. Section 5.3.4.3 of this standard specifies allowable differences between the air temperature at head level and the air temperature at ankle level. Figure I4 shows the expected percentage of occupants who are dissatisfied due to the air temperature difference where the head level is warmer than the ankle level. Thermal stratification in the opposite direction is rare, is perceived more favorably by occupants, and is not addressed in this standard.

The allowable difference in air temperature from ankle level to head level is based on Figure I4 and assumes that a maximum of 5% of occupants are dissatisfied by the vertical air stratification.

I5. FLOOR SURFACE TEMPERATURE

Occupants may feel uncomfortable due to contact with floor surfaces that are too warm or too cool. The temperature of the floor, rather than the material of the floor covering, is the most important factor for foot thermal comfort while wearing shoes. Figure I5 gives the percentage of occupants expected to be dissatisfied due to floor temperature t_f based on people wearing lightweight indoor shoes. Thus, it is acceptable to use these criteria for people wearing heavier footgear, as they will be conservative. This standard does not address the floor temperature required for people not wearing shoes, nor does it address acceptable floor temperatures for people sitting on the floor.

The limit for floor temperature t_f is based on Figure I5 and assumes that a maximum of 10% of occupants are dissatisfied by warm or cold floors.

I6. TEMPERATURE VARIATIONS WITH TIME

Fluctuations in the air temperature and/or mean radiant temperature $\bar{t}_r$ may affect the thermal comfort of occupants. Those fluctuations under the direct control of the individual occupant do not have a negative impact on thermal comfort, and the requirements of this standard do not apply to these fluctuations. Fluctuations that occur due to factors not under the direct control of the individual occupant (e.g., cycling from thermostatic control) may have a negative effect on comfort, and the requirements of this standard apply to these fluctuations. Fluctuations that occupants experience as a result of moving between locations with different environmental conditions are allowed by Section 5 of this standard as long as the conditions at all of these locations are within the comfort zone for these moving occupants.

I7. CYCLIC VARIATIONS

Cyclic variations refer to those situations where the operative temperature t_o repeatedly rises and falls and the period of these variations is not greater than 15 minutes. If the period of the fluctuation cycle exceeds 15 minutes, the variation is treated as a drift or ramp in operative temperature, and the requirements of Section 5.3.5.2 apply. In some situations, variations with a period not greater than 15 minutes are superimposed on variations with a longer period. In these situations, the requirements of Section 5.3.5.1 apply to the component of the variation with a period not greater than 15 minutes, and the requirements of Section 5.3.5.2 apply to the component of the variation with a period greater than 15 minutes.

I8. DRIFTS OR RAMPS

Temperature drifts and ramps are monotonic, noncyclic changes in operative temperature t_o. The requirements of Section 5.3.5.2 also apply to cyclic variations with a period greater than 15 minutes. Generally, "drifts" refer to passive temperature changes of the enclosed space, and "ramps" refer to actively controlled temperature changes.

Section 5.3.5.2 specifies the maximum change in operative temperature t_o allowed during a period of time. For any given time period, the most restrictive requirements from Table 5.3.5.2 apply. For example, the operative temperature may not change more than 2.2°C (4.0°F) during a 1.0 h period, and it also may not change more than 1.1°C (2.0°F) during any 0.25 h period within that 1.0 h period. If the user creates variations as a result of control or adjustments, higher values may be acceptable.

These local thermal comfort criteria were developed in order to keep the expected percent of occupants who are dissatisfied due to all of these local discomfort factors at or below 10%. The operative temperature t_o ranges required in the standard were developed in order to keep the predicted percent dissatisfied of occupants due to operative temperature only, without factoring in local thermal factors. When both local discomfort factors and operative temperature considerations are combined, the goal of this standard to standardize thermal conditions acceptable to a substantial majority of occupants (80%) is achieved. This is especially true if there is some overlap between those who are dissatisfied due to local factors and those who are dissatisfied due to operative temperature.

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INFORMATIVE APPENDIX J OCCUPANT-CONTROLLED NATURALLY CONDITIONED SPACES

For the purposes of this standard, occupant-controlled naturally conditioned spaces (see Section 5.4) are those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of fenestration in the envelope. Field experiments have shown that occupants' thermal responses in such spaces depend in part on the outdoor climate and may differ from thermal responses in buildings with centralized HVAC systems, primarily because of the different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations. This optional method is intended for such spaces.

In order for this optional method to apply, the space in question must be equipped with operable fenestration to the outdoors that can be readily opened and adjusted by the occupants of the space.

It is permissible to use mechanical ventilation with unconditioned air, but the space must not have a mechanical cooling system installed. Opening and closing of fenestration must be the primary means of regulating the thermal conditions in the space. It is permissible for the space to be provided with a heating system, but this optional method does not apply when the heating system is in operation. It applies only to spaces where the occupants are engaged in near-sedentary physical activities, with metabolic rates ranging from 1.0 to 1.3 met. This optional method applies only to spaces where the occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions. The permitted range of acceptable clothing must be at least as broad as 0.5 to 1.0 clo. Table J-1 shows example clothing ensembles that achieve 0.5 clo or lower.

For spaces that meet these criteria, it is acceptable to determine the allowable indoor operative temperatures t_o from Figure 5.4.2. This figure includes two sets of operative temperature limits, one for 80% acceptability and one for 90% acceptability. The 80% acceptability limits are for typical applications. It is acceptable to use the 90% acceptability limits when a higher standard of thermal comfort is desired. Figure 5.4.2 is based on an adaptive model of thermal comfort that is derived from a global database of 21,000 measurements taken primarily in office buildings.

The input variable in the adaptive model in Figure 5.4.2 is prevailing mean outdoor air temperature $\overline{t_{pma(out)}}$. This temperature is based on the arithmetic average of the mean daily outdoor temperatures over some period of days. It represents the broader external climatic environment to which building occupants have become physiologically, behaviorally, and psychologically adapted. At its simplest, $\overline{t_{pma(out)}}$ can be approximated by the climatically normal monthly mean air temperature from the most representative local meteorological station available. When used in conjunction with dynamic thermal simulation software in which outdoor weather data is formatted as a TMY, the preferred expression for $\overline{t_{pma(out)}}$ is an exponentially weighted, running mean of a sequence of mean daily outdoor temperatures prior to the day in question. Days in the more remote past have less influence on the building occupants' comfort temperature than more recent days, and this can be reflected by attaching exponentially decaying weights to the sequence of mean daily outdoor temperatures:

$$\overline{t_{pma(out)}} = (1-\alpha)[t_{e(d-1)} + \alpha t_{e(d-2)} + a^2 t_{e(d-3)} + \alpha^3 t_{e(d-4)} + \ldots \qquad \text{(J-1)}$$

where α is a constant between 0 and 1 that controls the speed at which the running mean responds to changes in weather (outdoor temperature). Recommended values for α are between 0.9 and 0.6, corresponding to a slow- and fast-response running mean, respectively. Adaptive comfort theory suggests that a slow-response running mean ($\alpha = 0.9$) could be more appropriate for climates in which synoptic-scale (day-to-day) temperature dynamics are relatively minor, such as the humid tropics. But for midlatitude climates, where people are

Table J-1 Example Clothing Ensembles

Garment Description	I_{clu}, clo	Garment Description	I_{clu}, clo
Sample Woman's Ensemble		Sample Man's Ensemble	
Bra	0.01	Men's briefs	0.04
Panties	0.03	Shoes	0.02
Pantyhose/stockings	0.02	Calf-length socks	0.03
Shoes	0.02	Short-sleeve dress shirt	0.19
Short-sleeve dress shirt	0.19	Straight trousers (thin)	0.15
Skirt (knee-length thin)	0.14	Net, metal- or wooden-side arm chair	0.00
Net, metal- or wooden-side arm chair	0.00	**Total**	**0.43**
Total	**0.41**		

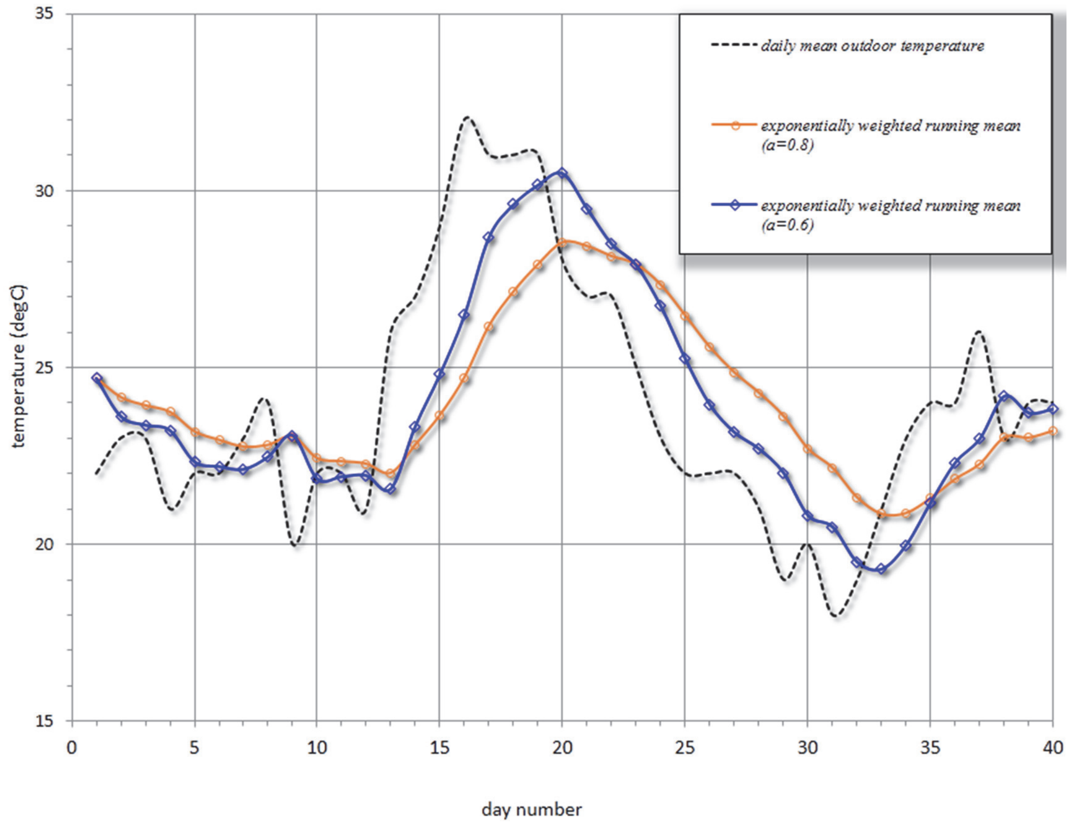

Figure J-1 Exponentially weighted running mean outdoor temperature $\overline{t_{pma(out)}}$ with α set to 0.8 (slower responding) and 0.6 (faster responding).

more familiar with synoptic-scale weather variability, a lower value of α could be more appropriate. In Equation J-1, $t_{e(d-1)}$ represents the mean daily outdoor temperature for the previous day, $t_{e(d-2)}$ is the mean daily outdoor temperature for the day before that, and so on. The equation contains a sum to infinity, but is reducible to this more convenient form:

$$\overline{t_{pma(out)}} = (1-\alpha)t_{e(n-1)} + \alpha\, t_{rm(n-1)} \quad \text{(J-2)}$$

where $t_{e(n-1)}$ is the mean daily outdoor temperature for the day before the day in question, and $t_{rm(n-1)}$ is the running mean temperature for the day before the day in question ($n-1$). For example, if $\alpha = 0.7$, the prevailing mean outdoor temperature for today would be 30% of yesterday's mean daily outdoor temperature plus 70% of yesterday's running mean outdoor temperature. This form of the equation advances the value of the running mean from one day to the next and is convenient both for computer algorithms and for manual calculations. A value for running mean temperature has to be assumed for day one in order to seed the sequence, but from then on it can be calculated with Equation J-2. The running mean may be initiated seven days prior to the start of the period of interest, and the actual daily mean outdoor temperature can be used for that first day to seed the sequence.

The allowable operative temperature t_o limits in Figure 5.4.2 may not be extrapolated to outdoor temperatures above and below the end points of the curves in this figure. If the prevailing mean outdoor temperature is less than 10°C (50°F) or greater than 33.5°C (92.3°F), this option may not be used, and no specific guidance for such conditions is included in this standard.

Figure 5.4.2 accounts for local thermal discomfort effects in typical buildings, so it is not necessary to address these factors when using this option. If there is reason to believe that local thermal comfort is a problem, it is acceptable to apply the criteria in Section 5.3.4.

Figure 5.4.2 also accounts for people's clothing adaptation in naturally conditioned spaces by relating the acceptable range of indoor temperatures to the outdoor climate, so it is not necessary to estimate the clothing values for the space. No humidity or air speed limits are required when this option is used.

Figure 5.4.2 includes the effects of people's indoor air speed adaptation in warm climates, up to 0.3 m/s (59 fpm) in operative temperatures t_o warmer than 25°C (77°F). In naturally conditioned spaces where air speeds within the occupied zone exceed 0.3 m/s (59 fpm), the upper acceptability temperature limits in Figure 5.4.2 are increased by the corresponding Δt_0 in Table 5.4.2.4, which is based on equal SET values as illustrated in Section 5.3.3. For example, increasing air speed within the occupied zone from 0.3 m/s (59 fpm) to 0.6 m/s (118 fpm) increases the upper acceptable temperature limits in Figure 5.4.2 by a Δt_0 of 1.2°C (2.2°F). These adjustments to the upper acceptability temperature limits apply only at $t_0 >$ 25°C (77°F) in which the occupants are engaged in near sedentary physical activity (with metabolic rates between 1.0 met and 1.3 met).

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX K
SAMPLE DESIGN COMPLIANCE DOCUMENTATION

SAMPLE COMPLIANCE DOCUMENTATION TEMPLATE TO SUPPLMENT SECTION 6 OF THE STANDARD

Based on Standard 55-2013

SECTION ONE

COMPLETE SECTION ONE FOR ALL PROJECTS

Assumptions for personal factors in each space type category & season

Space Type (i.e.. Office, Lobby, Gym)	Clothing Level (CLO)		Metabolic Rate (MET)
	Summer	Winter	

SECTION TWO

COMPLETE SECTION TWO FOR PROJECTS USING THE PMV/PPD METHOD

Weather data used for design calculations

Weather design conditions used for peak load calculations (0.5%, 1%, etc.)

Cooling		Heating	

Hours per typical year that outdoor temperature exceeds design conditions

Cooling		Heating	

	Space Type (i.e.. Office, Lobby, Gym)	Design Operative Temperature (degF)*		Maximum Design Humidity (RH)		Average Air Speed	
		Summer	Winter	Summer	Winter	Summer	Winter
Cooling Mode							
Heating Mode							

* Operative temperature includes radiant effects. See Standard 55.

Verify that the combinations of assumed personal factors, operative temperature, air speed, and humidity above results in Predicted Mean Votes (PMV) of less plus or minus 0.5. (Include supporting documentation with PMV/PPD calculation, ASHRAE comfort tool results, and/or psychrometric comfort zone chart from Standard 55). Predicted Mean Vote calculations shall use SET model adjustment for air speeds greater than 40 fpm.

Elevated Air Speed

When average air speed at design conditions exceed 40 ft/min.

Verify that average air speeds are within specified limits of figure 5.3.3 when occupants do not have local control over air speed.

Verify that average air speeds are within specified limits of figure 5.3.3 when occupants have local control and that there are separate controls for every 84 sq. meters (900 sq.ft.)

Local Discomfort Effects

Verify that local discomfort effects have been considered and are not likely to exceed Standard 55 limits. When local discomfort effects are likely to occur, verify that calculations were performed to demonstrate that local discomfort effects are predicted be within Standard 55 Section 5.3.4 limits.

Local Discomfort Effect	Not Likely	Calculations Performed
Radiant Temperature Asymmetry		
Vertical Air Temperature Difference		
Floor Surface Temperature		
Draft		

SECTION THREE

COMPLETE SECTION THREE FOR OCCUPANT-CONTROLLED NATURALLY CONDITIONED SPACES

Verify that each occupant-controlled naturally conditioned space meets all the criteria of Section 5.4 of Standard 55.

a) The spaces have operable windows open to the outdoors readily adjustable by occupants.

b) There is no mechanical cooling system (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling) installed. No heating system is in operation.

c) Occupants are engaged in near-sedentary physical activities, with metabolic rates ranging from 1.0 to 1.3 met.

d) Occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5-1.0 clo.

e) The prevailing mean outdoor temperature is greater than 10°C (50°F) and less than 33.5°C (92.3°F).

Weather data used for mean monthly outdoor temperature calculations

Verify that the prevailing mean outdoor temperature is within the limits of Figure 5.4 for all months when occupant-controlled natural conditioning is in effect.

Increased air speed adjustment to upper operative temperature limit.

Verify that operative temperature is predicted to be within the 80% acceptability limits on Figure 5.4 from ASHRAE 55 included adjustment for elevated air speed. (Provide supporting documentation with inputs and results of calculations or simulations. Include worst case design outdoor conditions and worst case predicted indoor conditions for each month. Show predicted worst case indoor conditions for each month on Figure 5.4 of ASHRAE 55.)

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX L MEASUREMENTS, SURVEYS, AND EVALUATION OF COMFORT IN EXISTING SPACES: PARTS 1 AND 2

L1. PHYSICAL MEASUREMENTS

L1.1 Overview of Comfort Prediction Using Physical Measurements. Measurements of indoor environmental parameters are converted to predictions of occupants' thermal satisfaction through calculations and tests against comfort limits.

a. In the predicted-mean-vote-based (PMV) method (Section 5.3.2), environmental measurements are combined with assumptions about clothing and activity level to calculate PMV, a measure of an average occupant's thermal sensation. In Standard 55, *comfort zone* is defined as conditions falling within and including PMV levels from –0.5 PMV to +0.5 PMV.

   At any given PMV level, a population's proportion of dissatisfied members may be predicted via the predicted percentage dissatisfied (PPD) curve. This is an empirical profit fit of thermal sensation (TSENS) survey scores obtained in a range of test environments in which dissatisfaction was assumed to occur at TSENS absolute values of 2 or greater. With this method, a PMV of ±0.5 predicts 90% of a population satisfied, or a 10% PPD.

   However, in most buildings this 90% satisfied rating is rarely obtained, with maximum satisfaction around 80%. The difference has been ascribed to discomfort perceived in local parts of the body. The probability of local discomfort is predicted by testing environmental parameters measured in sensitive locations against empirically-determined limits. Rates of temperature change are also limited to avoid discomfort. Local discomfort effects are assumed to contribute an additional 10% PPD to the discomfort predicted by PMV, so that the total PPD expected in a building with PMV ±0.5 will be 20%.

b. In the adaptive method, used for naturally ventilated spaces, environmental measurements are linked to satisfaction through an empirical model in which the prevailing mean air outdoor temperature determines the position of percent satisfied contours bordering the comfort zone. Section 5.4 defines prevailing mean outdoor air temperature. Local discomfort limits are not used in the adaptive method.

L1.2 Environmental and Occupant Measurements. Environmental parameters are described in Section 5.1, and their measurement requirements are described in Section 7.3. For nonsteady conditions, the Section 7.3.3 prescribes measurement timing.

The two personal parameters, activity level and clothing, must also be estimated for the occupants of the space. Estimation methods are presented in Informative Appendices F and G. For evaluating a space, each of these parameters shall be estimated in the form of mean values over a period of 0.25 to 1.0 hours immediately prior to measuring the indoor environmental parameters.

If the occupants are not yet present, such as during design and commissioning, one may use clothing and activity values agreed on by owners and designers as appropriate for the building's function.

L2. SURVEYING OCCUPANTS

The use of occupant thermal environment surveys is an acceptable way of assessing comfort conditions for the acceptability ranges discussed in this standard. With surveys, one may measure the percent who are "satisfied," "acceptable," or "comfortable" by putting those direct questions to a representative sample of the occupants. One may also obtain the percent satisfied using the ASHRAE thermal sensation scale, making the traditional assumption that satisfaction occurs when the seven-point scale is within TSENS = $-1.5 \leq$ satisfied $\leq +1.5$ (when using a scale unit resolution of 0.5 or less) or $-2 <$ satisfied $< +2$ (when the scale resolution is limited to integers).

Surveys obtain occupants' comfort perceptions directly, whereas measurements of the environment predict those perceptions indirectly through models. However, surveys cannot be administered in all cases. Because surveys require engaging the occupants and consuming some of their time, it is necessary to have a well-planned communications approach and to use a survey that is optimized for length and content. The timing and frequency of repetition must also be weighed.

All surveys should strive for a representative sample size and a high response rate across the occupied space in the building. If the objective of the survey is to assess an entire building or installation, an adequate sample size and response rate help lower the risks of generalizing a limited observation to the entire occupant population. Section 7.3.1 prescribes minimum response rates for surveys. It is possible that in operating buildings, the perceptions of nonrespondents may be less important than those of respondents who take the time to answer the questions.

Thermal environment surveys are invaluable tools for diagnostic purposes in existing buildings and facilities. As a diagnostic tool, the goal is not a broad-brush assessment of environmental quality but rather a detailed insight into the building's day-to-day operation through occupant feedback. For such purposes, each response is valuable, regardless of the size or response rate of the survey.

There are two types of thermal environment surveys. In either type of survey, the essential questions relate to thermal comfort, but additional questions can help identify problems and formulate possible responses.

L2.1 Point-in-time, or "right-now," surveys are used to evaluate thermal sensations of occupants at a single point in time. Thermal comfort researchers have used these surveys to correlate thermal comfort with environmental factors such as those included in the PMV model: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity.

A sample point-in-time survey is included in Figure L2.1. This is a thermal sensation survey that asks occupants to rate their sensation (from "hot" to "cold") on the ASHRAE seven-point thermal sensation scale. The scale units are sometimes designated "TSENS."

One may, however, ask the direct question "Is the environment thermally acceptable?" with a scale of "very unacceptable" to "very acceptable." The scale is best divided into seven scale units or more.

Sometimes preference scales for temperature and air movement are also used (e.g., these scales are common in the comfort field study database found in ASHRAE RP-884, *Towards an Adaptive Model of Thermal Comfort and Preference* [ASHRAE 1998]):

"Prefer to be:"	"cooler/no change/warmer"
"Prefer":	"less air movement/no change/more air movement"

In order to use the results of a point-in-time survey to assess comfort acceptability ranges over time, the survey would have to be implemented under multiple thermal conditions and in multiple building operating modes. The difficulty of arranging multiple surveys in workplace environments usually limits the feasibility of using the point-in-time survey approach for assessing comfort over time. This limitation may diminish with the advent of web-based applications oriented toward building operation.

L2.2 A second form of thermal environment survey, a satisfaction survey, is used to evaluate thermal comfort response of the building occupants in a certain span of time. Instead of evaluating thermal sensations and environmental variables indirectly to assess percentage dissatisfied, this type of survey directly asks occupants to provide satisfaction responses.

An example thermal satisfaction survey is included in Figure L2.2. It asks occupants to rate their satisfaction with their thermal environment (from "very satisfied" to "very dissatisfied") on a seven-point satisfaction scale. Acceptability is determined in two ways: by the percentage of occupants who have responded "neutral" through "very satisfied" (0, +1, +2, or +3) with their environment or by taking a slightly broader view of acceptability, including the percentage who have responded (–1, 0, +1, +2, +3).

The basic premise of the satisfaction survey is that occupants by nature can recall instances or periods of thermal discomfort, identify patterns in building operation, and provide "overall" or "average" comfort votes on their environment. The surveyor may identify a span of time for the respondents to consider. The occupants provide the time integration.

Questions to identify the nature (causes) of dissatisfaction may be included in satisfaction surveys (e.g., questions 7a through 7e in Figure L2.2).

Because the survey results encompass a larger time frame, the survey can be administered every six months or repeated in heating and/or cooling seasons. In a new building, the first thermal satisfaction survey may be performed approximately six months after occupancy, late enough to avoid assessing the effects of putting the building into commission but early enough to help identify and solve long-term building problems that have escaped detection in the commissioning process.

The thermal satisfaction survey can be used by researchers, building operators, and facility managers to provide acceptability assessments of building systems' performance and operation in new buildings, in addition to periodic postoccupancy evaluation in existing facilities.

1. Record the approximate outside-air temperature _____ and seasonal conditions:

☐ Winter ☐ Spring ☐ Summer ☐ Fall

2. What is your general thermal sensation? (Check the one that is most appropriate)

*(**Note to survey designer:** This scale must be used as-is to keep the survey consistent with ASHRAE Standard 55.)*

☐ Hot
☐ Warm
☐ Slightly Warm
☐ Neutral
☐ Slightly Cool
☐ Cool
☐ Cold

3. Either (a) place an "X" in the appropriate place where you are located now:

*(**Note to survey designer:** Provide appropriate sketch for your space or building.)*

or (b) place an "X" in the check box that best describes the area of the building where you are located now.

☐ North
☐ East
☐ South
☐ West
☐ Core
☐ Don't know

4. On which floor of the building are you located now?

☐ 1st
☐ 2nd
☐ 3rd
☐ Other (provide the floor number):

5. Are you near an exterior wall (within 15 ft)?

☐ Yes
☐ No

6. Are you near a window (within 15 ft)?

☐ Yes
☐ No

7. Using the list below, please check each item of clothing that you are wearing right now. (Check all that apply):

*(**Note to survey designer:** This list can be modified at your discretion.)*

☐ Short-Sleeve Shirt	☐ Dress	☐ Nylons
☐ Long-Sleeve Shirt	☐ Shorts	☐ Socks
☐ T-shirt	☐ Athletic Sweatpants	☐ Boots
☐ Long-Sleeve Sweatshirt	☐ Trousers	☐ Shoes
☐ Sweater	☐ Undershirt	☐ Sandals
☐ Vest	☐ Long Underwear Bottoms	
☐ Jacket	☐ Long Sleeve Coveralls	
☐ Knee-Length Skirt	☐ Overalls	
☐ Ankle-Length Skirt	☐ Slip	

☐ Other: (Please note if you are wearing something not described above, or if you think something you are wearing is especially heavy.) ____________________

8. What is your activity level right now? (Check the one that is most appropriate)

☐ Reclining
☐ Seated
☐ Standing relaxed
☐ Light activity standing
☐ Medium activity standing
☐ High activity

Figure L2.1 Thermal environment point-in-time survey.

1. **Either (a) place an "X" in the appropriate place where you spend most of your time:**

*(**Note to survey designer:** Provide appropriate sketch for your space or building.)*

or (b) place an "X" in the check box that best describes the area of the building where your space is located.

☐ North
☐ East
☐ South
☐ West
☐ Core
☐ Don't know

2. **On which floor of the building is your space located?**

☐ 1st
☐ 2nd
☐ 3rd
☐ Other (provide the floor number)____________________

3. **Are you near an exterior wall (within 15 ft)?**

☐ Yes
☐ No

4. **Are you near a window (within 15 ft)?**

☐ Yes
☐ No

5. **Which of the following do you personally adjust or control in your space? (Check all that apply.)**

*(**Note to survey designer:** This list can be modified at your discretion.)*

☐ Window blinds or shades
☐ Room air-conditioning unit
☐ Portable heater
☐ Permanent heater
☐ Door to interior space
☐ Door to exterior space
☐ Adjustable air vent in wall or ceiling
☐ Ceiling fan
☐ Adjustable floor air vent (diffuser)
☐ Portable fan
☐ Thermostat
☐ Operable window
☐ None of these
☐ Other: ____________________________

Please respond to the following questions based on your overall or average experience in the past [six] months.

(***Note to survey designer:*** The above statement can be modified for a different span of time.)

6. **How satisfied are you with the temperature in your space? (Check the one that is most appropriate)**

Very Satisfied  **Very Dissatisfied**

7. **If you are dissatisfied with the temperature in your space, which of the following contribute to your dissatisfaction:**

   a. **In warm/hot weather, the temperature in my space is (check the most appropriate box):**

   *(**Note to survey designer:** Include a scale or, as shown below, check boxes.)*

   ☐ Always too hot
   ☐ Often too hot
   ☐ Occasionally too hot
   ☐ Occasionally too cold
   ☐ Often too cold
   ☐ Always too cold

   b. **In cool/cold weather, the temperature in my space is (check the most appropriate box):**

   *(**Note to survey designer:** Include a scale or, as shown below, check boxes.)*

   ☐ Always too hot
   ☐ Often too hot
   ☐ Occasionally too hot
   ☐ Occasionally too cold
   ☐ Often too cold
   ☐ Always too cold

   c. **When is this most often a problem? (check all that apply):**

   ☐ Morning (before 11am)
   ☐ Midday (11am–2pm)
   ☐ Afternoon (2pm–5pm)
   ☐ Evening (after 5pm)
   ☐ Weekends/holidays
   ☐ Monday mornings
   ☐ No particular time
   ☐ Always
   ☐ Other:

Figure L2.2 Thermal environment satisfaction survey (continued on next page).

d. **How would you best describe the source of this discomfort? (Check all that apply):**

(Note to survey designer: This list can be modified at your discretion.)

- ☐ Humidity too high (damp)
- ☐ Humidity too low (dry)
- ☐ Air movement too high
- ☐ Air movement too low
- ☐ Incoming sun
- ☐ Heat from office equipment
- ☐ Drafts from windows
- ☐ Drafts from vents
- ☐ My area is hotter/colder than other areas
- ☐ Thermostat is inaccessible
- ☐ Thermostat is adjusted by other people
- ☐ Clothing policy is not flexible
- ☐ Heating/cooling system does not respond quickly enough to the thermostat
- ☐ Hot/cold surrounding surfaces (floor, ceiling, walls, or windows)
- ☐ Deficient window (not operable)
- ☐ Other: ______________________________

e. **Please describe any other issues related to being too hot or too cold in your space:**

____
____
____
____
____
____
____
____
____
____
____
____
____
____
____

Note: This survey has been adapted from the CBE occupant IEQ survey developed by the Center for the Built Environment at the University of California at Berkeley.

Figure L2.2 (Continued) Thermal environment satisfaction survey.

L3. EVALUATION OF COMFORT IN EXISTING SPACES

The evaluation approach depends on the intended application. The list of possible evaluation applications is extensive. They require evaluation over varying time periods, from short term (ST) to long term (LT):

a. Real-time operation of a building using comfort metrics (ST)
b. Evaluating HVAC system performance (ST, LT)
c. Building management decisions regarding upgrades, continuous commissioning, and rating the performance of operators and service providers (LT)
d. Real-estate portfolio management: rating building quality and value (LT, ST)
e. Validating compliance with LEED existing-buildings requirements (ST, LT)
f. Validating compliance with requirements of codes—energy, hospital, etc. (ST)

There are two main approaches to evaluating thermal comfort in operating buildings. One is to directly determine occupant thermal sensations and satisfaction through the statistical evaluation of occupant surveys. The other is to use comfort models to estimate sensations and satisfaction of the occupants from measured environmental variables. The measurements needed for each of these approaches are described in Sections L1 and L2.

Surveys and physical measurements may be used in combination with each other for the purpose of problem diagnosis and research (see Table L3). In the short-term, point-in-time surveys are used to obtain comfort perceptions coincident with short-interval logged environmental measurements or BAS system trend data. For evaluating building performance over time, occupant satisfaction surveys results are correlated with averages of long-term measurements of environmental conditions.

L3.1 Analysis Based on Occupant Surveys. Surveys can assess comfort directly, in contrast to the indirect approach of calculating comfort through comfort models using measured environmental variables.

a. Short-Term Analyses (Using Instantaneous Comfort Determinations)

1. Measures from Point-in-Time (Right-Now) Surveys

i. Thermal acceptability votes.
ii. Thermal sensation (TSENS) votes. (When averaged for a population, TSENS votes correspond directly to PMV votes.)
iii. Temperature preference votes and air-movement preference votes (“less”/“no change”/“more”).

2. Criteria for Passing

i. –0.5 to +0.5 on the PMV scale, inclusive, is the Standard 55 criterion for passing.
ii. Field surveys usually consider TSENS values of –1 and +1 as representing “satisfied”; the break along the categorical seven-point thermal sensation scale is at –1.5 and +1.5, inclusive.

3. Local Thermal Discomfort Determination

i. Questions about any local thermal discomfort (e.g., ankle, neck discomfort).
ii. Questions addressing solar radiation effects on comfort.

Table L3 Comfort Evaluation Approaches for Various Applications

<table>
<tr><td rowspan="4">Measurement Method</td><td></td><td colspan="2">Nature of Application</td></tr>
<tr><td></td><td>Short-Term</td><td>Long-Term</td></tr>
<tr><td>Occupant Surveys</td><td>Right-Now/Point-in-Time Survey (must survey relevant times and population):
• Binning (TSENS scores) leads to % comfort exceedance during period of survey.
• Needs coincident temperature to extrapolate to full range of conditions.
(Used for research, problem diagnostics)</td><td>Occupant Satisfaction Survey:
• Survey scores give % dissatisfied directly. (“dissatisfaction” may be interpreted to start either below –1, or below 0).
• Time period of interest can be specified to survey takers.
(Used for building management, commissioning, rating operators and real estate value, compliance with green building rating systems)</td></tr>
<tr><td>Environmental Measurements</td><td>Spot Measurements, Temporary (Mobile) Sensors (must select a relevant time to measure):
• Use measurements to determine PMV (Sections 5.3.1, 5.3.3).
• Use measurements to determine compliance with adaptive model (Section 5.4).
(Used for real-time operation, testing and validating system performance)</td><td>Logging Sensors over Period of Interest, or Trend Data from Permanently Installed (BAS) Sensors:
• Exceedance hours: sum of hours over PMV or adaptive model limits.
• Binned exceedances may be weighted by their severity.
• Instances of excessive rate-of-temperature change or of local thermal discomfort can be counted.
(Used for evaluating system and operator performance over time)</td></tr>
</table>

b. **Long-Term Analyses (Representing Time Periods Such as Season or Year).** In an occupant satisfaction survey, thermal environment questions apply over time (three to six months or more). The survey includes diagnostic questions to identify sources of dissatisfaction. Point-in-time surveys may be repeated over time to obtain a long-term record of comfort. Because occupants have other responsibilities and limited time, repeated surveys must be very short and quickly completed.

1. **Measures from Occupant Satisfaction Surveys**
   i. Thermal satisfaction scale (“very satisfied” to “very dissatisfied”).
2. **Criteria for Passing**
   i. From neutral (0 scale unit) to +3. (Votes below this range generally comprise 40% of a building’s total votes in the CBE survey benchmark database [ASHRAE 2013]).
   ii. Scale units –1 to +3. (Votes below this range generally comprise 20% of a building’s total votes in the CBE survey benchmark database).
3. **Branching Dissatisfaction Questions (Count Responses and Tally by Category)**
   i. Used to identify and correct problems. Analysis involves documenting the improvements made, resurveying the areas in which the problem occurred, and tallying the differences in responses obtained before and after the improvements.
4. **Accumulated Scores from Repeated Point-in-Time Surveys**
   i. If point-in-time surveys can be repeated sufficiently, the distribution of accumulated votes can be used to evaluate long-term comfort in the building. Such repetition becomes feasible, with short computer applications available to occupants via desktop and mobile devices.

L3.2 Analysis Based on Measurements of Environmental Variables. Environmental measurements are linked to occupant comfort through comfort models. Two comfort models, PMV and adaptive, are specific to mechanically conditioned and naturally ventilated buildings, respectively. Some “mixed-mode” buildings include a combination of both comfort model types. Active investigation is underway into how the two models apply in these cases.

The following measures and criteria underlie the documentation of comfort performance based on physical environmental measurements.

L3.2.1 Point-in-Time (Short-Term) Analyses

a. **PMV Model**
   1. **Measures.** PMV heat-balance model prediction of thermal sensation and satisfaction from environmental measurements are described in Section 5.3 (including air movement extension in Section 5.3.3). Limits to local thermal discomfort are described in Section 5.3.4, and rates of temperature change are described in Section 5.3.5.
   2. **Criteria for Passing.** –0.5 to +0.5 on the PMV scale, inclusive. This represents an estimated 90% satisfied with the thermal environment. Expressed as a comfort zone on a psychrometric chart, this represents a temperature range of 3 K to 5 K (5°F to 8°F), depending on clothing level and humidity (Figure 5.3.1).

b. **Local Thermal Discomfort Limits.** Local thermal should, by itself, not exceed the limits prescribed in Section 5.3.4. At a minimum, an assumed 10% dissatisfaction caused by local discomfort is added to PMV-predicted discomfort to obtain the overall thermal dissatisfaction of an environment.

Solar radiation on occupants in neutral or warm conditions should not exceed 10% of outdoor solar radiation incident on the window. The best-practice upper limit is 5% (ASHRAE 2013).

c. **Adaptive Model (Section 5.3).** The adaptive model is an empirical model of adaptive human responses to environments offering operable window control. The comfort zone on a given day is dependent on a running mean of previous outdoor air temperatures to which people continuously adapt over time.

   1. **Measures**
      i. Air temperature indoors
      ii. Running mean of outdoor air temperature, defined in Section 3 as the prevailing mean outdoor air temperature $t_{pma(out)}$
   2. **Criteria for Passing.** An environmental condition passes if it is within the 80% boundaries predicted by the adaptive model.

d. **Limits to Rate of Environmental Change**

   1. **Measures**
      i. Operative temperature t_o rate of change
      ii. Instances of rate-of-change exceedance within a defined time period

L3.2.2 Time-Integrated Analyses, (Long-Term over Typical Day, Season, or Year)

a. **Measures**

   1. Trend logging of physical measurements over time.
   2. Temperature and humidity in the occupied zone. Globe temperature (temperature measured within a globe exposed to radiation exchange with surrounding surfaces) closely approximates operative temperature t_o in most indoor situations. For greater accuracy, globe temperature measurements may be combined with shielded air temperature measurements to calculate MRT, which, when averaged with the shielded air temperature, provides operative temperature.
   3. Measuring indoor air movement over time is very difficult and rarely done. In many indoor situations the indoor air speed conforms to the still air conditions of the PMV comfort zone (0.2 m/s [40 fpm]), in which case air speed measurement is not necessary.
   4. The number of hours in which local discomfort may be expected is estimated using the local thermal discomfort limits in Section 5. Local discomfort exceedance hours are added to hours in which the comfort zone requirements are exceeded (exceedance occurs when |PMV| > 0.5).

b. **Criteria Metrics**

   1. The prescribed metric is the exceedance hour (semantically equivalent to discomfort hour) predicted during occupied hours within any time interval. See definition in Section 3 and formulas in Section 7.4.2.2.1. Units are in hours. No limits are prescribed.
   2. In addition, it is possible to account for the severity of exceedance at any time, using a metric analogous to the familiar degree-day. Weighted exceedance hours (equivalent to degree-of-discomfort hours) are the number of occupied hours within a defined time period in which the environmental conditions in an occupied zone are outside of the comfort zone boundary, weighted by the extent of exceedance beyond the boundary. Units are thermal sensation scale units times hours. The formula for the PMV comfort zone uses terms defined in Section 7.4.2.2.1:

      $$\text{WEH} = \Sigma\,[H_{disc}\,(|\text{PMV}| - 0.5)]$$

      Units are thermal sensation scale units times hours. This is a useful metric but is not required in Standard 55. No limits are recommended.
   3. Temperature-weighted exceedance hours. It may be useful to convert PMV comfort zone WEHs to a temperature times hours scale using the conversion 0.3 (thermal sensation scale units)/°C (0.15 [thermal sensation scale units]/°F). The unit for temperature-weighted exceedance hours is temperature times hours.).

      This is a useful metric but is not required in Standard 55. No limits are recommended.
   4. The WEH for the adaptive model also uses a temperature times hours scale:

      $$\text{WEH} = \Sigma\,[H_{>upper}\,(T_{op} - T_{upper}) + H_{<lower}\,(T_{lower} - T_{op})]$$

      This is a useful metric but is not required in Standard 55. No limits are recommended.
   5. Expected number of episodes of discomfort, rate-of-change exceedances, local discomfort exceedances within a time period of interest.

      These are useful metrics but not required in Standard 55. No limits are recommended.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX M BIBLIOGRAPHY AND INFORMATIVE REFERENCES

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(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX N
ADDENDA DESCRIPTION

ANSI/ASHRAE Standard 55-2017 incorporates ANSI/ASHRAE Standard 55-2013 and Addenda a, b, c, d, e, f, and g to ANSI/ASHRAE Standard 55-2013. Table N-1 lists each addendum and describes the way in which the standard is affected by the change. It also lists the ASHRAE and ANSI approval dates for each addendum.

Table N-1 Addenda to ANSI/ASHRAE Standard 55-2013

Addendum	Section(s) Affected	Description of Changes [a]	Approval Dates
a	5.3.4.4; 6.2	This addendum separates vertical air stratification limits for standing vs. seated occupants because the previous requirement did not distinguish between the two and would be overly restrictive when applied to standing occupants. This clarification only applies to occupants who are standing still with metabolic rates less than 1.3 met because the entire Section 5.3.4, "Local Thermal Discomfort," does not apply above 1.3 met.	Std. Comm. June 28, 2014 BOD July 2, 2014 ANSI July 31, 2014
b	5.3; 5.3.3; 5.3.4.3; Table 5.3.1; Figure 5.3.3B; 6.2; 7.2.2; Informative Appendix F; Normative Appendix C; H3 Draft;	This addendum clarifies the three comfort calculation approaches in Section 5.3.3, "Elevated Air Speed," by providing a new applicability table (Table 5.3.1, "Applicability of Methods for Determining Acceptable Thermal Conditions in Occupied Spaces") and reorganizing Section 5.3.3 to cover an Elevated Air Speed Comfort Zone Method. In addition, the standard now explicitly states that when "average air speed" (Va) is greater than 0.2 m/s (40 fpm), Section 5.3.3 shall be used to calculate the upper and lower bounds of the comfort zone. This requirement was not clearly stated previously. Other changes include removal of the upper limit to air speed when occupants have control, and change of the draft limit to 0.2 m/s (40 fpm) to align with the still-air comfort zone in Figure 5.3.3B.	ASHRAE November 18, 2014 ANSI December 1, 2014
c	Normative Appendix A	This addendum simplifies Normative Appendix A, "Methods for Determining Operative Temperature," to be a single procedure for calculating operative temperature. Case 1 is removed because it is overly permissive, and Case 3 is removed because it is redundant with Case 2.	ASHRAE April 3, 2017 ANSI May 1, 2017
d	5.3.3.4; 5.3.4.3; Figure 5.3.3A; Figure 5.3.3B; Normative Appendix D; H3; Table H1	Addendum b to Standard 55-2013 changed the still-air threshold from 0.15 to 0.2 m/s (30 to 40 fpm) to align the compliance paths that previously had differing definitions of "still air." This addendum updates additional references and figures in the standard that were impacted by Addendum b. The air speed limit to prevent draft sensation in cool environments is moved to Section 5.3.3.4, "Average Air Speed (Va) without Occupant Control," to clarify how the limit fits into the other air speed limits and Figure 5.3.3A, "Acceptable ranges of operative temperature (t0) and average air speed (Va) for the 1.0 and 0.5 clo comfort zones presented in figure 5.3.1, at humidity ratio 0.010." Normative Appendix C, "Procedure for Evaluating Cooling Effect of Elevated Air Speed Using SET" is also modified to state that the SET model cooling effect applies to both air and radiant temperature. Addendum b to Standard 55-2013 is published and available for free download from the ASHRAE website at https://www.ashrae.org/standards-research--technology/standards-addenda.	ASHRAE May 29, 2015 ANSI June 1, 2015
e	4.1; 4.3; 4.5; 5.2.1.1 5.2.1.2; 5.2.1.3; 5.2.2.1.2; 5.2.2.2; 5.3 5.4.2.1.1; 6.2	This addendum removes permissive language found throughout the standard (excluding the title; Sections 1, 2, 3, and 7; and all Informative Appendices). In doing so, values for maximum differences of clothing level and metabolic rate between multiple occupants in a zone that allow averaging into a single representative occupant were established at 0.1 met and 0.15 clo. Reference Addendum b to Standard 55-2013 that is available for free download on the ASHRAE website at https://www.ashrae.org/standards-research-technology/standards-addenda.	ASHRAE May 29, 2015 ANSI June 1, 2015

a. These descriptions may not be complete and are provided for information only.

Table N-1 Addenda to ANSI/ASHRAE Standard 55-2013 (Continued)

Addendum	Section(s) Affected	Description of Changes [a]	Approval Dates
f	2.5	This is a modification to the scope (Section 2) of Standard 55 to ensure the standard is not used to override any safety, health, or critical process requirements.	ASHRAE September 30, 2015 ANSI October 1, 2015
g	3; 5.3.1; 5.3.2; 5.3.3; 5.3.4.2; Normative Appendix C; Informative Appendix L	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.	ASHRAE September 30, 2016 ANSI October 1, 2016

a. These descriptions may not be complete and are provided for information only.

NOTE

Approved addenda, errata, or interpretations for this standard can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

NOTICE

INSTRUCTIONS FOR SUBMITTING A PROPOSED CHANGE TO THIS STANDARD UNDER CONTINUOUS MAINTENANCE

This standard is maintained under continuous maintenance procedures by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. SSPC consideration will be given to proposed changes within 13 months of receipt by the Senior Manager of Standards (SMOS).

Proposed changes must be submitted to the SMOS in the latest published format available from the SMOS. However, the SMOS may accept proposed changes in an earlier published format if the SM`OS concludes that the differences are immaterial to the proposed change submittal. If the SMOS concludes that a current form must be utilized, the proposer may be given up to 20 additional days to resubmit the proposed changes in the current format.

ELECTRONIC PREPARATION/SUBMISSION OF FORM FOR PROPOSING CHANGES

An electronic version of each change, which must comply with the instructions in the Notice and the Form, is the preferred form of submittal to ASHRAE Headquarters at the address shown below. The electronic format facilitates both paper-based and computer-based processing. Submittal in paper form is acceptable. The following instructions apply to change proposals submitted in electronic form.

Use the appropriate file format for your word processor and save the file in either a recent version of Microsoft Word (preferred) or another commonly used word-processing program. Please save each change proposal file with a different name (for example, “prop01.doc,” “prop02.doc,” etc.). If supplemental background documents to support changes submitted are included, it is preferred that they also be in electronic form as word-processed or scanned documents.

For files submitted attached to an e-mail, ASHRAE will accept an electronic signature (as a picture; *.tif, or *.wpg) on the change submittal form as equivalent to the signature required on the change submittal form to convey non-exclusive copyright.

Submit an e-mail containing the change proposal files to:
change.proposal@ashrae.org

Alternatively, mail paper versions to:
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Senior Manager of Standards
1791 Tullie Circle, NE
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Or fax them to:
Attn: Senior Manager of Standards
404-321-5478

The form and instructions for electronic submittal may be obtained from the Standards section of ASHRAE’s Home Page, www.ashrae.org, or by contacting a Standards Secretary via phone (404-636-8400), fax (404-321-5478), e-mail (standards.section@ashrae.org), or mail (1791 Tullie Circle, NE, Atlanta, GA 30329-2305).

FORM FOR SUBMITTAL OF PROPOSED CHANGE TO AN ASHRAE STANDARD UNDER CONTINUOUS MAINTENANCE

NOTE: Use a separate form for each comment. Submittals (Microsoft Word preferred) may be attached to e-mail (preferred), or submitted in paper by mail or fax to ASHRAE, Senior Manager of Standards, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: change.proposal@ashrae.org. Fax: +1-404-321-5478.

1. Submitter:

Affiliation:

Address: City: State: Zip: Country:

Telephone: Fax: E-Mail:

I hereby grant ASHRAE the non-exclusive royalty rights, including non-exclusive rights in copyright, in my proposals. I understand that I acquire no rights in publication of the standard in which my proposals in this or other analogous form is used. I hereby attest that I have the authority and am empowered to grant this copyright release.

Submitter's signature: ____ Date: ____________________________

All electronic submittals must have the following statement completed:

I *(insert name)*____, through this electronic signature, hereby grant ASHRAE the non-exclusive royalty rights, including non-exclusive rights in copyright, in my proposals. I understand that I acquire no rights in publication of the standard in which my proposals in this or other analogous form is used. I hereby attest that I have the authority and am empowered to grant this copyright release.

2. Number and year of standard:

3. Page number and clause (section), subclause, or paragraph number:

4. I propose to: [ ] Change to read as follows [ ] Delete and substitute as follows
(check one) [ ] Add new text as follows [ ] Delete without substitution

Use underscores to show material to be added (added) and strike through material to be deleted (~~deleted~~). Use additional pages if needed.

5. Proposed change:

6. Reason and substantiation:

7. Will the proposed change increase the cost of engineering or construction? If yes, provide a brief explanation as to why the increase is justified.

[ ] Check if additional pages are attached. Number of additional pages: _______

[ ] Check if attachments or referenced materials cited in this proposal accompany this proposed change. Please verify that all attachments and references are relevant, current, and clearly labeled to avoid processing and review delays. *Please list your attachments here:*

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

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.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

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.

ASHRAE · 1791 Tullie Circle NE · Atlanta, GA 30329 · www.ashrae.org

About ASHRAE

ASHRAE, founded in 1894, is a global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability. Through research, Standards writing, publishing, certification and continuing education, ASHRAE shapes tomorrow's built environment today.

For more information or to become a member of ASHRAE, visit www.ashrae.org.

To stay current with this and other ASHRAE Standards and Guidelines, visit www.ashrae.org/standards.

Visit the ASHRAE Bookstore

ASHRAE offers its Standards and Guidelines in print, as immediately downloadable PDFs, on CD-ROM, and via ASHRAE Digital Collections, which provides online access with automatic updates as well as historical versions of publications. Selected Standards and Guidelines are also offered in redline versions that indicate the changes made between the active Standard or Guideline and its previous version. For more information, visit the Standards and Guidelines section of the ASHRAE Bookstore at www.ashrae.org/bookstore.

IMPORTANT NOTICES ABOUT THIS STANDARD

To ensure that you have all of the approved addenda, errata, and interpretations for this Standard, visit www.ashrae.org/standards to download them free of charge.

Addenda, errata, and interpretations for ASHRAE Standards and Guidelines are no longer distributed with copies of the Standards and Guidelines. ASHRAE provides these addenda, errata, and interpretations only in electronic form to promote more sustainable use of resources.

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