

STANDARD 55 USER'S MANUAL

Based on
ANSI/ASHRAE Standard 55-2013
Thermal Environmental Conditions for Human Occupancy

This manual provides

- Explanation of Standard 55's requirements
- Guidance on designing for thermal comfort
- Sample calculations and examples using the ASHRAE Thermal Comfort Tool
- Descriptions of compliance tools
- Useful references
- Operation and maintenance tips

ASHRAE®

Standard 55-2013 User's Manual

ANSI/ASHRAE Standard 55-2013

Thermal Environmental Conditions for Human Occupancy

ASHRAE®
Atlanta

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1791 Tullie Circle, N.E., Atlanta, GA 30329 USA; telephone +1-404-636-8400; www.ashrae.org.

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Preface

General

ASHRAE Standard 55 addresses thermal environmental conditions for human occupancy. Standard 55 was first published in 1966 and republished in 1974, 1981, and 1992. As of 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 on the ASHRAE website.

Explanatory material, detailed information, figures, and examples contained in this user's manual are provided to aid the user in designing, commissioning, and measuring and rating thermal comfort in buildings in accordance with Standard 55-2013 (referred to in this manual as "Standard 55" or simply "the standard").

Standard 55 was written to be code enforceable and therefore contains only mandatory language. This manual does not reproduce the requirements of the standard but rather paraphrases and explains them. Intended to be used in conjunction with the standard, this manual

a. provides information on the intent and application of Standard 55;
b. explains the standard through the use of sample calculations and examples;
c. encourages the user to apply the principles of acceptable thermal comfort and effective thermal control when designing buildings and building systems;
d. provides useful reference material to assist designers, owners, and users in efficiently completing a successful and compliant design; and
e. provides guidance to building operation and maintenance personnel.

This manual informs the user in the application of tools used for compliance with Standard 55, in particular the ASHRAE Thermal Comfort Tool. If users wish to explore third-party implementations of Standard 55, it is their responsibility to confirm that these implementations accurately reflect the requirements of the standard.

Audience

This user's manual is intended to be used by

a. architects, engineers, and other designers who choose to design spaces that will comply with Standard 55;
b. manufacturers of systems and components who choose to provide the industry with complying equipment;
c. plan examiners and field inspectors who will be charged with enforcing the standard in areas where it is adopted as code;
d. general and specialty contractors who must construct buildings in compliance with the standard;
e. commissioning agents, raters, and similar quality control specialists whose goal is to see that systems operate according to the owner's requirements and design intent; and
f. operation and maintenance personnel who must maintain occupant thermal comfort compliance of the building throughout its lifespan (assuming the building and its systems have been designed for thermal comfort).

Scope

The purpose of this user's manual is to aid in understanding and complying with the requirements of Standard 55-2013 as published in its entirety. The user's manual does not address changes made by addenda approved or currently in review that are not included in the current published version of Standard 55-2013 available through the ASHRAE website.

It is intended that this manual be used in conjunction with the standard; requirements are explained in the manual but are not repeated verbatim. Examples are intended to be generally compliant with the standard and have been reviewed and approved by the committee. Circumstances related to specific building designs may result in requirements that deviate from the examples. The examples given in this manual do not create new requirements or represent the only methods of achieving compliance with the standard.

Addenda

Standard 55 is a dynamic document undergoing continuous maintenance, with addenda, errata, and interpretations issued throughout its life. The ASHRAE committee responsible for maintaining the standard (SSPC 55) may approve addenda at any time in the continuous maintenance process. Users of this manual are encouraged to consult the ASHRAE website for approved addenda to the most recent edition. The scope of this manual does not encompass errata, addenda, or interpretations to the 2013 edition of the standard.

When using this manual to comply with a code based on or referencing Standard 55, determine whether any addenda have been incorporated into that code, and read those addenda carefully. If the adopted code references a version of the standard prior to 2013, then the information contained within this manual may not apply.

Anyone may submit a proposed change to the standard, and the SSPC is required to consider it as a possible addendum under the continuous maintenance process. Instructions for submitting a proposed change to the standard can be located online at http://www.ashrae.org.

Official Interpretations of the Standard

Standing Standards Project Committee (SSPC) 55 provides official interpretations of the standard upon written request. Interpretations are restricted to the words contained within the standard itself and cannot encompass design reviews and/or proposals for changes. Address requests for interpretations to

ASHRAE
Senior Manager of Standards
1791 Tullie Circle, NE
Atlanta, GA, 30329-2305

The SSPC usually assigns the request to a subcommittee, which then reviews it and develops an interpretation. This interpretation is then voted on by the full committee. A common timeframe for a response is six to twelve months. Interpretations are also posted on the ASHRAE website at http://www.ashrae.org.

Standard 55 Organization

Standard 55 is divided into eight sections and thirteen appendices. Sections 1, 2, and 3 are administrative and do not contain any requirements:

- Section 1, "Purpose"—states the purpose of the standard.
- Section 2, "Scope"—describes where the standard does and does not apply.
- Section 3, "Definitions"—provides definitions of terms that are used throughout the standard.

Sections 4 through 8 are the technical sections of the standard and contain requirements for the design and evaluation of thermal comfort in buildings:

- Section 4, "General Requirements"—requires documentation and describes the general procedures for identifying space types and representative occupants.
- Section 5, "Conditions that Provide Thermal Comfort"—describes the specific requirements or several methods for the selection of thermal environmental conditions based on characteristics of the representative occupants.
- Section 6, "Design Compliance"—presents the requirements for documenting a compliant building and systems design.
- Section 7, "Evaluation of Comfort in Existing Buildings"—contains methods for evaluation of comfort in existing buildings when such evaluation is required by code or another standard. As a design standard, such evaluation is not a requirement of Standard 55.
- Section 8, "References"—contains a list of reference documents that provide additional information on key concepts used in Standard 55.

In addition to the eight primary sections, the standard contains a foreword and thirteen appendices. The foreword provides a historical perspective on the development of the standard. Appendices A and B are normative[1] and therefore part of the standard:

- Normative Appendix A, "Methods for Determining Operative Temperature"
- Normative Appendix B, "Computer Program for Calculation of PMV-PPD"

The remaining appendices are informative. They provide additional explanation and are not part of the standard:

- Informative Appendix C, "Conditions that Provide Thermal Comfort"
- Informative Appendix D, "Use of Metabolic Rate Data"
- Informative Appendix E, "Clothing Insulation"
- Informative Appendix F, "Analytical and Graphic Comfort Zone Methods"
- Informative Appendix G, "Procedure for Evaluating Cooling Effect of Elevated Air Speed Using SET"
- Informative Appendix H, "Local Discomfort and Variations with Time"
- Informative Appendix I, "Occupant-Controlled Naturally Conditioned Spaces"
- Informative Appendix J, "Sample Design Compliance Documentation"
- Informative Appendix K, "Measurements, Surveys, and Evaluation of Comfort in Existing Spaces: Parts 1 and 2"
- Informative Appendix L, "Bibliography and Informative References"
- Informative Appendix M, "Addenda Description"

Organization and Use of the User's Manual

In general, the chapters of this user's manual follow the organization of the standard. To aid the user in correlating requirements of the standard with the explanations in the user's manual, all major headings contain section number references in parentheses. This allows the user to quickly reference a corresponding section of the standard. Similarly, each section of the standard has a corresponding section in the user's manual.

1. ASHRAE uses the term *normative* to refer to text that is a requirement of the standard. Normative text appears in the body of the standard or in a separate appendix identified as "normative." Informative text is material that is explanatory and not a part of mandatory requirements. It can be interspersed in the body of the standard, where it is prefaced by "Informative Note," or in a separate appendix identified as "informative."

References to Standard 55 in Building Codes and Standards

One notable example in which Standard 55 is referenced[2] specifically for ensuring occupant thermal comfort is ANSI/ASHRAE/IES/USGBC Standard 189.1-2014, *Standard for the Design of High-Performance Green Buildings*. However, in most cases where Standard 55 is referenced in codes, references are related to energy modeling or avoiding the negative energy-use consequences of oversizing equipment. These codes, standards, guidelines, and contract provisions adopt Standard 55 by reference in several ways:

- As criteria for determining indoor design conditions in support of energy efficiency regulations:
  - California Code of Regulations, Title 24, Part 6, Building Energy Efficiency Standards, Section 140.4, Prescriptive Requirements for Space Conditioning Systems, requires mechanical heating and mechanical cooling equipment to be sized appropriately to meet the design heating and cooling loads of the building, as calculated with indoor design temperature and humidity conditions determined in accordance with ASHRAE Standard 55 or 2009 *ASHRAE Handbook—Fundamentals*. The 2016 version of Title 24, Part 6, references the 2010 version of Standard 55.
- As a means to determine equivalency of real or hypothetical buildings or operation methods:
  - As a requirement during the design stage to perform modeling using prescribed indoor thermal conditions for a baseline building and a proposed building. This modeling is performed for the purpose of demonstrating that a proposed design meets the performance requirements of an energy code.
  - As a requirement that an energy conservation improvement, whether by hardware or operational strategy, meets certain minimum requirements of human thermal comfort post-retrofit.
- As a requirement to design heating and cooling systems to achieve thermal comfort conditions to meet thermal acceptability criteria:
  - ANSI/ASHRAE/IES Standard 90.1-2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, includes a newly clarified requirement for modeling systems in a proposed building that provides occupant thermal comfort by means other than directly controlling the air dry-bulb and wet-bulb temperature (i.e., radiant cooling/heating, elevated air speed, etc.). It permits the use of Standard 55 for calculation of thermal comfort.
  - ANSI/ASHRAE/USGBC/IES Standard 189.1-2014, *Standard for the Design of High Performance Green Buildings*, in addition to incorporating the modeling requirement in Standard 90.1 above, says in Section 8.3.2 that the building should be designed in compliance with Standard 55, Section 6.1, "Design," and Section 6.2, "Documentation." Compliance with Standard 189.1 is required by the U.S. Army and is a compliance path of the International Code Council (ICC) International Green Construction Code (IGCC).

Some designers will choose to use Standard 55 as their standard of care or best practice method for the benefit of their clients or to clarify the scope of their services to clients. Following are other standards, documents, and procedures that have been known to require or encourage a design to comply with one or more provisions contained in Standard 55:

- U.S. Green Building Council (USGBC) has typically awarded points in several of its Leadership in Energy and Environmental Design (LEED) rating systems, including

2. Because of differences in their development and publication schedules, ASHRAE Standards 90.1-2013, 62.2-2013, and 189.1-2014, and the 2013 edition of Title 24, Part 6, reference the 2010 edition of Standard 55.

LEED-NC (New Construction), EB (Existing Buildings), CI (Commercial Interiors), and Core and Shell.

- ANSI/ASHRAE 62.2-2013, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*, refers to Standard 55 for evaluation of thermal comfort.
- The U.S. General Services Administration (GSA), in the "Mechanical Engineering" chapter of its *Facilities Standards for the Public Buildings Service*, requires air-handling unit/coil designs to assure that conditioned space temperatures and humidity levels are within acceptable limits per Standard 55[3].
- Building owners have been known to require that designs comply with Standard 55, and Section 6 contains the applicable requirements.
- Energy Service Performance Contracts (ESPCs) have been known to require that postretrofit energy projects provide thermal comfort conditions no less than preretrofit as evaluated by Standard 55. This could be evaluated in the design of such projects (which would invoke Section 6) and/or the operation of such projects (which could invoke Section 7).
- The Collaborative for High Performance Schools (CHPS) requires calculations and supporting documentation to show that spaces meet Standard 55 requirements in order to obtain credit EQ9.1, which provide 4 out of a possible 82 points for meeting indoor environmental quality standards for CHPS.

CBE/ASHRAE Thermal Comfort Tool

University of California Berkeley Center for the Built Environment (CBE) hosts a Web-based graphical user interface for thermal comfort prediction based on ASHRAE Standard 55-2013. The CBE/ASHRAE Thermal Comfort Tool can be accessed at the following location:

http://ashrae55.berkeley.edu/

Navigating the User's Manual

The electronic version of this user's manual includes hyperlink cross references for ease of navigation. General topics can be navigated by clicking the corresonding section in the Table of Contents. Sections, figures, and tables that are cross referenced throughout the document can likewise be navigated directly by clicking on the shaded text within each section.

3. The GSA's design requirement for indoor temperatures and humidity exceeds the requirements of Section 6.

Acknowledgments

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ASHRAE Standard 55 was first published in 1966. The initial initiative for a user's manual began many years ago with the help of Peter Simmonds, PhD (Building and Systems Analytics, LLC), and Hal Levin (Building Ecology Research Group), and launched under the leadership of former chair of SSPC 55, Gwelen Paliaga, PE (Taylor Engineering).

The Project Monitoring Subcommittee was directed by Robert Bean, RET, PL(Eng) (Indoor Climate Consultants Inc.), and supported by Peter Simmonds; Tim McGinn, PEng (Dialog); and Michael Tillou, PE (Atelier Ten), along with members of SSPC 55.

This document would not have come to fruition without support from ASHRAE leadership under past President Bill Bahnfleth, PhD, PE, and without funding from ASHRAE Technology under the supervision of staff liaison and Senior Manager of Standards, Stephanie Reiniche.

This user's manual is in part an accumulation of past and present academic and practical knowledge from an exhaustive list of ASHRAE members from around the world. For those who are present and those who have passed, acknowledgment of their contributions to this important field of study is given with due respect.

1 Purpose (§ 1)

The stated purpose of Standard 55 is limited to specifying environmental and personal factors that will produce an acceptable thermal environment. In practice, and in its actual content, the standard impacts the design of buildings for acceptable thermal comfort and for the evaluation of thermal comfort in existing buildings. Section 1 further states that the environmental conditions should be "acceptable to a majority of the occupants." There is no requirement that all occupants in the space be comfortable. The standard uses the term *representative occupant*, which is explained further in Chapter 3 of this user's manual.

2 Scope (§ 2)

Scope of Standard 55-2013 (§ 2.1 through § 2.4)

a. **The core of the standard specifies methods to determine general thermal environmental conditions.** The standard specifies four environmental factors (temperature, thermal radiation, humidity, and air speed) and two personal factors (metabolic rate and clothing level) that a representative proportion of the occupants will find acceptable. While it is a commonly held belief that indoor air temperature and humidity are the primary drivers of thermal comfort—and often the only parameters considered by designers—the standard makes it clear that all six factors are important and must be considered when specifying thermal comfort.

b. **The standard requires additional compliance to local thermal environments when occupants are wearing light clothing during low activity.** The standard specifies four localized factors (radiant asymmetry, temperature stratification, floor temperatures and draft) that a representative proportion of the occupants will find acceptable wearing light clothing during low met rate activities.

c. **The scope of the standard is limited to healthy adults.** The requirements in Standard 55 are developed based on data collected over a number of thermal comfort studies across the world but all of those studies were conducted on healthy adults. In practice, designers have applied Standard 55 provisions to spaces that also include nonadults and nonhealthy persons, such as children or patients in hospitals, but the standard expressly allows calculation of thermal comfort only for the healthy adults in those spaces, such as teachers in classrooms, parents at home, or nurses and doctors in health care settings. Children and patients in a health care setting who are ill and therefore not healthy, may require conditions that differ from the populations on which the standard is based; however, there are (as yet) no universally accepted international or national standards specifically for these groups.

d. **The standard is limited to those locations where the atmospheric pressure is equivalent to altitudes up to 3000 m (10,000 ft).** The atmospheric pressure exclusion is common to several ASHRAE standards. Most notable is ANSI/ASHRAE Standard 41.6, *Standard Methods for Humidity Measurement*. In addition to the difficulty of measuring humidity in a standardized manner, human physiology also changes at higher altitudes. Note that there are very few major cities located at altitudes greater than 3000 m (10,000 ft). *ASHRAE Handbook—Fundamentals* lists climate data for five such locations worldwide (La Paz/Alto, Bolivia; Sog Xian [Tibet] and Emei Shan, China [PRC]; Pian Rosa, Italy; and Piz Corvatsch, Switzerland.)

e. **The standard applies to only those occupants that have or are likely to spend 15 minutes or more in an indoor space designed for human occupancy.** The 15-minute threshold for occupancy is one found in similar standards, such as ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*. This is because it takes time for occupants to acclimate to environments in several ways, including physiologically (e.g., metabolism and skin temperature), psychologically (e.g., expectation) and behaviorally (e.g., clothing adjustments). This limitation of the standard scope is important when evaluating thermal comfort in transitional spaces such as hallways and lobbies. Only those occupants who are likely to spend at least 15 minutes at any given time in that space need to be considered for evaluating thermal comfort. Thus, a recep-

tionist in an office is covered by the standard, and so is a visitor who sits in the lobby for at least 15 minutes. On the other hand, occupants who pass through the lobby or do not spend at least 15 minutes in the lobby need not be considered for evaluating compliance with Standard 55.

f. **The standard is intended for enclosed spaces in the built environment.** For this reason, the standard applies to indoor spaces only. Thus, outdoor seating areas, even those with radiant heat or evaporative cooling, are not covered by its requirements.

Factors Not in the Scope of Standard 55-2013 (§ 2.4)

The standard does not address nonthermal environmental factors, such as air quality, contaminants, acoustics, and illumination. ASHRAE Standards 62.1 and 62.2 address air quality and contaminants. Illumination is covered by publications such as the Illuminating Engineers Society (IES) *The Lighting Handbook*. HVAC-related acoustics and noise are addressed in 2011 *ASHRAE Handbook—HVAC Applications*, Chapter 48. ASHRAE Guideline 10, *Interactions Affecting the Achievement of Acceptable Indoor Environments*, enumerates potential interactions between thermal and other environmental factors that are not currently addressed in Standard 55.

Illumination and acoustics may also be covered in design guidelines promulgated by building owners and managers such as government agencies and private operators. All of these nonthermal factors affect occupants' experience of the indoor environment. They can also influence the perception that people have of the acceptability of the thermal environment.

Standard 55 also does not address one potentially significant factor affecting the thermal sensation of building occupants, namely, the shortwave solar radiation that is incident directly on the occupants. Fenestration design that lets direct sunlight into the space and allows occupants to be subjected to shortwave solar radiation can result in warm thermal sensations. These effects are not currently captured in Standard 55-2013.

3 Definitions (§ 3)

List of Definitions

Table 3-A ASHRAE Standard 55 Defined Terms

adaptive model	occupant-controlled openings
air speed	outdoor design condition
air speed, average (V_a)	predicted mean vote (PMV)
climate data	predicted percentage of dissatisfied (PPD)
clo	**radiant temperature asymmetry**
comfort, thermal	sensation, thermal
draft	temperature, air
environment, acceptable thermal	temperature, air average (t_a)
environment, thermal	temperature, dew-point (t_{dp})
exceedance hours	temperature, floor (t_f)
garment	**temperature, mean daily outdoor air ($\overline{t_{mda(out)}}$)**
generally accepted engineering standard	temperature, mean radiant ($\overline{t_r}$)
humidity	temperature, operative (t_o)
insulation, clothing (I_{cl})	temperature, plane radiant (t_{pr})
insulation, garment (I_{clu})	**temperature, prevailing mean outdoor air ($\overline{t_{pda(out)}}$)**
local thermal discomfort	temperature, standard effective (SET)
metabolic rate (met)	**zone, comfort**
occupant, representative	**zone, occupied**
occupant-controlled naturally conditioned spaces	

*Note: Definitions listed in **bold** have a specific meaning for Standard 55.*

Standard 55-2013 includes 37 definitions covering a range of terms necessary to specify occupant thermal comfort in buildings.

In most cases, the terms and definitions that appear in Standard 55 are based on or adapted from other publications, such as *ASHRAE Handbook—Fundamentals*. Section 3 of Standard 55 includes definitions of these terms so that there is no confusion as to their meaning in the context of the standard.

In other cases, the definition of a term is specific to Standard 55 and this user's manual (shown in bold in Table 3-A). For example, Standard 55 defines *temperature, prevailing mean outdoor air* as follows:

> [W]hen used as an input variable in Figure 5.4.2.1 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.

To understand this definition, the reader must be aware of the requirements of Section 5.4.2.1 of the standard.

Further, some definitions are referenced in multiple sections, whereas others appear in only one subsection. Table 3-B shows where each of the definitions in Section 3 are referenced within the various sections of the standard.

Understanding Key Definitions

Thermal Comfort

Thermal comfort is that condition of the 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.

Representative Occupant

Standard 55 defines the representative occupant as being an individual, or composite or average of several individuals, that is representative of the population occupying a space for 15 minutes or more. To understand this, it is illustrative to use an example for a typical office space facing north.

Figure 3-A shows a north-facing perimeter open office space. For the sake of simplicity, this example assumes there is only one glazed exterior wall (floor-to-ceiling glazing) facing north and one opaque exterior wall facing east. The ceiling height is 3 m (9.83 ft). The conditioned floor area for the space is 13.4 × 4.6 m, or 61.3 m^2 (44 × 15 ft, or 660 ft^2). The building is located in Baltimore, MD, where the design conditions used for sizing the cooling and heating system are as follows:

- 99% heating: –8.21°C (7.3°F)
- 1% cooling: 32.9°C (91.2°F) db, 23.4°C (74.2°F) mcwb
- Summer indoor design conditions 23.9°C (75°F) db
- Winter indoor design conditions: 21.1°C (70°F) db

The space has 10 workstations with an average area of 6.1 m^2/person (66 ft^2/person). The space is heated with perimeter hydronic baseboard heating and cooled (and ventilated) with an overhead variable-air-volume (VAV) system. The design cooling airflow is 363 L/s (770 cfm), and design heating airflow is 42 L/s (90 cfm), corresponding to minimum ventilation requirements.

In the case of Figure 3-B, the 10 occupants can be assumed to have similar activity levels (office desk work) but may experience different thermal conditions due to their location in relation to the windows, HVAC supply and return ducts, and other surfaces. Therefore, it is possible to identify one representative occupant located close to the window and another one located more in the interior space, as denoted by “R” in Figure 3-B.

A user may choose not to make such a distinction between occupants and instead choose one of the 10 occupants as being representative of all the occupants. While this may be technically in compliance with Standard 55, the predictions of comfort may not be accurate if the occupants closer to the windows are subjected to much different thermal conditions that the ones away from windows. It is in the user’s interest to carefully choose representative occupants for the space, and to choose several representative occupants where necessary rather than resorting to a default occupant located in the middle of the space. Note that the representative occupants are those who are occupying the space more than 15 minutes as outlined in Section 2 of Standard 55. Thus, other occupants may enter this space for a few minutes, such as a work colleague visiting one of the 10 occupants for a quick chat, but these transient occupants are not considered for determining the representative occupant.

Table 3-B References to Definitions in Standard 55

Section	1	2				3	4					5				6		7				Appendices									
Term	**1**	**2.1**	**2.2**	**2.3**	**2.4**	**3**	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**5.1**	**5.2**	**5.3**	**5.4**	**6.1**	**6.2**	**7.1**	**7.2**	**7.3**	**7.4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**K**
adaptive model																			■		■			■							■
air speed		■										■		■	■		■			■	■	■	■	■			■	■	■	■	■
air speed, average														■	■		■		■	■	■	■						■			
climate data						■																									
clo										■			■	■	■				■				■	■		■	■	■	■	■	
comfort, thermal												■	■	■								■	■	■	■	■	■	■	■	■	
draft														■															■		
environment, acceptable thermal												■			■									■			■				
environment, thermal	■			■							■	■	■	■						■	■			■		■	■				■
exceedance hours																					■										■
garment													■													■				■	
generally accepted engineering standard																	■														
humidity		■										■		■	■		■		■	■			■	■			■	■			■
insulation, clothing												■	■	■	■		■							■		■	■		■		■
insulation, garment													■																		
local thermal discomfort														■	■		■		■	■	■			■					■		■
metabolic rate										■		■	■	■	■		■		■			■	■	■	■	■	■	■	■	■	■
occupant, representative									■			■	■	■			■					■					■				
occupant-controlled naturally conditioned spaces															■		■														
occupant-controlled openings						■																									
outdoor design condition						■																									
predicted mean vote													■	■					■	■	■		■	■	■		■	■	■		■
predicted percentage of dissatisfied													■	■									■	■			■				■
radiant temperature asymmetry														■			■			■									■		
sensation, thermal																				■			■		■		■	■	■		■
temperature, air												■	■	■	■		■			■			■	■		■	■	■	■	■	■

Table 3-B References to Definitions in Standard 55

Section	1	2				3	4					5				6		7				Appendices									
Term	**1**	**2.1**	**2.2**	**2.3**	**2.4**	**3**	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**5.1**	**5.2**	**5.3**	**5.4**	**6.1**	**6.2**	**7.1**	**7.2**	**7.3**	**7.4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**K**
temperature, air average																															
temperature, dew-point																															
temperature, floor																															
temperature, mean daily outdoor air																															
temperature, mean radiant																															
temperature, operative																															
temperature, plane radiant																															
temperature, prevailing mean outdoor air																															
temperature, standard effective																															
zone, comfort																															
zone, occupied																															

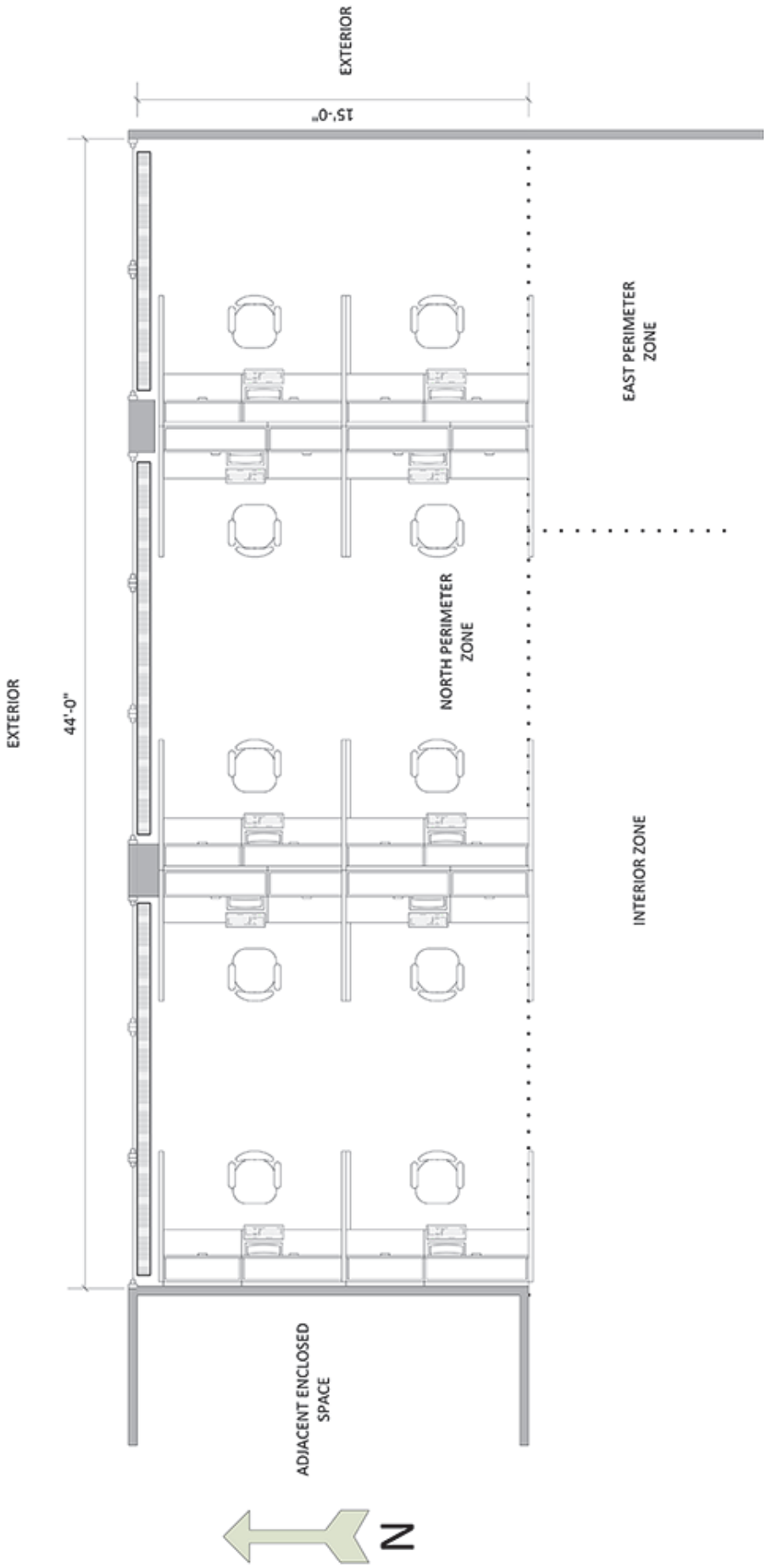


Figure 3-A Office space layout.

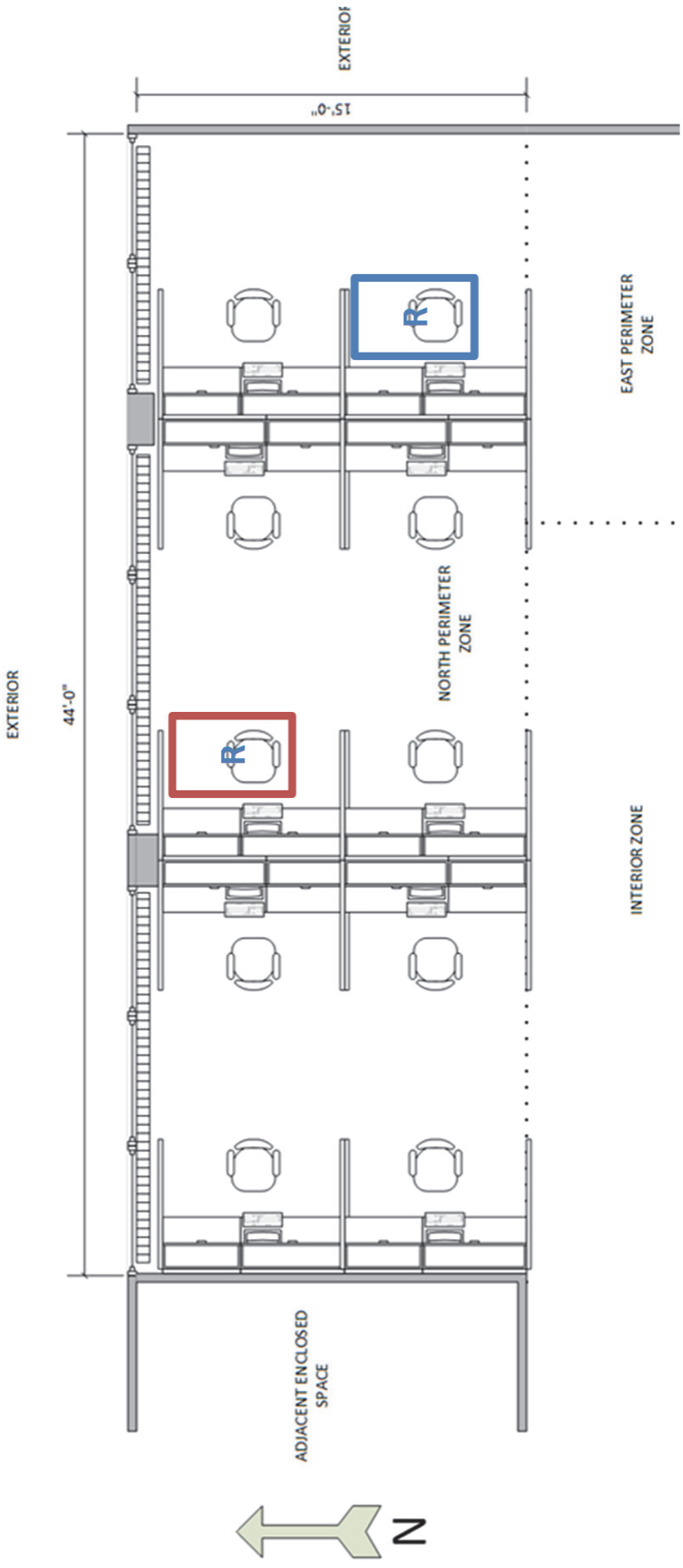


Figure 3-B Designating representative occupants.

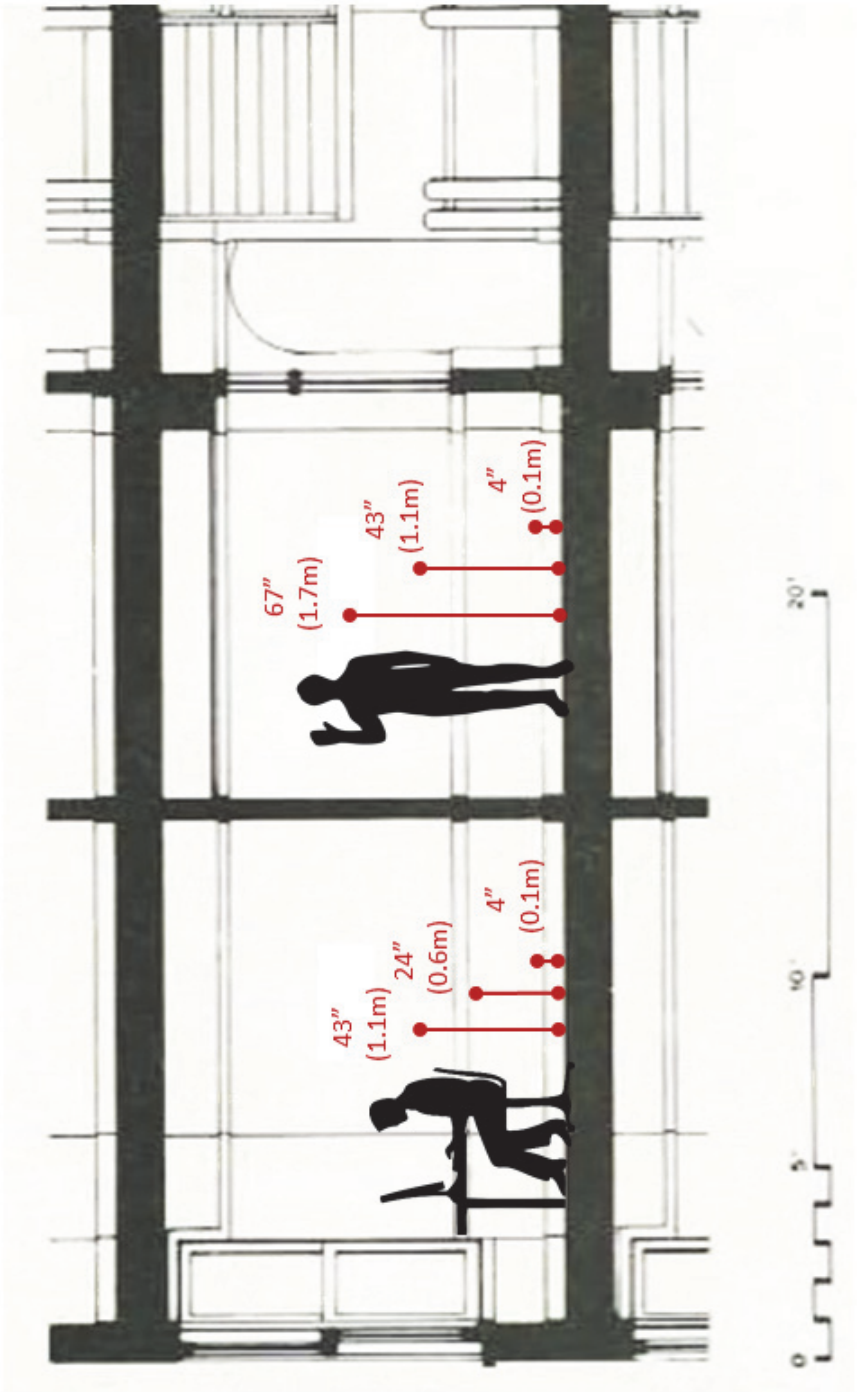


Figure 3-C Sectional view showing different heights for air speed measurements to calculate average air speed.

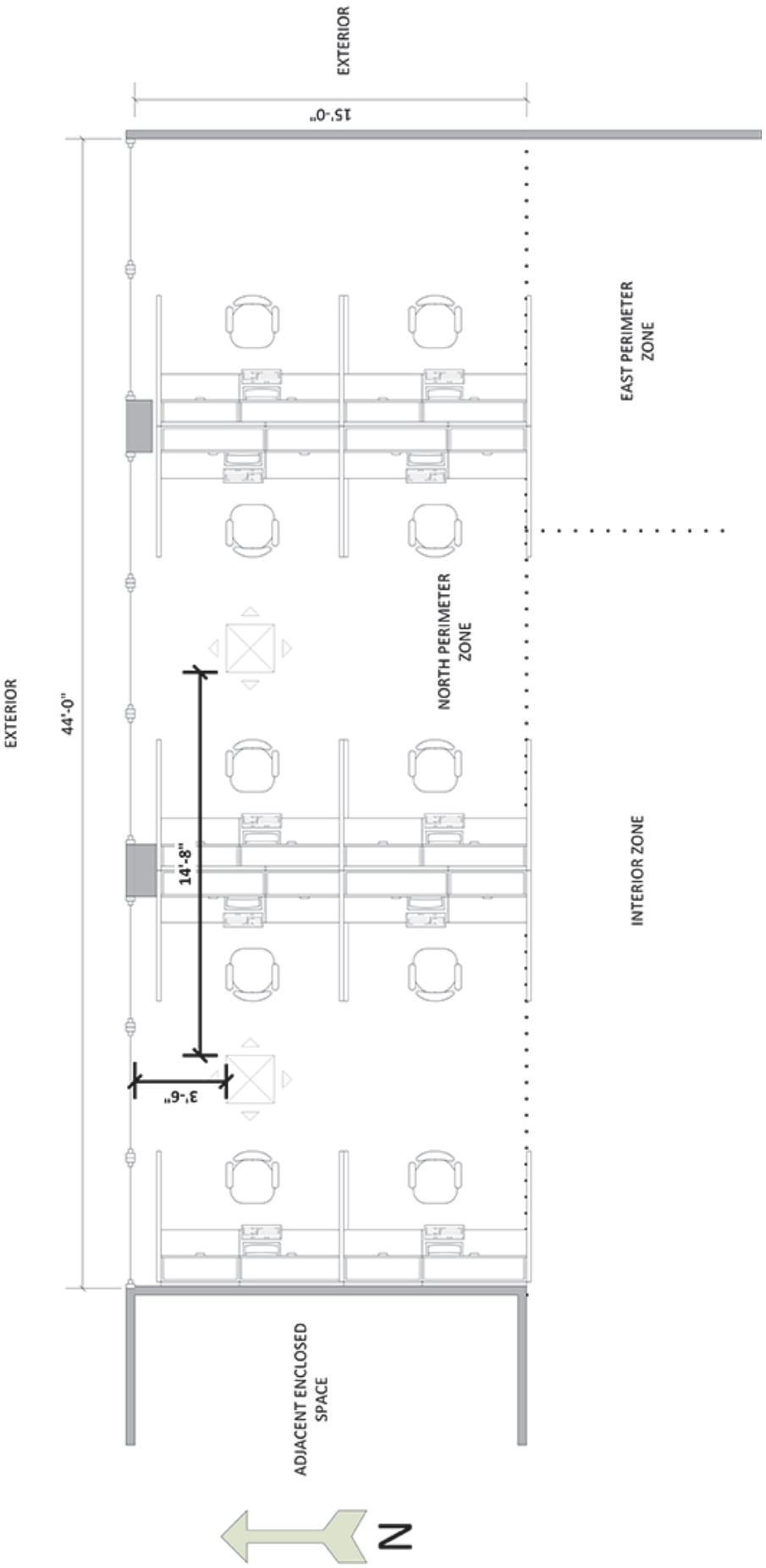


Figure 3-D Office space showing diffuser layout.

Average Air Speed

Average air speed is defined as the average air speed surrounding a representative occupant with respect to location and time. The spatial average is for three heights, –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 (Figure 3-C). In terms of time, the air speed is averaged over a period between one and three minutes. Standard 55 requires that variations that occur over a period greater than three minutes be treated as multiple different average air speeds.

As explained later in this manual, Standard 55 requires that the average air speed be less than 0.2 m/s (40 fpm) for the graphical and analytical methods of determining thermal comfort of the representative occupants. The standard allows air speeds greater than 0.2 m/s (40 fpm) if certain conditions are met as described in Section 5.3.3. Regardless, the standard requires that the user calculate the average air speed prior to choosing an appropriate method described in the standard for evaluating occupant thermal comfort.

In practice, during the design stage, the average air speed needs to be calculated by the designer using known engineering principles and data available from manufacturers for air distribution equipment.

Example 1: Using the Air Diffuser Performance Index (ADPI)

For overhead air distribution systems, diffuser manufacturers often rate their products based on the Air Diffuser Performance Index (ADPI). ADPI is defined by ASHRAE Standard 113 as the percentage of points measured in a room that are within both the ASHRAE temperature and velocity ranges for comfort. ADPI is based on the acceptance and recognition that it is not possible to achieve a comfort level of 100%, but 80% acceptance is achievable and measurable.

Using the example space identified in Figure 3-A, in cooling mode the designer needs to provide 79.6 W/m^2 (25.2 Btu/h·ft^2) of sensible cooling.

As shown in Figure 3-D, the diffuser type is ceiling-mounted with 4-way throw, and the return is at the ceiling. Characteristic length of the diffuser is 1.07 m (3 to 6 in.) to the wall, 2.23 m (7 to 4 in.) to midpoint between diffusers.

From *ASHRAE Handbook—HVAC Applications*, Chapter 57, Table 4, the closest room load is 63 W/m^2 (20 Btu/h·ft^2) with a maximum achievable ADPI of 93, a $T_{0.25}/L$ of 0.8 for maximum ADPI, and a range of $T_{0.25}/L$ of 0.7 to 1.3 to achieve an ADPI greater than 90.

The designer selects a diffuser with an isothermal throw of 1.2 m (4 ft) to 0.25 m/s (50 fpm) ($T_{0.25}/L$) for this selection is 1.12, which is within the range needed for ADPI > 80, and therefore ADPI requirements are met.

Based on ADPI > 80, the designer concludes that the average air speed is less than 0.35 m/s (70 fpm) for greater than 80% of the space. The designer also concludes from the ADPI calculations that the temperature stratification is less than 2.8°C (5°F) for locations between ankle and head level (1.8 m [6 ft] above floor level) and at least 0.6 m (2 ft) away from the exterior wall.

In many cases, achieving ADPI of this value will also meet the requirement to not exceed 0.2 m/s (40 fpm) and even 0.15 m/s (30 fpm) if the operative temperature (to) is below 22.5°C (72.5°F). ADPI does not predict air speeds in heating mode, but if the overhead air system is the only potential source of elevated air speed (window drafts have been accounted for with perimeter baseboard heating systems), then it is also likely that the air speed criteria will not be exceeded in heating, as the terminal box has been tuned to minimum vent rate in heating mode. See Chapter 5, Elevated Air Speed (p. 34) for more discussion.

Example 2: Using Manufacturer Data

A conference room is served by a displacement ventilation system. Based on the displacement diffuser manufacturer's information, the designer has obtained the following air speed

profile at heights corresponding to the three heights required for calculating the average air speed for a seated occupant:

- 0.1 m (4 in.): 0.20 m/s (40 fpm)
- 0.6 m (24 in.): 0.08 m/s (15 fpm)
- 1.1 m (43 in.): 0.08 m/s (15 fpm)

The average air speed for the seated occupant is therefore 0.2 + 0.08 + 0.08]/3 = 0.12 m/s ([40 + 15 + 15]/3 = 23.3 fpm).

Average Air Temperature

The average air temperature is based on the temperature of air surrounding a representative occupant. This is an important differentiation in the standard, because the average is *not* based on an average of air temperature across the entire space; rather, it is an average as relates to the specific locations of the representative occupants. In a large volume of space, such as an auditorium, the average air temperature for the standard is within the area immediately surrounding the representative occupant and is not necessarily the same as the average of air temperatures across the volume of the space.

Note: Designers are cautioned to not attribute the effects of radiant losses from the body as a drop in air temperature around the body.

The standard specifies that 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.

Example 3: Using Manufacturer Data

For the same conference room described in Example 2 (p. 13), the designer obtains the following air temperature information from the displacement diffuser manufacturer:

- Air temperature at 0.1 m (4 in.) above the floor: 20.5°C (69°F)
- Head-to-foot temperature difference: 2.2°C (3.9°F)

The designer has the information for two of the heights required for the calculation. It is reasonable to assume a roughly linear correlation between temperature and height. Therefore, the designer calculates the following temperatures:

- 0.1 m (4 in.): 20.5°C (69°F)
- 0.6 m (24 in.): (20.5 + 22.7)/2 = 21.6°C ([69 + 72.9]/2 = 71°F)
- 1.1 m (43 in.): 20.5 + 2.2 = 22.7°C (69 + 3.9 = 72.9°F)

The average air temperature for the seated occupant is therefore [20.55 + 21.66 + 22.72]/3 = 21.64°C ([69 + 71 + 72.9)/3 = 71°F]).

Mean Radiant Temperature

Mean radiant temperature (MRT) is defined as the temperature of a uniform, black enclosure that exchanges the same amount of heat by radiation with the occupant as the actual enclosure. It is a single value for the entire body expressed as a spatial average of the temperature of surfaces surrounding the occupant, weighted by their view factors with respect to the occupant. See *ASHRAE Handbook—Fundamentals*, Chapter 9, for a more complete description of mean radiant temperature.

Example 4: Space without Radiant Heating/Cooling

For this example, we use a room with the following dimensions:

- 10 m (33 ft) wide, 5 m (16.4 ft) deep, 4 m (13 ft) high

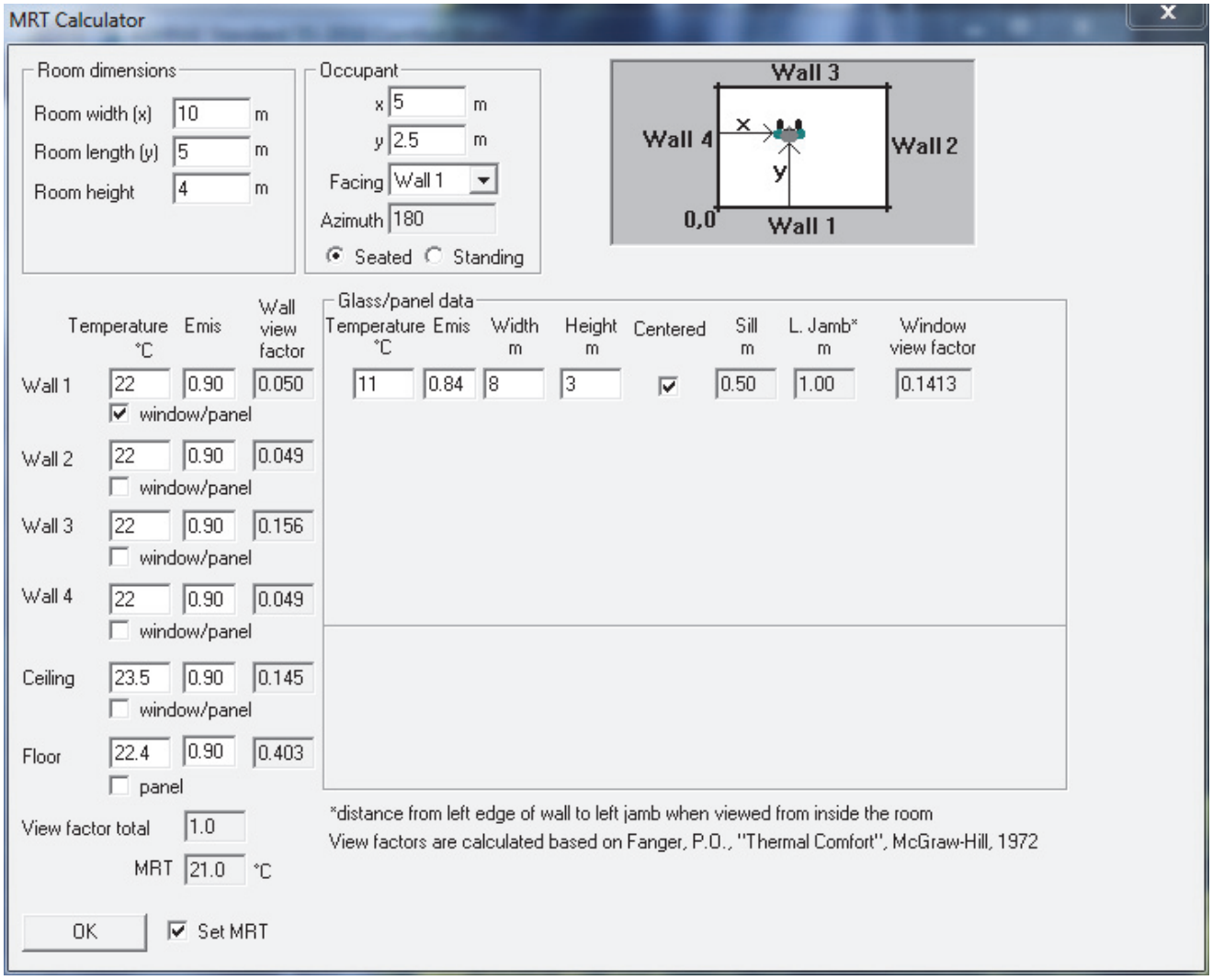


Figure 3-E MRT calculation using ASHRAE Thermal Comfort Tool for space without radiant system.

- One external wall, 10 × 4 m (33 × 13 ft) with 8 × 3 m (26 × 10 ft) window, centered in wall

The designer chooses the following design conditions:

- External conditions: –12°C (10.4°F)
- Indoor air temperature: 23°C (73.4°F)

To calculate the interior surface temperatures, the designer calculates the radiant exchange and thermal heat loss using dynamic simulation software and identifies the following interior surface temperatures:

- Floor: 22.4°C (72.32°F) (Note: The floor is not heated but is exposed to the ceiling of the floor below.)
- Ceiling: 23.5°C (74.3°F)
- Interior walls: 22.0°C (71.6°F)
- Exterior wall, opaque: 22.0°C (71.6°F)
- Window interior surface: 11.0°C (51.8°F)

The designer identifies the location of the representative occupant and chooses an occupant centered in the room, facing the exterior wall. Based on these input assumptions, the

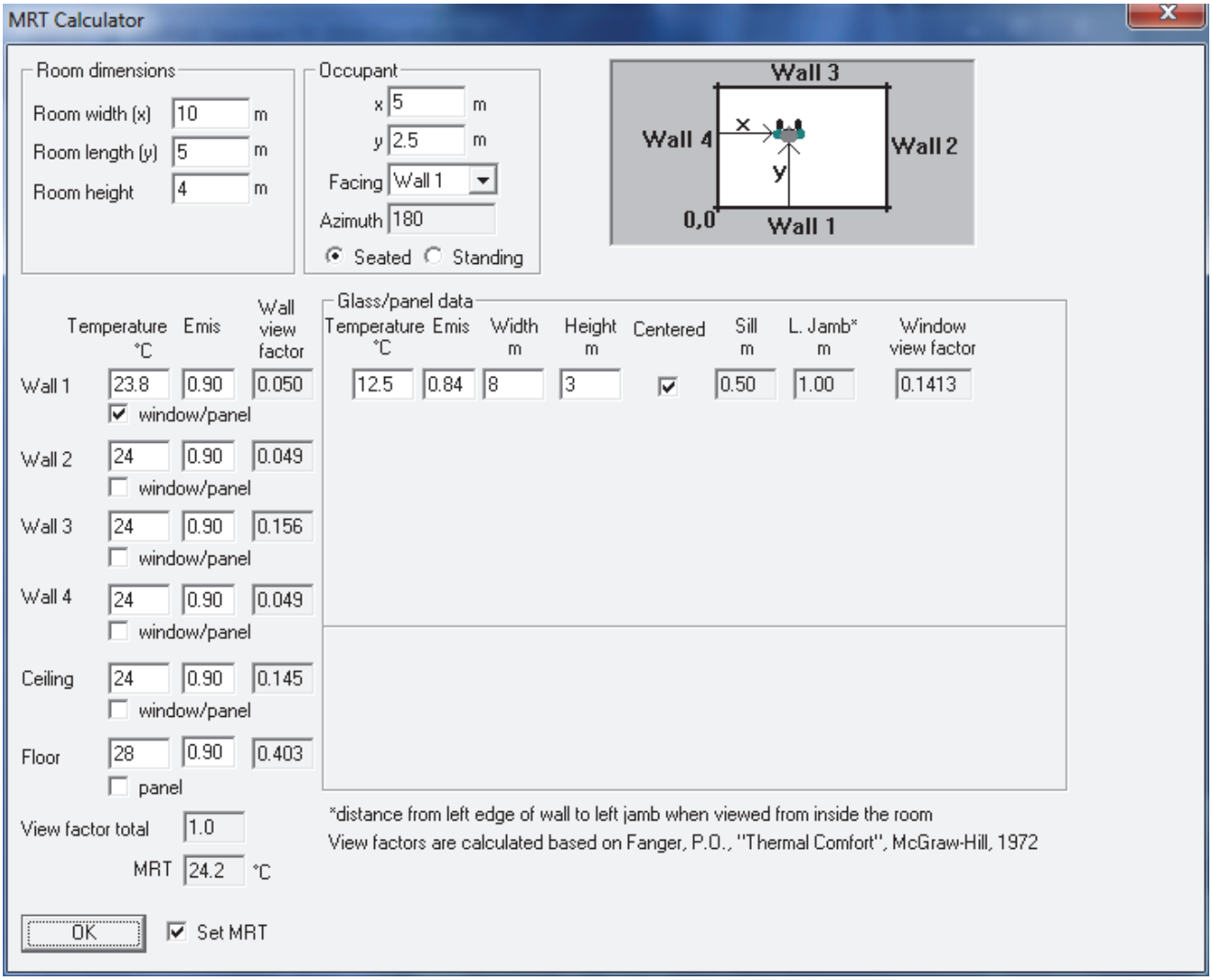


Figure 3-F MRT calculation using ASHRAE Thermal Comfort Tool for space with radiant system.

designer uses the ASHRAE Thermal Comfort Tool to calculate the mean radiant temperature (MRT) using the embedded MRT calculator as shown in Figure 3-E The designer calculates the MRT to be 20.9°C (70.0°F) per Figure 3-E.

Example 5: Space with Radiant Heating

Using the same space as defined in Example 4 (p. 14), the designer now decides to add a radiant heating system and chooses to heat the floor to 28°C (82.4°F).

The designer calculates the radiant exchange and thermal heat loss calculations using dynamic simulation software to yield the following interior surface temperatures:

- Floor: heated to 28°C (82.4°F)
- Ceiling: 24.0°C (75.2°F)
- Interior walls: 24.0°C (75.2°F)
- Exterior wall, opaque: 23.8°C (74.84°F)
- Window interior surface: 12.5°C (54.5°F)

The designer identifies the location of the representative occupant and chooses an occupant centered in the room, facing the exterior wall. Based on these input assumptions, the designer uses the ASHRAE Thermal Comfort Tool to calculate the MRT using the embed-

Table 3-C Case 2 Values for *A* as a Function of Relative Air Speed (V_r)

V_r	<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

ded MRT calculator as shown in Figure 3-F. The designer calculates the MRT to be 24.2 °C (75.56 °F) as shown in Figure 3-F.

Operative Temperature

Operative temperature is defined as 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.

Standard 55 requires that the operative temperature be calculated in accordance with *ASHRAE Handbook—Fundamentals*, Chapter 9, or one of the allowed methods in Normative Appendix A of the standard per the following:

Case 1: Average air temperature is permitted to be used in place of operative temperature when the following three conditions are met:

a. There is no radiant and/or radiant panel/slab heating or radiant panel/slab cooling system.
b. The area weighted average U-factor of the outside window/wall satisfies the following inequality:

$$U_W < \frac{50}{t_{d,i} - t_{d,e}} \qquad \text{(SI)}$$

$$U_W < \frac{15.8}{t_{d,i} - t_{d,e}} \qquad \text{(I-P)}$$

where

U_w = average U-factor of window/wall, W/m^2·K (Btu/h·ft^2·°F)
$t_{d,I}$ = internal design temperature, °C (°F)
$t_{d,e}$ = external design temperature, °C (°F)

c. Window solar heat gain coefficients (SHGC) are less than 0.48.

Case 2: Calculation of the operative temperature is based on average air temperature and mean radiant temperature. Operative temperature is permitted to be calculated per the following formula:

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

where

t_o = operative temperature
t_a = average air temperature
t_r = mean radiant temperature
A = can be selected from the values shown in Table 3-C as a function of the relative air speed (V_r).

Case 3: For representative occupants with metabolic rates between 1.0 and 1.3 met, not in direct sunlight, when the average air speed is less than 0.2 m/s (40 fpm), and where the difference between mean radiant temperature and average air temperature is less than 4°C (7°F), the operative temperature is permitted to be calculated as the mean of the average air temperature and mean radiant temperature.

4 General Requirements (§ 4)

Documentation Requirements (§ 4.1)

Section 6 specifies the documentation necessary to show compliance with the standard, including the design inputs, calculations and other assumptions. Section 4 states that when the standard requires that certain information be identified for compliance, the documentation of that information needs to meet the requirements of Section 6. However, in some cases, Section 5 requires the identification of additional information above and beyond Section 6 requirements as necessary and required by the authority to be in compliance with Standard 55. Appendix J provides an example template for documenting information necessary for compliance with the standard.

Note that the standard does not prescribe specific criteria for key design inputs, such as the selection of design weather conditions, when evaluating occupant thermal comfort. It is expected that the user will choose design conditions (for example in adaptive comfort) that are appropriate for a given location and building/space type. Typically, designers will choose ASHRAE climatic design conditions from *ASHRAE Handbook—Fundamentals*. For this user's manual, all examples have been developed based on using the ASHRAE climatic design conditions.

Identify Spaces (§ 4.2)

The user must declare to which space types the standard is being applied for any given building. Further, the user is required to clearly identify any spaces where the standard is not being applied. When identifying spaces where the standard is to be applied, the user should confirm that the space type is covered by the scope of the standard.

The standard has broad applicability to evaluating occupant thermal comfort in residential and nonresidential buildings. The standard itself does not specify a particular building or space type that is expressly included or excluded from its use. Based on the scope and limitations as explained in Section 2.1, Figure 4-A illustrates the limitations on the types of spaces to which the standard can be applied.

For some space types, the applicability of the standards needs to be evaluated on a case-by-case basis by the person conducting the evaluation. For example, a designer may choose to apply Standard 55 for kitchens in restaurants or to server rooms in office buildings, but there may be additional considerations, such as environmental conditions, necessary for the operation of certain process loads (e.g., computers in server rooms) that may supersede the evaluation of thermal comfort of the occupants.

Other space types, such as outdoor spaces, fall expressly out of the standard's scope, whereas support spaces within the building, such as stairwells and elevators, may not generally qualify for Standard 55 evaluation because the occupants in these spaces generally do not spend at least fifteen minutes in that space.

Identify at Least One Representative Occupant (§ 4.3)

A number of definitions and requirements in Standard 55 are applicable or dependent on establishing a representative occupants, though the standard does not dictate how a representative occupant should be chosen for a given space. Standard 55 leaves the decision to designate the status of representative occupant to the project design team and building operators. The intent is for a representative occupant or occupants to represent the range of con-

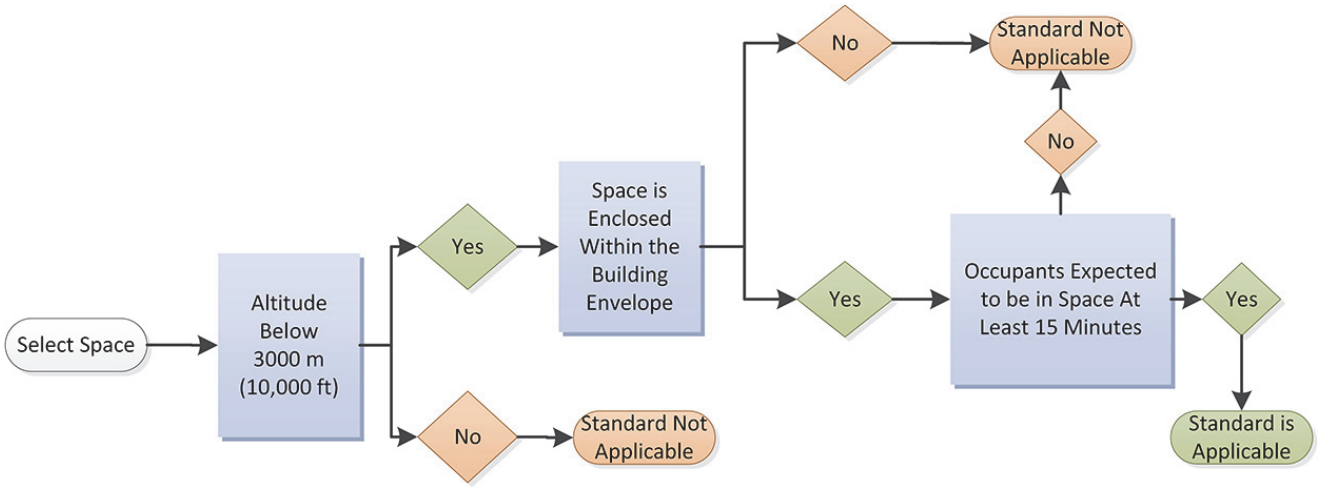


Figure 4-A Applicability criteria for identifying spaces.

ditions that will be experienced by the majority of occupants of a space in terms of the six factors affecting thermal comfort, as described in Section 5 of the standard.

The standard also specifies that the practitioner must identify any known persons that they are not including in the consideration for a representative occupant. There is no requirement in the standard to include all individuals in a given space to be represented in the compliance documentation. However, it is the responsibility of the designer to ensure that the representative occupants are indeed representative.

In some spaces, such as restaurants, where multiple activities are occurring at once, those occupants providing service are likely to have a different metabolic rate and clothing than those being served. Thus, the analysis must account for the different comfort needs of these types of occupants. The standard requires that in such instances the analysis be conducted separately for those providing service and those being served to show compliance.

Determine Met and Clo for a Representative Occupant (§ 4.4)

The standard requires the evaluator to specify two personal factors that affect the representative occupants' thermal comfort, namely metabolic rate (met) and the clothing insulation value (clo). Metabolic rate is used in the standard to represent the heat that the occupants generate depending on their level of activity while in the space. The clo value in turn represents the insulation quality of the occupants clothing while in the space.

It is important to note that in any given building, there is expected to be a range of metabolic rates and clothing insulation values for a given set of occupants. The user must exercise care in selecting appropriate met and clo values to represent these occupants. This user's manual presents more information on met and clo values used for Standard 55 calculations in Chapter 5 (p. 21).

Thermal Environment Required for Comfort (§ 4.5)

The standard specifies the indoor thermal environmental conditions that are required for predicting comfort of the representative occupants in Section 5. This user's manual explains the requirements in detail in Chapter 5 (p. 21).

5 Conditions that Provide Thermal Comfort (§ 5)

General Requirements (§ 5.1)

Section 5 of the standard outlines the core requirements that are used to determine acceptable thermal environment for each representative occupant of a space. Section 5.2 of the standard provides necessary information to determine the characteristics (met and clo) of the representative occupants. Sections 5.3 and 5.4 describe the method used to determine thermal comfort for the representative occupants in the space.

Factors Affecting Determination of Thermal Comfort

The standard uses six factors in determining acceptable thermal environment for the representative occupants in space in a steady state:

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

The first two factors are personal to the occupant and the remaining four factors are conditions of the thermal environment.

Personal Factors

The personal factors addressed in the standard are as follows:

a. Occupant activities and their associated **metabolic rate.** The level of activity of the occupant is associated with their metabolic rate, which in turn affects the thermal conditions at which they are likely to be comfortable. Of course the standard does not regulate or in any way try to control occupant activities. Rather, the expected or observed activity is used as an input to thermal comfort determination.
b. In a manner similar to that for occupant activities, the standard uses expected or observed occupant **clothing insulation properties** as an input to the determination of thermal comfort.

More details on how the metabolic rate and clothing insulation properties are provided in Method for Determining Occupant Characteristics (§ 5.2) (p. 25).

Environmental Factors

While many HVAC systems use closed-loop control for dry-bulb temperature alone, this is only one of four categories of environmental factors within the scope of the standard. The other three are thermal radiation, air speed, and humidity. In addition, there are four local factors that also must be considered.

Basic engineering states that the three modes of heat transfer are conduction, convection, and radiation.

Convection airflow may be thermally induced by buoyancy differences in heated or cooled air, or be forced by natural wind or mechanical fans. For this reason, both air temperature and air speed are important thermal comfort parameters and are addressed within the scope of Standard 55.

With regard to heat transfer by conduction to or from the human body in the interior environment, the consideration is for direct contact with furnishings and/or the floor. Floor temperature, which may be a significant source of heat loss or gain, or in the case of radiant cooling and heating, may be used to condition occupants and the space, is within the scope of the standard. Furnishings may have a significant effect on comfort (as when sitting on a conductive metal chair in a cool environment), and the standard addresses this by allowing the user to adjust the representative occupants' clothing insulation value in Table 5.2.2.2C of the standard.

Heat transfer by long-wave radiation to and from surrounding surfaces is within the scope of the standard. While the scope also allows for heat transferred to the body by direct solar radiation or diffuse sky radiation, solar (short-wave) radiant gains are not currently addressed.

Therefore, the four broad environmental factors addressed in the standard are as follows:

a. **Air temperature** may be expressed as local at a point or average in a space. Discomfort may be global, based on the room average, or may be local, for instance due to temperature stratification. Both are within the scope and are addressed in the body of the standard.

b. Thermal radiation effects due to surface temperatures are used in determination of mean **radiant temperature** and operative temperature and local discomfort caused, for example, by a cold window on one side and a hot wall on the other, an effect referred to as "radiant asymmetry."

c. Space **humidity** is important to the evaporative heat transfer process from the human body. Humidity is addressed only as a room average and not as having a local effect.

d. **Air speed**, as described above, is important to the rate of convective cooling of the body as well as its rate of evaporative heat transfer. This effect can be room-wide or local. It may be experienced as a beneficial cooling effect or as a negative effect, as in draft. Draft is considered by the standard to be a local effect (i.e., local to a person and not to the entire space).

It is important to note that all six of these general factors can vary with time. The standard uses average conditions for factors such as air speed and air temperature. "Average air speed" and "average air temperature" have precise definitions in the standard, as described in Section 3.2. Many engineers, designers, raters, and practitioners incorrectly equate thermal comfort with acceptable indoor air temperature and humidity alone. It is important to note that the standard requires that all six general factors must be addressed together with the four local factors in defining conditions for acceptable thermal comfort (see Local Thermal Discomfort [§ 5.3.4] [p. 37] for compliance with local factors).

Flow Chart for Applicability of Using Section 5

Figure 5-A shows the applicability of Section 5 to a project.

Choice of Method for Determining Thermal Comfort

When a user decides to determine thermal comfort for the representative occupants, the standard allows a choice of prescribed methods (Figure 5-B), which are outlined in Section 5 of the standard.

Sections 5.3 and 5.4 offer two distinct approaches to determine thermal comfort, and the standard requires that the user select one of the two in its entirety. This is critical because Section 5.4 of the standard applies only to those spaces that are naturally conditioned and where thermal comfort is directly in control of the occupants. Section 5.3 of the standard applies to any space that is within the scope of the standard.

Section 5.3 identifies three methods of determining thermal comfort of the representative occupants: the graphical method, the analytical method, and the elevated air speed method

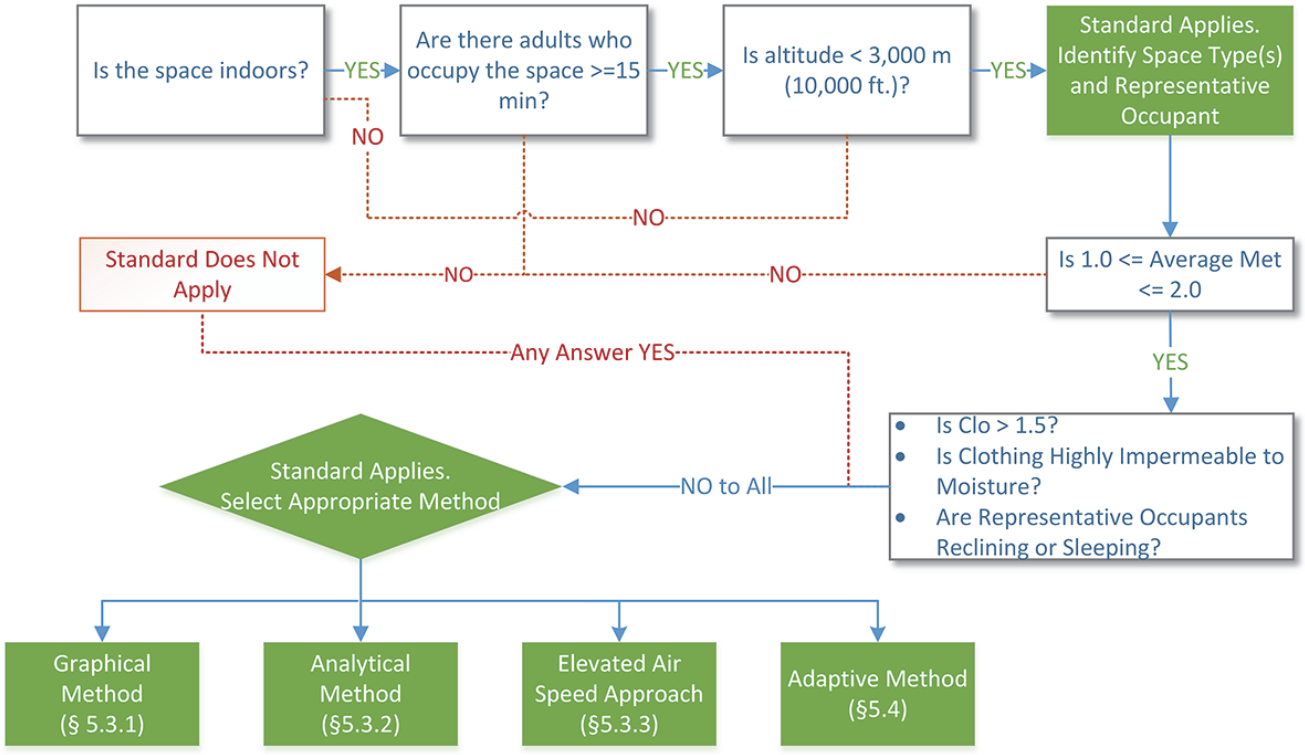


Figure 5-A Standard 55 usage flow chart for using Section 5.

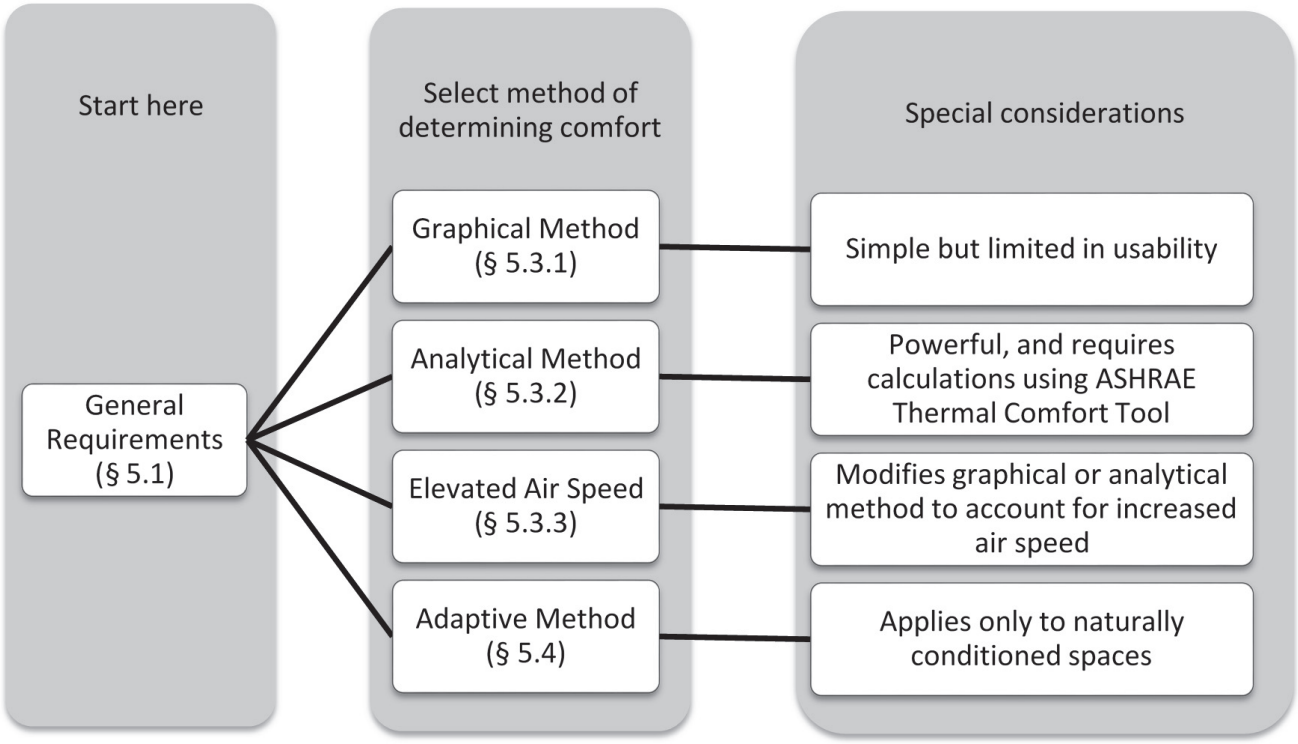


Figure 5-B Methods of determining thermal comfort.

Table 5-A Thermal Comfort Factors Limiting Choice of Method of Determining Thermal Comfort

Air Speed	Humidity Ratio	met	clo	Other	Comfort Zone Method
<0.2 m/s (40 fpm)	<0.012 kg H_2O/kg dry air	1.0 to 1.3 met	0.5 to 1.0 clo		§ 5.3.1 (graphical method)
< 0.2 m/s (40 fpm)	Any	1.0 to 2.0 met	0 to 1.5 clo		§ 5.3.2 (analytical method)
>0.2 m/s (40 fpm)	Any	1.0 to 2.0 met	0 to 1.5 clo		§ 5.3.3 (elevated air speed method)
Any	Any	1.0 to 1.3 met	Free to adjust within a range at least as wide as 0.5 to 1.0 clo	$t_{db} \approx$ MRT; No cooling installed, heat not operating, occupants control openings, prevailing mean OAT 10°C to 33.5°C (50°F to 92.3°F)	§ 5.4 (adaptive method)

(to accommodate thermal comfort impacts of higher air speeds than are allowed under the graphical or analytical methods). In this user's manual, we expand on each of these approaches and methods in more detail.

The four methods (graphical, analytical, elevated air speed, and adaptive) of evaluating thermal comfort are not necessarily applicable to every situation. The standard defines limits on the range of environmental and personal factors that each method is allowed to consider. Generally speaking, the standard sets tighter limits on the range of factors when using the graphical method and is least restrictive when using the adaptive method.

It is the evaluator's responsibility to ensure that they are using the correct method based on the known and predicted conditions of the space and the representative occupants within the space. When documenting compliance with the standard, Section 6 of the standard requires the practitioner to document assumptions regarding the six comfort factors described in Factors Affecting Determination of Thermal Comfort (p. 21) and whether the use of the specific method of compliance is justified.

Table 5-A shows the limits on thermal comfort factors that can be used within each of the four methods of determining thermal comfort of the representative occupant.

A few things stand out in terms of comfort factors that are outside the scope of the standard:

a. Metabolic rates above 2.0

b. Clothing insulation values above 1.5 clo

The standard does not address these higher metabolic and clothing levels because little comfort research has been conducted at these levels, and there are insufficient generalizable data for this purpose. The standard takes care in disclaiming responsibility for these levels.

However, existing studies show that comfort expectations at higher met rates (such as standing and walking somewhere or exercising in a gym) are lower than those for sedentary activity. People are less sensitive to the thermal environment when exercising. Similarly, comfort outdoors is perceived with less sensitivity than comfort indoors, especially in cool conditions with higher clothing levels. As a result, current evidence suggests that use of Standard 55 for these higher met and clo levels would be conservative, producing a lower estimate of comfort than is actually the case.

The same applies to transient, nonsedentary situations common indoors that are not addressed by the standard because they take place in less than 15 minutes time. An example would be a momentary excursion away from the desk, such as standing and climbing a flight

of stairs or moving to lift boxes of copier paper. In such circumstances, the metabolic rate responds to the activity change in seconds, but it takes several minutes for the heat from the step-up in metabolic rate to impact comfort. The delay is partly due to the lower expectation mentioned above, partly due to cooling by self-generated air motion as one walks or exercises, and partly due to the time it takes for metabolic heat to be absorbed into the body's tissue. This time delay causes comfort perceptions to lag as much as 15 minutes and encompasses many kinds of typical transient activities indoors. The step back down also takes time but not if the person has an available mechanism (fan or operable window) for accelerating the removal of accumulated heat after sitting. In this case, the resumption of sedentary comfort occurs within seconds. People anticipate the resumption of expected comfort levels if their condition is moving in the comfortable direction.

Finally, there are spatially nonuniform situations that are not addressed by the standard, such as heated benches that warm people by conduction, overhead radiant heaters that heat people's upper bodies in outdoor cafés in cool weather, and fan and mist cooling used to cool the upper body in outdoor cafés in warm weather. These can be perceived as very comfortable over long time periods but are not addressed by the standard. They rely on the body's perceptions of pleasant temperature differences between individual parts and the whole body. If the whole body is cooler or warmer than neutral, stimulating a local body part in the opposite direction is perceived as very pleasant, not only for the part but for the body as a whole. In this way a wider range of ambient temperatures can be comfortable than is possible for uniform temperatures.

Method for Determining Occupant Characteristics (§ 5.2)

Rate for Each Representative Occupant (§ 5.2.1.1)

The standard requires that the metabolic rate for each representative occupant be taken into consideration. Section 5.2.1.1 of the standard specifies that it is not allowed to use the average metabolic rate to represent multiple occupants with significantly different metabolic rates. The standard provides the example of a restaurant where the customers may have a metabolic rate close to 1.0 met and the servers may have a metabolic rate close to 2.0 met. The standard specifies that the customer and server must be considered separately to determine acceptable thermal comfort conditions. It is likely in some cases that an acceptable level or the same level of comfort may not be achievable for all of the different occupants. Thus the choice of which occupant types are chosen as representative plays a large role in determining the comfort requirements for the space.

Another example for differing metabolic rates is 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, the occupants can be grouped as a single representative occupant. If the same seated occupant is compared with an occupant who is seated and filing at 1.2 met, each should be considered separately when determining the conditions required for thermal comfort.

High Metabolic Rates (§ 5.2.1.4)

The standard does not apply to occupants whose time-averaged metabolic rate exceeds 2.0 met. As seen in Figure 5-C, activities such as walking at 6.8 km/h (4.2 mph), house cleaning, dancing, playing sports, working with heavy machinery, and many recreational activities have met rates above 2.0 and therefore do not fall under the purview of the standard.

Rate Determination (§ 5.2.1.2)

The standard allows one or a combination of the following methods for determining metabolic rate for the representative occupant:

a. Table 5.2.1.2 of the standard provides metabolic rates for a variety of common activities, such as sitting, standing, walking, office activities, and leisure activities, among others.

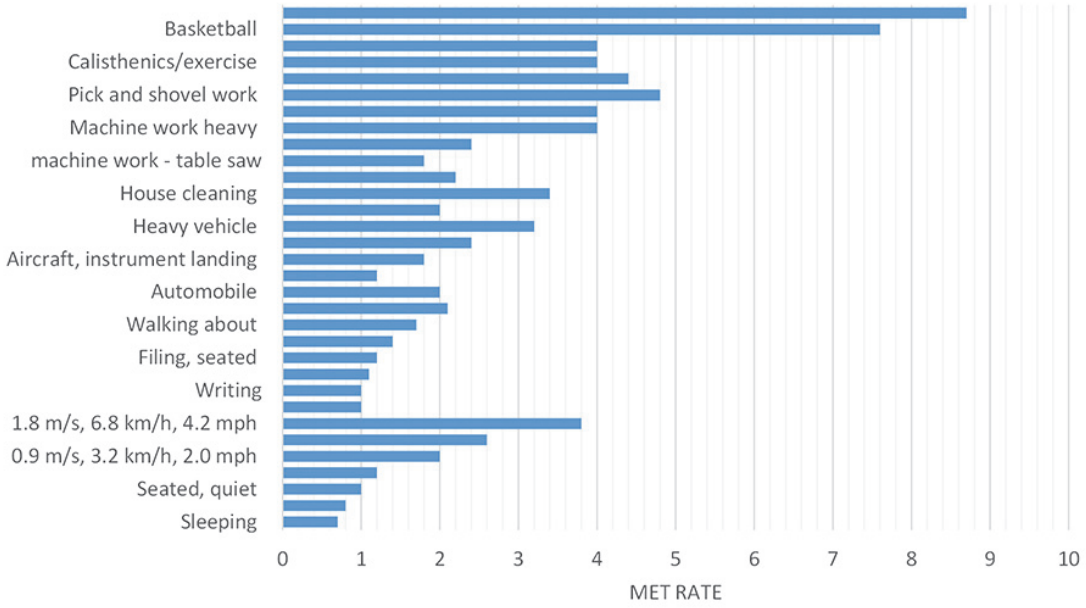


Figure 5-C Metabolic rate by activity level.

b. It is permissible to interpolate between or extrapolate from the values given in Table 5.2.1.2 of the standard.
c. Users can also refer to the estimation and/or measurement methods described in *ASHRAE Handbook—Fundamentals*, Chapter 9.
d. The standard allows other approved engineering or physiological methods to estimate metabolic rates.

This user's manual does not reproduce the Table 5.2.1.2 from the standard, but Figure 5-C presents a simplified representation of how the met rate increases with increased activity level.

Generally speaking, the more sedentary the activity is, the less the metabolic rate tends to be. Thus sleeping and reclining have the lowest met rate. On the other hand, activities such as playing basketball or using heavy machinery, which involve hard physical labor, will result in high metabolic rates. For most office spaces, at home or in commercial settings, the metabolic rate will likely fall between 1.0 and 2.1 met.

Time-Weighted Averaging (§ 5.2.1.3)

In most instances, the metabolic rate of the representative occupant changes over time. The standard allows averaging metabolic rate for a representative occupant as long as the activities in which the occupant are engaged are less than one hour in length. When an activity extends for more than an hour, the metabolic rate for that activity must be considered separate from the other metabolic rates for that representative occupant.

To take the example of the office space explained in Section 3.2.2, metabolic rates for the office workers can be estimated using expected activity levels, and using the time-weighted averaging method described above, the user can develop the estimates for met rates shown in Table 5-B, depending on what level of activity they predict for the representative occupant.

Clothing Insulation (§ 5.2.2)
Determination of Clo Value for Representative Occupants (§ 5.2.2.1)

The standard requires that the clothing insulation (I_{cl}) described in units of clo must be determined for each representative occupant. The standard does not dictate or require specific clo values for the representative occupant but rather decides on whether or not a user

Table 5-B Calculating Time-Weighted Met Rate for Representative Occupant

Representative Occupant Groups	Activity	
	Description and Duration	Time-Weighted Met Rate
Sedentary worker	100% of time: seated, typing	1.1
Mildly active worker	50% of time: seated, typing 50% of time: filing, standing	(0.5 × 1.1) + (0.5 × 1.4) = 1.25
Active worker	15% of time: seated, typing 85% of time, walking about	(0.15 × 1.1) + (0.85 × 1.7) = 1.61

can apply the standard to a space, depending on the predicted clo values of the representative occupants.

It is likely that a given space contains occupants with clo values that differ due to personal choice and gender-based clothing, among other factors. Thus, even in a space that has a strict dress code, male occupants are likely to have a different clo value than female occupants.

Averaging of Clo Values across Multiple Representative Occupants not Allowed (§ 5.2.2.1.2)

The standard anticipates situations where occupant clo values may differ from person to person and prohibits the averaging of clo values across multiple representative occupants. The reason for this is that when the representative occupants cannot vary their clo values on a real-time basis, the average will result in those with higher clo likely feeling too warm and those with the lower clo likely feeling too cold.

The standard does allow an exception when the occupants are allowed and are free to adjust clothing to respond to the thermal environment. In such instances, the standard allows the use of a single representative occupant with an average clothing insulation value to represent all of the representative occupants. This may be the case, for example, in a residential setting where occupants generally have full control over their clothing assemblies.

Methods for Determining Clothing Insulation Levels (§ 5.2.2.2)

As with metabolic rate, the clothing insulation values are predicted based on what a representative occupant is likely to wear while being within the space. The standard allows several methods for determining the clothing insulation value for the representative occupant and is permissive in allowing one or a combination of the following methods to determine clo:

a. The simplest method is to look up the clothing insulation values for a given ensemble of clothing. The standard provides these ensembles and their associated clo values in Table 5.2.2.2A, presented here in Figure 5-D.

b. The Standard allows the user to adjust the clo values from Table 5.2.2.2A by adding or subtracting clo values for individual garments. Clo values for typical individual garments are provided in Table 5.2.2.2B. This allows the user to build a custom assembly of clothing that is most representative of the occupants.

c. The standard also allows one to create a new clothing ensemble by combining individual garments listed in Table 5.2.2.2B.

d. The standard allows the user to consider the clothing insulation value of the chair if the representative occupant is seated. Table 5.2.2.2C provides a range of clo values for different types of chairs (Table 5-C), which can be added to the clo value of the representative occupant themselves. Note that this is only allowed if the clothing ensemble would otherwise have a clo value between 0.5 and 1.2 when the occupant is standing. Thus, one cannot use the chair as clo if the representative occupant is wearing minimal clothing (clo < 0.5) or if the representative occupant is wearing thick protective clothing (clo > 1.2).

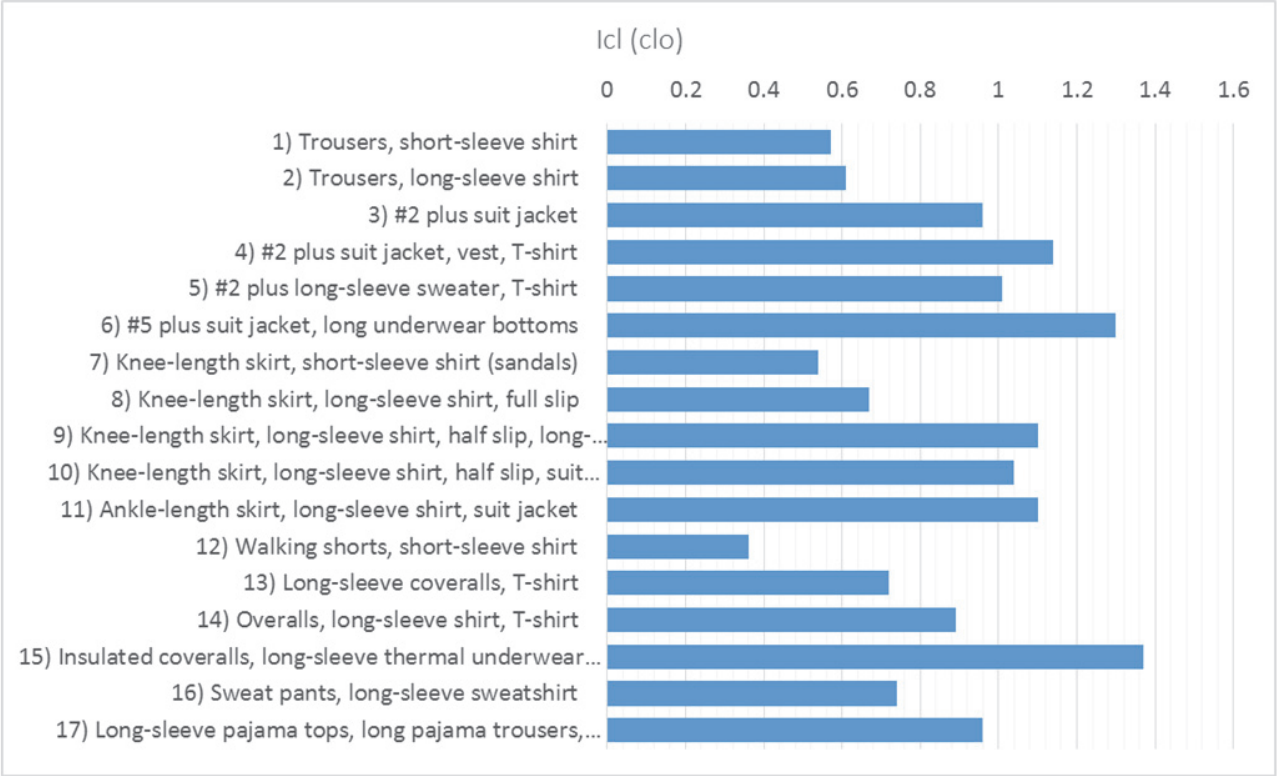


Figure 5-D Representative clo values for various clothing ensembles.

Table 5-C Clo Values for Chairs
(Source: Standard 55-2013, Table 5.2.2.2C)

Net chair	0.00 clo
Metal chair	0.00 clo
Wooden side arm chair	0.00 clo
Wooden stool	+0.01 clo
Standard office chair	+0.10 clo
Executive chair	+0.15 clo

e. Further, the standard allows the user to interpolate or extrapolate from the values given in Tables 5.2.2.2B and 5.2.2.2C as necessary to more accurately represent the occupants.

f. In some cases, the user may not know the specifics of the clothing assemblies that the representative occupants are likely to wear. The standard does allow for a method to calculate the likely representative clo value for the representative occupant as a function of the outdoor air temperature at 6:00 a.m (Figure 5-E). The rationale is that the occupant is likely to dress according to the weather and will likely dress up or down as necessary based on the prevailing temperature that morning.

   The standard allows the user to adjust the clo value higher or lower based on either cultural factors or unique dress codes using the other methods described in this section of the standard or using approved engineering methods.

g. Last, the standard allows the user to specify clo value based on measurements with thermal manikins or using other approved engineering methods.

As seen from this exhaustive list of allowed methods, and interpolations or extrapolations from the allowed methods, the standard allows a wide range of latitude for the user to determine the appropriate clothing insulation values for the representative occupant.

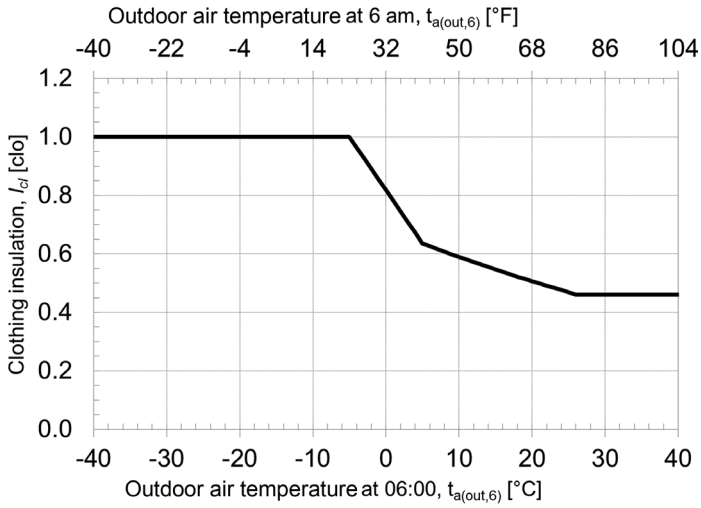


Figure 5-E Estimating clo values based on outdoor air temperature at 6:00 a.m.
(Source: ASHRAE Standard 55-2013, Figure 5.2.2.2)

Table 5-D Example Clothing Insulation Values for Office Occupants

Representative Occupant Groups	Summer Ensemble	Clo	Winter Ensemble	Clo
Male worker	Long pants (thin), socks, undergarments, shoes, t-shirt, long sleeve dress shirt (no jacket)	0.57	Long pants (thick), socks, undergarments, shoes, t-shirt, long sleeve dress shirt, suit jacket (thick)	1.10
Female worker	Skirt, no socks, sandals, undergarments, short sleeve blouse	0.39	Long pants (thick), socks, undergarments, shoes, long sleeve dress shirt, suit jacket (thick)	0.97

Table 5-E Example Calculation Using Standard 55-2013, Table 5.2.2.2B, for a Male Worker in Winter

Clothing Item	Clo Value
Men's briefs	0.04
T-shirt	0.08
Calf-length socks	0.03
Shoes	0.02
Straight trousers, thick	0.24
Long sleeve dress shirt	0.25
Single-breasted suit jacket, thick	0.44
Total Ensemble:	**1.10**

Example Clo Calculation for Office Occupants

Representative occupant clothing levels are based on assumptions of typical office workplace attire commensurate with outdoor weather conditions that correspond to design day conditions. This example assumes that the occupant is dressed in clothing that is suitable for the outdoor conditions—for example, in winter, wearing a heavy-weight suit based on a design day temperature of –8°C (7.3°F).

The user should consult with the client related to office attire ranges and any workplace requirements that prescribe clothing levels to determine appropriate clothing ensembles. In this example, it is assumed that the user selects the clothing ensembles and overall clo values shown in Table 5-D. Example calculations are shown in Table 5-E.

Table 5-F Limitations to Applicability of the Graphical Method

Air Speed	Humidity Ratio	Met	Clo
<0.2 m/s (40 fpm)	<0.012 kg H_2O/kg dry air [a]	1.0 to 1.3 met	0.5 to 1.0 clo

a. 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).

Graphical Method (§ 5.3.1)

The graphical method, as the name implies, is a method where the user can use an easy to read graphical representation of the range of thermal comfort factors that can result in a comfortable thermal environment for the representative occupant.

Applicability of the Graphical Method (§ 5.3.1.1)

The graphical method is limited in its applicability to those situations where the representative occupants and the environmental conditions are within the ranges shown in Table 5-F.

Methodology (§ 5.3.1.2)

The graphical method builds on the psychrometric chart that is known to most practicing engineers or HVAC technicians. Figure 5.3.1 (Figure 5-F) of the standard specifies the comfort zone for environments that meet the criteria described in this user's manual.

The graphical method shows two thermal comfort zones—one for a representative occupant with 0.50 clo of clothing and one for a representative occupant with 1.0 clo of insulation. Note that in many instances, and in past versions of the standard, the two comfort zones have been colloquially called the "summer" and "winter" comfort zones. While it is possible that in summer conditions the representative occupants are at 0.50 clo and in winter they are at 1.0 clo, that is not always the case. Thus, the comfort zones should be associated with clo value of the occupants and *not* with the seasons (summer/winter).

Figure 5.3.1 of the standard includes several notes that clarify the limitations and use of the graphical method. One note of specific importance is that the graphical method is based on the operative temperature (t_{op}) of the space and not on the dry-bulb air temperature (t_{db}). The standard specifies in Normative Appendix A how to calculate the operative temperature.

Further, the graphical method encourages the user to review the requirements of Section 5.3.4, "Local Thermal Discomfort," and Section 5.3.5, "Temperature Variations with Time."

The graphical method is based on a series of calculations conducted using the analytical method for set of comfort inputs and resultant PMV and PPD values shown in Table 5-G.

Estimate Thermal Comfort for clo Values between 0.5 and 1.0

The standard allows the user to estimate thermal comfort for clothing insulation values between 0.5 and 1.0 clo by linearly interpolating between the limits for the two clo values using the following equations:

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

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

where

$t_{max,\ Icl}$ = upper operative temperature (t_o) limit for clothing insulation (I_{cl})
$t_{min,\ Icl}$ = lower operative temperature (t_o) limit for clothing insulation (I_{cl})
I_{cl} = thermal insulation of the clothing in question, clo

Increased Air Speed

Section 5.3.1 of the standard only applies when the average air speed is less than 0.2 m/s (40 fpm). The standard, however, provides a separate method that can be used to decrease the lower limit and increase the upper limit on operative temperature for the comfort zone. This method is described in Section 5.3.3 of the standard and explained in Elevated Air Speed (§ 5.3.3) (p. 34).