



Fundamentals of HVAC

Thermal Comfort



What you will Learn in this Lesson

- Introduction: What is Thermal Comfort?
- Seven Factors Influencing thermal Comfort
- Conditions for Comfort
- Managing Under less than ideal conditions
- Requirements of non-standard groups
- ASHRAE Standard 55

At the end of this Lesson you will:

- List seven factors influencing thermal comfort
- Explain why thermal comfort depends on the individual as well as the thermal conditions
- Choose acceptable thermal design conditions
- Explain the component parts of Standard 55
- Explain how to effectively use Standard 55 in a thermal comfort dispute

Introduction: What is Environmental Comfort?

- There are six different aspects of *Environmental Comfort*
 - Thermal Conditions
 - Air Quality
 - Pollutants
 - Odors
 - Acoustics
 - Sound pressure
 - Sound quality
 - Lighting
 - Lumens
 - Color
 - Physical space
 - Size, color, ergonomics
 - Psychosocial
 - Relationships

Introduction: What is Thermal Comfort?

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

Introduction: What is Thermal Comfort?

- This lesson deals only with Thermal Comfort

Seven factors influencing Thermal Comfort

- 1) Activity Level
- 2) Clothing
- 3) Occupant Expectations
- 4) Air Temperature
- 5) Radiant Temperature
- 6) Humidity
- 7) Air Speed

Activity Level

- We are all heat engines!
- Our engines run on food and generate heat through a process called “metabolism”
- The unit of measure (we measure everything) is called the “met”
- One met is the heat output per unit area of skin for an individual who is seated and at rest

Activity

- In order to predict thermal comfort we need to know the met level of the occupants
- Most met measurements have been done in office settings
- The standard comfort parameters assume a certain met level
- The first controlled experiments in human metabolism were published by [Santorio Santorio](#) in 1614 in his book *Ars de statica medicina*. He described how he weighed himself before and after eating, sleep, working, sex, fasting, drinking, and excreting. He found that most of the food he took in was lost through what he called "insensible perspiration".

Metabolism

- [Santorio Santorio](#) in his steelyard balance, from *Ars de statica medicina*, first published 1614

Met Levels

Activity	Met*
Sleeping	0.7
Reading or writing, seated in office	1.0
Filing, standing in an office	1.4
Walking about in office	1.7
Walking 2 mph	2.0
Housecleaning	2.0 to 3.4
Dancing, social	2.4 to 4.4
Heavy machine work	4.0

* 1 met = 18.4 Btu/hr-sqft

Clothing

- Most people wear clothes
- Some even wear them for reasons other than style
- Clothes are an insulator
- In order to predict comfort we need to know about clothes
- The insulating value of clothes has a metric also:
 - The “clo”

Clothes

- clo values of all the articles on a person are added together to form the total clo value

<u>Ensemble Description</u>	<u>clo</u>
Trouser, short sleeve shirt	0.57
Knee-length skirt, short-sleeve shirt (sandals)	0.54
Trousers, long-sleeved shirt, skirt w/ half slip, panty hose, long-sleeved sweater	1.10
Long-sleeved coveralls, T-shirt	0.72

**Includes shoes, socks and light underwear

Table 8 Garment Insulation Values

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

^a"Thin" garments are summerweight; "thick" garments are winterweight.

^b1 clo = 0.88 °F · ft² · h/Btu

^cKnee-length

What is your clo value?

Occupants Expectations

- Perception means a lot in thermal comfort
- There is a phenomenon known as adaptation
- When someone walks into an air-conditioned building, they expect the building to be thermally “comfortable”
- If someone walks into an economical motel building with obvious natural ventilation and open windows, they have lower expectations
- People who can control their own environment are usually more satisfied

Air Temperature

- The temperature of the air in most rooms is not uniform
- Dry bulb temperature can and does vary from place to place in the room and from head to toe
- Temperature will vary with time

Stratification

- Some designs purposefully stratify the air

Radiant Temperature

- Radiant heat is transmitted from a hotter body to a colder body with no effect on the intervening space.
- The radiant temperature is the temperature at which a black body emits as much radiant heat as it receives from its surroundings.

Radiant Temperature

- A person sitting next to a large window on a hot summer day will experience a radiant heat gain from the window and “feel” hotter than the air temperature would indicate
- The temperature that the person feels is the weighted average of the temperatures of the air and all the surfaces in the room, including the windows

Mean Radiant Temperature

$$T_r^4 = T_1^4 F_{p1} + \dots T_n^4 F_{pn}$$

Where:

T_r = Mean Radiant Temperature

F_p = Angle factor between person and surface

T_n = Temperature of surface

Floor/Ceiling

- Heating ceiling panels
 - Relatively high temperature
- Heated radiant floor
 - Modestly elevated temperature

Wall/Window

- Window can be either very hot or very cold
- Baseboard can be convective only or both convective and radiant

Operative Temperature

The operative temperature is the uniform temperature of a radiantly black enclosure in which an occupant exchanges the same amount of heat by radiation plus convection as in the actual non-uniform environment

$$T_o = (T_a + T_r)/2$$

Where:

T_o = operative temperature

T_a = air temperature

T_r = mean radiant temperature

Effective Temperature

- For given values of humidity, air speed, metabolic rate, and clothing insulation, a comfort zone may be determined
- This particular chart is specific to the conditions indicated in the standard
- The sloped lines are lines of constant Effective Temperature (ET*)

Effective Temperature

$$ET^* = T_o + wi_m LR(p_a - 0.5p_{ET^*,s})$$

Where:

T_o = operative temperature

w = skin wetness, dimensionless (0.06)

p_a = water vapor pressure in ambient air, psi

ET^* = effective temperature

$p_{ET^*,s}$ = saturated vapor pressure at ET^* , psi

LR = Lewis Ratio (205 F/psi)

i_m = vapor permeation efficiency (~0.4)

Humidity

- As a parameter for thermal comfort, humidity has an important place
- High humidity reduces the bodies ability to regulate internal core temperature and, in excess, can cause adverse health effects
- Low humidity however, is not considered an important parameter to thermal comfort
- Low humidity will cause specific problems such as dry skin, dry eyes, and static electricity
- The current standard for thermal comfort is to limit the humidity ratio to less than $0.012 \text{ lb}_{\text{mw}}/\text{lb}_{\text{da}}$ or 84 gr/lb

Air Speed

- The higher the air speed over a persons body the greater the cooling effect
- Air velocities over 40 feet per minute (fpm), or cool temperatures combined with any air movement, may cause discomfort (also known as a draft)
- Drafts are most noticeable when they blow across the feet and/or the head and neck level, because individuals tend to have less protection from clothing in these areas

Effective Draft Temperature

$$\Theta_{ed} = (T_x - T_c) - 0.07(V_x - 30)$$

Where

Θ_{ed} = effective draft temperature

T_x = local airstream dry-bulb temperature °F

V_x = local air speed, fpm

T_c = average room dry-bulb temperature °F

Conditions for Comfort

- Occupant control of thermal environment
 - Operable windows?
 - Operable thermostat?
 - Air velocity and direction control?
- Gender
- ASHRAE thermal sensation scale

Occupant Control of Environment

- Operable Windows
 - People behave differently when they have a window they can open
 - Less demanding because they take ownership of the environment
 - More likely to modify their clothing to match the outdoor environment
 - More likely to accept a wide range of temperatures
- Operable thermostat
 - Not a placebo
 - Must actually affect the space temperature
- Air velocity and direction

Gender

- There are real physiological reasons for gender preferences
- Metabolic rate differences
- Clothing choice differences
- Thermal sensation differences (ASHRAE Scale)

ASHRAE Thermal Sensation Scale

- An index from:
 - +3 Hot
 - +2 Warm
 - +1 Slightly Warm
 - 0 Neutral
 - -1 Slightly Cool
 - -2 Cool
 - -3 Cold
- Calculated at CLO 0.5 and velocities < 40 fpm
- Different scales for men and women
- A function of temperature, vapor pressure, and time

ASHRAE Thermal Sensation Scale

- 1.0 hour exposure
 - Men $Y = 0.122t + 1.61p - 9.584$
 - Women $Y = 0.151t + 1.71p - 12.080$
 - Both $Y = 0.136t + 1.71p - 10.880$
- 2.0 hour exposure
 - Men $Y = 0.123t + 1.86p - 9.953$
 - Women $Y = 0.157t + 1.45p - 12.725$
 - Both $Y = 0.140t + 1.62p - 11.339$
- 3.0 hour exposure
 - Men $Y = 0.118t + 2.02p - 9.718$
 - Women $Y = 0.153t + 1.76p - 13.511$
 - Both $Y = 0.135t + 1.92p - 11.122$

Managing Under Less Than Ideal Conditions

- The comfort envelope chart assumes ideal conditions
 - Velocity < 40 fpm
 - Uniform air temperature distribution
 - Normal radiant temperatures on walls, ceiling and floor
- Not all situations have these conditions

Managing Under Less Than Ideal Conditions

- Elevated air speed
 - Excess air speed causes increased cooling on skin
 - This cooling effect can be used when dry bulb temperatures are elevated
 - Up to 5 °F if velocity is below 160 fpm (e.g. desk fan)
 - Occupant control is critical
 - Drafts cause complaints depending upon the temperature
- Vertical temperature difference
 - In heated spaces, a large temperature difference between feet and head causes complaints
 - Cold floor slabs causes cold air temps at the floor
 - A 5 °F variation is the maximum acceptable difference

Managing Under Less Than Ideal Conditions

- Floor surface temperature
 - Should be within the range of 66 to 84 °F
 - If occupants sit on floor or are shoeless, the range is smaller
 - Cold floors can make it impossible for comfort even if the air temp is normal
- Cyclic Temperature Changes
 - Occupants experience discomfort when the air temperature cycles quickly
 - On/off HVAC will cause this such as a unit heater with slow response
 - If cycles are frequent (i.e. < 15 minutes) temperature range should be < 2 °F

Managing Under Less Than Ideal Conditions

- Radiant temperature variation
 - Some radiant variation is acceptable
 - Most people will accept warm walls, or warm windows
 - Warm ceilings cause discomfort
 - Radiant panels or ceiling tile with temps > 9 °F above space setpoint cause discomfort
 - Poor roof insulation can cause this
 - In some cases, displacement ventilation can cause the occupant to experience warm ceiling due to the high air temp above
 - Stay < 9 °F above set point.

Requirements for Non-Standard Groups

- Comfort conditions for children, the disabled, the infirm or for sleeping occupants are different than for standard healthy adults
- Comfort conditions are different for occupants with different activity levels or different clothing levels than the standard values
- Occupants desire different space temps in different seasons:
 - Warmer in winter; cooler in summer
 - Due to radiant wall temps

Introduction to ANSI/ASHRAE Standard 55

ANSI/ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy

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.

Scope

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 since comfort in the indoor environment is complex and responds to the interaction of all of the factors that are addressed.

Scope

- 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.

Component Parts of Standard 55

- General Requirements
- Conditions that provide thermal comfort
- Compliance
- Evaluation of the thermal environment

General Requirements

- The first requirement is to be careful how the standard is applied
 - It is specific to a space, and to specific people who are adapted (i.e. resident for more than 15 minutes)
 - It is specific to the activity level and the clothing of the people
 - It isn't possible to achieve an acceptable thermal environment for all occupants in a space
- Compliance follows one of two optional paths
 - For traditionally controlled environments, the values of the environment parameters that will satisfy 80% of occupants are specified
 - For naturally controlled environments a range of acceptable operative temperatures is shown for outdoor temperature ranges between 50 and 92.3 °F

Proper Use of Standard 55 in Dispute Resolution

- The standard can establish the proper values of the important parameters for comfort
- Investigation must establish the activity levels and clothing insulation of the people in question
- Measurements:
 - Air velocity and the change of velocity with time
 - Average temperature
 - Temperature gradient with height and time
 - Humidity

Educate all parties that the standard is written to satisfy 80% of occupants.

End of Lesson

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