Thermal Comfort

Where the person goes,
so goes their thermal
experience.

A Guide for Owners and Occupants

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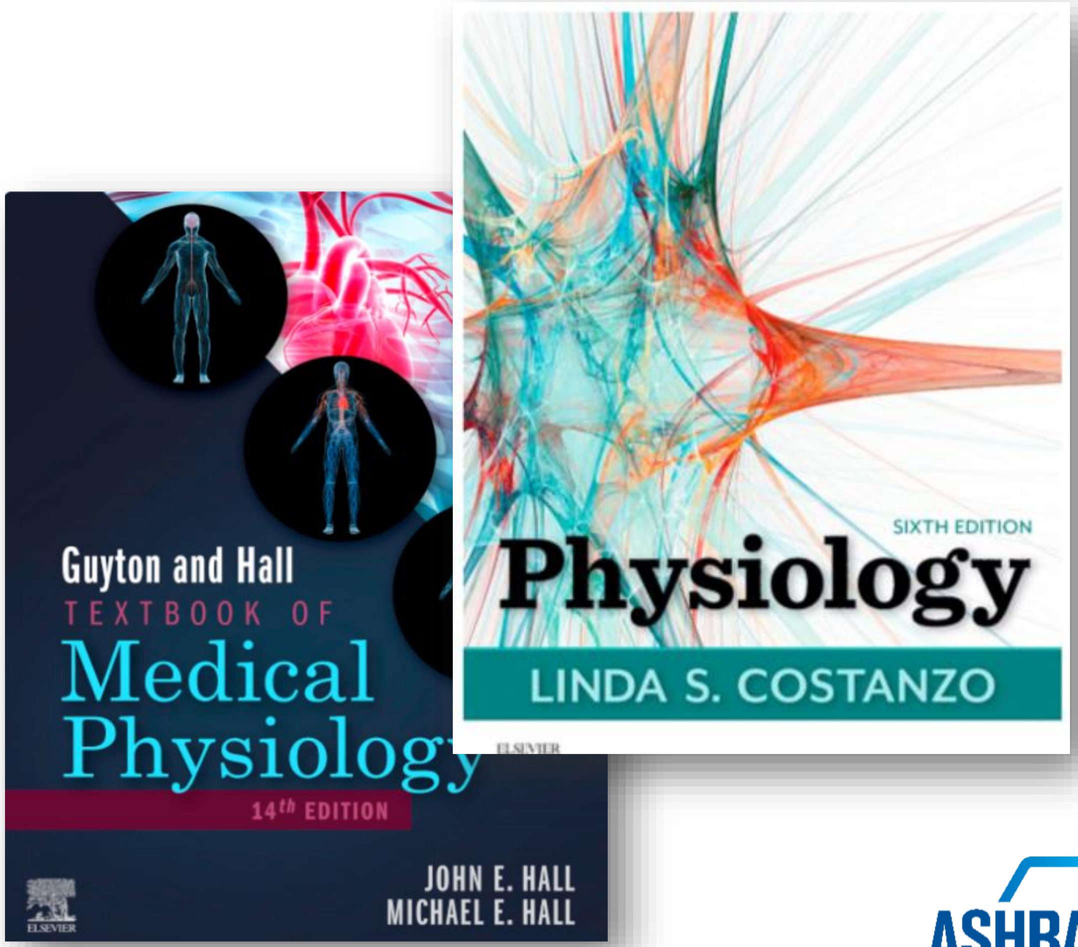
What is Indoor Environmental Quality?

Indoor Environmental Quality (IEQ)

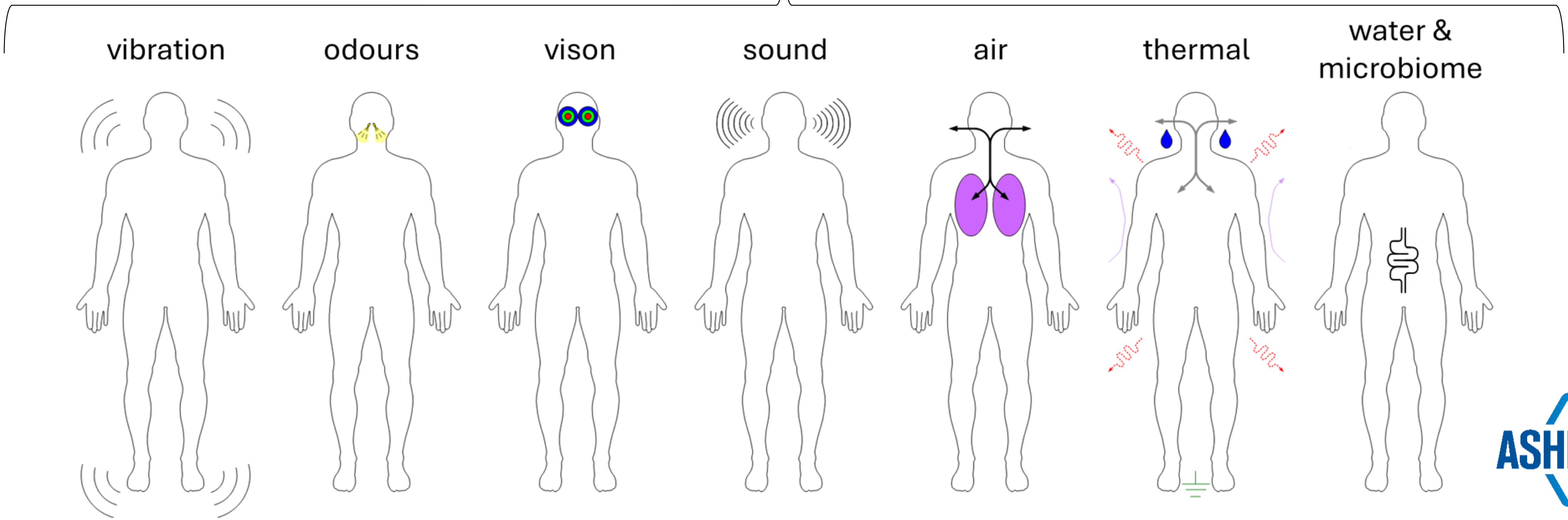
- It is, first and foremost, a study of physiology and psychology as it relates to the built environment.
- Subjects are rarely taught to building design professionals.
- Suggested Reading
    - Chapters on sensory systems, including thermal regulation, vision and sound, plus cardiovascular and respiration.
    - Hall, John, E. and Michael E. Hall. *Guyton and Hall Textbook of Medical Physiology, 14th Edition*
    - Costanzo, Linda. *Physiology, Sixth Edition*



What represents all the environmental sensory systems? *(Page 1 of 2)*

Indoor Environmental Quality (IEQ) is the umbrella that represents all the environmental sensory systems.

- IAQ is not a proxy for IEQ or thermal comfort. They are not synonymous terms.
- It now includes water and microbiome as an IEQ metric.



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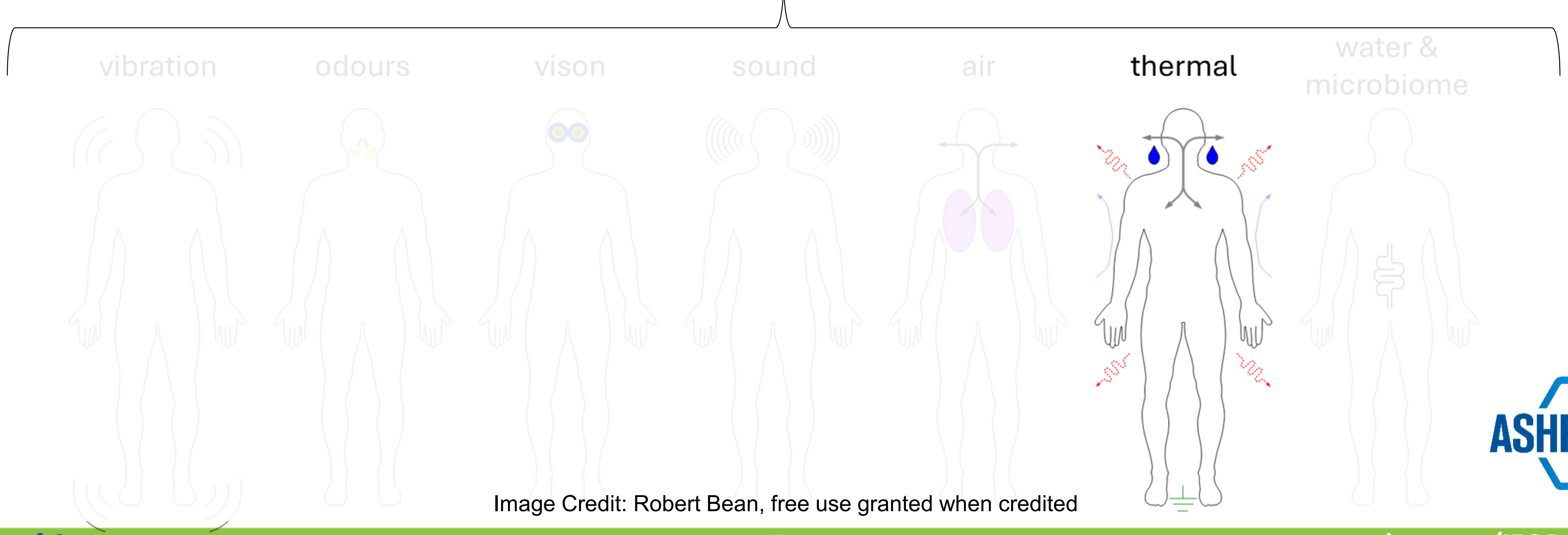
What represents all the environmental sensory systems? *(Page 2 of 2)*

Indoor Environmental Quality (IEQ) is the umbrella that represents all the environmental sensory systems.

- Thermal Comfort
- For existing and new buildings including residential, commercial, institutional and other occupied spaces not covered by other standards and regulations.



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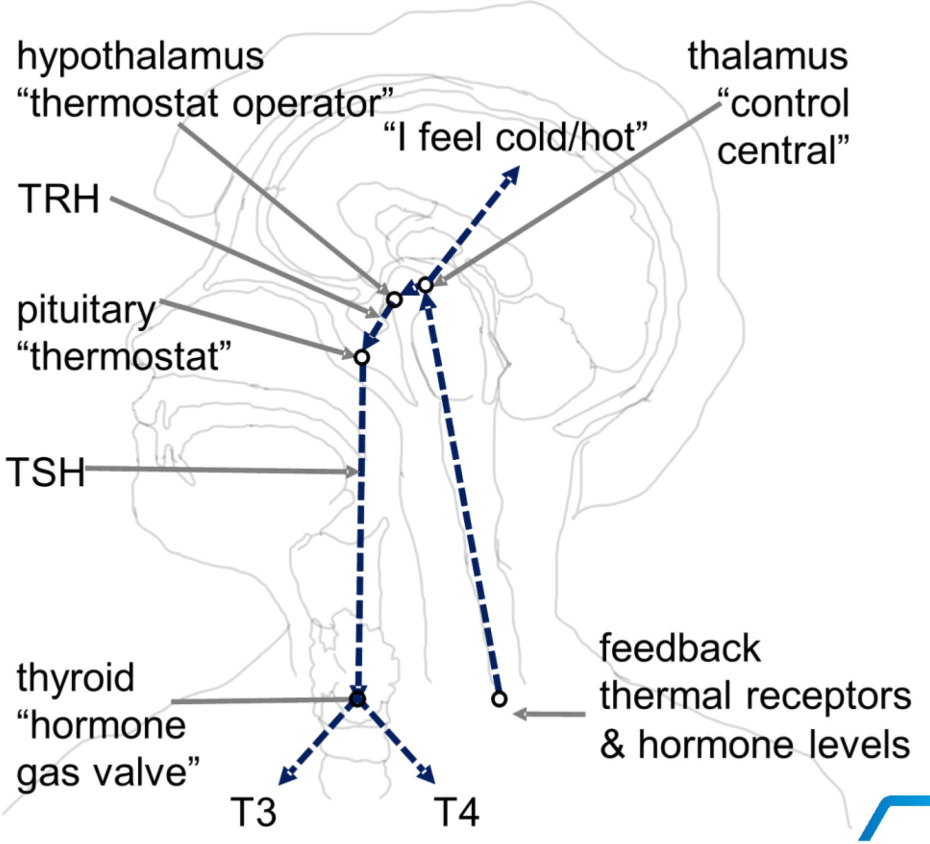
How does the mind come into play?

- **Thermal Comfort Universal Definition**

“Condition of Mind”

- Thermal regulation as part of the central/autonomic/sympathetic nervous, cardiovascular and endocrine systems.
- Co-existence of homeostasis and alliesthesia.
  - Metabolic balance vs sensory exercise.
  - Survival vs. pleasure.
- Thermogenesis/vasodilation/vasoconstriction.
- Subjective: people do not always share the same thermal experience.
- Expect diversity in sensation and perception.



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How do sensations inform reactions?

e.g., loss of heat → **Sensation**

physical

physiological/

neurological

→

e.g., I'm cold → **Perception**

psychological/

subjective

→

e.g., complaint/adaption → **(Re)action**

psychological

physical

physiological

below conscious

above conscious

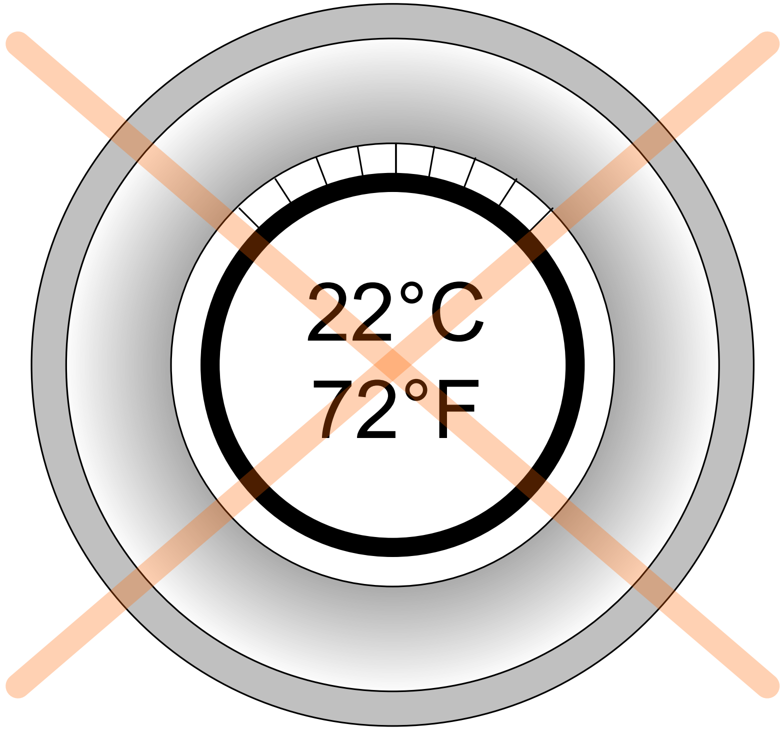
What don’t thermostats do?

Elephant in the Room: Thermostats <u>ARE NOT</u> proxies for thermal comfort

- They <u>DO NOT</u> fully sense what people sense.
- They <u>DO NOT</u> represent the combination of thermal environmental factors ***at the location of the occupant.***

Air temperature alone is not a valid or accurate indicator of a comfortable workplace temperature or heat stress.

UK’s Government Health and Safety Executive, 2024



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ASHRAE Standard 55

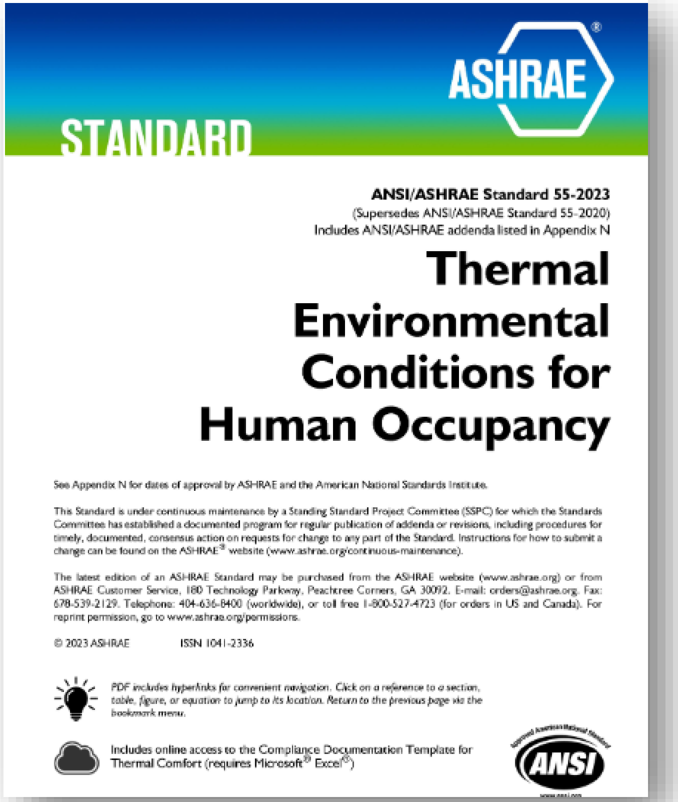
Thermal Environmental Conditions for Human Occupancy

Compliance reduces discomfort risks and improves the probability for the majority of occupants to sense and perceive acceptable thermal comfort.

What is the purpose of ASHRAE Standard 55?

History & Purpose

- **The purpose of this standard is to specify the <u>combinations</u> of indoor thermal environmental factors and personal factors that will produce satisfactory thermal environmental conditions acceptable for a majority of the occupants within the space.**
- Published in 1966.
- 60th anniversary in 2026.
- Colloquially called ASHRAE's Thermal Comfort Standard.
- It is intended that <u>all of the criteria</u> in this standard be applied together, as comfort in the indoor environment is complex and responds to the interaction of all of the factors…



STANDARD

ASHRAE®

ANSI/ASHRAE Standard 55-2023
(Supersedes ANSI/ASHRAE Standard 55-2020)
Includes ANSI/ASHRAE addenda listed in Appendix N

Thermal Environmental Conditions for Human Occupancy

See Appendix N for dates of approval by ASHRAE and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

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PDF includes hyperlinks for convenient navigation. Click on a reference to a section, table, figure, or equation to jump to its location. Return to the previous page via the bookmark menu.

Includes online access to the Compliance Documentation Template for Thermal Comfort (requires Microsoft® Excel®)

ANSI

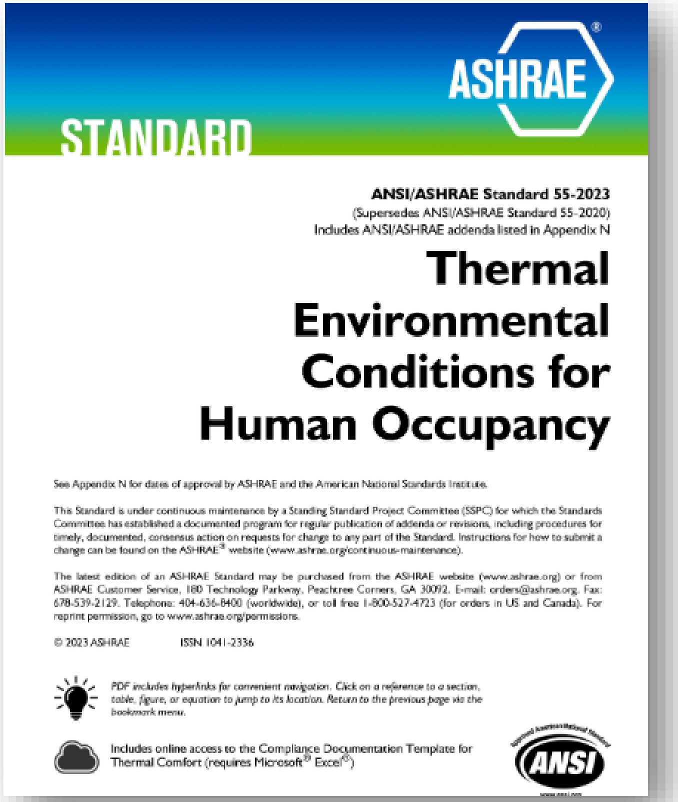
What does Standard 55 not do?

Key Facts

- For healthy adults (however, doesn't exclude other groups).

Does not Cover

- People sleeping, people in contact with bedding, nor people in spaces less than 15 minutes.
- Met rates over 4.0.
- Clo values over 1.5.
- Heat stress,
  - However, spaces designed and built to Standard 55 could have a lower probability of occupants developing heat stress relative to buildings not designed to Standard 55.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ANSI

How does the ASHRAE Standard 55 User's Manual apply?

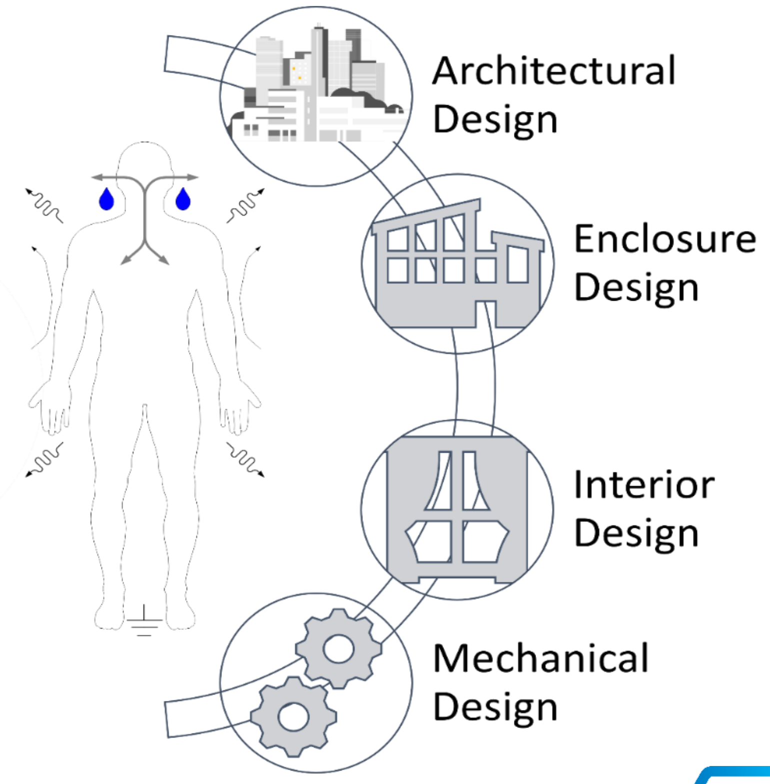
Key Facts

- Standard 55 User's Manual provides expanded information.
- Is aligned with the 2013 version; however, much of it still applies.
- A revised version aligned with the most current editions is under consideration by the Standing Standards Project Committee 55 (SSPC-55).

How does ASHRAE Standard 55 function as a roadmap for integrated design?

- **ASHRAE Standard 55 is the Quintessential Road Map for Integrated Design**
- Four Pillars of Thermal Environmental Conditions for Human Occupancy must be .
    - ~~A hierarchy in design starting with architecture, followed by enclosure, interior and mechanical designs.~~

  done correctly and in the correct order.



Comfort is incredibly important to building occupants but the traditional air temperature-centric design approach used in buildings for decades is ineffective, inefficient, and expensive.

Rocky Mountain Institute, Re-defining and Delivering Thermal Comfort In Buildings, 2016

Image Credit: Robert Bean, free use granted when credited

What are the four pillars of thermal environmental conditions?

Architectural Systems

- Specifically, adjacent properties, predominant winds and precipitations, building geometry, orientation, window-to-wall ratios, solar loading, shading, and color.

Enclosure Systems

- Specifically, elements associated with heat & mass transfer; outside wants in, inside wants out.
- Driven by differentials in pressure, temperature and moisture.
- Fenestration performance, thermal bridging, leakage/tightness.

Interior Systems

- Shading, colors, thermo-optical characteristics (emissivity, absorptivity, reflectivity, conductivity).
- Geometry and layout of interior partitions and furnishings.

HVAC Systems

- Convection systems for convective problems, radiant systems for radiant problems, hybrids.

ASHRAE Standard 55

Benchmark for Understanding and Applying ASHRAE Standard 55

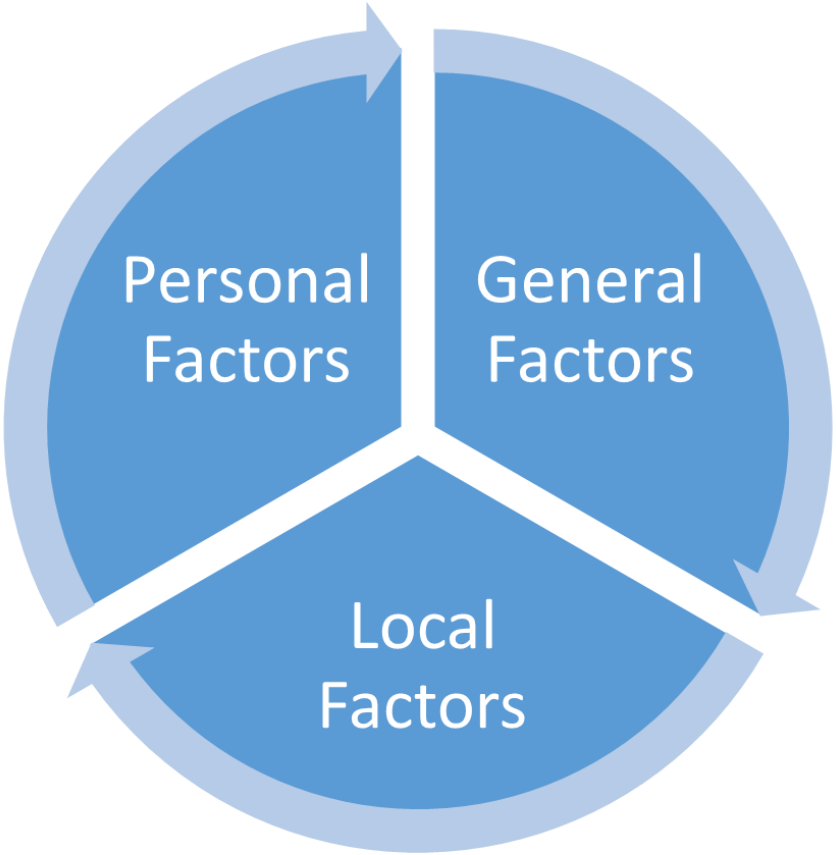
- Categorized under indoor environmental ergonomics (**important: it IS NOT an HVAC Standard**).
  - Ethos derived from studying human physiology and psychology related to the built environment.
  - Focuses on the body's central/autonomic/sympathetic nervous, cardiovascular and endocrine systems.
- Integrates the health and building sciences through the occupants as the common denominator.
- It requires an introductory understanding of the heat and mass transfer between occupants and the indoor environment, as covered by the ASHRAE Handbooks.
- Analysis is based on a "representative occupant".
- Multiple occupancies, where people wear different clothing (clo value) and do various activities (met rates), require assessments for each representative occupant
  - e.g., customers at a restaurant are treated separately from serving staff,
  - e.g., administration staff at a recreation facility are treated separately from coaches,
  - e.g., nursing and support staff at a long-term care facility are treated differently than residents.

What is the objective of ASHRAE Standard 55? *(Page 1 of 2)*

The Objective is to Create Acceptable Indoor Environmental Conditions for the Majority of People

- Conditions created by a combination of factors.
- Factors are ranges of values and NOT specific values.

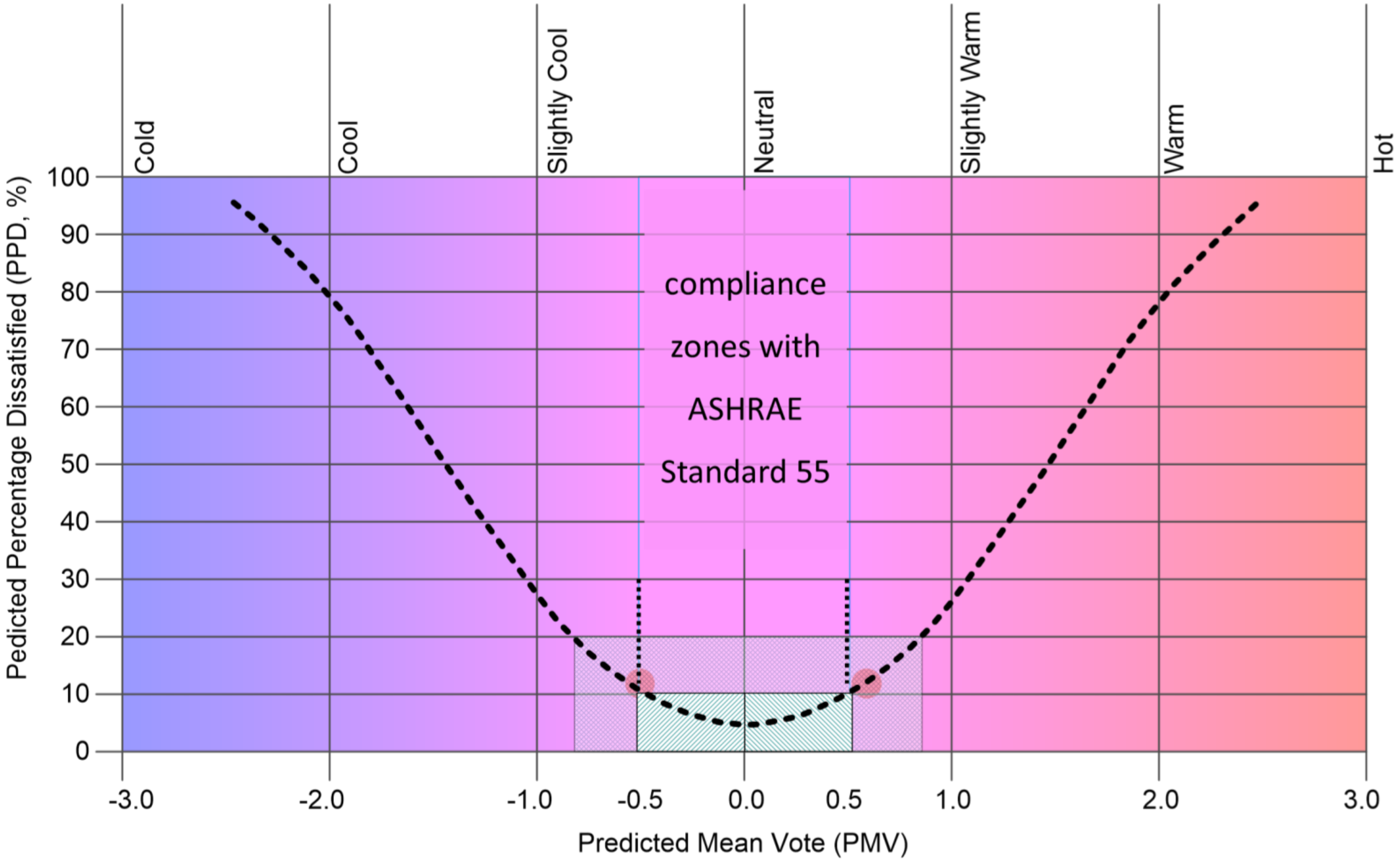
***Important:* When the representative occupants' met rate is less than 1.3 (e.g., standing, filing, typing, reading) and their clo values are less than 0.7 (business casual, shorts, light shirt or less), local factors MUST BE assessed.**



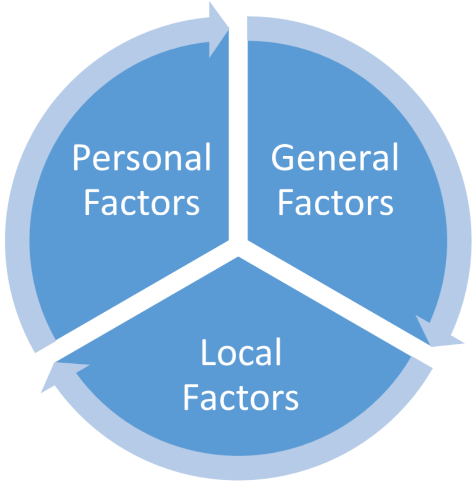
What is the objective of ASHRAE Standard 55? *(Page 2 of 2)*

- **The Objective is to Create Acceptable Indoor Environmental Conditions for the Majority of People**
- Conditions created by a combination of factors.
- Factors are ranges of values and NOT specific values.
- Factors fall into three categories.
  - Personal (metabolic rate, clothing).
  - General (mean radiant temperature, dry bulb temperature, humidity, air velocity).
  - Local (floor temperatures, radiant asymmetry, stratification, general draft, ankle draft).
- The combination of ranges of factors are indexed to a predicted mean vote (PMV).
  - PMV is on a 7-point scale, (-3, -2, -1, 0, +1, +2, +3).
  - Zero (0) represents neutral sensation.
  - Negative values represent increasing perceptions of cold.
  - Positive values represent increasing perceptions of warm.

What is one way to increase the probability of compliance?



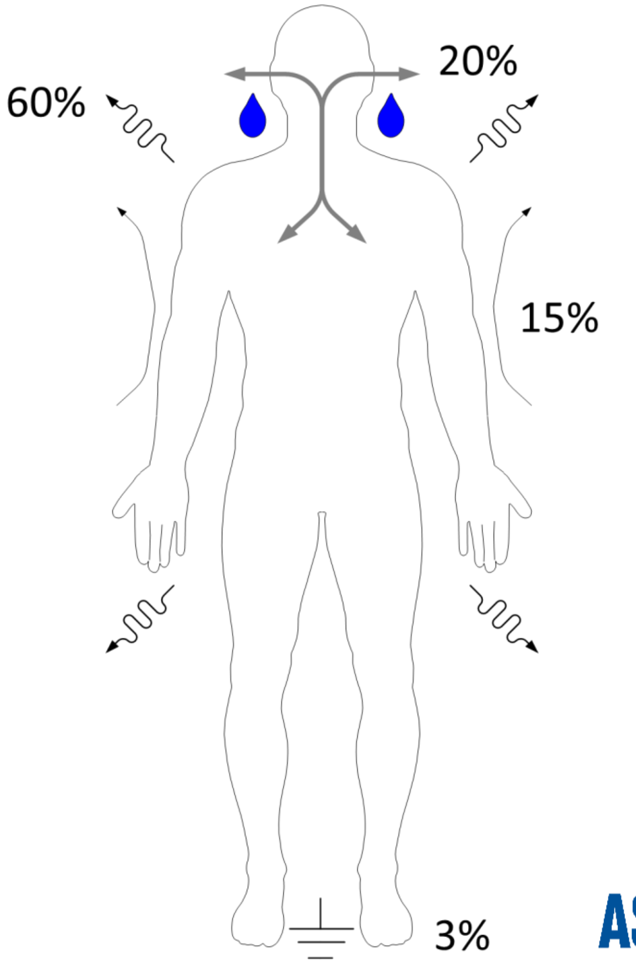
When spaces are designed with the three categories in mind, getting the architecture, enclosure, interior and mechanical systems right…the probability of compliance increases and the likelihood of discomfort decreases.



How does heat transfer between the body and the environment?

Heat Transfer Between the Body and the Built Environment

- Appx. 60% by radiation of sensible, appx. 40% of total.
- Appx. 20% to 25% by respiration/evaporation.
- Appx. 15% to 20% by convection.
- Appx. 3% by conduction.



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How does activity impact heat transfer?

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity

Degree of Activity	Location	Total Heat, Btu/h: Adult Male	Total Heat, Btu/h: Adjusted, M/F[a]	Sensible Heat, Btu/h	Latent Heat, Btu/h	% Sensible Heat that is Radiant[b]: Low V	% Sensible Heat that is Radiant[b]: High V
Seated at theater	Theater	390	350	245	105	60	27
Seated, very light work	Offices, hotels, apartments	450	400	245	155		
Moderately active office work	Offices, hotels, apartments	475	450	250	200		
Standing, light work; walking	Department store; retail store	550	450	250	200	58	38
Walking, standing	Drug store, bank	550	500	250	250		
Sedentary work	Restaurant[c]	490	550	275	275		
Light bench work	Factory	800	750	275	475		
Moderate dancing	Dance hall	900	850	305	545	49	35
Walking 3 mph; light machine work	Factory	1000	1000	375	625		
Bowling[d]	Bowling alley	1500	1450	580	870		
Heavy work	Factory	1500	1450	580	870	54	19
Heavy machine work; lifting	Factory	1600	1600	635	965		
Athletics	Gymnasium	2000	1800	710	1090		

Notes:

1. Tabulated values are based on 75°F room dry-bulb temperature. For 80°F room dry bulb, total heat remains the same, but sensible heat values should be decreased by approximately 20%, and latent heat values increased accordingly.
2. Also see Table 4, Chapter 9, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 Btu/h.

[a]Adjusted heat gain is based on normal percentage of men, women, and children for the application listed, and assumes that gain from an adult female is 85% of that for an adult male, and gain from a child is 75% of that for an adult male.

[b]Values approximated from data in Table 6, Chapter 9, where *V* is air velocity with limits shown in that table.

[c]Adjusted heat gain includes 60 Btu/h for food per individual (30 Btu/h sensible and 30 Btu/h latent).

[d]Figure one person per alley actually bowling, and all others as sitting (400 Btu/h) or standing or walking slowly (550 Btu/h).

credit/source: 2021 ASHRAE Fundamentals Handbook, Chapter 18, Table 1 Available in SI units

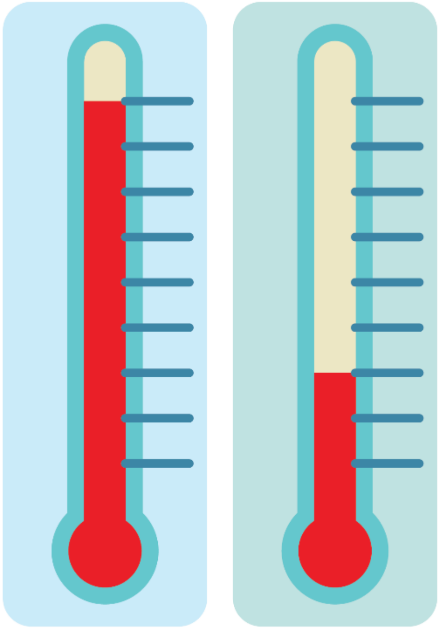
How does thermal comfort relate to building codes?

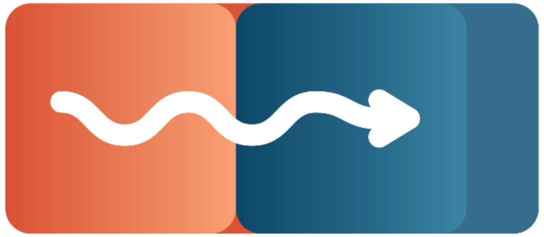
Thermal Comfort and its Relationship to Building Codes

- The general objective of building codes is to mitigate safety hazards and reduce the probability that a person is exposed to an unacceptable risk of illness.
- Codes DO NOT address levels of dissatisfaction expressed by occupants due to thermal discomfort.
- Risk of illness IS NOT the same as risk of discomfort.
- Compliance with ASHRAE Standard 55 IS NOT a requirement in building codes unless the building codes require compliance with the Standard.
- Even though the codes require air temperatures of 22°C (e.g., Canada) and 68°F (e.g., United States), they ARE NOT a requirement of ASHRAE Standard 55 and DO NOT serve as a proxy for thermal comfort.
- The minimums in building codes have become maximums in practice and DO NOT reflect the objectives of ASHRAE Standard 55.
- Compliance with Standard 55 requires design teams to evaluate up to nine essential environmental values and two personal factors.
- With caveats, the calculations are not tricky and are mainly within the skills of the ordinary practitioner.

Notes on Occupants and Perceptions

A Few Notes on Heat Transfer from Occupants as it Relates to Their Perceptions of Thermal Comfort





Operative Temperature – What is it, really?

A Note on Operative Temperature

- Operative temperature (t_{op}) represents the combined influence of the mean radiant temperature (MRT) and the dry bulb temperature (t_{db}) (aka air temperature).
- In many climate zones with high performance architecture and enclosures or in interior spaces the mean radiant temperature and dry bulb temperature can be very close in values.
- However, with poorer enclosures (e.g., ones with thermal bridging), large window to wall ratios (>40%), less than ideal fenestrations especially in extreme climates, the MRT WILL NOT be the same as the t_{db} for those representative occupants adjacent to aggressive (hot and cold) surface temperatures.
- Shortwave (solar) radiation has a non-trivial impact on the MRT and thus the occupants' perceptions.
- Several "authoritative" publications have misinterpreted **operative temperature** substituting it with "operating temperature" which has frequently been interpreted by practitioners as "air temperature".
- "Operating temperature" IS NOT a metric in Standard 55.
- Authors of those authoritative publications are advised to make the necessary corrections.

What is radiant transfer?

A Note on Radiant Transfer

- Frequently, manuals and guides use the “feeling of the sun” as a means of describing radiant heat, BUT this should be clarified for interior spaces and thermal comfort…here’s why:
- Technically, there is no “heat” in radiant; it is electromagnetic energy (EME) converted to/from heat when absorbed or released (radiated/emitted) by a surface (aka thermal radiation). The electromagnetic energy is described by its wavelength.
- The wavelength of solar is shortwave (appx 0.5 μm), with a few exceptions the wavelength of radiant floor heating and cooling, interior surfaces and the human body are all longwave (appx 10 μm)
- In the absence of shortwave (solar) energy, warm interior surfaces DO NOT heat the body per se.
- Warm surfaces (MRT) reduce radiant transfer from the occupant, enabling the person to retain their own heat. This retention of heat gives the perception of warmth.
- Cooler surfaces (MRT) promote heat rejection via radiant (negative radiation). The heat leaving the occupant via EME provides the perception of cooling comfort.
- If the interior surfaces radiated with a shortwave frequency of the sun (as often described), it would be wise to leave the building.

How and why does sweating help?

A Note on Evaporative Cooling

- In aggressive, hot/humid thermal environments, the body will respond through vasodilation and sweating.
- Vasodilation is the widening of blood vessels to enable more flow to the skin.
- For cooling, more blood flow to the skin means more heat is brought to the skin surface for release to the environment via radiation and convection. This works effectively, provided the surrounding surfaces and air are cooler than the skin temperature.
- Sweating (also respiration) is a means of cooling the body by releasing latent heat via evaporation.
- However, for evaporation to occur on the skin, the vapour pressure of the room must be lower than that of the skin.
- This is where dehumidification is effective. By lowering the absolute moisture in the space relative to the skin, latent energy can be released from the body via evaporation, which is perceived as cooling comfort.
- The perception of evaporative cooling comfort can be enhanced using elevated air speeds and lower operative temperatures..

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Why should moisture/humidity be managed within (35%-55%)+/-5%?

A Note on Moisture/Humidity: Why Should It Be Managed Within (35%-55%)$^{+/-5\%}$?

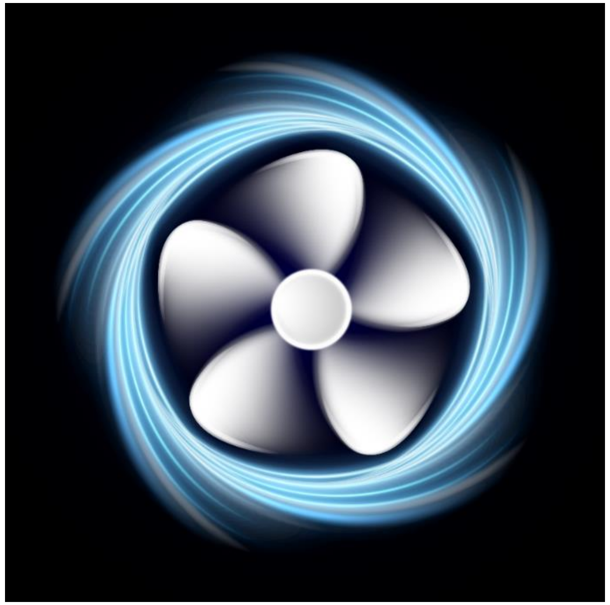
- To control hydrolysis (VOC emissions).
- To control viruses*, bacteria, moulds, mites, and some insects.
- To support immune systems and suppress infections.
- To enable comfort in mucous membranes (respiratory, eyes (skin)).
- To enable positive perceptions of thermal comfort and indoor air quality.
- To enable positive perceptions of indoor odour quality.
- To enable or suppress evaporative cooling.
- To maintain dimensional stability in hygroscopic materials (woods).
- To prevent condensation on hydrophobic materials (glass).
- To prevent condensation in hydrophilic materials (drywall).
- To preserve moisture-sensitive artifacts / collectibles / musical instruments.
- To suppress static electricity.

*see ASHRAE Positions on Infectious Aerosols and mold and building dampness.

Can we just use a fan?

A Note on Elevated Air Speeds for Cooling Effect

- Elevated air speeds increase the conduction/convection of air across the body and surfaces in the room.
- When there are vapor pressure and temperature differentials in the conductive/convective flow, there will be an increase or decrease in the moisture and heat in the air. In this regard, elevated air speeds can change the mass and thermal characteristics of the air and surrounding surfaces.
- Such changes in the cooling mode can invoke perceptions of cooling comfort (cooling effect).
- In many circumstances, elevated air speeds using ceiling fans (as an example) may be sufficient.
- Lowering the dry bulb temperature and absolute moisture in conjunction with elevated air speeds, may be necessary for more aggressive environments.
- However, the first solution for cooling is at design stage. That is to use passive solutions before mechanical solutions (refrigerant based or fan based or both).
- Passive solutions include: reducing the solar load on buildings through less window area, higher-performance enclosures, exterior shading, and low-emissivity light-colored exterior surfaces.



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What about opening a window or putting on a sweater?

A Note on Adaptive Comfort and Naturally Ventilated Spaces

- Tactics for thermally adapting to spaces are considered part of a “tried and true” strategy.
- Adaptation includes clothing adjustments, shutting off mechanical cooling and opening windows, workstation/personal fans and heaters, and relocating to different spaces, working hours which avoid extreme temperatures.
- A restrictive clothing policy can lead to unnecessarily overcooled spaces to compensate for individuals wearing more insulative clothing. Consider changing the clothing policy if it exists. Search “Japan +Cool Biz”
- Consider the benefits of exterior shading solutions over interior solutions.
- Use the adaptive assessment procedure outlined in ASHRAE Standard 55 including use of elevated air speeds.
- Perform post-occupancy surveys with occupants to help identify problems.
- For open windows and doors, consider outdoor air, noise, and light pollution and security issues.
- Hybrid (mixed mode) approaches should be considered, those buildings with full mechanical systems and adaptive strategies including natural ventilation.

Does it help to give the occupant some control?

A Note on Controls and Controllability

- Research demonstrates that occupants will perceive improvements in thermal comfort when they can control the thermal environmental quality in their spaces.
- Contributing to discomfort (and complaints) is the inability to affect thermal change in their personal spaces.
- Levels of controllability are addressed in ASHRAE Standard 55 (see Control Classifications) and include the ability to change the air temperature and airflow in their general shared spaces or personal spaces.
- The greater the ability for a person to manage their thermal experience the less complaints.
- There is ongoing research into Personal Comfort Systems (PCS) which includes using desk fans for cooling effects and heated panels for warming feet, legs, seats and backs. These can be stand-alone solution or integrated into desks and chairs.
- During design stages, zoning as part of the control strategy, is an important aspects not to be underestimated. Spaces should be zoned based on solar orientation, who is the room, what will they be doing, what will they be wearing, what are the extraordinary loads such as solar and IT/AV office equipment; space geometry changes including elevations and floor plates, and changes to interior systems.
- The fewer the controls and greater the number of occupants in mixed spaces, the greater the odds of complaints.

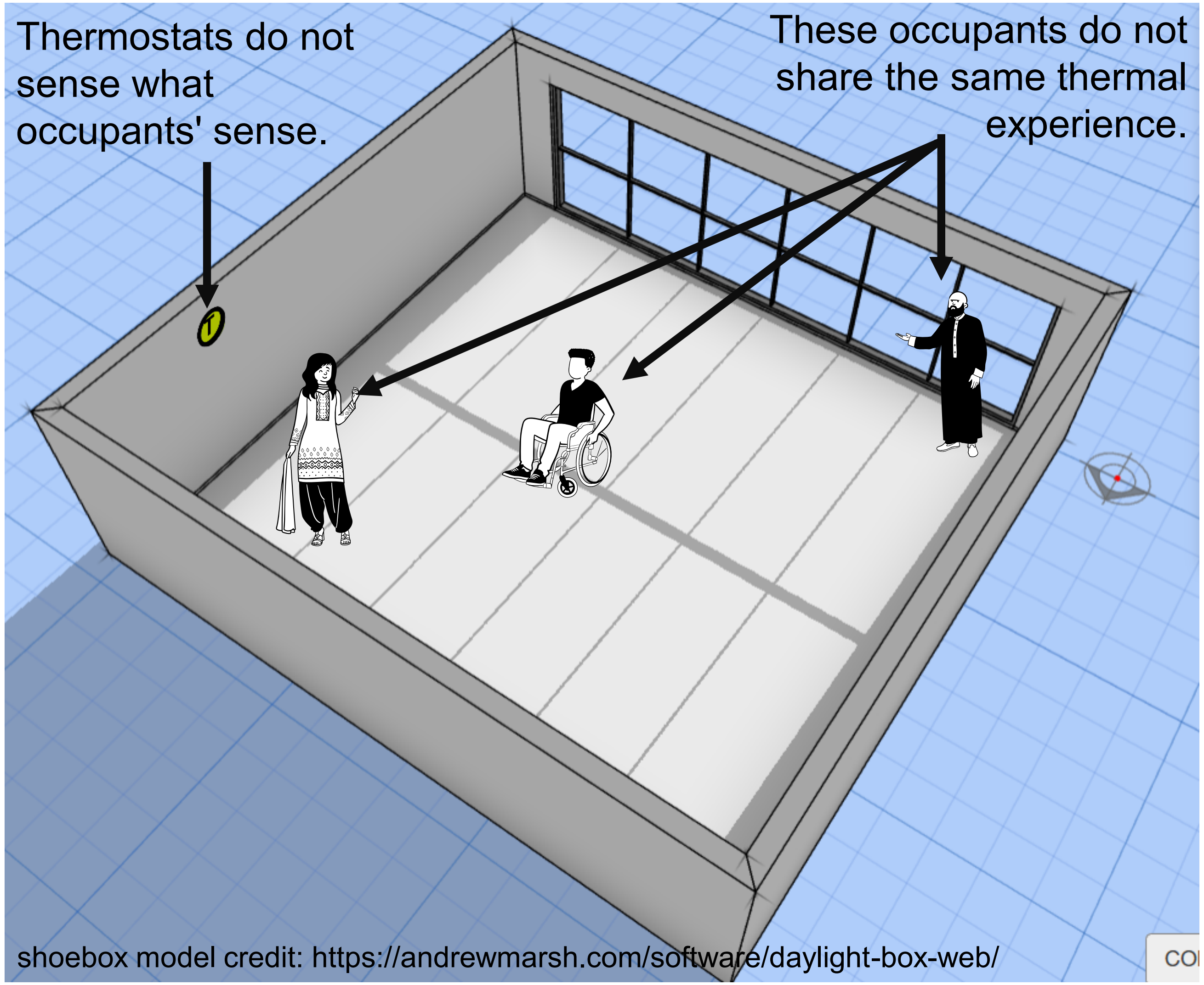
Why Thermostat Wars Exist

Why Thermostat Wars Exist

Thermostats do not sense what people fully experience.

Thermostats do not know what people are wearing nor what they are doing.

Thermostats do not represent the combination of factors at the location of the occupants…(mean radiant temperature, humidity, air speed, general and ankle drafts, temperature stratification, floor temperatures, radiant asymmetry).



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Observations

One strategy to have thermostats become a reasonable proxy for thermal comfort is to eliminate thermal flaws created by poor architecture, enclosures and interior systems. Solve convective problems with convective solutions, radiant problems with radiant solutions, then encourage adaptive behaviours and solutions.

Real World Examples of What NOT to Do

ASHRAE Standard 55 Metrics
Project Photos and Notes on Failure to Comply

What about putting a lock on the thermostat?

Photo Credit: Robert Bean, free use granted when credited

Dry Bulb Temperature & Operative Temperature

Unless designed for operative temperature (MRT with t_{db}), traditional thermostats only manage the air temperature (t_{db}). It is often the only connection between occupants and their perception of thermal comfort, even though it does not represent the required combination of thermal comfort metrics. Nor do thermostats represent the conditions at the location of the occupants. As such, thermostats have become fodder for the thermostat wars and the reasons for locking them behind protective covers, often accompanied by threatening notes.

Reminder: Using air temperature as a proxy for thermal comfort is akin to calling baking soda a cake.

Does it help to trick the thermostat?

Photo Credit: Robert Bean, free use granted when credited

Dry Bulb Temperature & Operative Temperature

Here is the consequence of an overcooled conference space where the occupants' hung bags of ice over the top of the air temperature sensor to “trick” the cooling system into turning off. It was in an interior space with no external radiant energy source, thus was an air(dry bulb) temperature issue. There could be numerous reasons for this overcooled setpoint, from lower-than-anticipated occupancies to a poorly set up BMS system.

What is the impact of window to wall ratio?

Photo Credit: Robert Bean, free use granted when credited

Mean Radiant Temperature & Operative Temperature

A significant source of discomfort is due to window-to-wall ratios and fenestration performance. These lead to unnecessarily high mean radiant temperatures, which can cause overheating. To compensate, dry bulb temperatures are kept unnecessarily low, which can lead to further discomfort from low dry bulb and radiant asymmetry. In the winter, in the absence of solar, such configurations lead to unnecessarily low mean radiant temperatures. To compensate, dry bulb temperatures are kept high, which lowers the relative humidity and causes stratifications and down drafts off windows.

Exterior shading is non-existent and likely insulated interior shades are absent as well.

What about blankets or personal heaters?

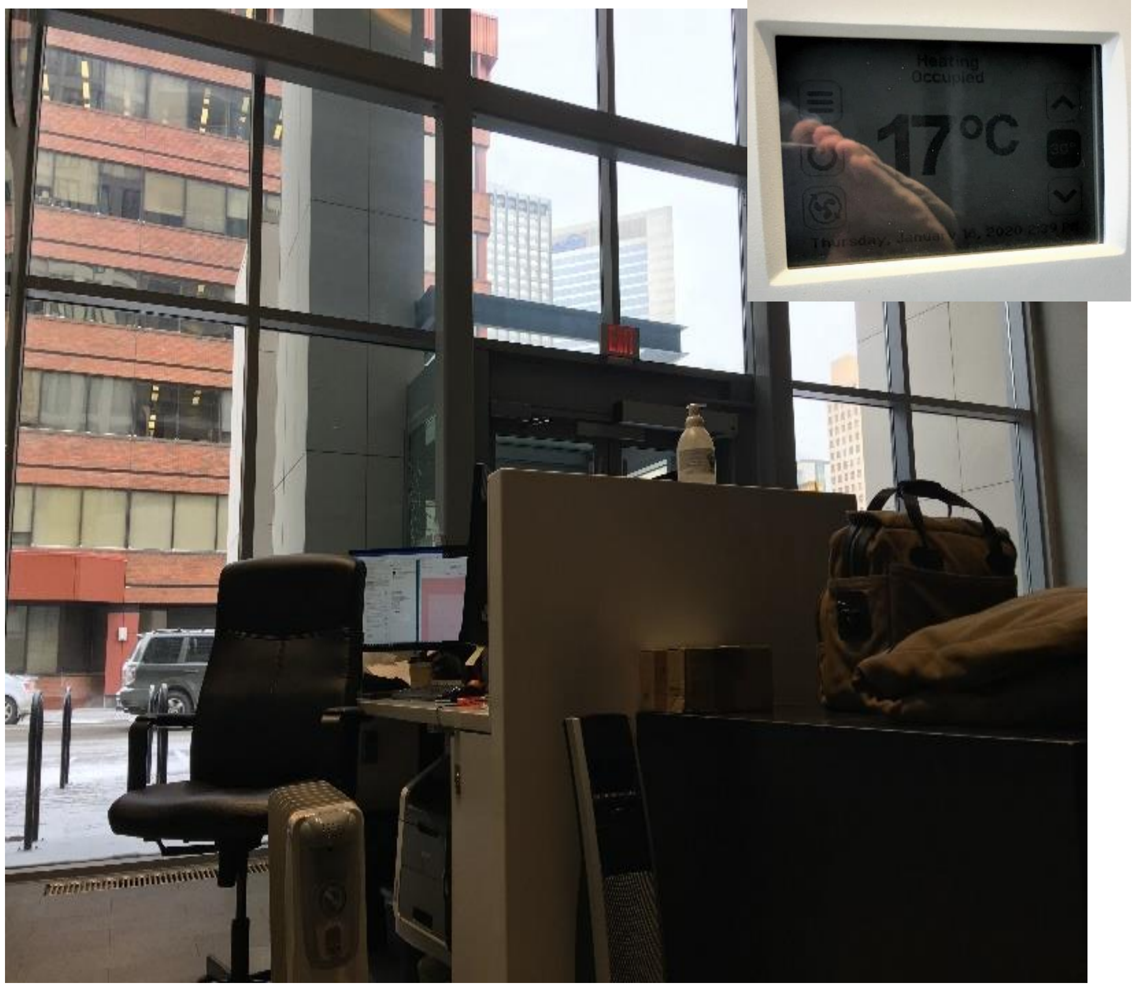


Photo Credit: Robert Bean, free use granted when credited

Mean Radiant Temperature & Operative Temperature

Modern multi-purpose, multi-story high rise with 100% window-to-wall ratio in the lobby. The outdoor air temperature was -30°C /-22°F with the dry bulb temperature set to 22°C / 72°F, but the mean radiant temperature was approaching 15°C/60°F. The down draft and stratification pulled the air temperature to 17°C/63°F (determined by the thermostat located 20ft/6m from the exterior), well below the building code requirement. The in-floor convective units were incapable of compensating for the downdraft. The concierge tried to adapt for discomfort (ankle draft, general draft, mean radiant) with heavier clothing and a personal heater, which provided some warmth but not comfort and contributed further to radiant asymmetry.

What is the best strategy to solve convective problems?

Photo Credit: Robert Bean, free use granted when credited

Mean Radiant Temperature & Operative Temperature

Frequently, convective solutions are used with poor results to solve radiant problems. That is, to move air through a space of sufficient temperature and quantity to counter the effects. However, the radiant exchange between a person and a surface will happen regardless of the characteristics of the air. Such compensation contributes further to discomfort, just as trying to solve convective problems is ineffective using radiant.

The best strategy is to solve convective problems with convective solutions and radiant problems with radiant solutions, which starts with the architecture, enclosure and interior systems, then, if necessary, with radiant cooling and heating systems (as shown).

How does radiant asymmetry impact comfort?

Photo Credit: Gary Hayden, free use granted when credited

Radiant Asymmetry and Floor Temperature

Anytime there is a horizontal or vertical surface temperature difference, the resulting radiant asymmetry can cause discomfort. This is often associated with mean radiant temperature issues. Radiant cooling and heating systems (as shown) can help compensate for these radiant issues. Ideally, the architectural and enclosure problems should be identified before the final mechanical design. Here, the glass block wall created a low surface temperature relative to the interior. To compensate, the staircase was turned into a radiator, and the floors were heated to influence the mean radiant temperature.

What are some issues with attempting to compensate for non-compliance?

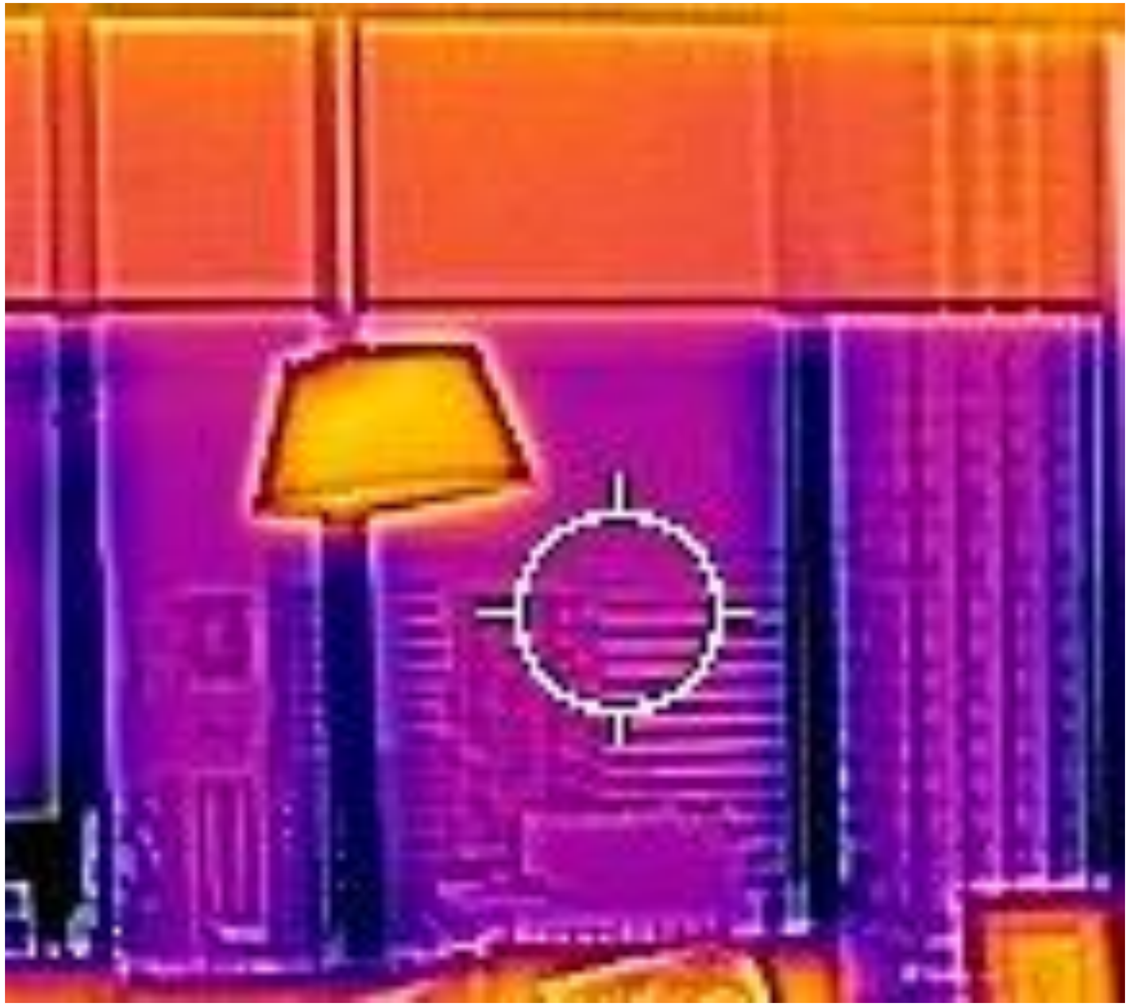


Photo Credit: Robert Bean, free use granted when credited

Mean Radiant Temperature / Stratification / Down Draft

Here, a modern high-rise condominium has thermal problems caused by large window-to-wall ratios, down drafts, and stratifications. To compensate, dry bulb set points were kept above 22°C/ 72°F, lowering relative humidity and increasing stratifications and radiant asymmetry. Humidification was added to compensate, which led to condensation on the glass and sills.

All of this discomfort occurred while the thermostat reading was still compliant with building codes but not with ASHRAE Standard 55.

Is it possible to have compliant temperature and non-compliant IEQ?

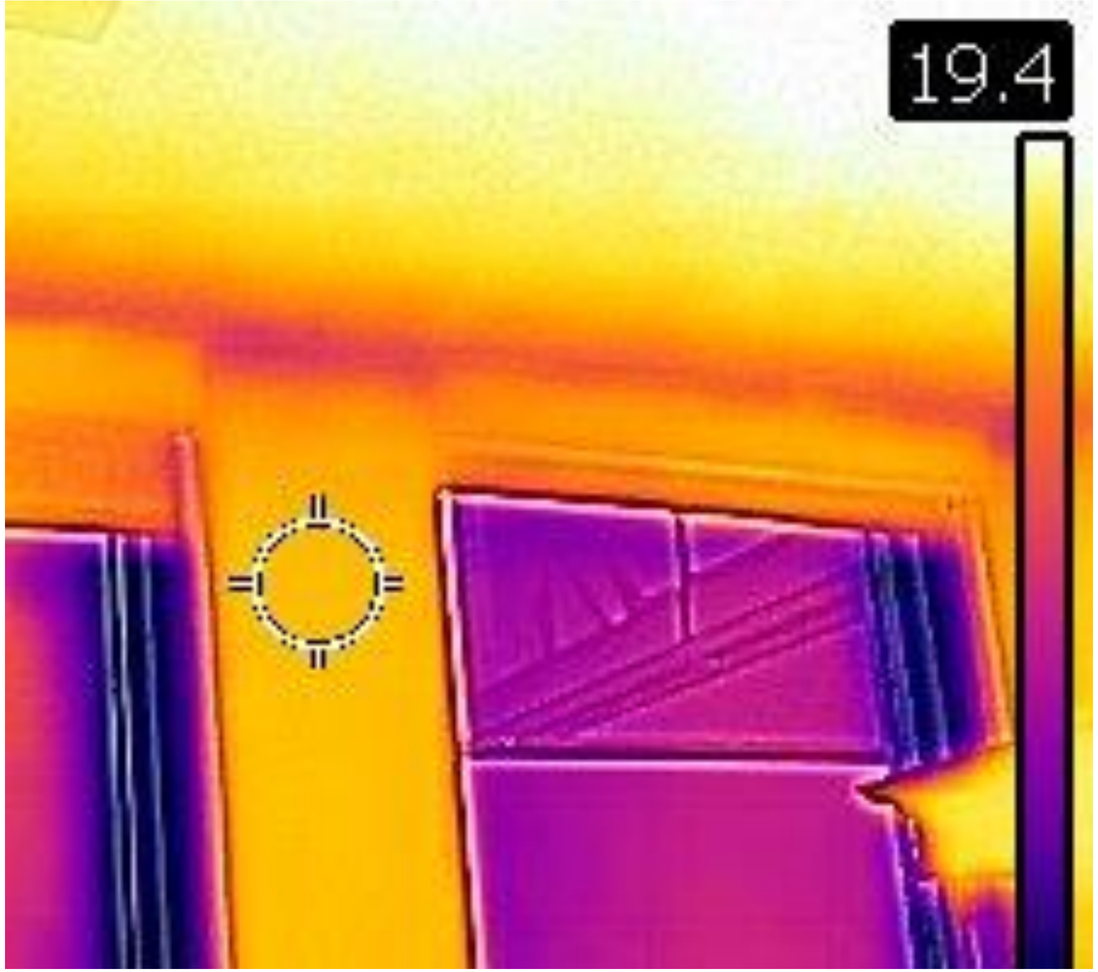


Photo Credit: Robert Bean, free use granted when credited

Stratification / Draft / Mean Radiant Temperature

The same modern high-rise housing project had thermal bridging issues at the ceiling/floor intersection and underwhelming glazing performance, which lowered the mean radiant temperature. This combination, in combination with a forced air heating system, affected the buoyancy of the air, causing general and ankle drafts, stratifications and non-compliant operative temperatures.

The thermostat controlled the air temperature in compliance with the building code, but the “environment” failed to comply with ASHRAE Standard 55.

How can stratification impact comfort?

Photo Credit: Robert Bean, free use granted when credited

Stratification

Aggressive stratification across an occupant causes discomfort. It is caused by stack effects/changes in density, which affects its buoyancy. Cool, denser air has a lower buoyancy, and its downward pressure puts upward pressure on warmed, less dense air with a higher buoyancy (as shown in the photo, displacement of the flag). The upward-motivated mass of air comes in contact with cold surfaces (conduction) at the ceiling and walls, changing its buoyancy (convection), and the cycle of stratification and down drafts continues. With caveats, so long as there are motive forces within the space or between the inside and outside (density differentials), there will be changes in buoyancy.

What about drafts?

Photo Credit: Bob Rohr, free use granted when credited

General Draft

Infiltration (inside pressure lower than outside pressure) and thermal bridging are shown here. Both contributing to drafts and lower mean radiant temperature.

This discomfort is experienced while the thermostat holds 22°C/72°F air temperature in compliance with building codes. If the air temperature is raised to compensate, the consequences are lower relative humidity, greater stratifications and radiant asymmetry.

Examples and Notes on Non-Compliance

Photo Credit: Robert Bean, free use granted when credited

Ankle Draft

Relative to the cold surface temperature of the glass, warm air conducts its heat to the glass, changing its density. Shown here, the blind serves as a chimney guiding a plume of cold air down and across the floor, resulting in an ankle draft. It also amplified stratifications and radiant asymmetry.

All of this discomfort while the thermostat maintained 22°C/72°F air temperature in compliance with building codes but not in compliance with ASHRAE Standard 55.

Why not just tape over the diffuser?

Photo Credit: Robert Bean, free use granted when credited

General Draft / Air Velocity

Here, the dumping of cold air over the office workers motivated the staff to tape over offending sections of the diffusers, which created further problems in the office space. This became a cat-and-mouse game with building maintenance staff, who removed the tape on the weekends. Subsequently, staff replaced the tape on Monday mornings. To tape up the diffuser, staff had to first stand on the chairs and then stand on their desks to reach the ceiling.

The sensor for the BMS was in an adjacent south-facing space flooded with solar energy for most of the day, causing sustained non-representative feedback to the HVAC system. It met the building codes but did not comply with ASHRAE Standard 55.

What's a practical example of architecture's impact?

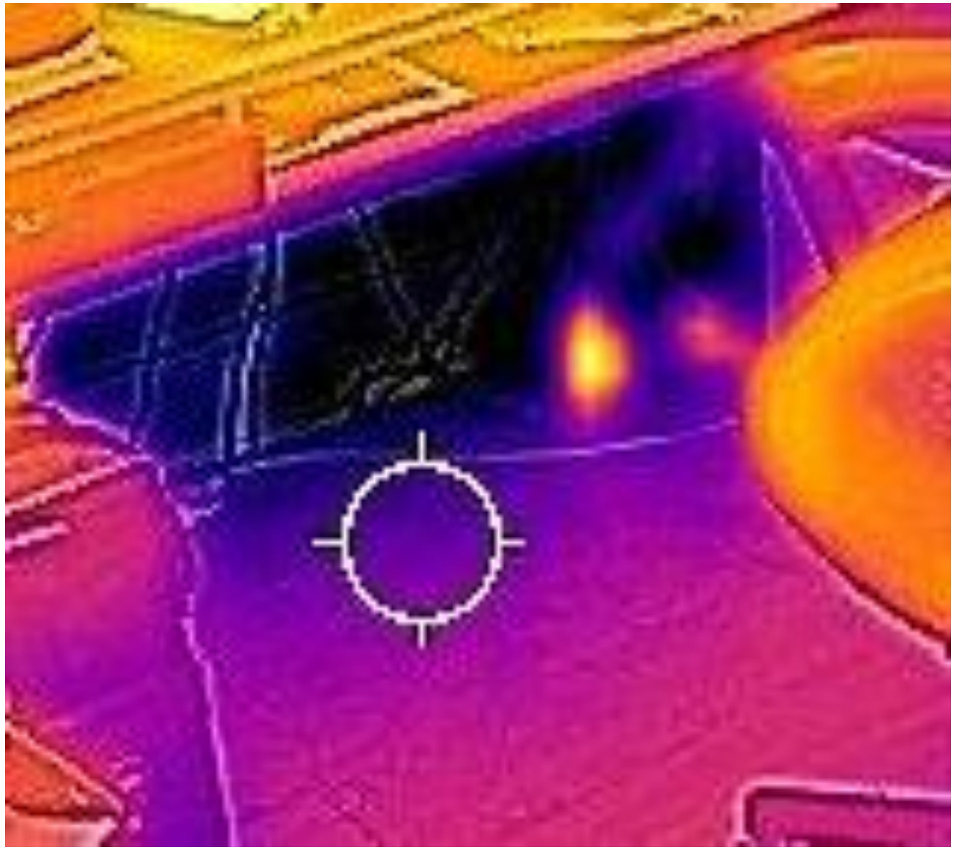


Photo Credit: Robert Bean, free use granted when credited

Floor Temperature, Ankle Draft & Radiant Asymmetry

This cold floor shown here, results from structural balconies coupled to the interior slab without thermal breaks. The balcony slab acts as a cooling fin, conducting heat from the interior space to the exterior, lowering the floor temperature and contributing to discomfort. With elevated humidity, this would also lead to condensation on the floor. It also amplifies ankle drafts, stratifications, and floor-to-ceiling radiant asymmetry. The reverse is true in the summer, especially on balconies exposed to solar radiation (EME). EME absorbed by the concrete gets conducted as heat to the interior cooled space, adding to the load. All of this discomfort while the thermostat maintained 22°C/72°F air temperature in compliance with building codes but not in compliance with ASHRAE Standard 55.

What about relative humidity?

Photo Credit: Robert Bean, free use granted when credited

Relative Humidity

ASHRAE Standard 55 does address humidity’s role in thermal comfort, although the standard does not regulate minimums or maximums. These become more important in indoor air quality and the building and health sciences. The challenge in using humidity as a compensatory strategy is the unintended consequence of setting up potential condensation on colder surfaces and inside enclosure cavities. Here, the lower-performing glass led to downdrafts, low MRT and radiant asymmetry. To compensate, the air temperature was raised, but this caused further stratifications and lowered the relative humidity, so humidity was increased, which led to the condensation. The space complied with building codes but not ASHRAE Standard 55.

Considerations for the Metrics of ASHRAE Standard 55 When Evaluating Architecture for Compliance

Assessment of Metrics and Architecture (Page 2 of 14)

Examples of Building Orientations, Window-to-wall Ratio, Clothing, Met Rates and Seasonal Changes

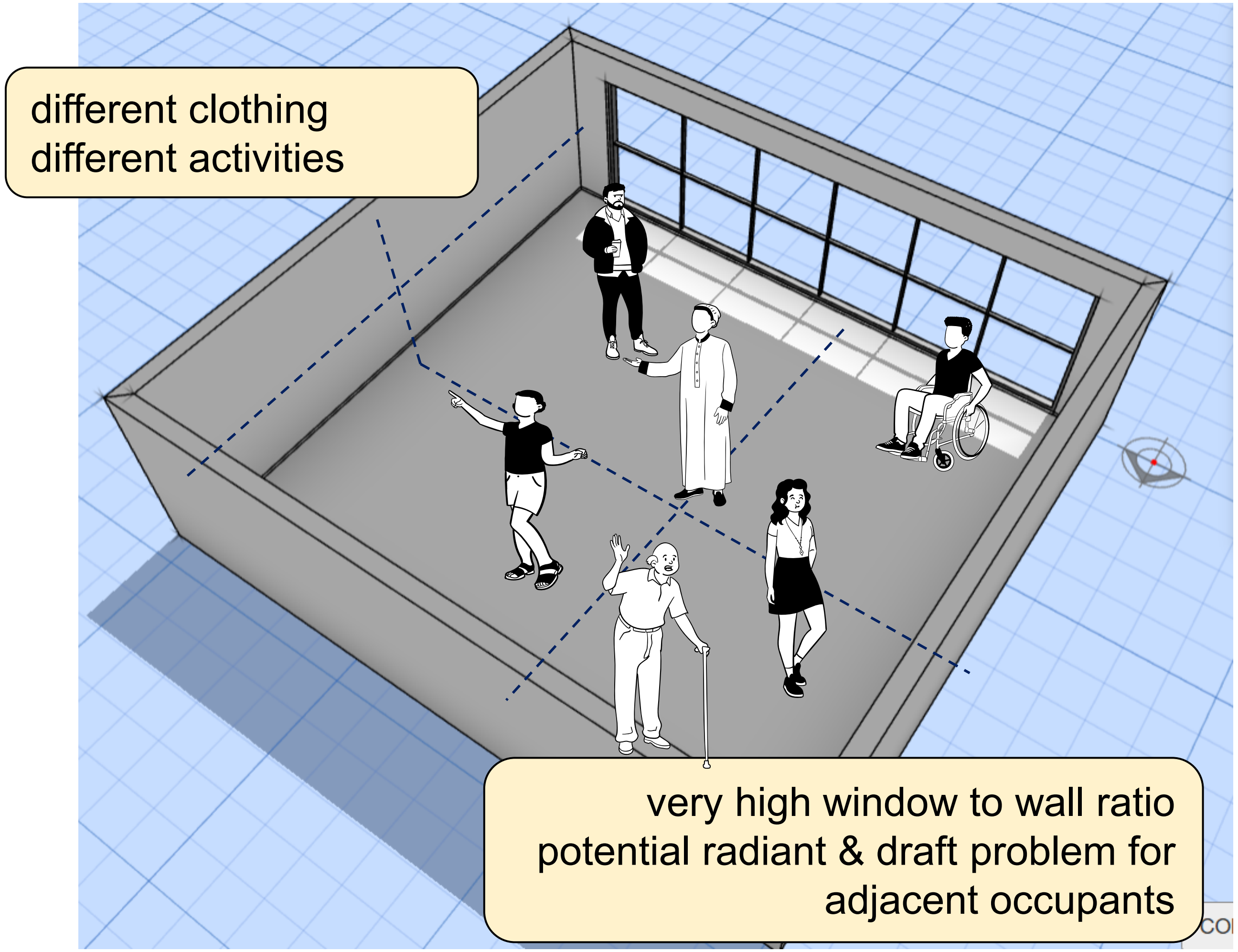
- The first step in addressing thermal comfort challenges is to understand the scope of the challenge.
- There is a high probability that the architecture, enclosure, interior and mechanical systems were never designed, constructed and commissioned to comply with ASHRAE Standard 55.
- When observing a space, consider the relationships between people and their surroundings, including their clothing and activities.
- Visualize how solar loading on a building and through its windows affects the space differently throughout the year, day, and hour.
- With caveats, it is important to remember that approximately 40% to 60% of the energy exchanged between occupants and their environment occurs via radiation. In contrast, thermostats or room sensors typically only measure air temperature via convection, which accounts for about 15% of heat transfer. Also, the location of the sensor does not represent the combination of thermal factors at the location of the occupant.
- In specific interior spaces, especially those with minimal solar gains or spaces designed for high performance, the radiant and air temperatures (operative temperature) can be similar.

Assessment of Metrics and Architecture *(Page 3 of 14)*

Personal Factors
Metabolic Rate
Clothing Value

General Factors
Mean Radiant Temp.
Dry Bulb Temp.
Humidity
Air Velocity

Local Factors
Stratification Temp.
General Draft
Ankle Draft
Floor Temp.
Radiant Asymmetry



Shoebox model credit: https://andrewmarsh.com/software/daylight-box-web/
Adapted Image Credit: Robert Bean, free use granted when credited

Key Points
Representative
Occupant
>15Min
Local Assessment if
Met <1.3 & Clo <0.7

Methods
Analytical
Adaptive

Other Considerations
Absorptivity, Emissivity
Shortwave Radiation
Shading & Windows
Glazing Performance
Elevated Air Speed
Temp. Ramps
Temp. Drifts

Assessment of Metrics and Architecture *(Page 4 of 14)*

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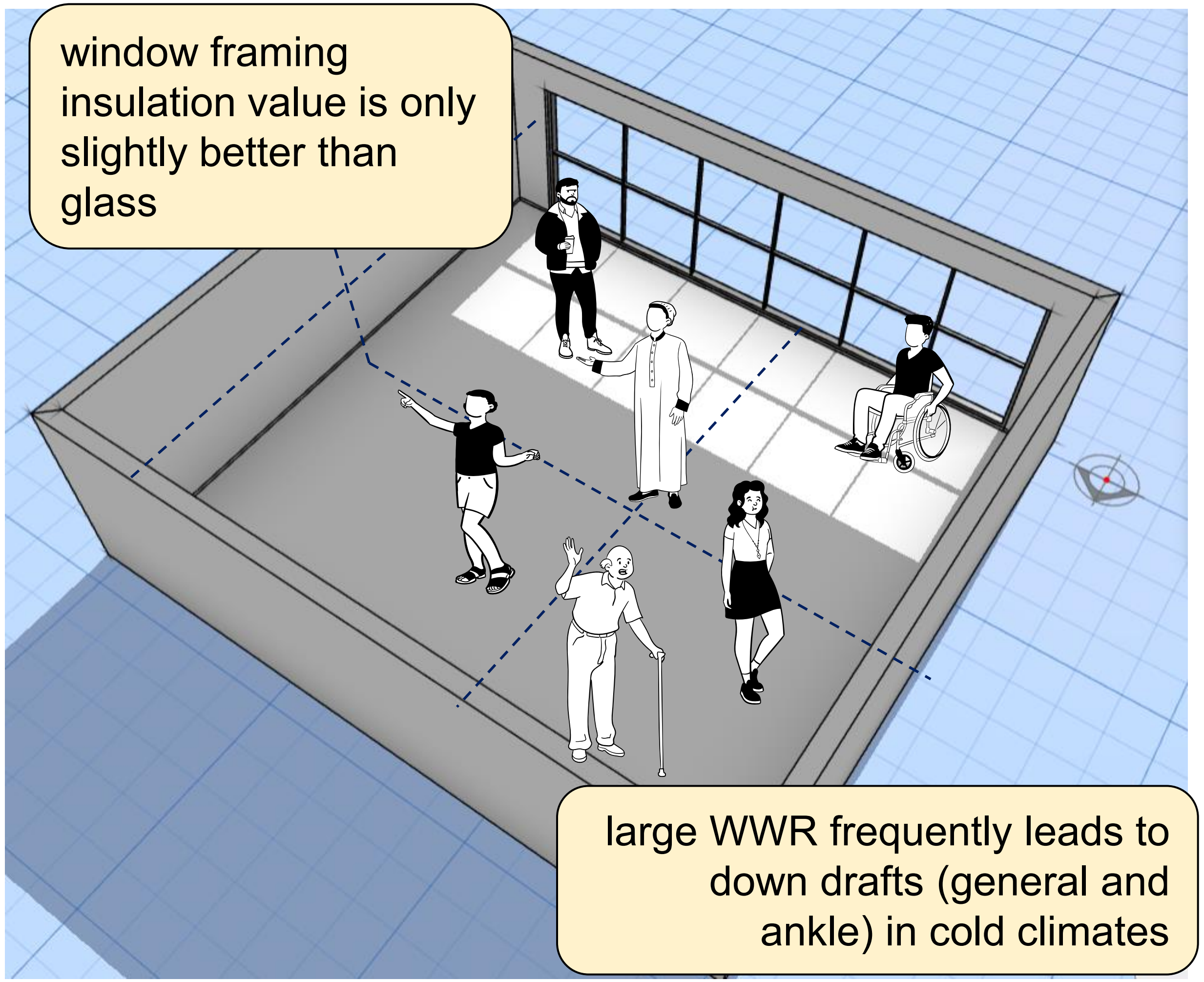

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Assessment of Metrics and Architecture *(Page 5 of 14)*

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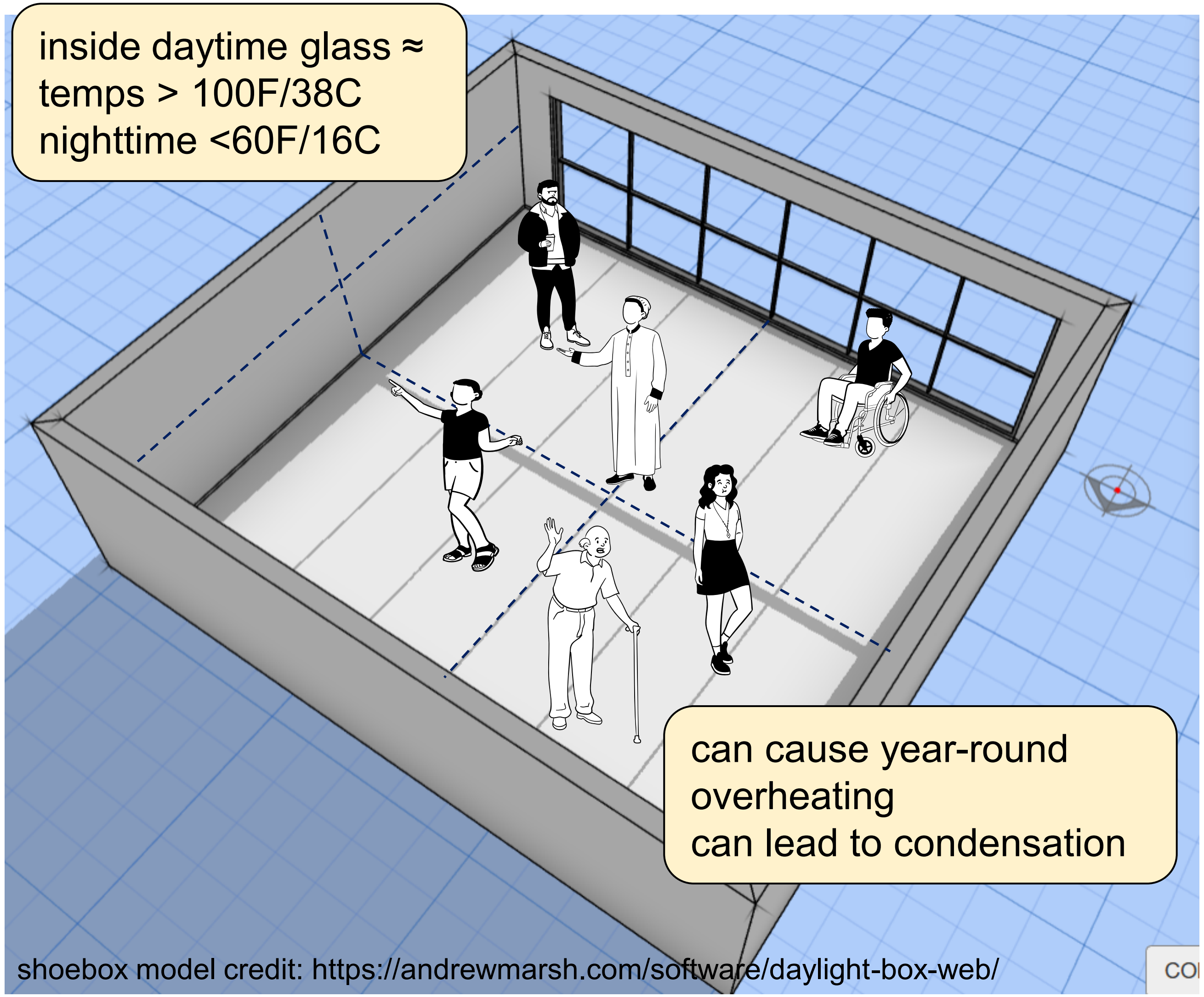
Floor Temp.
Radiant Asymmetry



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Assessment of Metrics and Architecture (Page 6 of 14)

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Dry Bulb Temp.
Humidity
Air Velocity

Local Factors
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Floor Temp.
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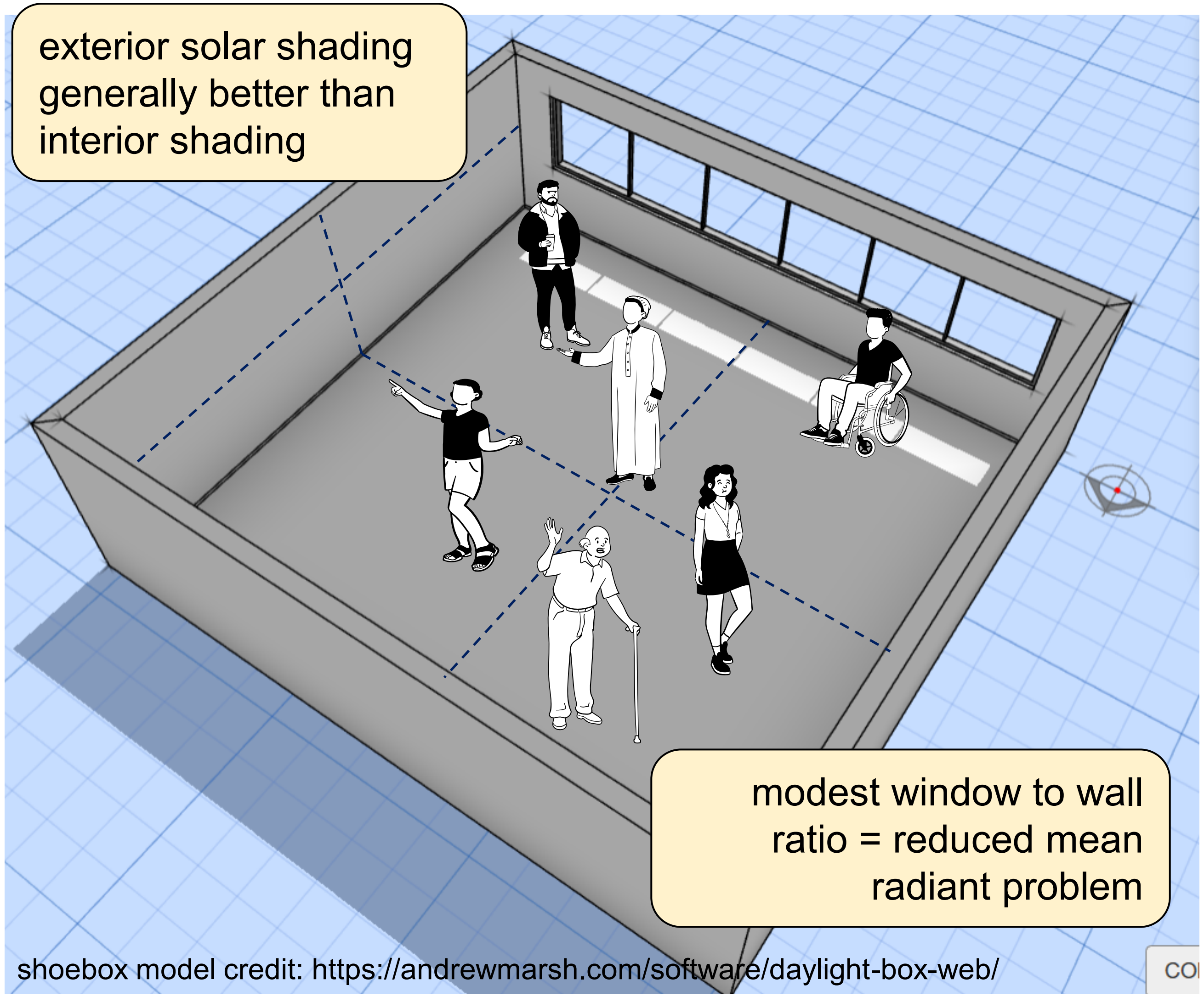

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Assessment of Metrics and Architecture (Page 7 of 14)

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General Factors
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Dry Bulb Temp.
Humidity
Air Velocity

Local Factors
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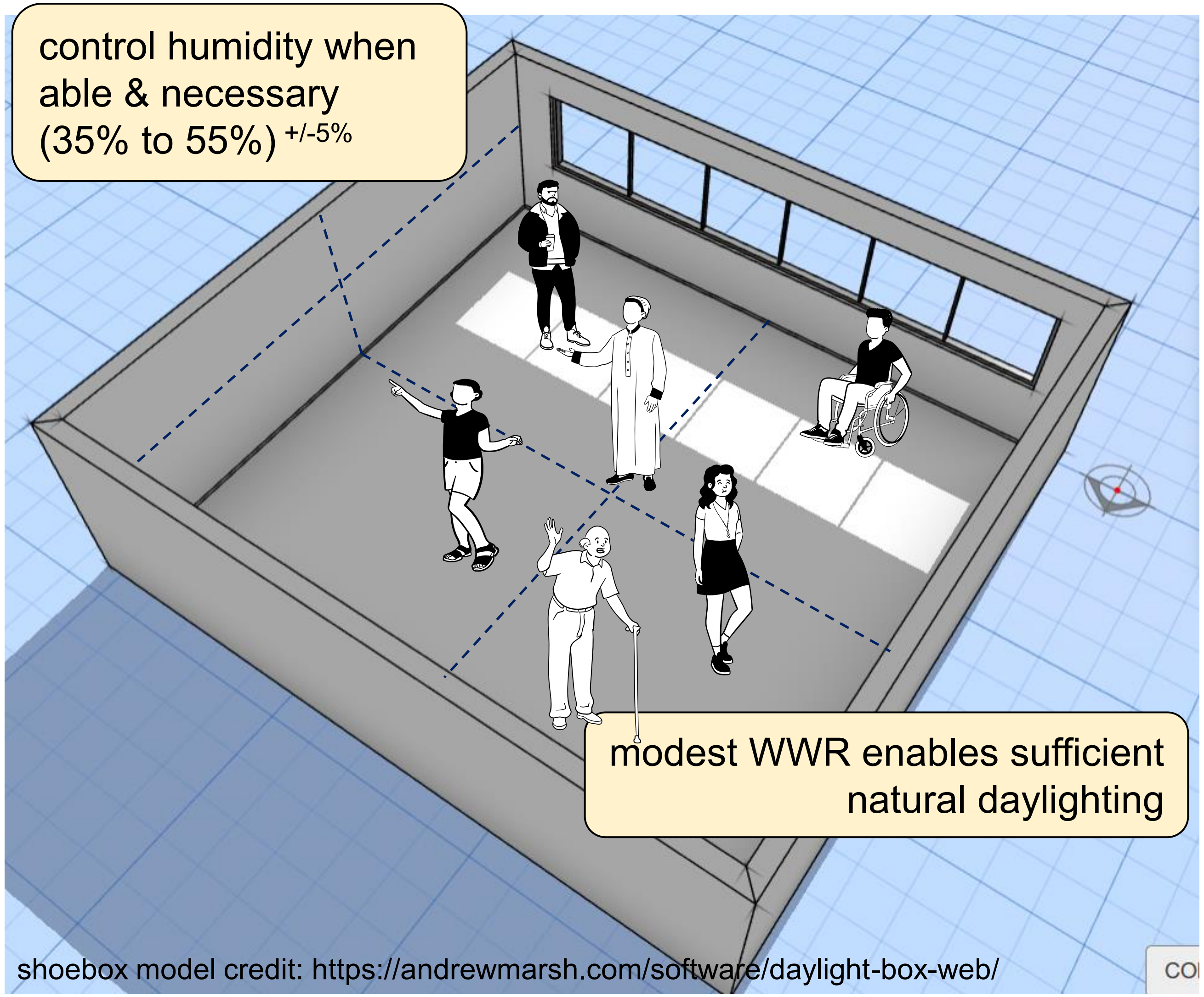
General Draft
Ankle Draft
Floor Temp.
Radiant Asymmetry



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Floor Temp.
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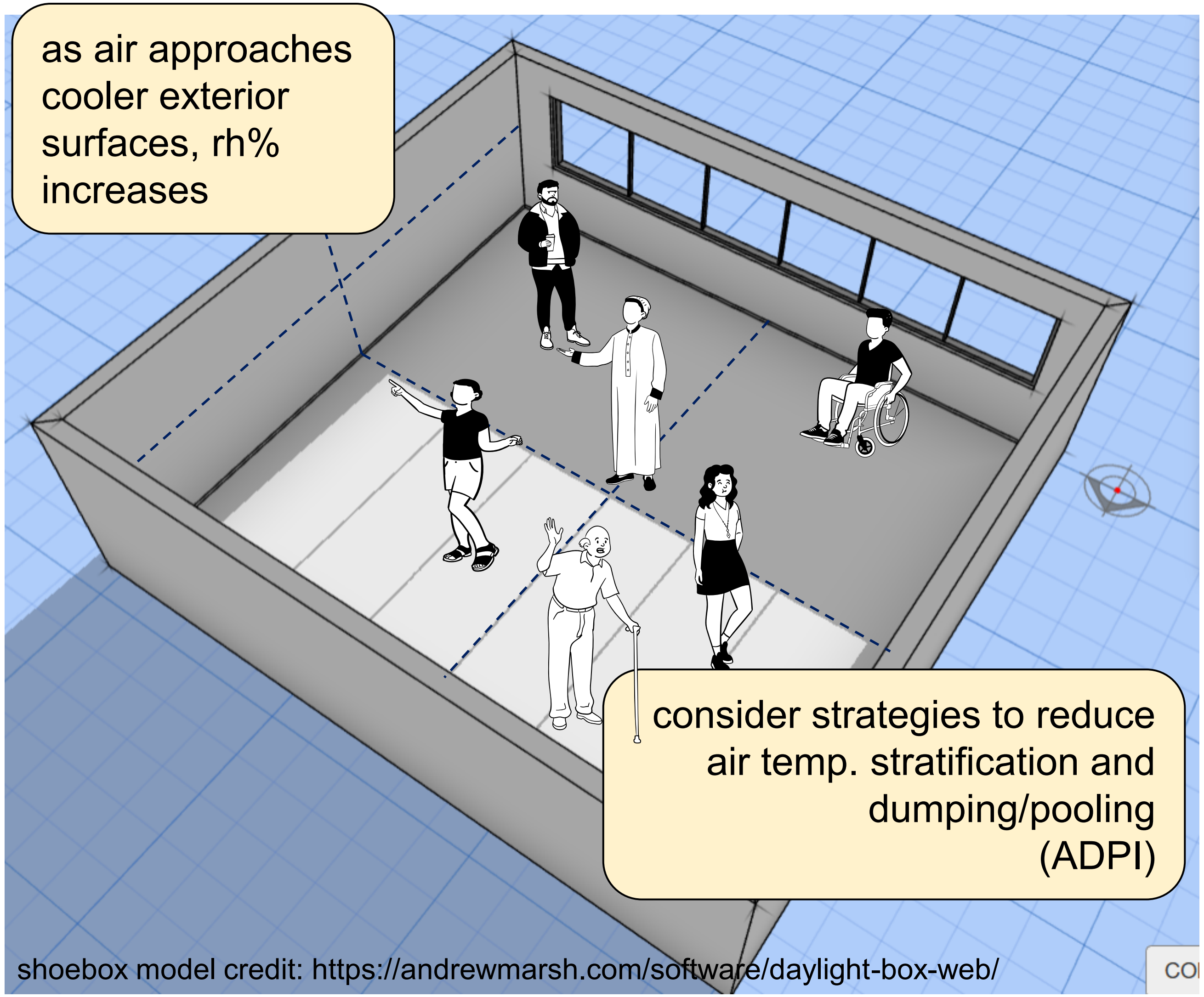

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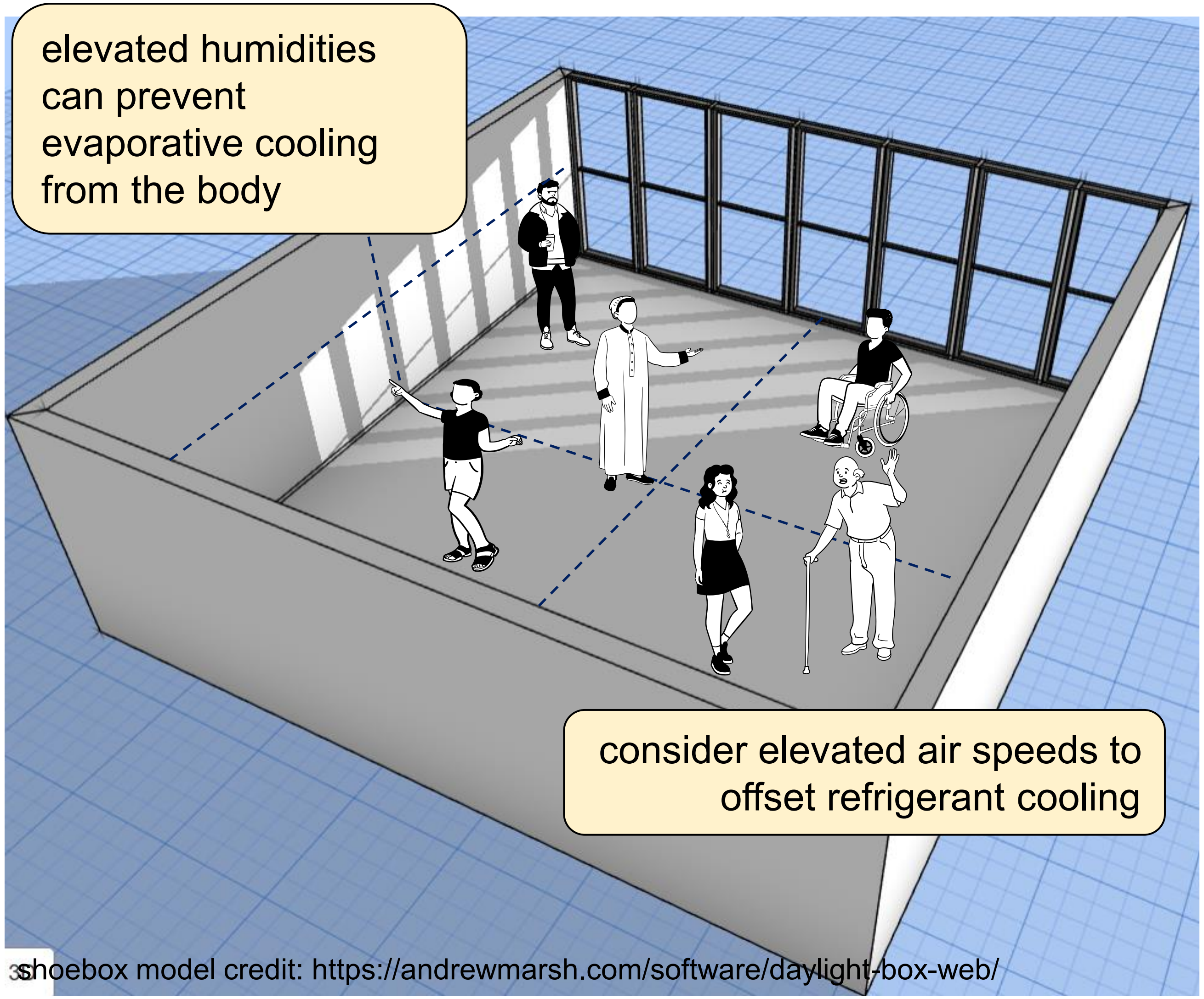

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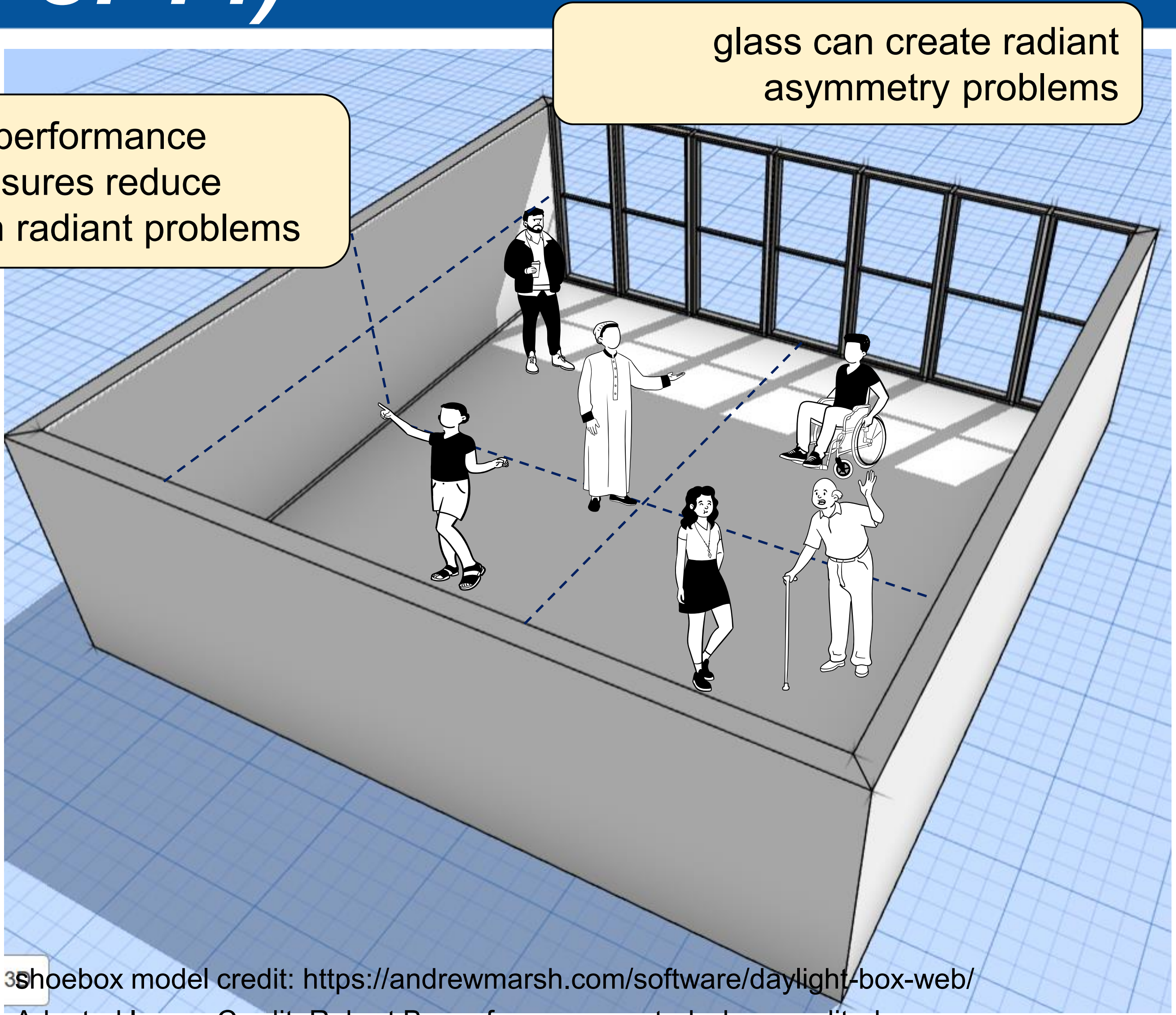
Radiant Asymmetry



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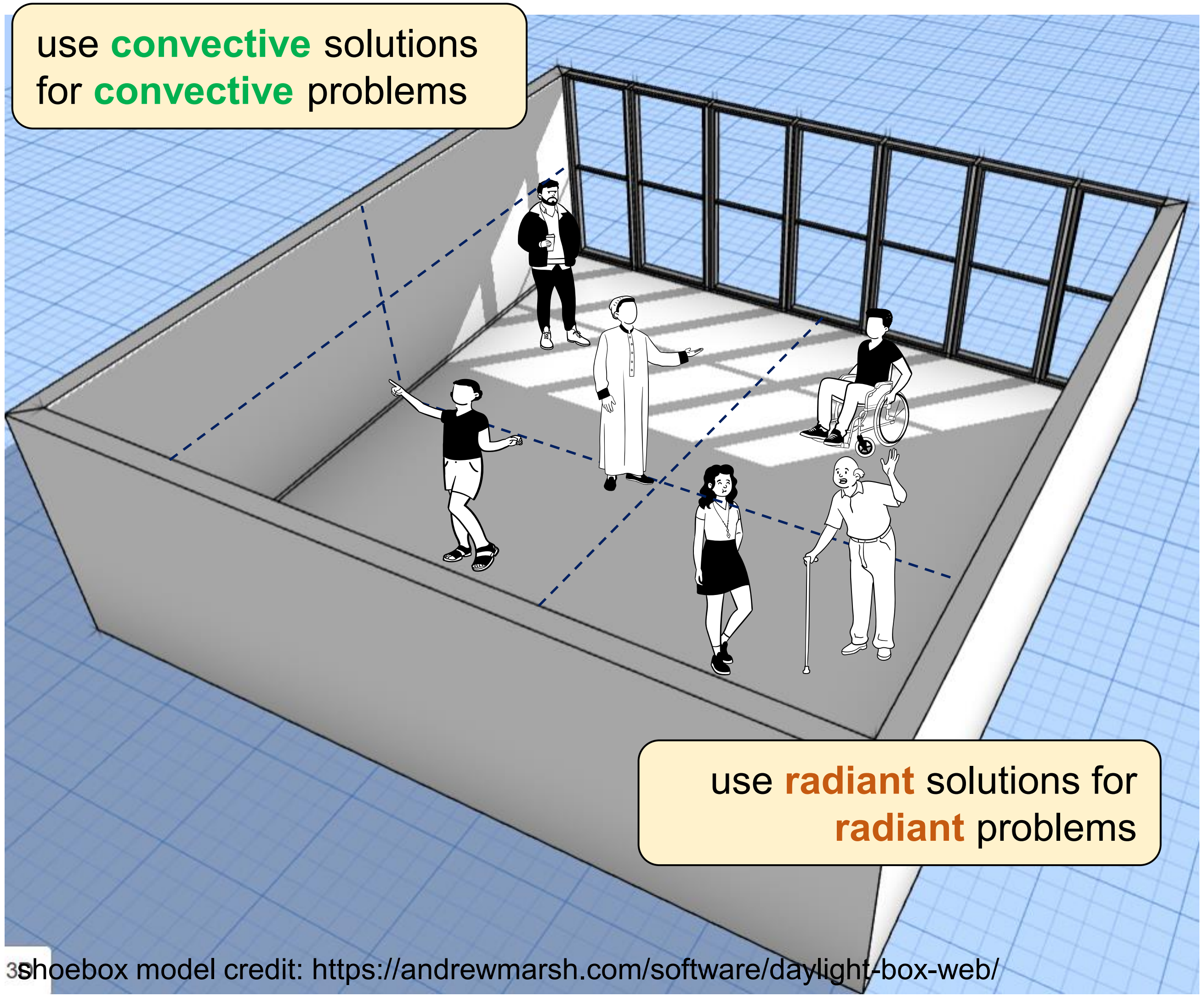

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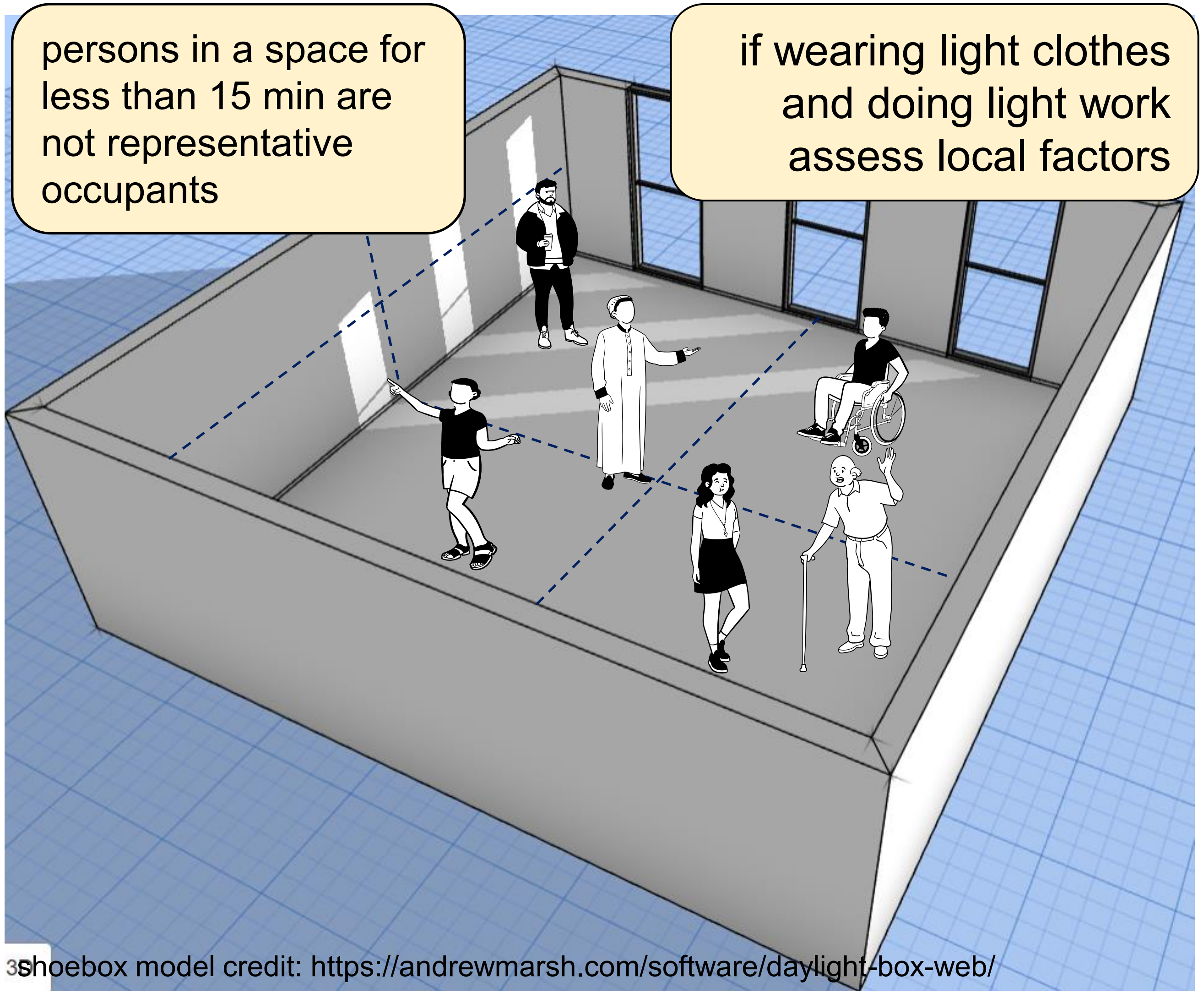

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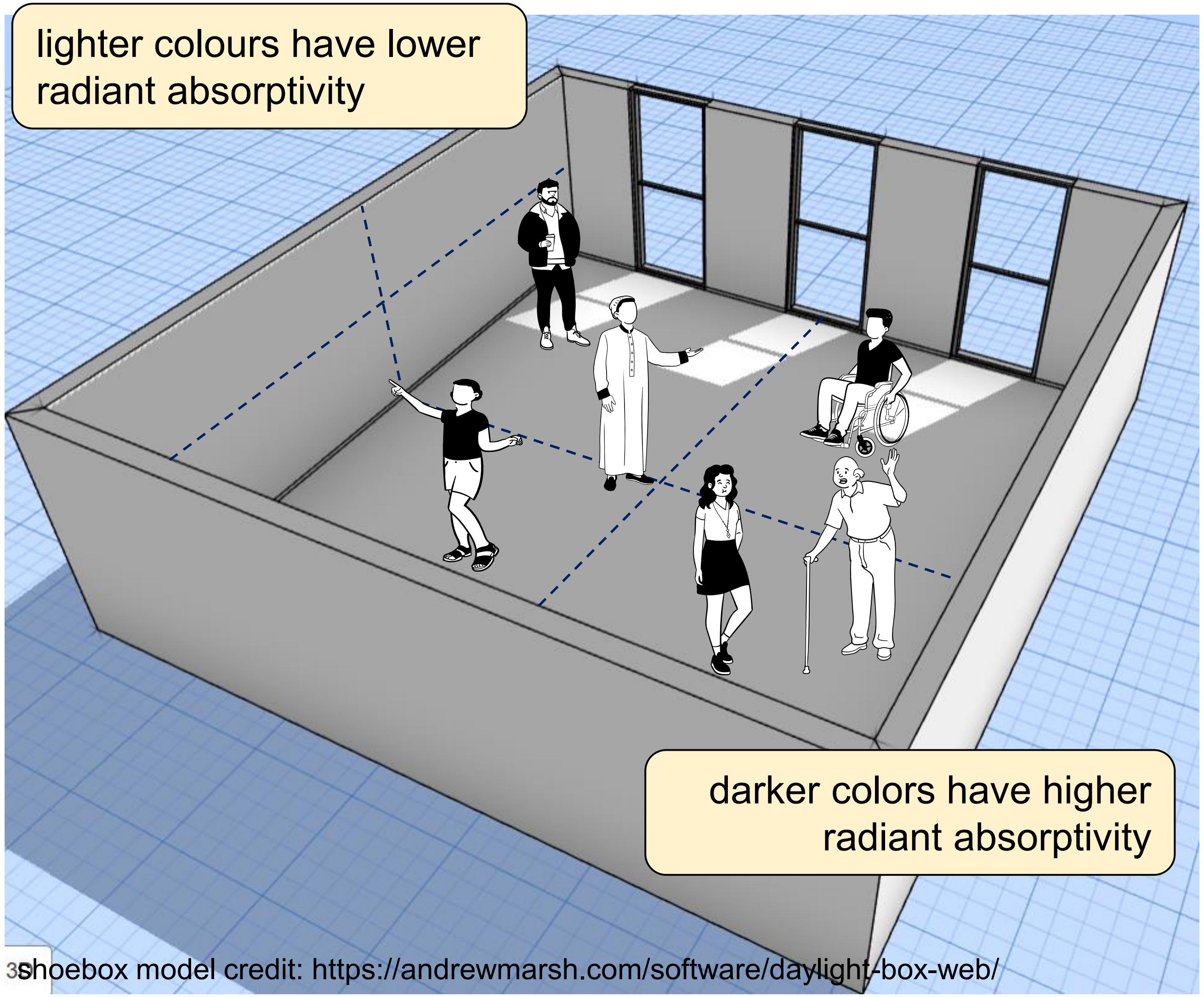

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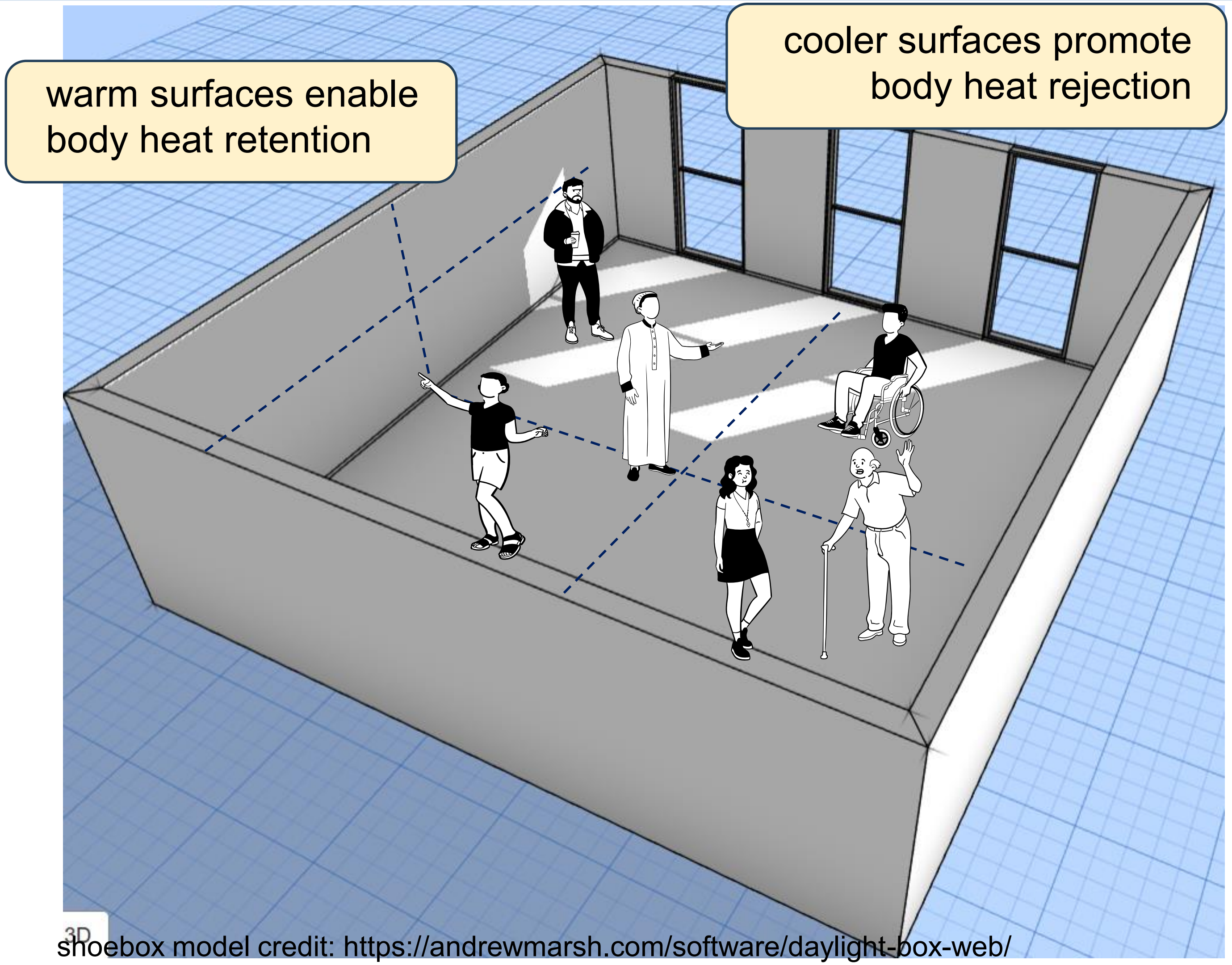

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What is the Online Thermal Comfort Tool and how can it help?

ASHRAE Standard 55
Online Thermal Comfort Tool

For Design and Evaluation

Center for the Built Environment, University of California Berkeley, hosts a compliance tool for ASHRAE Standard 55, which represents the most current published version of the Standard.

First, a quick disclaimer…

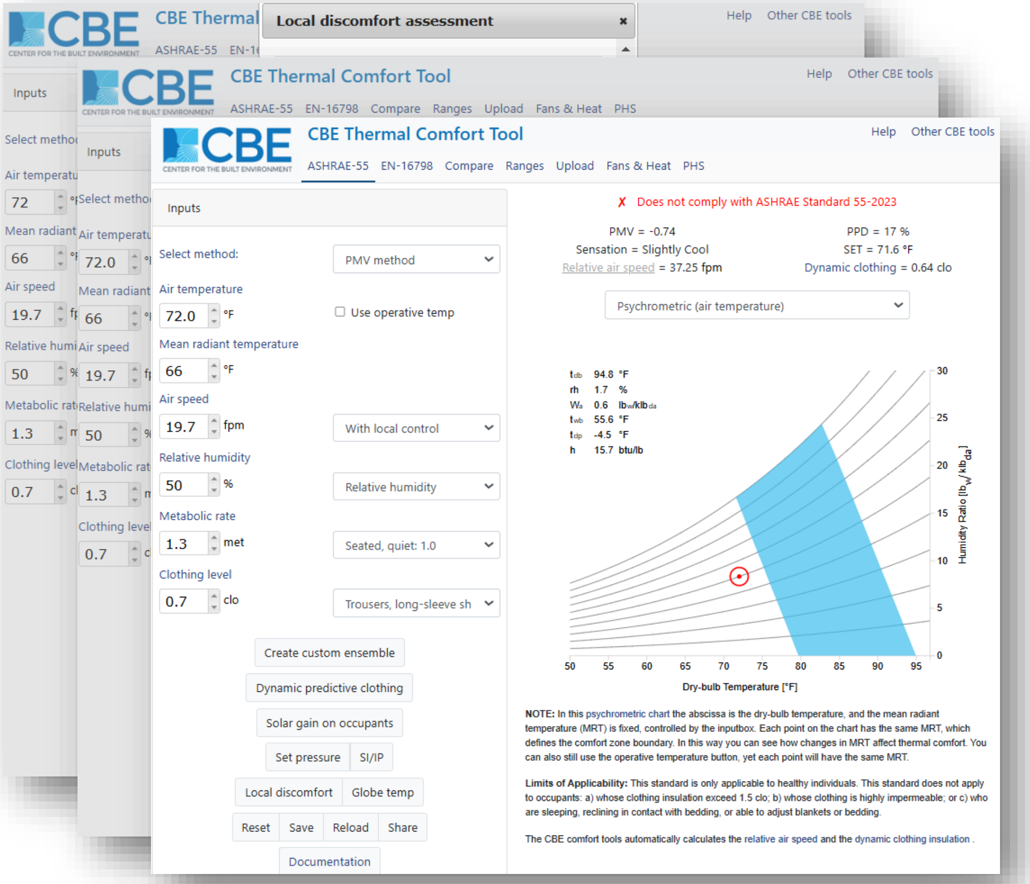
IMPORTANT

For building owners, operators and occupants, it's one thing for people to express thermal discomfort and another to try to understand where that discomfort comes from. The online thermal comfort tool can help identify problems under steady-state conditions. It can represent a single snapshot or can be used to compare up to three scenarios. For a broader understanding of space, populate the inputs using values derived from strategic days and hours of the year. It is a practical tool for assessing preliminary architectural, enclosure and interior systems during the design stage or to evaluate existing spaces. It does not do transient analysis, though more sophisticated tools exist for advanced modelling. There are help files for new users to assist in the inputs and interpreting outputs.

What’s in the Thermal Comfort Tool?

Free Accessible Thermal Comfort Tool

- https://comfort.cbe.berkeley.edu/
- Inputs for
  - Personal Factors
  - General Factors
  - Local Factors
- Calculator
  - Clothing Predictor
  - Solar Gain Calculator
- Additional Calculators
  - Mean Radiant Temperature
  - Ceiling Fan Influencer
- Dual units (SI and I-P), examples shown in I-P
- Click here to view Case Studies



Graphic source: ASHRAE Thermal Comfort Tool, Hosted by Center for the Built Environment, Adapted Credit: Robert Bean, free use granted when credited

How can the Online Ceiling Fan Tool help?

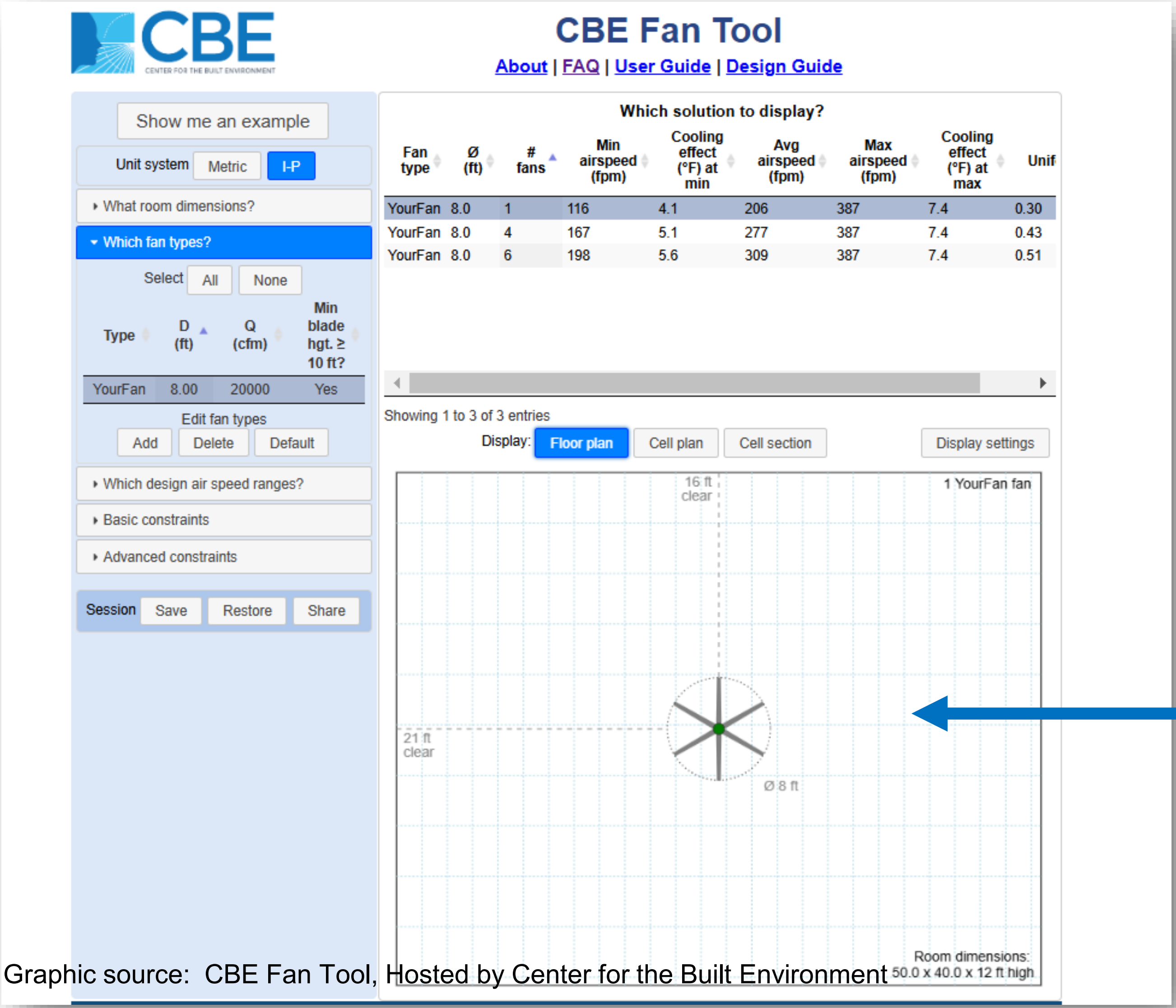
CBE Ceiling Fan Tool Elevated Air Speeds

For Design and Evaluation

Online Ceiling Fan Tool: Elevated Air Speeds

Using a ceiling fan simulator, the practitioner can create environments that are perceived to be cooler through increased convective flow across the body (cooling effect)…this effect can be ramped up, if necessary, by lowering the dry bulb temperature and if necessary, the humidity.

[Click here to view Case Studies]



Graphic source: CBE Fan Tool, Hosted by Center for the Built Environment

Make note of the cooling effect at min. and max. air flow.

Fan–space geometry

Summary on Thermal Comfort

Removing or introducing heat into a space or building is a heating, ventilation and air conditioning (HVAC) system process. Successfully warming and cooling a space or building as verified by a thermostat setpoint IS NOT the same process as creating conditions for occupants to sense and perceive thermal comfort. Campfires and fireplaces provide warmth but force people to turn around or step back due to discomfort. Cold air provides coolth but can be sensed as an uncomfortable draft forcing people to move away, block the flow or turn off the source. Terminology matters, and thermal comfort, being a subjective human experience, is not automatically achieved by simply adding warmth and coolness to a space via the HVAC system.

That is why ASHRAE Standard 55 is not specifically an HVAC standard – it is a standard that integrates the sciences of people and buildings. For compliance, the standard requires ALL factors that humans thermally experience to be considered - not just the air temperature. Successful compliance with ASHRAE Standard 55 requires an assessment first of the architecture, followed by the enclosure and interior systems then, the mechanical systems.

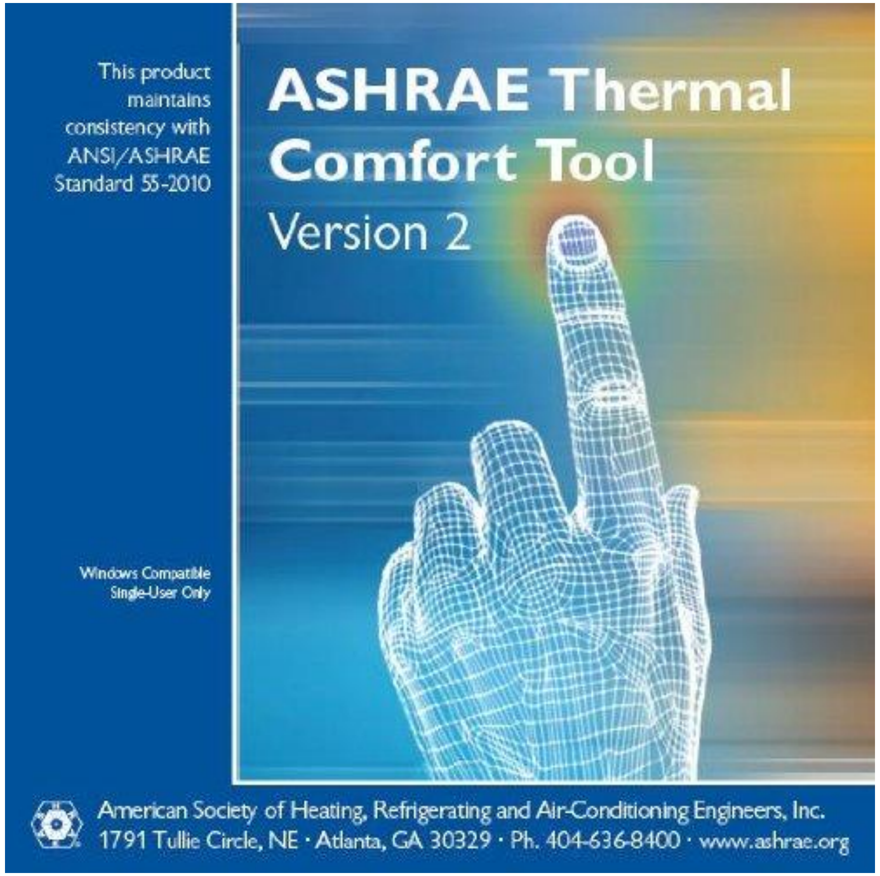
What are some ASHRAE Research Projects on Thermal Comfort?

ASHRAE Research Projects
2D & 3D Thermal Comfort Tools

For Design and Evaluation

ASHRAE's Thermal Comfort Tool Software

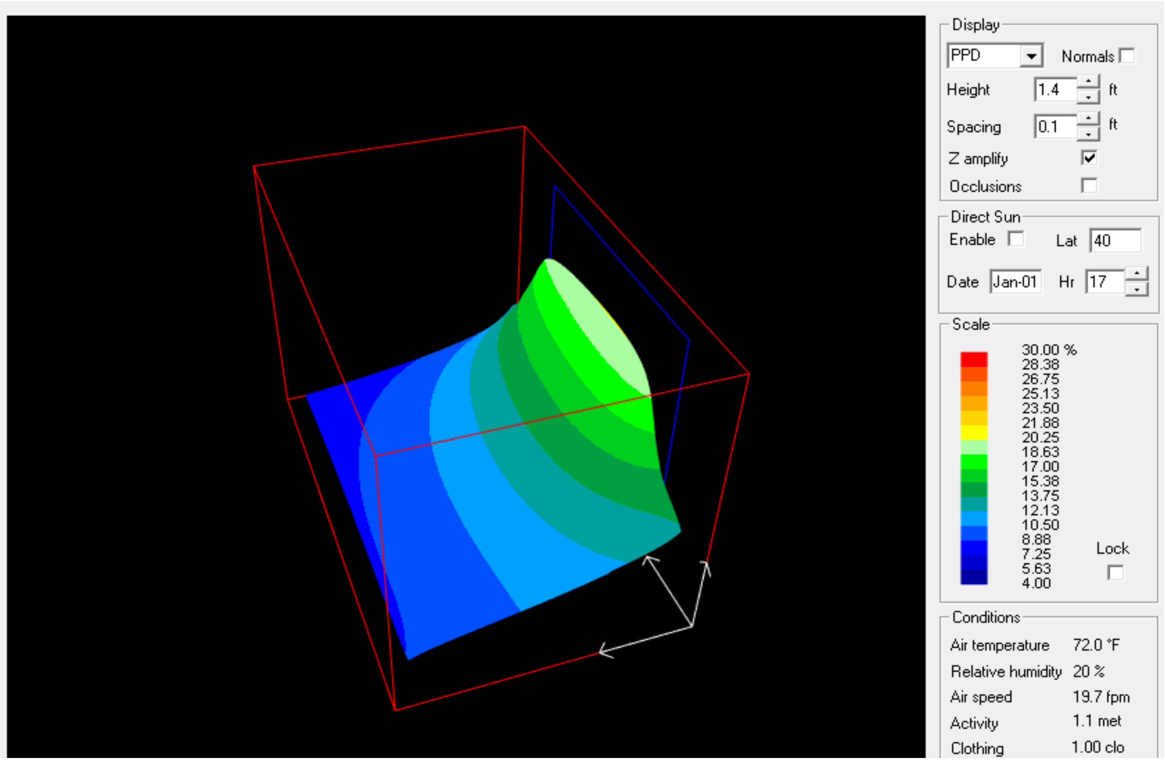
- ASHRAE's Thermal Comfort Tool software provides a user-friendly interface for calculating thermal comfort parameters and making thermal comfort predictions using several existing thermal comfort models. This new version focuses on the Adaptive and Predicted Mean Vote (PMV) Models and has an updated user interface. ASHRAE Thermal Comfort Tool, Version 2 maintains consistency with ANSI/ASHRAE Standard 55-2010 and can be used to comply with USGBC's LEED.
- This tool was replaced with the most current online version.



ASHRAE RP-1383

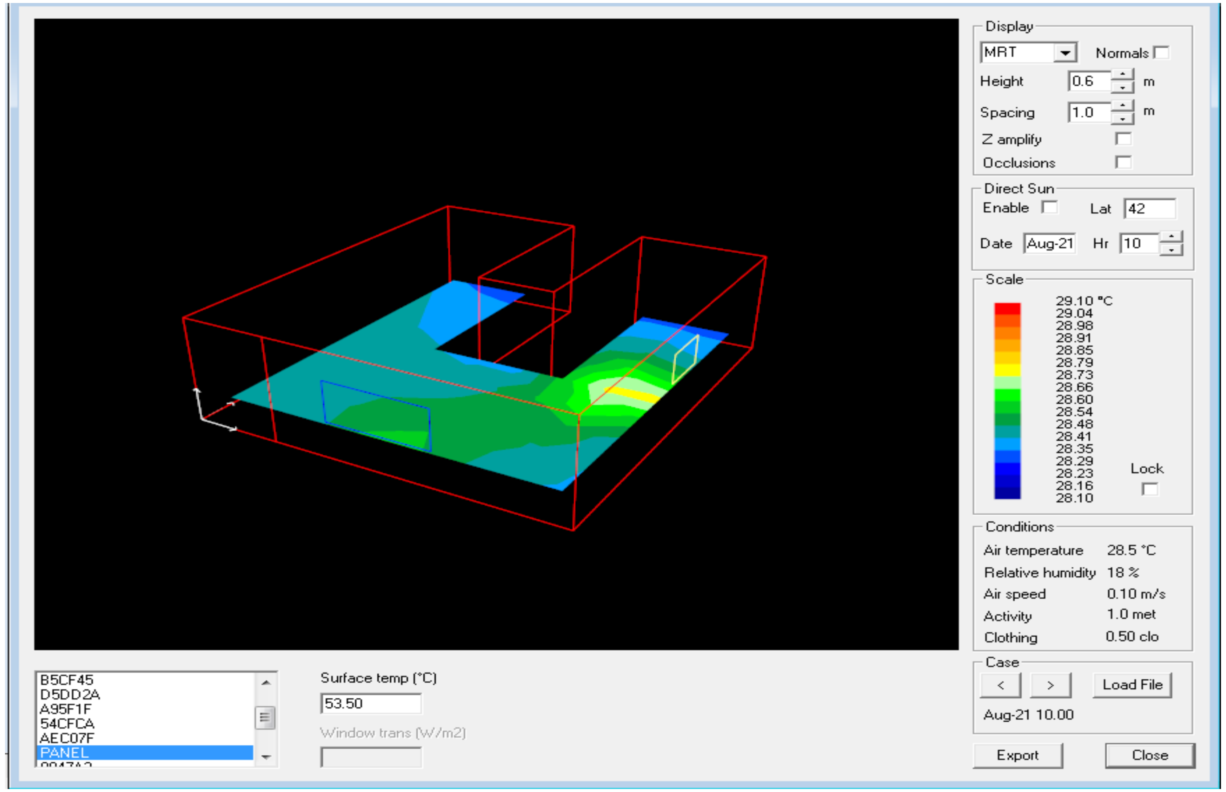
ASHRAE RP-1383

- Develop a Radiant System Module for the Simulation and Analysis of Spaces and Systems, produced analysis procedures that allow calculation and display of comfort conditions at any point within a room. These procedures are implemented in a PC-based application called Radiant Performance Explorer (RPE), an enhanced version of the ASHRAE Thermal Comfort Tool.



ASHRAE RP-1766

- Development of a Unified Tool for Analysis of Room Loads and Conditions. The primary result of the project is the Radiant Performance Explorer/Heat Balance (RPEHB), a PC-based Windows application that derives and displays comfort results for multiple positions within an arbitrarily shaped room.



Measurements
Design, Commissioning, Return to Service, Sample Specification

What are some ways to evaluate for compliance?

Evaluating Environments for Thermal Comfort Compliance

- Standard 55/ISO 7730 Measuring Instrument
  - Radiant temperature
  - Dry bulb temperature
  - Humidity
  - Air velocity
  - Drafts
  - Radiant asymmetry
  - Stratification
  - Floor temperature

Image credit: Delta Ohm Sri

What are some ways to use Standard 55 in the building lifecycle?

Procedures – Design, Commissioning, Return to Service

- Use the Standard to drive passive solutions using architectural, enclosure and interior systems.
  - Analytical Method
  - Adaptive Method
- Use the Standard to influence choices in HVAC systems.
  - Radiant for radiant problems starting with architecture, enclosure and interior, then mechanicals.
  - Convective for convective problems.
- Use the Standard to address rogue zones – the goal is to harmonize fluxes to optimize designs.
- Require building & enclosure commissioning to verify that the construction meets design intents.
- Require HVAC & controls commissioning to verify the installation meets design intents.
- Require operational training and occupant initiation.
- Require Post Occupancy Surveys (POE) to check against expectations and direct remediation work if needed.

What are some sample specifications for code officials & standards development?

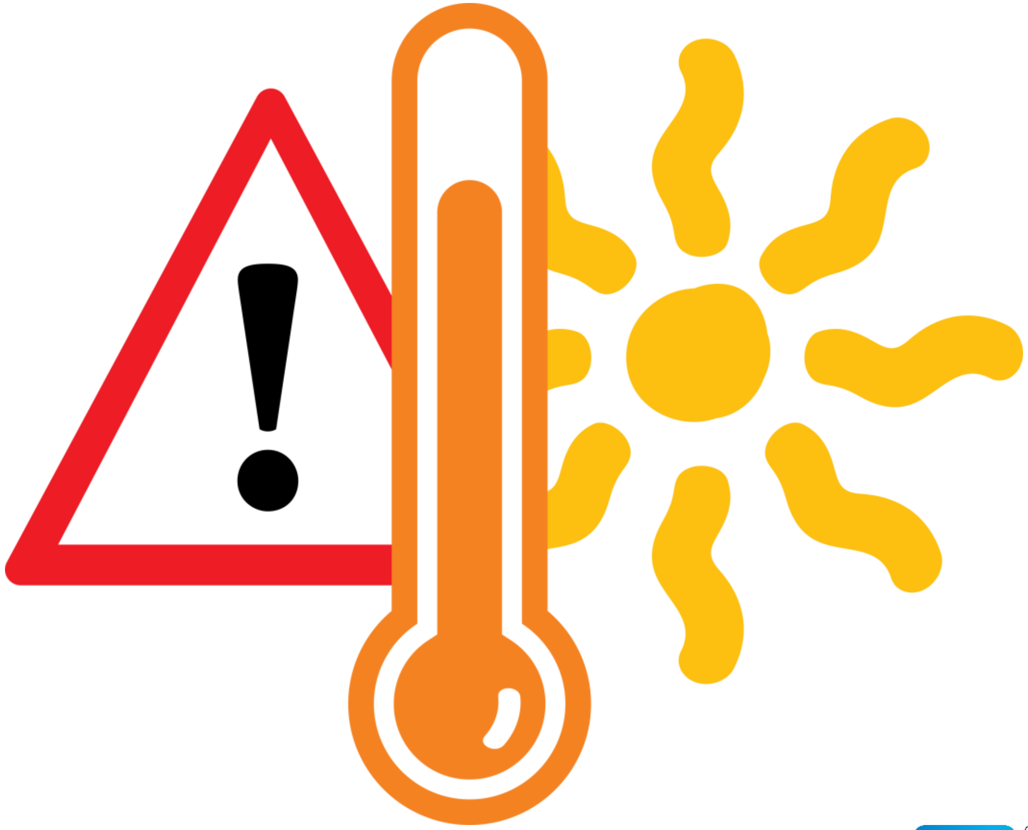
Sample Specifications for Code Authorities and Standards Development

- Spaces occupied for more than 15 minutes shall be designed, commissioned and operated to comply with the most current version of ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy*.
- The primary method of assessment shall be the analytical method.
- The adaptive method shall be assessed where and when applicable, considering privacy, security, air, light and noise pollution.

Suggestions for extreme events *(Page 1 of 3)*

Though thermal stress is currently outside the purpose and scope of ASHRAE Standard 55, its application in design can promote thermal safety. The following are suggestions for mitigating occupant overheating and underheating during extreme events.

If occupants are experiencing thermal stress, contact local first responders.



Suggestions for extreme events *(Page 2 of 3)*

Heat Stress: Passive / Low Energy Cooling Tactics - Not part of the Standard, provided here for information only	
1	Seek/create higher air velocities/drafts by using ceiling, floor, and desk fans; room air purifiers, and cross flow ventilation. Where possible use night time outdoor air for natural ventilation and cooling.
2	Decrease humidity, use cross flow dry ventilation air (if possible) or use dedicated in space dehumidifiers. Use split systems for discharging heat to outdoors. Caution for dehydration – see below.
3	Stay hydrated to reduce blood viscosity, ensure vasodilation for efficient flow to the skin for radiant and convective cooling, and prevent dehydration due to evaporative cooling (sweating and respiration).
4	Decrease met rate through lower-intensity activities (relaxation and rest). If it's hot outside, monitor CO2 and ventilate for short periods. It is a balance between keeping acceptable air quality and staying cool.
5	Decrease clothing to reduce insulation and expose more skin surface area to a cooler environment (if possible – see below). If safe, apply cool towels to the neck, chest & groin area and elevate air speed across the body. Have cool baths.
6	Seek lower MRT enclosures and avoid shortwave (solar) radiation by activating external shading. Relocate to below-grade and northside spaces. Closing internal window treatments will provide some relief, though internal shades usually become hot and radiate energy into the space, where it will get absorbed by surfaces and converted to heat.
7	Avoid using heat-generating appliances, cooking, laundry, etc.

Suggestions for extreme events *(Page 3 of 3)*

Cold Stress: Passive / Low Energy Heating Tactics - Not part of the Standard, provided here for information only	
1	Avoid air velocities by slowing down or turning off unnecessary source of air flow. Repair building enclosure to mitigate infiltration and drafts. Avoiding cold surfaces known to cause down drafts.
2	Increase humidity (limited solution for colder climates). Use in-space or ducted humidifiers. Preference for steam to prevent microbial growth. Reduces evaporative cooling from skin. Caveat for dew point concerns on windows and within enclosure cavities. Caution when using this strategy.
3	Stay hydrated to reduce blood viscosity, promote vasoconstriction, ensure efficient flow from skin to internal organs
4	Increase met rate by activity, exercise, walking etc. If possible, monitor CO2 and ventilate for short periods.
5	Increase clothing to increase insulation and reduce skin surface exposure to the environment.
6	Avoid lower MRT enclosures and seek shortwave (solar) radiation by deactivating external shading, relocate to above grade and southside spaces. Opening internal window treatments can work if the glazing area and performance does not cause further cooling through down drafts and radiant asymmetry.
7	With safety as a priority, use backup source of heat. Follow manufacturer operating manuals and building codes.

Is compliance really an upgrade?

Perspective

- Basic morals and ethics demand that principles of thermal comfort be applied to rodents in laboratory settings.
- Despite the beneficial evidence for human health, productivity and learning, compliance with ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy is considered an upgrade, ergo not requiring compliance to the Standard, should be considered a downgrade.

Thermal Comfort in Rodents: A Key Factor in Laboratory Environments
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Universidade de Brasília | Laboratory Animal Science

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Additional Resources

For more resources related to this guide, visit the Thermal Comfort topic page within IEQ Resources on ASHRAE.org.