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Sustainable HVAC Design: Using Air Movement in Air Conditioned Buildings

Sustainable HVAC Design: Using Air Movement in Air Conditioned Buildings

Presented by: Big Ass Solutions
2348 Innovation Road
Lexington, KY 40511

Description: Provides an overview of the principles of thermal comfort, heat transfer, and the benefits of the innovative HVAC (heating, ventilation, and air conditioning) strategy that pairs traditional air conditioning with energy-efficient air movement.

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Purpose and Learning Objectives

Purpose: Provides an overview of the principles of thermal comfort, heat transfer, and the benefits of the innovative HVAC (heating, ventilation, and air conditioning) strategy that pairs traditional air conditioning with energy-efficient air movement.

Learning Objectives:

At the end of this program, participants will be able to:

- identify the factors that affect thermal comfort
- explain the sustainability benefits of a design strategy that uses air movement in conjunction with traditional air conditioning
- describe how elevated air speed can improve building indoor air quality (IAQ), and
- discuss how ASHRAE Standards 55 and 90.1 are applied in air conditioned spaces.

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Table of Contents

Click on title to view

Thermal Comfort

What Is Thermal Comfort?

ASHRAE is a professional society of engineers focused on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability.

ANSI/ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy*, defines the range of indoor environmental conditions acceptable to a majority of building occupants. The 2013 version of the Standard has been revised with a renewed focus on the application of the Standard by practitioners and the use of clear, enforceable language.

Standard 55 defines thermal comfort as, “That condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.”

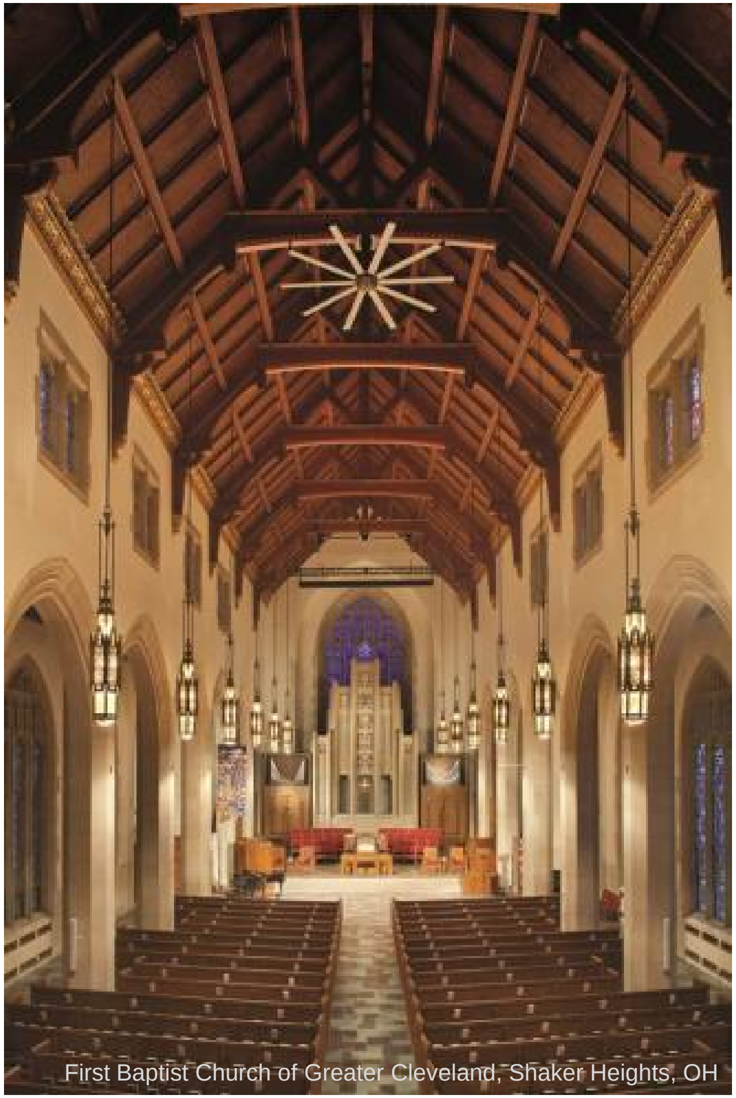
Rice Fergus Miller Office, Bremerton, WA

What Is Thermal Comfort?

It's important to remember that thermal comfort is all a matter of perspective.

Every individual has a slightly different perception of what is comfortable. What is comfortable for one occupant may not be comfortable for another.

Comfort can be thought of as a lack of noticing discomfort. If you don't notice that you're hot, for example, this could mean you're comfortable in the space.



First Baptist Church of Greater Cleveland, Shaker Heights, OH

What Is Thermal Comfort?

Thermal comfort theory is built around providing comfort for the majority of the occupants of a space, not for every single, individual occupant.

One reason thermal comfort is so important is that it provides us the ability to focus on the work at hand, rather than how to eliminate the discomfort factor from our experience.

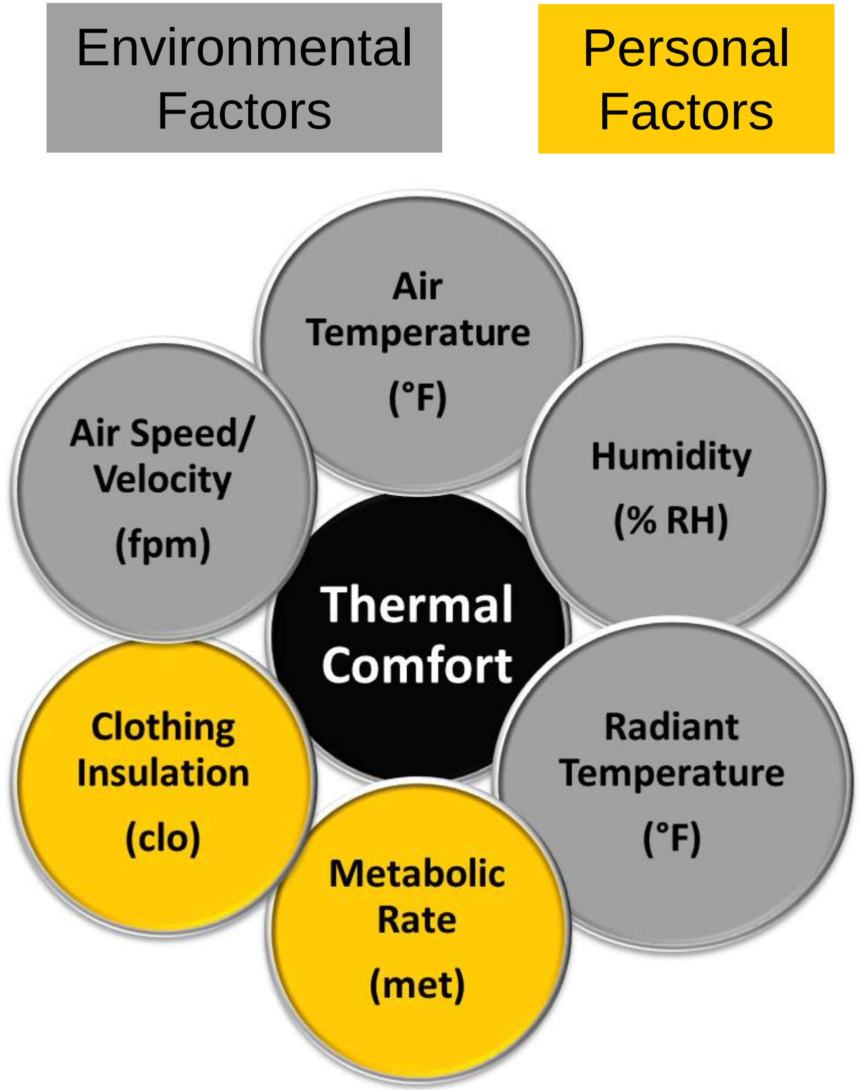
Residence, Alford, MA

Thermal Comfort: What Affects It?

ASHRAE Standard 55 states that there are six primary factors that affect occupant thermal comfort. Four are environmental factors, and two are personal factors.

The most commonly discussed environmental factors in regards to thermal comfort are air temperature and relative humidity.

These two factors are most often controlled by a comfort system, such as air conditioning. They are also the two most energy intensive means of achieving comfort.



Thermal Comfort: What Affects It?

Radiant temperature, another environmental factor, is often not an issue in a typical air conditioned space, but it can be important if an occupant is seated near large glass windows or large hot/cold surfaces.

Air speed or air velocity, the fourth environmental factor, often has a negative connotation as draft in the winter. However, elevated air speed can have positive impacts during the summer months.

The two personal factors, clothing insulation, which is related to the amount of clothing worn by the occupants, and metabolic rate, which is related to the activity level of the occupants, are generally givens based on the type of space being designed and can't typically be altered by the designer.

Let's take a closer look at each of these six primary factors that affect thermal comfort, as they will help us better understand how to design a comfortable space for the majority of occupants per ASHRAE Standard 55.

Clothing Insulation

Clothing insulation, the first personal factor, is measured in clo and is a sum of the individual clo values for each piece of attire. These values can be found in Table 5.2.2.2B Garment Insulation of ASHRAE Standard 55-2013.

If an occupant is wearing shoes, socks, underwear, trousers, and a polo, the individual clo factors are summed to give their overall clo value. As seen in the example in the chart on the right, if this was a representative occupant, the clo value for the thermal comfort calculations for this space would be used at 0.41 clo.

Clothing	clo units
Shoes	0.02
Socks	0.03
Underwear	0.04
Trousers	0.15
Polo	0.17
Total	**0.41**

Clothing Insulation

The more clothing that an occupant is wearing, the higher the thermal insulation or clo value, and the lower the temperature of a space must be to ensure occupant thermal comfort. Conversely, lower clo values allow for higher temperature set points in the space to provide equal comfort.

In certain settings, such as manufacturing operations, clothing insulation cannot be varied due to safety concerns. In office type settings where clothing insulation is more variable, outer garments can typically be added or removed as a means of controlling comfort for the occupants.


BicycleWorks, St. Louis, MO

Clothing Insulation

If occupants of a space have completely different ensembles, their clo values should not be averaged to find a single number. Instead, two separate calculations should be performed for each representative occupant. Ideally, the two different comfort zones will overlap, and the design can provide acceptable levels of comfort to both sets of occupants.

There is an exception to this requirement for spaces in which individuals can adjust their clothing levels to account for differences in their responses to their thermal environment. In this scenario, it is permitted to use a single representative occupant with an average clothing insulation value.

The 2013 version of Standard 55 also clarifies when the requirements pertaining to insulation values do not apply. For instance, the Standard does not apply to occupants with clothing insulation values over 1.5 clo, when clothing is highly impermeable to moisture (such as chemical protective clothing or rain gear), or to sleeping occupants.

Metabolic Rate

Metabolic rate (met rate), the second of the personal factors, relates to the activity level of the occupants and the amount of energy expended in a given period.

One (1) met is the basis of metabolic rate and is the energy produced by an average person seated at rest, which is typical for occupants of an office environment.

As occupant activity levels increase, so does the metabolic rate and the amount of heat generated by the occupants. To maintain thermal comfort, the five other thermal comfort factors will have to be altered to compensate for the additional heat generated by the human body. This will be discussed further later in the presentation.


Scripps Ranch Swim & Racquet Club, San Diego, CA

Metabolic Rate

Met rate is usually set by the type of tasks being performed in the space. For example, in a manufacturing setting, higher met rates are typical due to the more physically exertive tasks that occupants perform in the space. Occupants of an office space likely have lower met rates since the occupants are usually sedentary.

The 2013 version of Standard 55 specifies that activities of several occupants performing very different activities should not be averaged to find a single metabolic rate for the group. For example, customers in a restaurant will have a met rate near one (1) met which corresponds with a seated activity level, while the servers may have a met rate closer to two (2) met. In this case, servers and restaurant patrons should be considered separately when determining the conditions required for comfort. In some situations, it will not be possible to provide acceptable levels of comfort for both groups.


Hempfield Recreation Center, Landisville, PA

Metabolic Rate

When the activity levels of the individuals vary, Standard 55 allows the designer to use a time weighted average to calculate metabolic rate. For example, a person who spends 30 minutes lifting, 15 minutes standing, and 15 minutes walking around would have an average met rate that takes each activity and time period into consideration. However, this averaging should not be used if one activity lasts longer than 60 minutes. If the occupant spends 60 minutes lifting and then 60 minutes walking around, the occupant will have two distinct met rates, and separate calculations will need to be performed.

As a side note, the 2013 version of Standard 55 clarifies that these requirements do not apply to occupants whose metabolic rate is higher than two (2) met.

Gallrein Farms, Shelbyville, KY

Metabolic Rate

To illustrate the impact that metabolic rate has on thermal comfort, consider a skier skiing down a hill with a child on his back.

The skier will have a high met rate due to the level of activity required to ski down the hill. The child is essentially sedentary, riding on the adult's back. All other thermal comfort factors are the same for both skier and child.

Metabolic Rate

When the skier reaches the bottom of the hill, he could be at or near heat stress with a high met.

However, the child will have a much lower met rate, probably near one (1) met. In this case, even though the high clothing levels provide some insulation, the child may actually be experiencing hypothermia due to the lack of heat generated by his body.

This example illustrates how significant any single thermal comfort factor, in this case met rate, can be in determining comfort.

Air Temperature

We'll now take a closer look at the four environmental factors that affect thermal comfort, starting with air temperature.

Air temperature is measured with a thermometer and is also known as air dry bulb temperature (DBT).

Air temperature represents the amount of dry heat, or sensible heat, in the air surrounding the occupant.

Wow That's Fresh, Brandon, FL

Humidity

The second environmental factor, humidity, is often referred to as relative humidity and is the amount of moisture in the air compared to the total amount of moisture that could be held in the air at a specific temperature. Generally speaking, relative humidities of 20%–60% are typical for an air conditioned space.

Humidity ratio and absolute humidity are also measures of the amount of moisture in the air but are only used for specific scenarios.

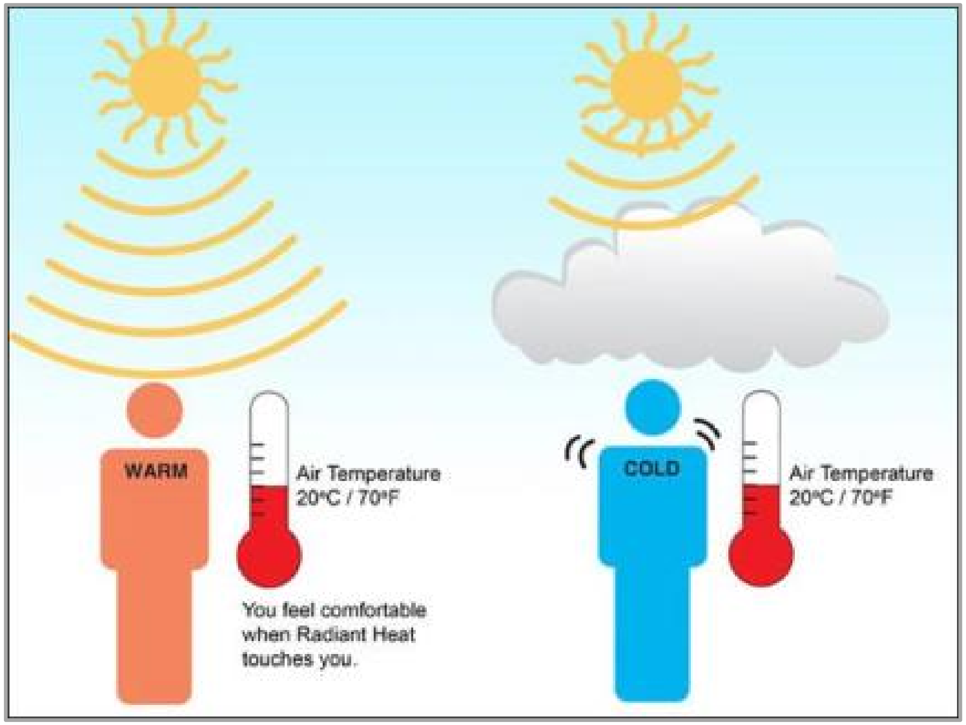
The lower the relative humidity or the less moisture in the air, the easier it is for the human body to evaporate moisture off of the skin, which means it is easier for the body to reject heat via sweating.

Voce Salon, Lexington, KY

Radiant Temperature

Radiant temperature is one of the more conceptually difficult environmental factors to visualize.

Radiant heat exchange occurs between two objects at different temperatures via radiation.



Source: The Masonry Heater Association of North America, www.mha-net.org (accessed April 2014)

Example: Radiant Effects

To better explain radiant temperature, consider two occupants of a car on a sunny day. If the driver is on the shady side of the car, he would not experience much radiant heat gain and would be comfortable at a given set of conditions.

However, if the passenger is on the sunny side of the car and experiences a large radiant heat gain from the sun, he would need either less clo or lower air temperatures to achieve the same level of comfort as the driver.

Even though the temperature is set to be the same on each side of the car, the comfort levels of the occupants are different due to the radiant heat gain experienced by the passenger.

Air Speed

The fourth environmental factor that affects thermal comfort is air speed or air velocity.

Elevated air speeds increase heat transfer via convection, which increases the rate at which heat leaves the human body. It also impacts the rate at which moisture evaporates off the skin.

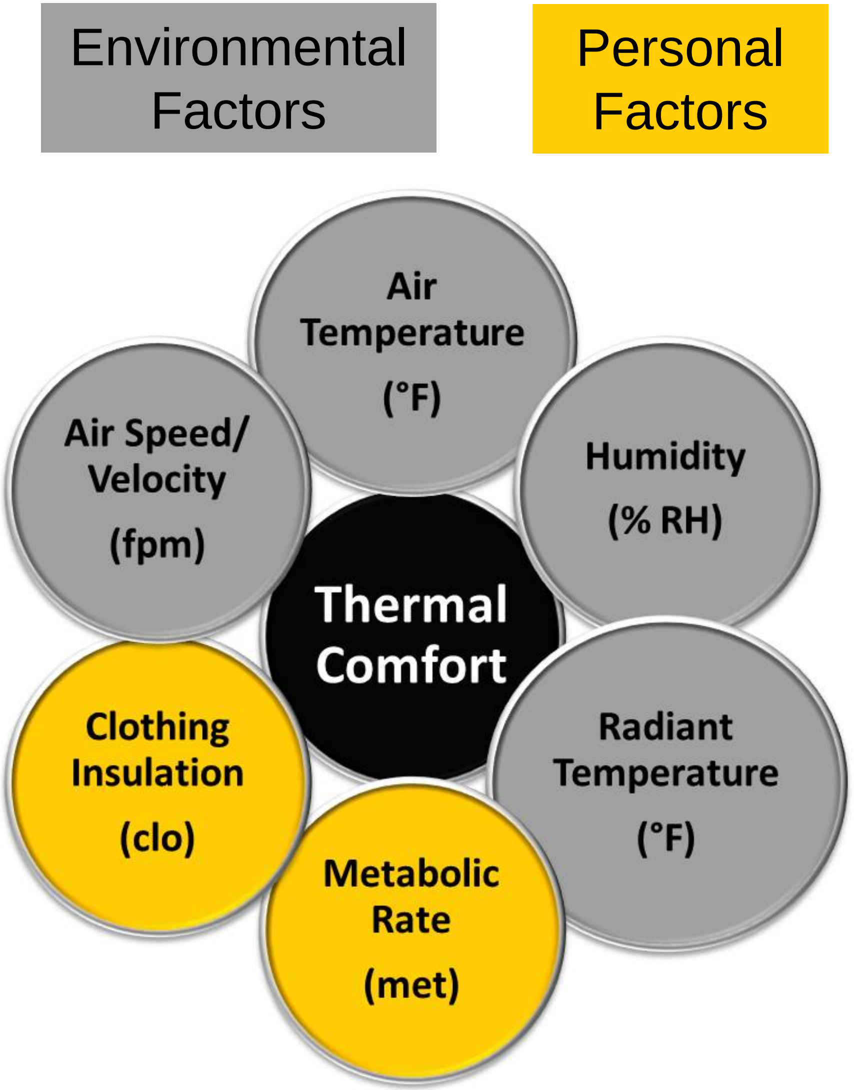
As a result, elevated air speeds create a perceived cooling effect that can help offset a rise in any of the other thermal comfort factors. We'll take a closer look at air speed later in the presentation.

Thermal Comfort: What Affects It?

The important thing to remember about thermal comfort is that all six factors (clothing insulation, metabolic rate, air temperature, humidity, radiant temperature, and air speed) must be considered together when assessing thermal comfort.

Simply stating that a specific temperature and humidity are provided to an occupant does not mean thermal comfort has been achieved.

Six factors must be calculated and combined to determine if a comfortable environment for the majority of occupants will be provided.

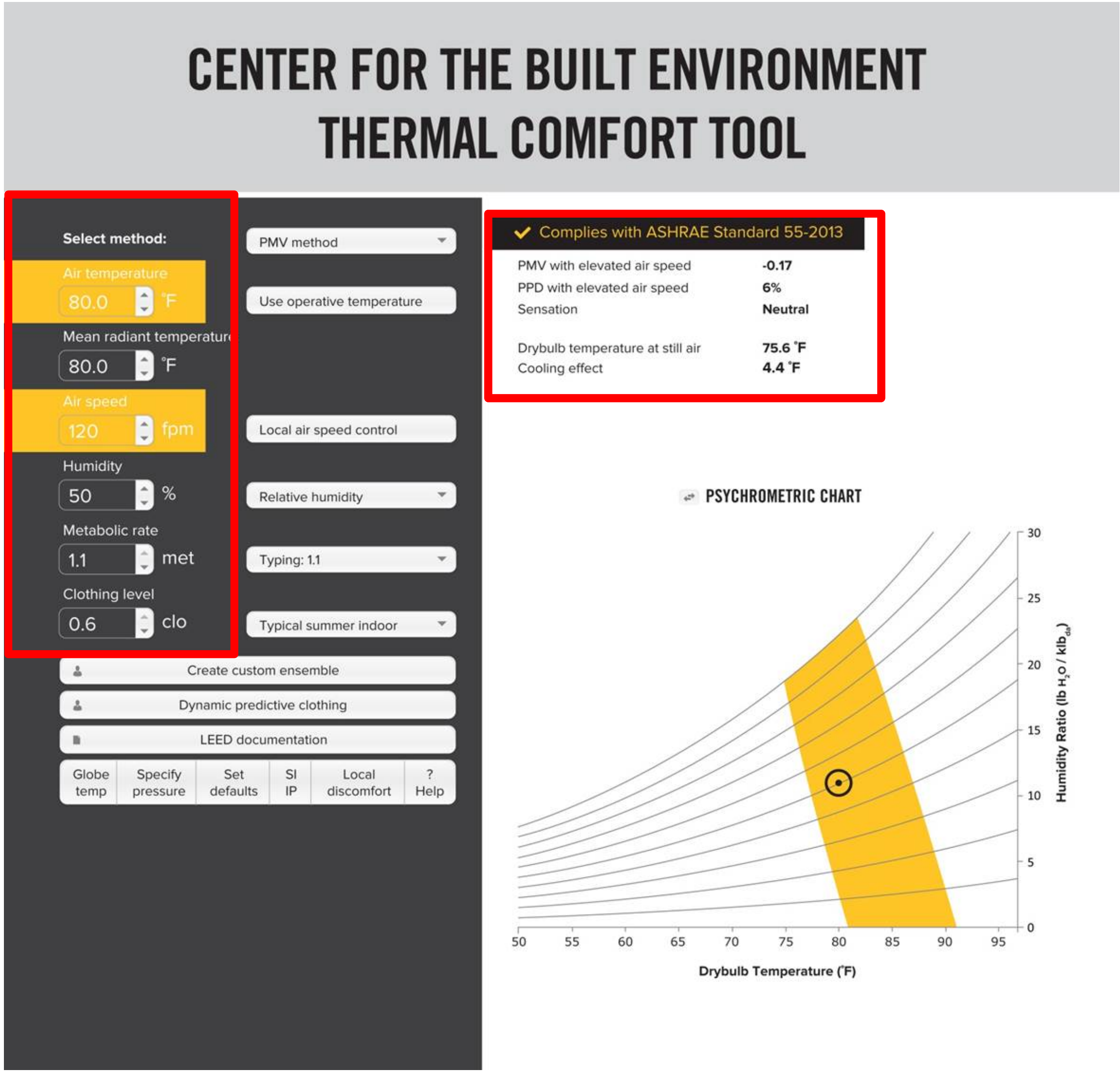


Thermal Comfort Tool

The thermal comfort tool from ASHRAE or the Center for the Built Environment (CBE) provides a means of evaluating the six factors together.

The thermal comfort tool is built on the equations provided in the appendices of ASHRAE Standard 55.

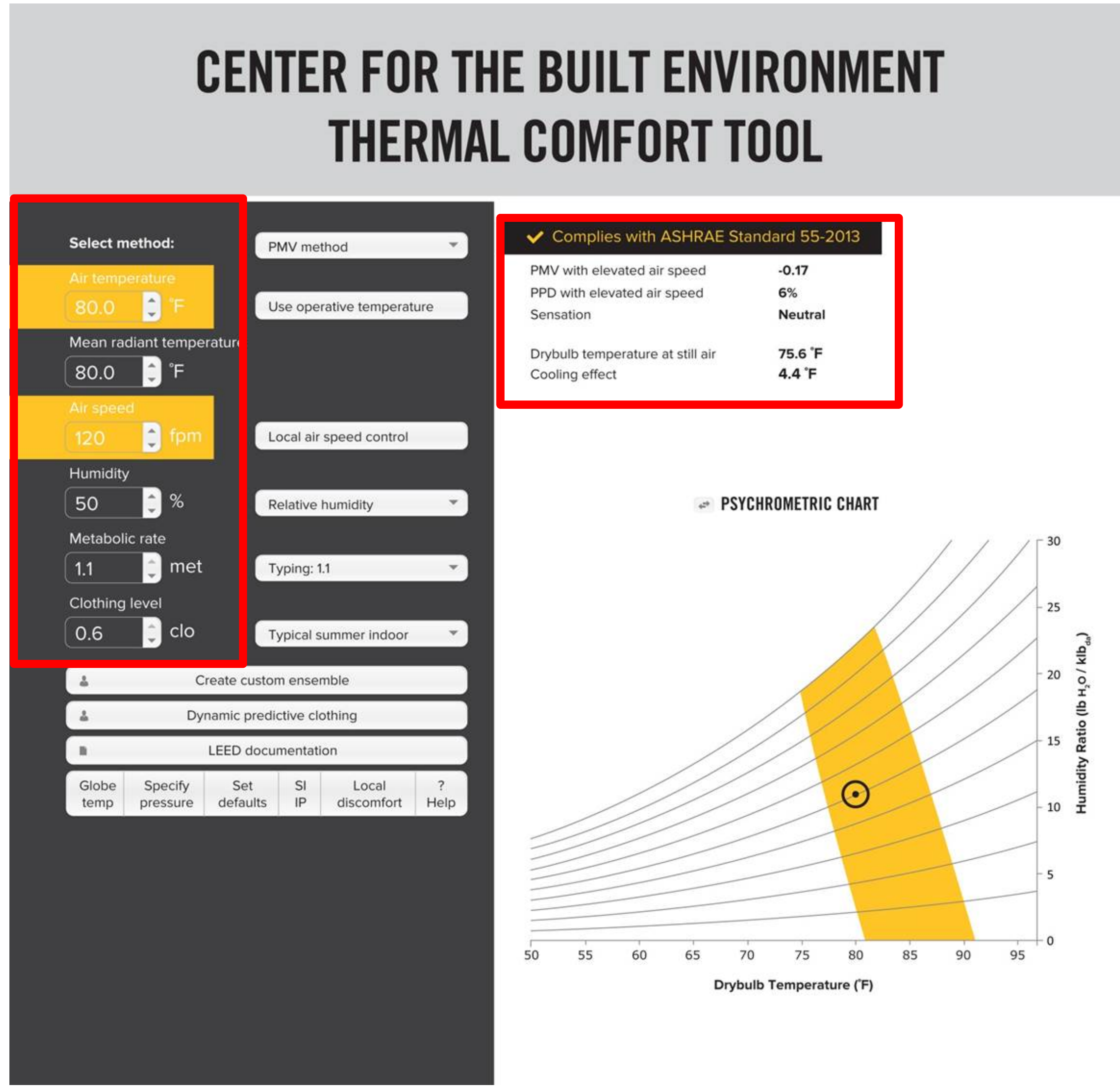
Source: CBE Thermal Comfort Tool, www.cbe.berkeley.edu/research/thermal-tool.htm (accessed April 2015)



Thermal Comfort Tool

Air temperature can be varied, as can humidity, air speeds, radiant temperature, met rates, and clo values—all can be fed into the software together, and the impact on the comfort level of the occupants can be more accurately determined.

Important values to note in the image on the right are PMV and PPD.



Thermal Comfort Tool

Predicted percent dissatisfied (PPD) is the percentage of occupants that are dissatisfied with the current thermal environment. Typical values for PPD are in the 10% to 20% range, meaning that 20% of the occupants are dissatisfied and 80% are satisfied with the thermal conditions. A PPD of 20% or less complies with the requirements of ASHRAE Standard 55. Note that this is based on a 10% dissatisfaction criterion for general (whole body) thermal comfort based on the PMV-PPD index, and an additional 10% dissatisfaction may occur on average from local (partial body) discomfort.

Predicted mean vote (PMV) is a scale from positive three (+3) to negative three (-3) that indicates what value the average person would assign a space regarding their thermal sensation for that space. So, +3 is high/warm, -3 is low/cold, and zero (0), which is the goal, is considered neutral. Values between -0.5 (slightly cool) and +0.5 (slightly warm) are acceptable ranges to aim for in a design per Standard 55.

Graphical Comfort Zone Method

In addition to the computer model method, designers can use the graphical method to show compliance. However, the graphical method is limited to occupants with metabolic rates between 1.0 met and 1.3 met, clothing insulation levels between 0.5 clo and 1.0 clo, and air speeds of less than 40 fpm (feet per minute). If these conditions are not met in the design, then the computer model method must be used.

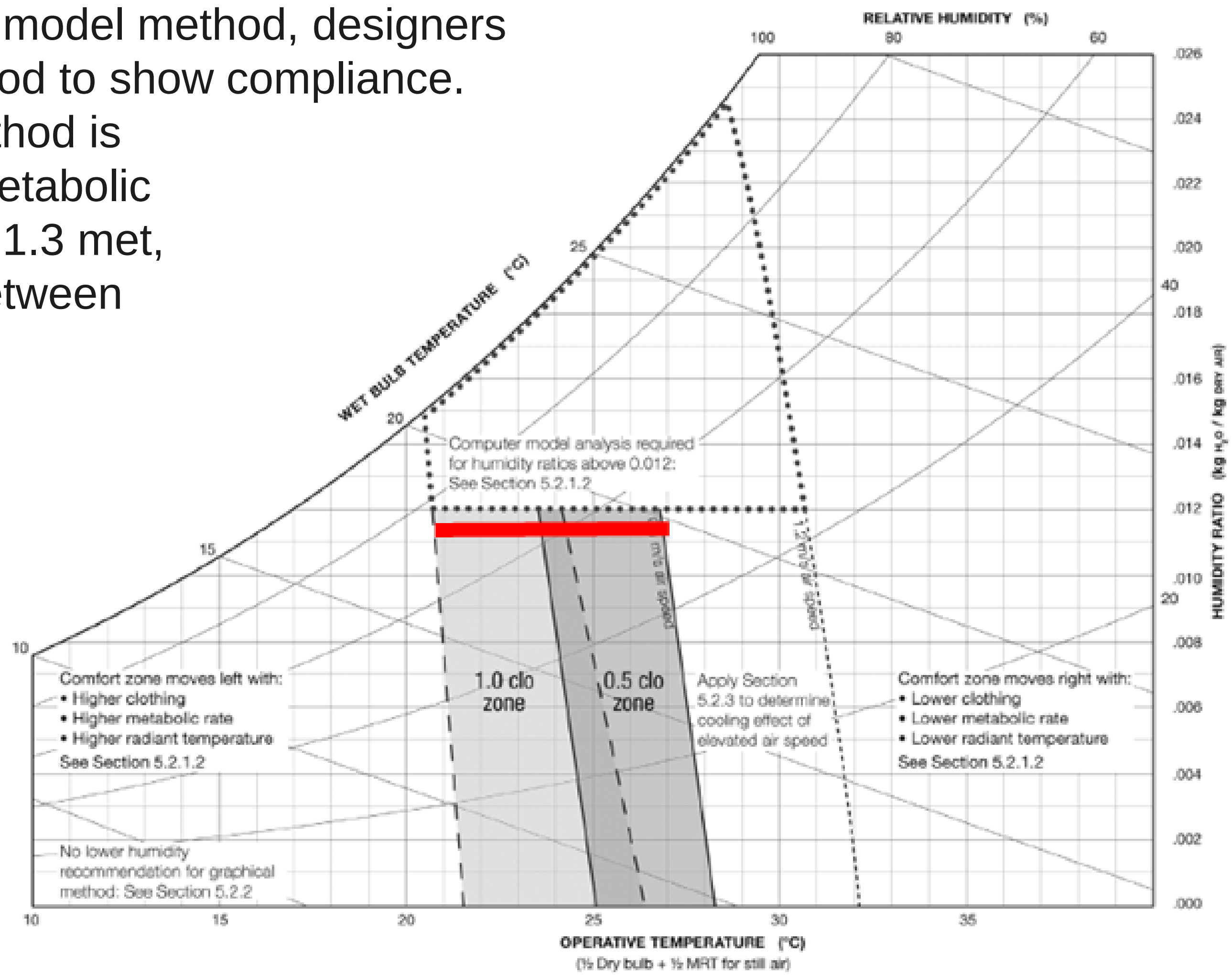


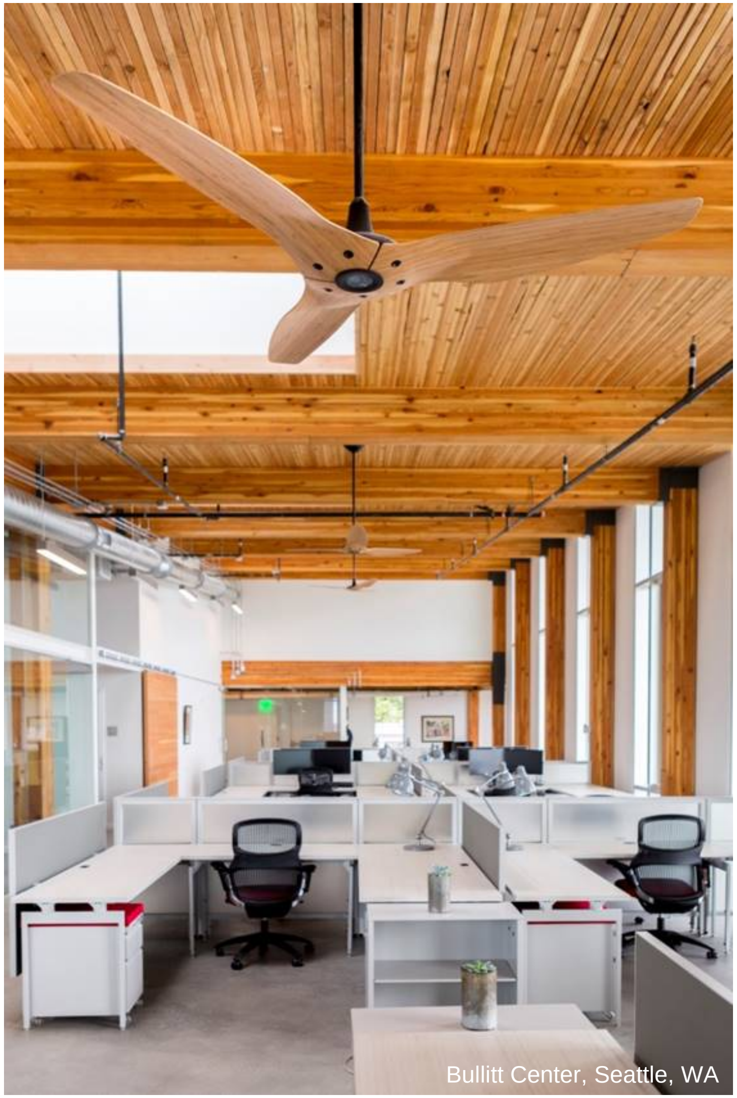
Figure 5.2.1.1 Graphical Comfort Zone Method – ASHRAE Standard 55-2010

Allowances for Air Movement

Recent changes to ASHRAE Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, allow for credit to be taken for elevated air speed in the proposed building design. Credit can be taken as long as equal thermal comfort is maintained in both the proposed and baseline buildings.

Equivalent thermal comfort is defined as equal PMV and PPD as calculated using the ASHRAE or CBE thermal comfort tool.

Towards the end of this course, two theoretical examples will be used to illustrate how equivalent thermal comfort can be demonstrated per the requirements of ASHRAE 90.1, Appendix G.



Bullitt Center, Seattle, WA

Allowances for Air Movement

It should be noted that any energy savings demonstrated using the methodology in Standard 90.1, Appendix G could be used to earn LEED® credits under:

- LEED BD+C EA Credit 1: Optimize Energy Performance
  (LEED Building Design and Construction, Energy and Atmosphere, Credit 1)

5/3 Pavilion, Lexington, KY

Heat Transfer

Heat Transfer

In order to better understand thermal comfort and thermal comfort calculations, it is necessary to first understand the basics of heat transfer.

Heat always flows from higher temperature objects to lower temperature objects, and heat transfer will continue to occur until an equilibrium is reached and both objects have the same temperature. The heating of one object will result in the cooling of the other object due to the removal of heat from that object.

There are three basic modes by which heat transfer can occur: conduction, convection, and radiation.


St. Joseph Mercy Ann Arbor Hospital, Ann Arbor, MI

Heat Transfer

Conduction is the transfer of heat through a solid, from a warmer area to a cooler area.

Consider a Bunsen burner used to heat a metal rod. When the tip of the rod is placed into the flame, it becomes very hot, and the heat gained will transfer rapidly down the metal rod to the person's hand. In this case, the heat transfer may be fast enough that the hand may be burned.

Convection is heat transfer that occurs through a moving fluid (gas or liquid).

A good example of convective heat transfer is blowing air onto a hot bowl of soup. In this case, air is the fluid which moves past the surface of the soup and removes heat more quickly than if the bowl of soup was left standing.

Heat Transfer

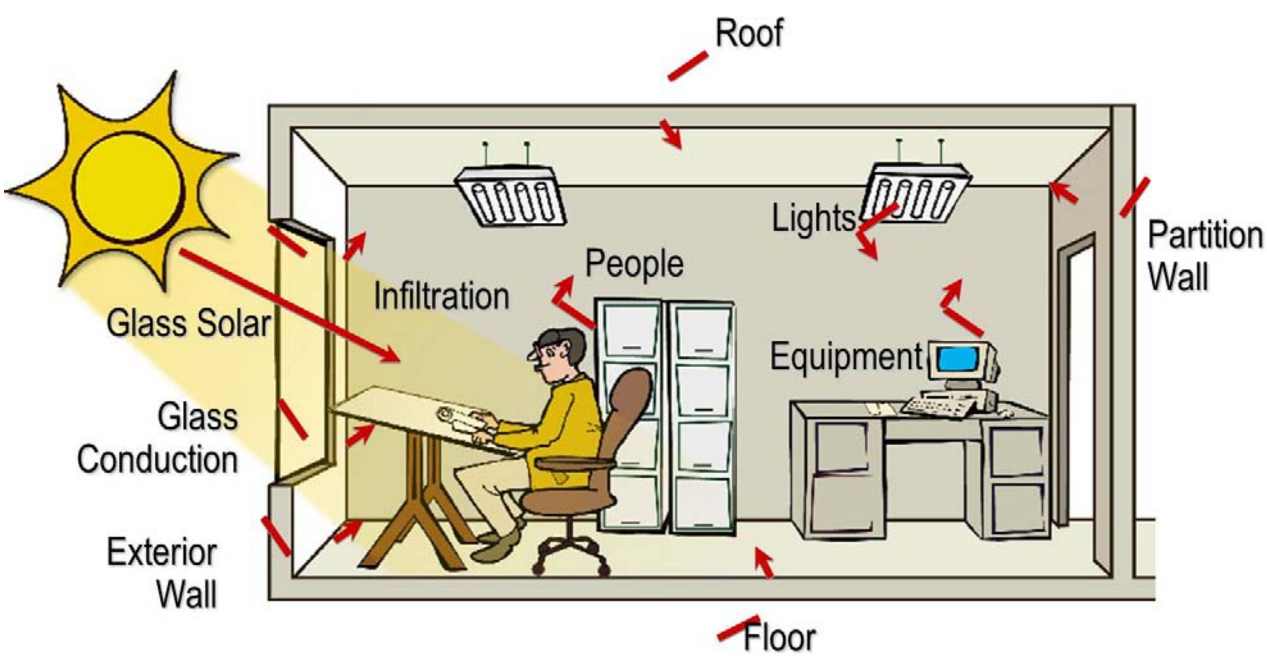
Heat transfer through radiation, which was mentioned previously, is energy that is carried by photons of light in the infrared and visible portions of the electromagnetic spectrum.

Two objects at different temperatures will exchange heat via radiation. For example, when standing in front of a camp fire on a cold day, the front surface of your body will be exposed to radiant heat transfer from the fire, while your back side will be left cold. When you turn around, your back side will be exposed to radiant heat transfer from the fire and your front side will radiate heat out to the surroundings.

The important thing to remember about radiant heat transfer is that it is dependent on line of sight. A hot object and a cold object transfer energy because they can essentially “see” each other. If another object is placed in between, then the radiant heat transfer between the first two objects stops.

Heat Transfer in a Building

To summarize heat transfer, let's consider a typical building design in which all forms of heat transfer are present. The sun provides radiant heat transfer into the space by shining through the glass and onto the interior surfaces and the occupants. Conduction occurs through the solid surfaces such as the walls, roof, and floor because there is a temperature difference between the outdoors and indoors. Lastly, heat transfer by convection occurs as the air moves around the inside of the space. As this air moves, it will transfer heat from the interior surfaces into the space itself.



Heat Transfer in the Human Body

Knowing the three methods of heat transfer will help us to understand how heat transfer occurs in the human body and how the human body maintains thermal comfort.

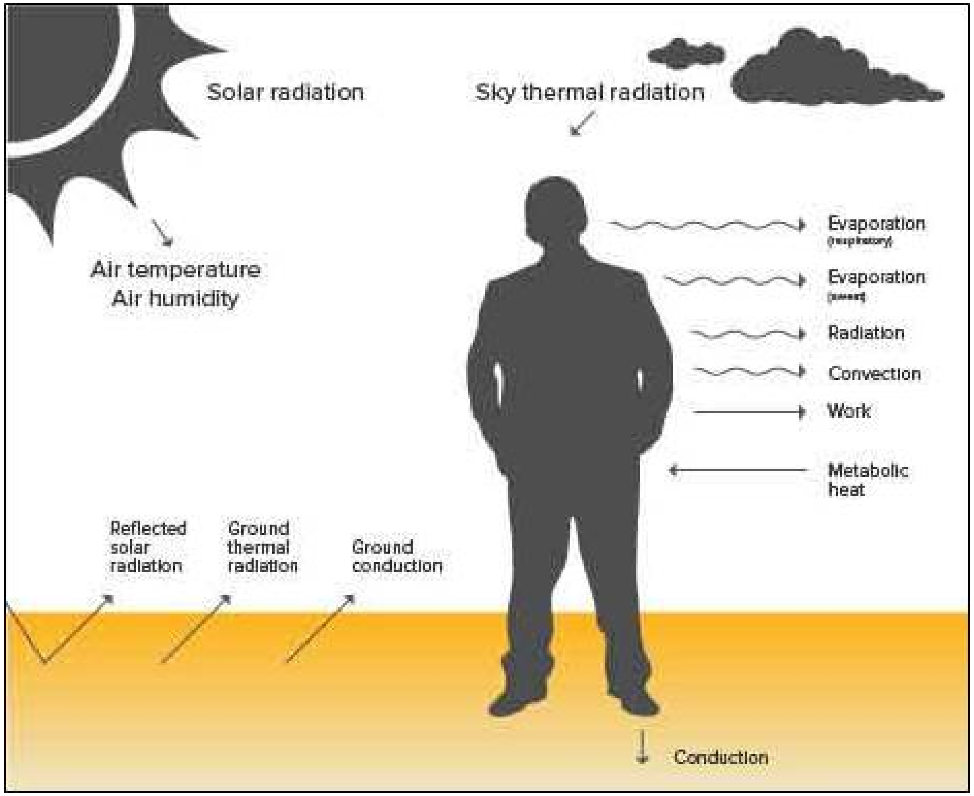
One of the key factors for human thermal comfort is a heat balance. The body generates heat via its metabolic rate and absorbs heat from its surrounding environment through conduction, convection, and radiation.

Heat Transfer in the Human Body

On a summer day, the human body gains heat via its metabolism and by radiant heat from the sun. To achieve comfort, the body needs to balance its heat gains with its heat losses.

To balance the amount of heat generated by the body and absorbed from the sun, the body uses the following methods:

- radiation (to the surrounding environment)
- conduction (to any solid object that it is touching)
- convection (to the surrounding air via air movement), and
- evaporation of moisture from the skin or respiration.



Human Thermometer

As we continue to consider human thermal comfort, it is important to keep in mind that the human body makes a poor thermometer.

While the human body attempts to maintain a heat balance, rejecting as much heat as is generated, we can become acclimatized to our surroundings. Our sensations of hot and cold are physiological phenomena based on our attempts to maintain heat transfer/heat balance.

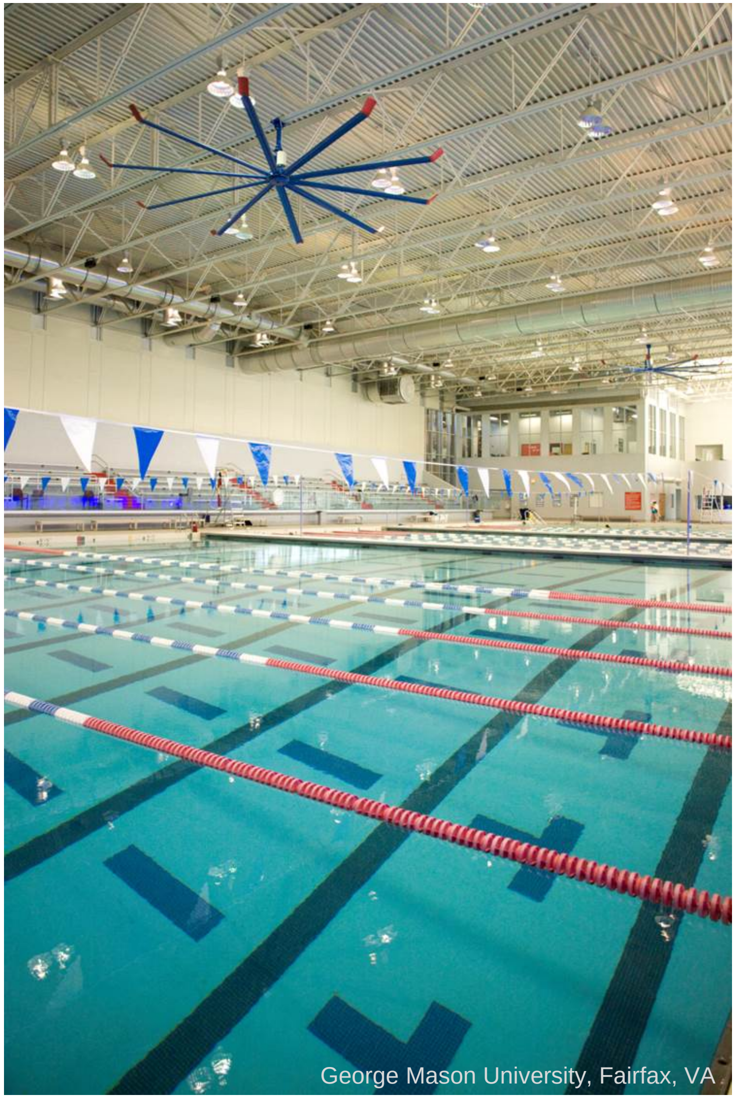

Turlington Elementary, Hockley, TX

Human Thermometer

As an example of how poor the human body works as a thermometer, consider two occupants in a swimming pool.

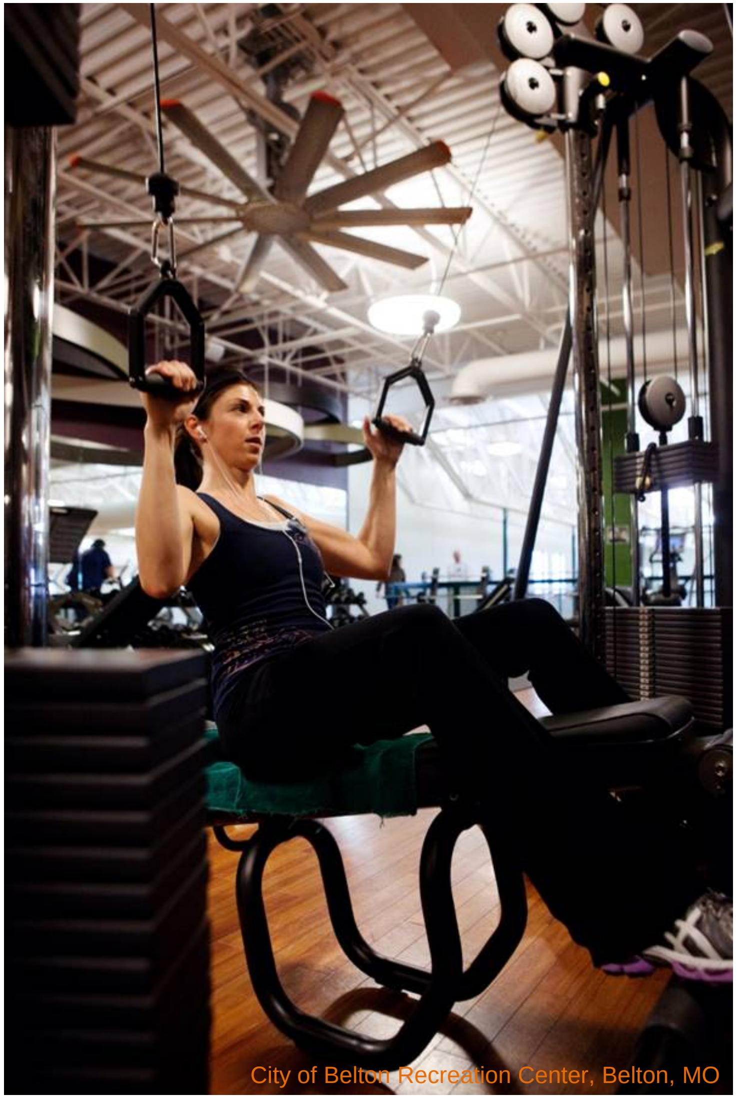
One has been in the pool for 15 minutes and is comfortable with the water temperature. A second occupant has been sitting in the hot tub for 15 minutes and then jumps into the pool.

The body of the person who has been in the pool for 15 minutes has acclimatized to the water temperature and would probably estimate that the water temperature is much higher than the person who has just jumped from hot tub to swimming pool. Though the pool's water temperature is the same for both individuals, they perceive it differently.


George Mason University, Fairfax, VA

Body Heat Gain/Loss

As mentioned, a key factor for human comfort is balancing heat gains and losses. The goal of the human body is to maintain a core temperature of approximately 98.6°F. This is accomplished by varying the amount of heat to the body's surroundings via sensible and latent heat transfer.

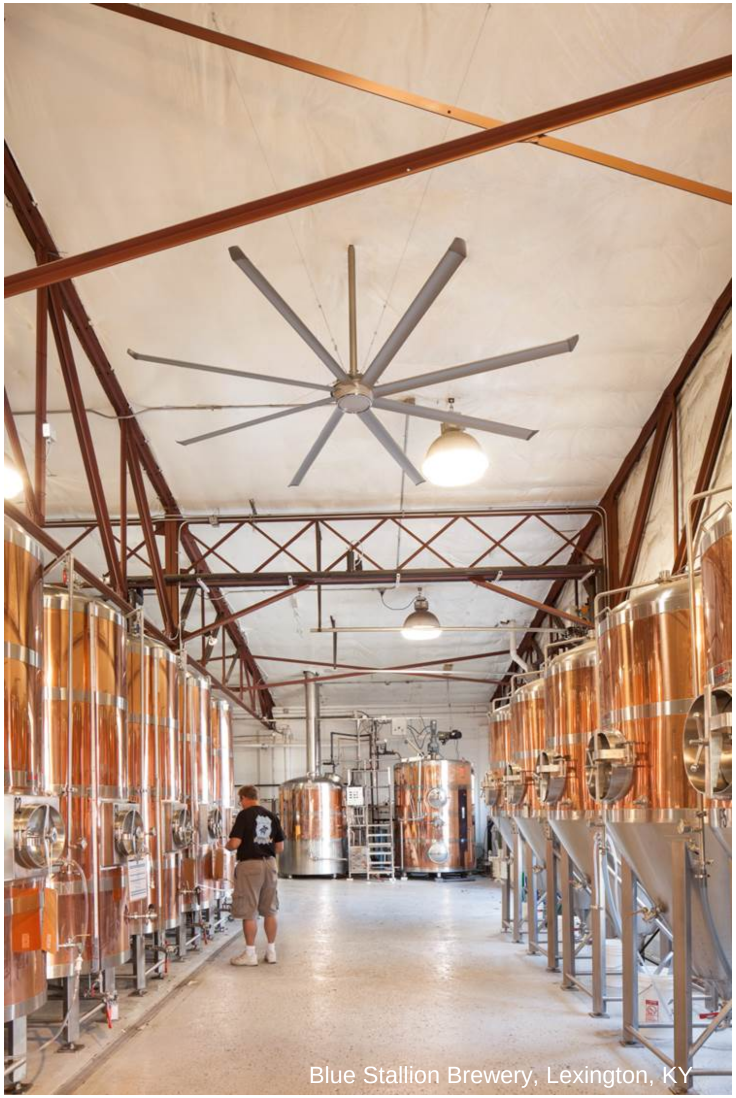

City of Belton Recreation Center, Belton, MO

Body Heat Gain/Loss

While the core of the body tries to maintain a temperature of 98.6°F, the temperature of the skin is usually lower.

When the body's heat losses and gains are balanced, skin temperatures are typically around 91.4°F.

When your skin temperature approaches core temperature, heat stress begins to become a concern.


Blue Stallion Brewery, Lexington, KY

Body Heat Gain/Loss

- If the heat lost by the body equals the amount of body heat generated, a core temperature of 98.6°F is maintained and thermal comfort is achieved.
- If the heat lost by the body is less than the amount of heat generated, the body's core temperature rises. This is first seen as an increase in skin temperature and then as elevated core temperatures. Thermal comfort is not achieved and heat stress may eventually occur.
- If the heat lost by the body is more than the amount of heat generated, then the body's core temperature drops. Again, thermal comfort is not achieved, but this time on the cold side and hypothermia may occur.

If…	Then…
Heat loss = heat generated	Body maintains core @ 98.6°F
Heat loss < heat generated	Body temperature rises
Heat loss > heat generated	Body temperature drops

Fans & Air Conditioning

Heat Loss from the Human Body

This section uses the information discussed up to this point to consider how fans and air conditioning systems can work together to achieve thermal comfort.

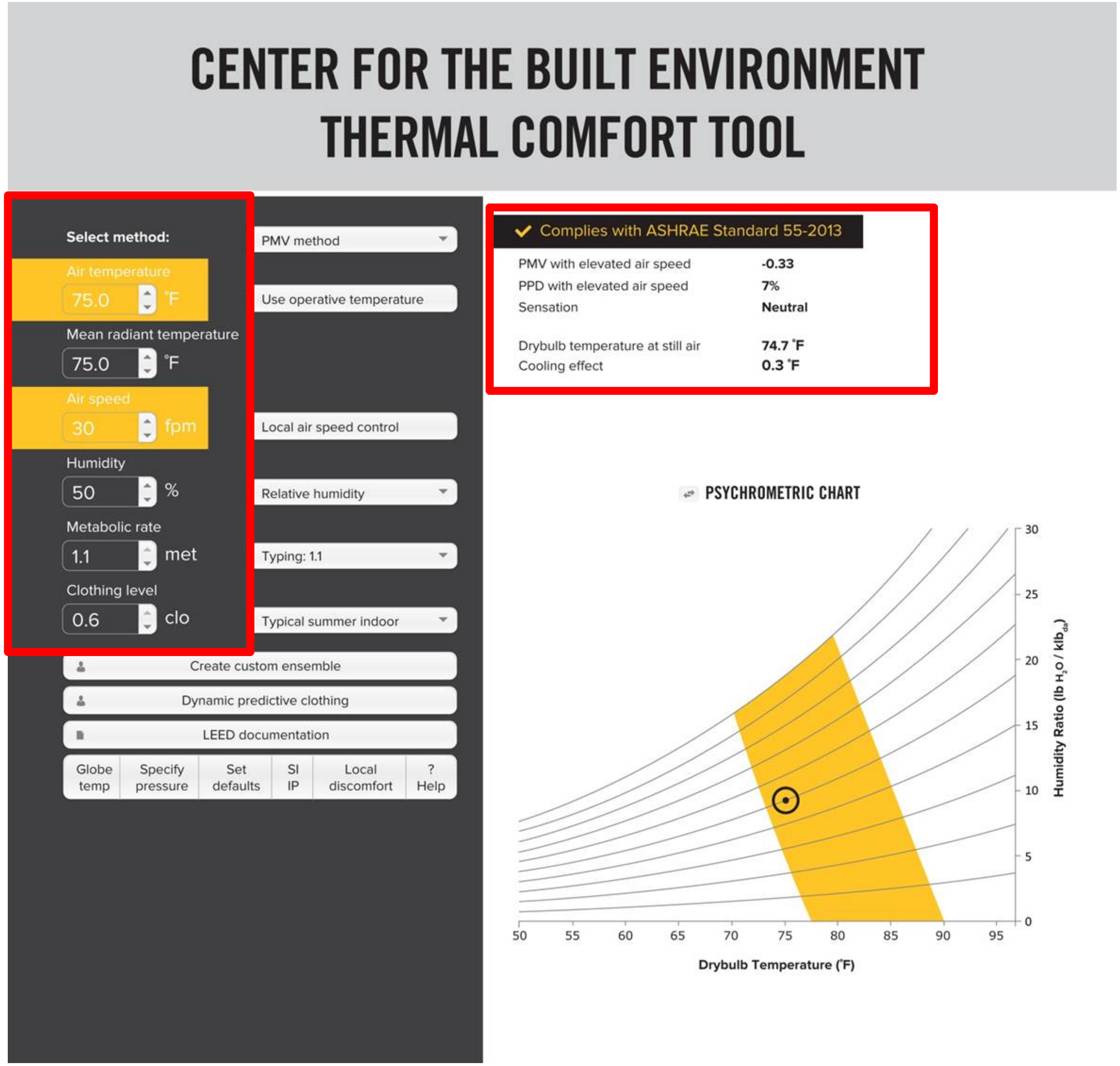
Our first example takes a look at an air conditioning (A/C) only design.

- Air dry bulb temperature is maintained at 75°F
- Mean radiant temperature is maintained at 75°F (the building envelope is sufficiently insulated so that there is no difference between the mean radiant temperature and air temperature)
- Relative humidity is maintained by the A/C system at 50% RH
- Air speeds of 30 fpm (non-perceptible) are maintained
- Metabolic rate is calculated to be 1.1 met—a typical office environment
- Clothing insulation is calculated to be 0.6 clo—typical for office summer clothing

Heat Loss from the Human Body

If we input these values into the thermal comfort tool, we can see that this design complies with the requirements of ASHRAE Standard 55.

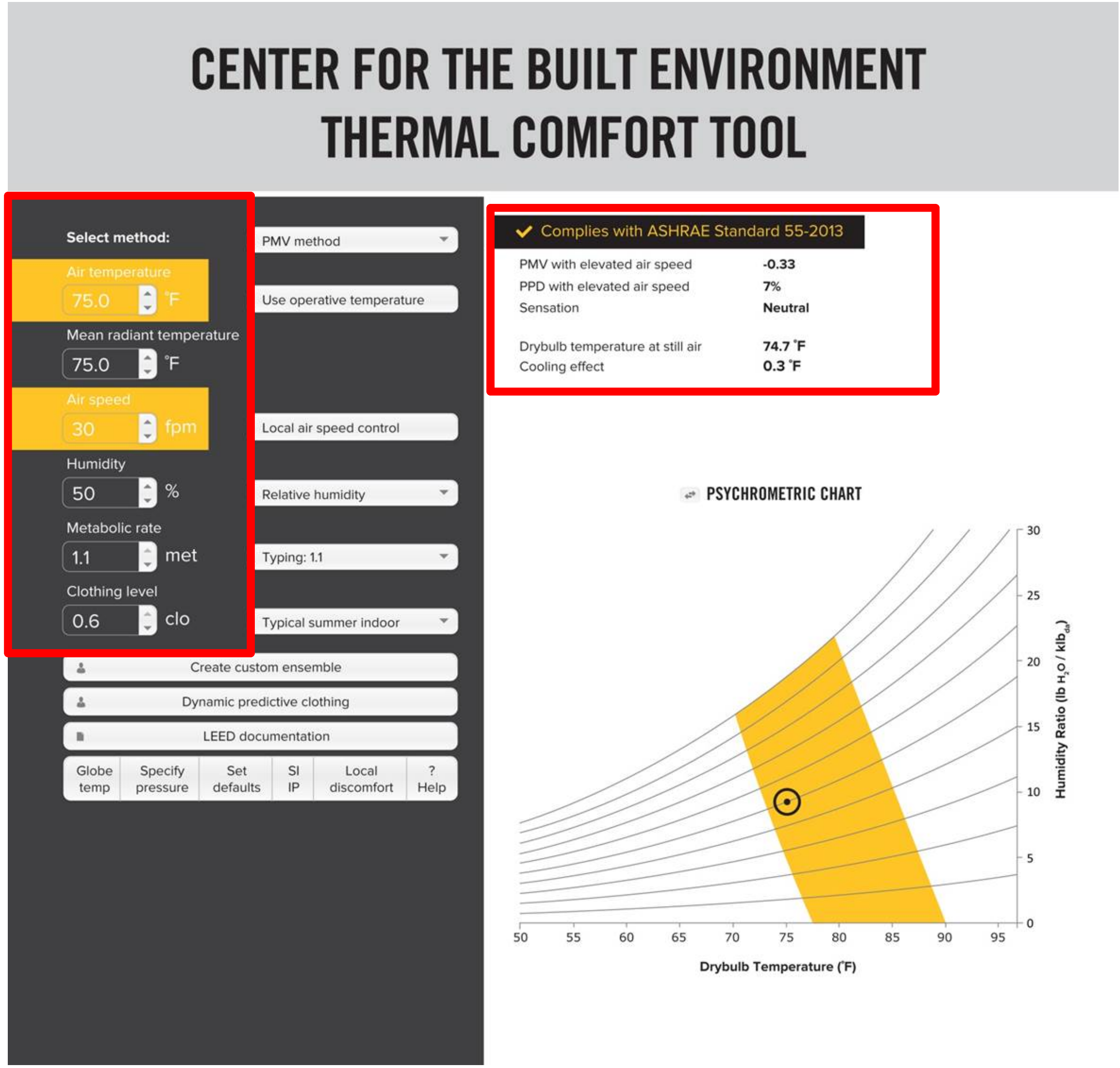
As mentioned, the acceptable range for PMV values is between -0.5 (cool) and +0.5 (slightly warm), and the acceptable range for PPD is less than 10%.



Heat Loss from the Human Body

For this design, a PMV of -0.33, an acceptable value, indicates a slightly cool space, and a PPD of 7%, also in compliance with the Standard, indicates a good comfort level for the occupants.

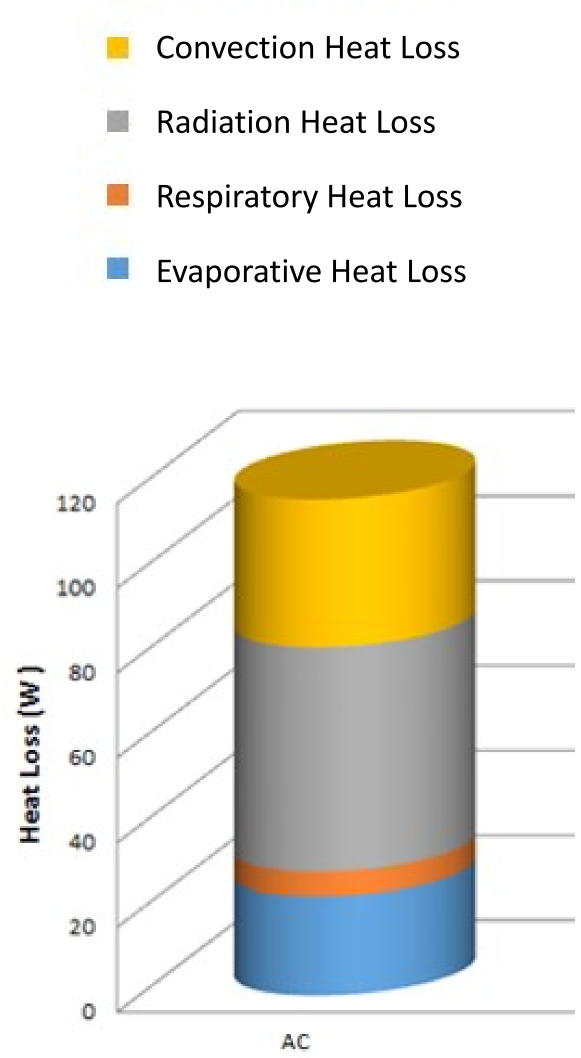
Therefore, this design would comply with Standard 55 and the occupants of the space would be comfortable with the conditions.



Heat Loss from the Human Body

In this scenario, at a metabolic rate of 1.1 met, the human body would be generating approximately 117 watts of heat. It would be in balance with its thermal environment, so it would also be losing 117 watts of heat. Heat loss from the body would be occurring in four different ways.

1. Radiation: primary means of heat loss in this scenario, as the skin temperature is well above the temperature of the surrounding air.
2. Convection: secondary means of heat transfer in this scenario.
3. Evaporation: caused by moisture evaporating off the skin.
4. Respiratory: smallest portion of heat loss in this scenario.



Heat Loss from the Human Body

Next, we'll consider an alternate design in which fans and A/C are used together, and higher temperatures are offset with elevated air speed.

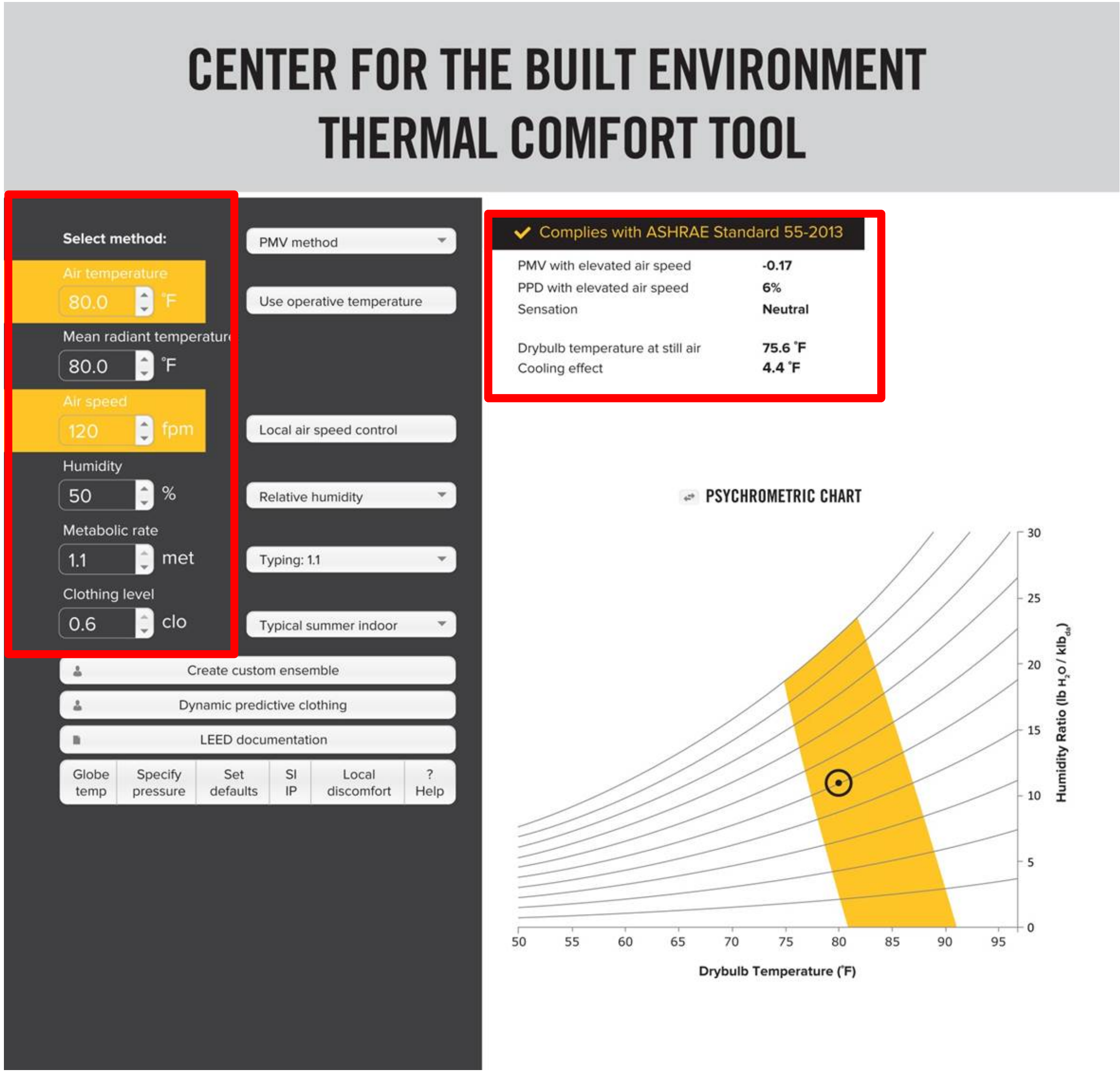
- Air dry bulb temperature is maintained at 80°F (A/C only design = 75°F)
- Mean radiant temperature is maintained at 80°F (A/C only design = 75°F)
- Relative humidity is maintained by the A/C system at 50% RH
- Air speeds of 120 fpm create a light breeze with no paper flutter (A/C only design = 30 fpm)
- Metabolic rate is calculated to be 1.1 met
- Clothing insulation is calculated to be 0.6 clo


DPR Construction, San Diego, CA

Heat Loss from the Human Body

Inputting these new values into the thermal comfort tool produces roughly the same (actually slightly better) PMV and PPD values as the A/C only design, indicating that both designs deliver an equal level of thermal comfort.

Both designs are likewise acceptable per the requirements of Standard 55.



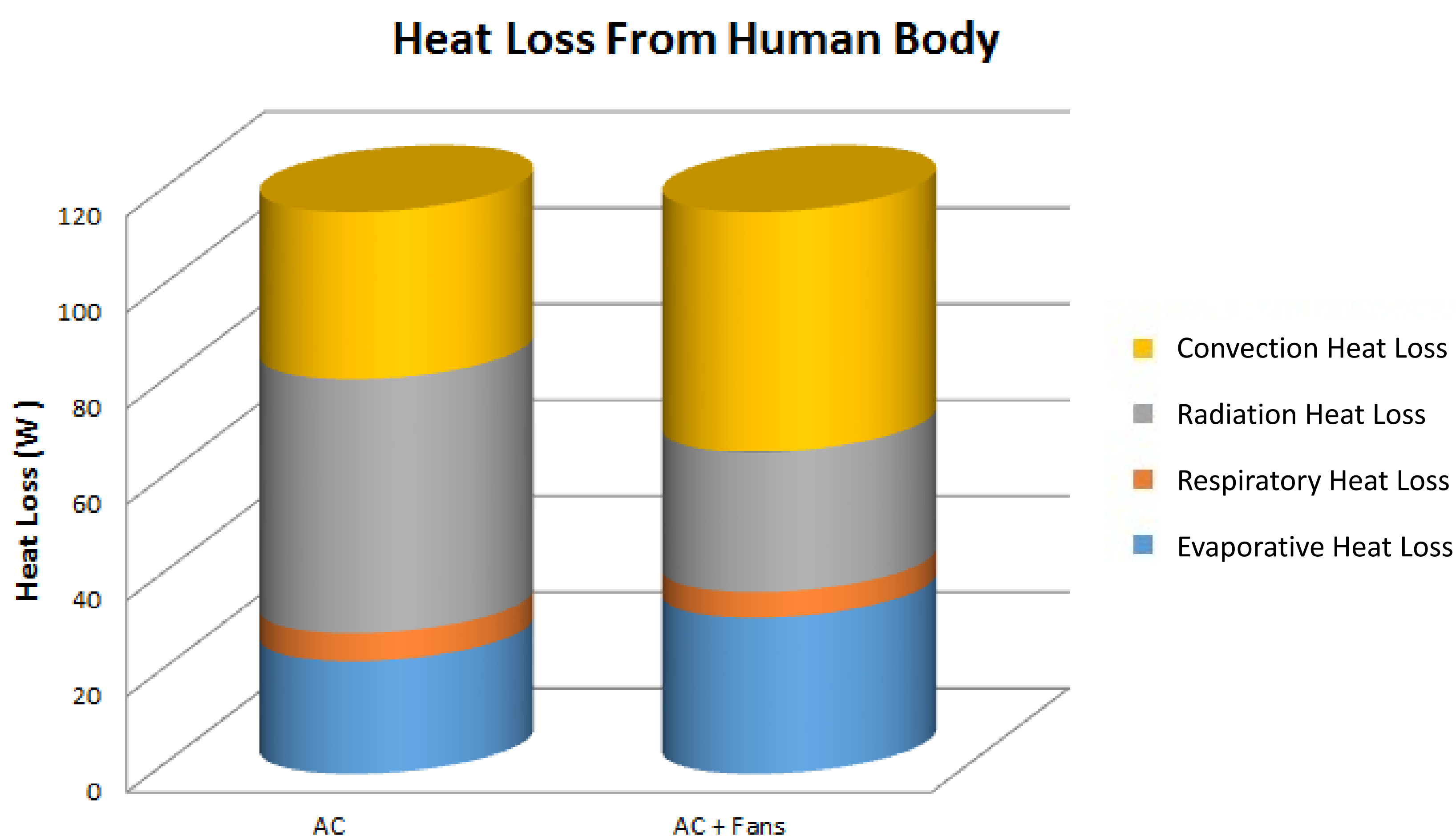
Heat Loss from the Human Body

Furthermore, in both scenarios, 117 watts of heat is rejected from the body and comfort is maintained. However, there is a difference in how that heat is lost in these two scenarios.

In the A/C only application, radiation is the primary means of heat loss from the body. In the fans and A/C application, convection is the primary means of heat loss from the body, as explained below.

1. Convection: primary means of heat loss. The elevated air speed moved warm air off the skin's surface and compensated for the decrease in radiant heat transfer.
2. Radiation: secondary means of heat loss. Raising the space temperature by 5°F caused the temperatures of the surfaces in the surrounding space to increase as well. This means the temperature difference between the human skin and the surrounding environment is reduced, resulting in a reduction in the amount of radiant heat lost.
3. Evaporation: the elevated air speed also resulted in a small increase in the amount of moisture evaporated off the skin, which helped to pick-up some of the heat lost through reduced radiation.
4. Respiratory: smallest portion of heat loss in this scenario.

Heat Loss from the Human Body

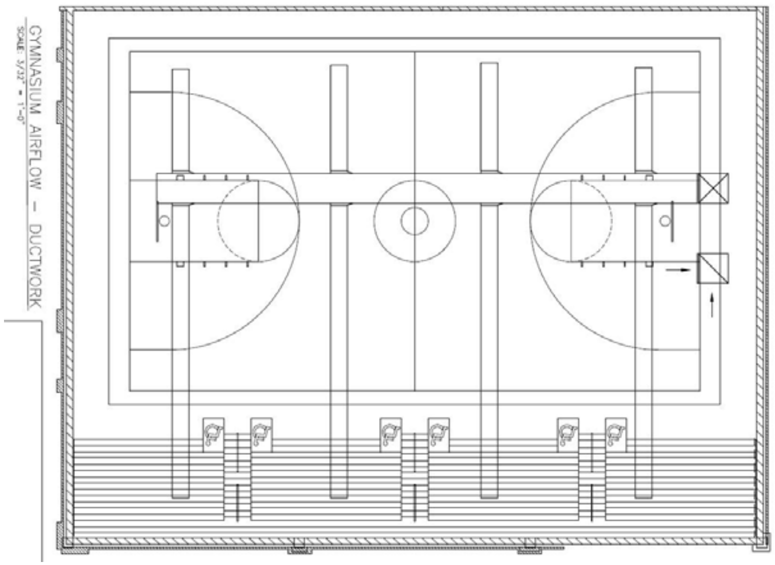


Heat Loss from the Human Body

Now that we've established that the human body can achieve equal comfort in both A/C only designs and designs that pair A/C with elevated air speed, let's take a look at a couple of application examples.

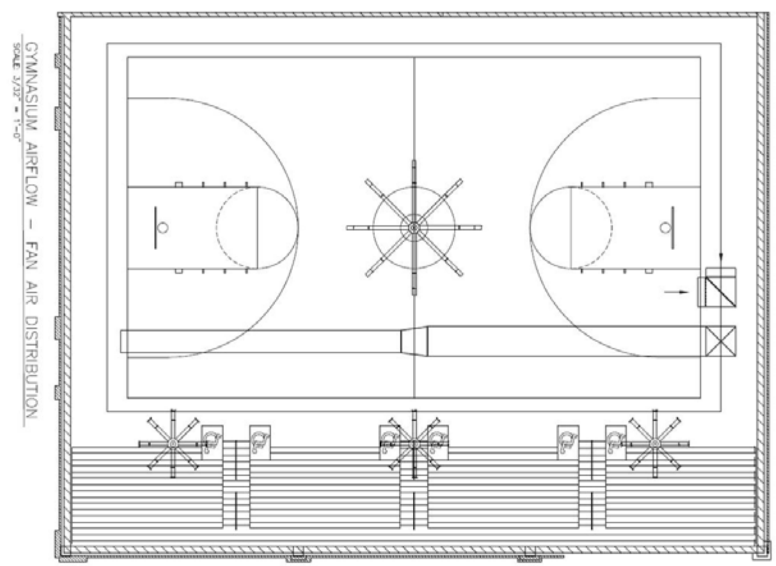
Example #1: School Gym – A/C Only

- **Application:** Traditionally designed school gymnasium
- **Location:** Lexington, Kentucky
- **Size:** 7,833 sq. ft. (square feet)
- **A/C system:** Designed to maintain a 72°F set point
- **Feels like:** 72°F
- **Materials and installation cost:** $7.39/sq. ft. of floor area (per RS Means 2013 Mechanical Cost Data)
    - Includes ductwork, insulation, diffuser, and the labor, but not the equipment (air handler)



Example #1: School Gym – Fans & A/C System

- **Application:** Traditionally designed school gymnasium
- **Location:** Lexington, Kentucky
- **Size:** 7,833 sq. ft.
- **A/C system:** Designed to maintain a 78°F set point
- **Fans:** The higher space set point is offset by elevated air speed and equal comfort is maintained
- **Feels like:** 72°F
- **Materials and installation cost:** $6.79/sq. ft. of floor area (per RS Means 2013 Mechanical Cost Data)
    - Includes the fans, ductwork, insulation, diffuser, and the labor, but not the equipment (air handler)



Example #1: School Gym – Fans & A/C System

At $6.79/sq. ft., the hybrid design results in a materials and installation cost reduction of $0.60/sq. ft. Additional savings reflecting electrical consumption of the entire space are shown in the table below. Note that more savings can be achieved via destratification during the winter months, but these calculations are not shown here.

	A/C only	Fans & A/C	Difference
Materials and Installation	$57,850 $7.39/sq. ft.	$53,183 $6.79/sq. ft.	$4667 $0.60/sq. ft.
A/C Electricity Consumption	21,498 kWh	13,382 kWh	38% reduction
Annual Utilities Cost	$3,966	$3,310	17% reduction

Example #1: School Gym – A/C Only

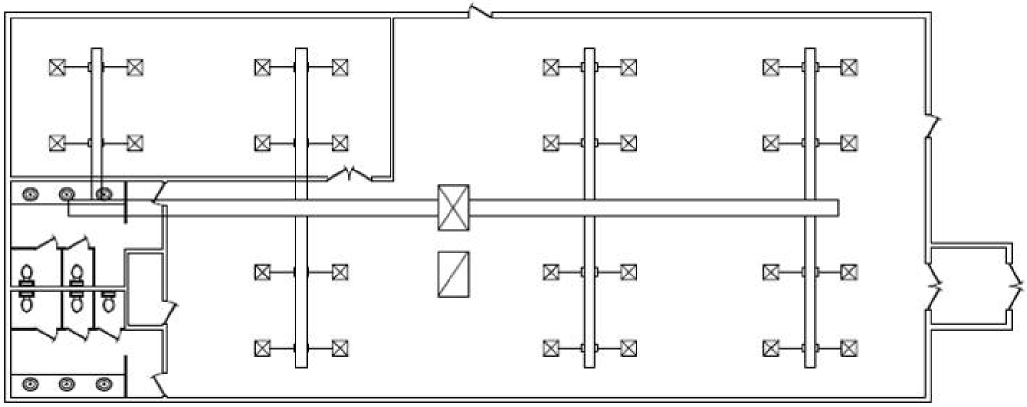
In addition to the energy and material savings, there is also a visual difference between the two designs. Shown below is the traditional A/C only system which has large ductwork runs that take up much of the ceiling space.

Example #1: School Gym – Fans & A/C System

In the hybrid design, the ductwork is minimized and the fans distribute air throughout the open space.

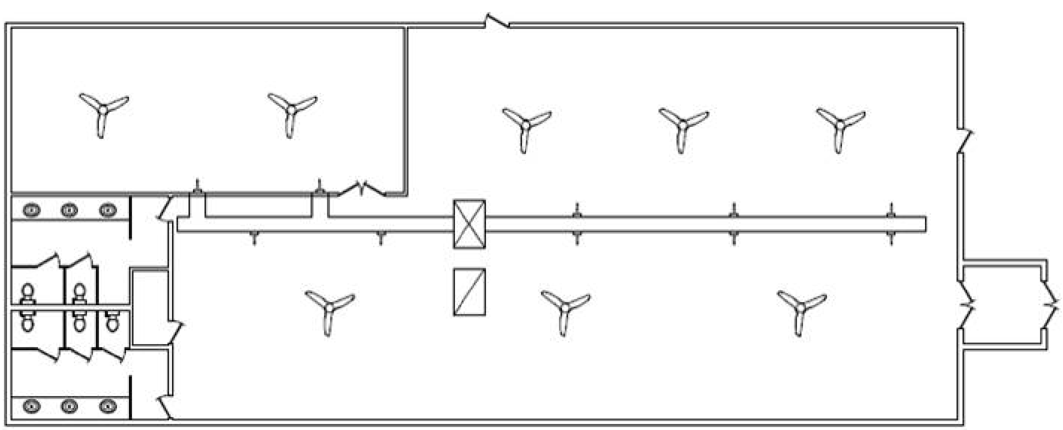
Example #2: Office Space – A/C Only

- **Application:** Office space
- **Location:** Lexington, Kentucky
- **Size:** 6,000 sq. ft.
- **A/C system:** Designed to maintain a 74°F set point
- **Feels like:** 74°F
- **Materials and installation cost:** $2.61/sq. ft. (per RS Means 2013 Mechanical Cost Data)
    - Includes the ductwork, insulation, and diffusor, but not the air handler



Example #2: Office Space – Fans & A/C System

- **Application:** Office space
- **Location:** Lexington, Kentucky
- **Size:** 6,000 sq. ft.
- **A/C system:** Designed to maintain a 78°F set point
- **Fans:** Air movement is used to compensate for the increase in temperature
    - (Note, the offset in set point temperatures is slightly smaller than the gymnasium scenario because lower air speeds are used in this office design to prevent paper flutter.)
- **Feels like:** 74°F
- **Materials and installation cost:** $2.32/sq. ft. (per RS Means 2013 Mechanical Cost Data)
    - Includes the ductwork, insulation, diffusor, and circulator fans, but not the air handler



Example #2: Office Space – Fans & A/C System

The hybrid fan and A/C system design saves $0.29/sq. ft. on first cost. Additional savings reflecting electrical consumption of the entire space are shown in the table below. Note that more savings can be achieved via destratification during the winter months, but these calculations are not shown here.

	A/C only	Fans & A/C	Difference
Materials and Installation	$15,660 $2.61/sq. ft.	$13,920 $2.32/sq. ft.	$1740 $0.29/sq. ft.
A/C Electricity Consumption	27,972 kWh	21,319 kWh	24% reduction
Annual Utilities Cost	$5,278	$4,471	15% reduction

Example #2: Office Space – A/C Only

The visual appearance of the first rendering shows a large run of ductwork through the middle of the space, with branches off to the sides, along with air diffusors which supply the air from up above.

Example #2: Office Space – Fans & A/C System

In the hybrid design, the distribution ductwork has been greatly minimized and the circulator fans provide the means to distribute air throughout the space.


DeTurk Round Barn, Santa Rosa, CA

Application Examples

Locust Trace High School

This section reviews a few real-world examples of facilities that use innovative HVAC strategies similar to the previously described designs that pair A/C with elevated air speeds.

Situated on 82 acres of government-donated land on the outskirts of Lexington, Kentucky, Locust Trace High School offers an innovative campus designed to educate students for careers in equine and agriculture sciences.

This net-zero facility includes clerestory windows for day lighting, solar tube illumination supplemented with high-efficiency lighting, and renewable energy through photovoltaic panels.

Locust Trace High School

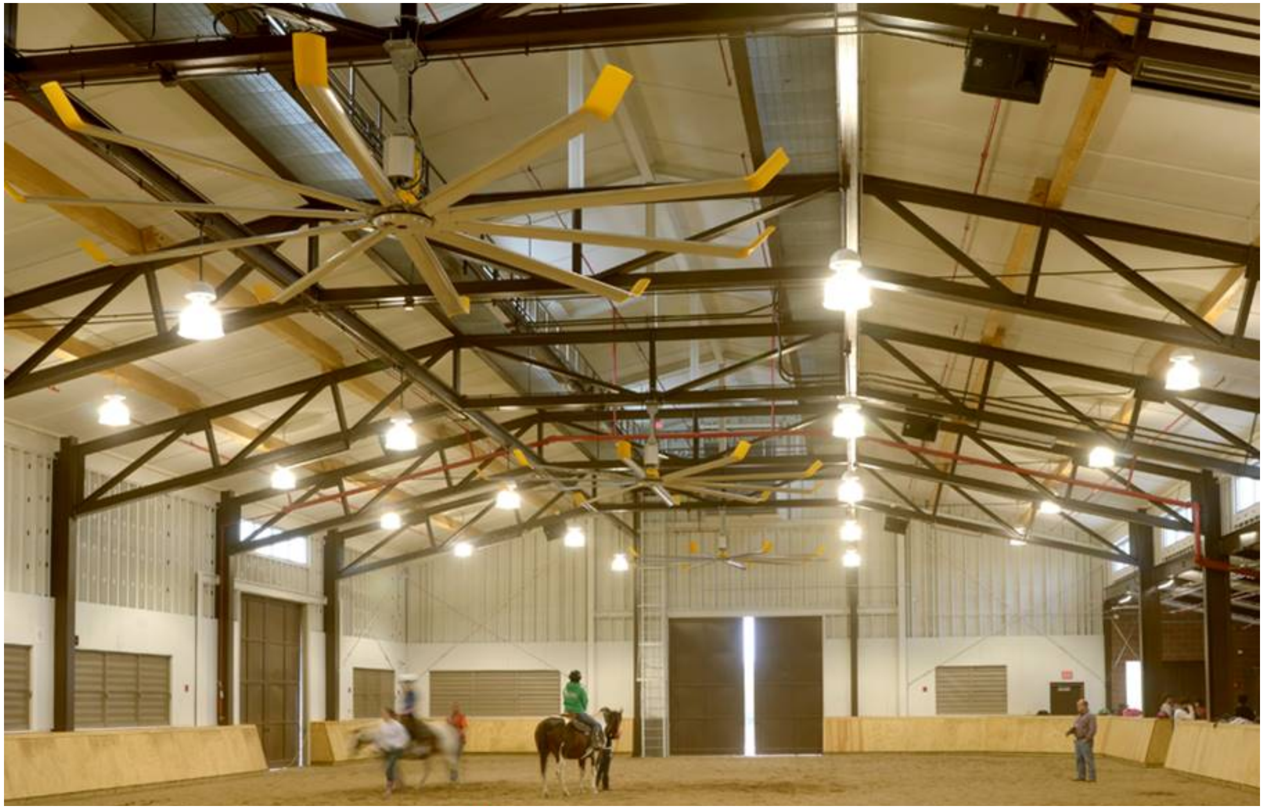
21 large-diameter, low-speed fans were installed in the campus's two buildings, encompassing classrooms, administration space, a small animal vet clinic, and large animal arena.

All of the spaces were designed with a minimal amount of ductwork and use fans as the primary means to circulate air throughout each individual space.

Inside, the introduction of air circulation helps regulate indoor environmental quality and aids in the distribution of conditioned air, augmenting natural ventilation and a roof solar thermal system to maximize comfort and energy conservation.

Locust Trace High School

The riding arena relies solely on large diameter circulator fans to provide comfort during the warmer months of the year.



Oakland Unified School District

The Oakland Unified School District (OUSD) Downtown Educational Complex Phase 1 includes 46,000 square feet of classrooms and administrative offices. New construction on OUSD campuses, located just across the bay from San Francisco, California, must comply with a policy stating compressor-based refrigeration (traditional HVAC) is not to be used in classrooms. This policy was paired with the engineers' goal of meeting the requirements of ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy* temperatures without using traditional, energy intensive air conditioning in the classrooms.

Oakland Unified School District

To meet the requirements, a three-layer strategy for maintaining comfort conditions was employed using a nighttime cooling cycle, high thermal mass walls, and large-diameter, low-speed ceiling fans specifically engineered for the space.

The fans provide a minimum air speed to provide acceptable comfort and a maximum air speed that does not disrupt papers on the desks.

Oakland Unified School District

These two criteria required the testing of a number of fan designs in a mocked-up space which is shown in this photo.

Engineers tailored a ceiling fan that met the exacting criteria for this project, such as providing equal thermal comfort for students at every desk in the classroom, which could then be used at other schools.

Oakland Unified School District

This photo shows the actual classroom.

The classrooms are supplied outdoor air from a central air handling unit. Supply airflow rates to the classrooms are varied based on CO_2 levels and outdoor air temperatures, and additional cooling is provided by a thermally-massive building charged by cool nighttime air and increased air circulation.

Oakland Unified School District

Each night, cool air is brought into the space, and the circulator fans are used to cool the high thermal mass walls and floor. During the day, the thermal mass walls and elevated air speeds keep the occupants cool and comfortable. The fans also improve comfort and IAQ, moving at a speed determined by the air temperature of the classrooms.

Solar photovoltaics, used to heat water in the kitchen, also offset classroom energy use. Building orientation and construction materials used were likewise important to designers when building OUSD to satisfy the requirements of the Collaborative for High Performance Schools (CHPS), which is similar to LEED for schools in California.

Oakland Unified School District

Larger diameter circulator fans were installed in the multi-purpose room which serves as a cafeteria and a gymnasium, and large evaporative cooling shower towers are used to cool this space during high occupancy load periods.

In the library, large fans are used to primarily distribute the air and provide a cooling effect during the warmest months of the year.

Oakland Unified School District

"*To satisfy CHPS,"* said Brent Eubanks, a mechanical engineer and LEED AP for Taylor Engineering, LLC*, "one of its requirements is that you meet ASHRAE [Standard] 55's comfort conditions. If your comfort limit is 78 degrees [Fahrenheit], it can be 83 degrees [Fahrenheit] in the room and you're still within your comfort threshold, thanks to the air movement from the ceiling fans*."

Ancillary Benefits of Elevated Air Speed

Comfort vs. Productivity & Accuracy

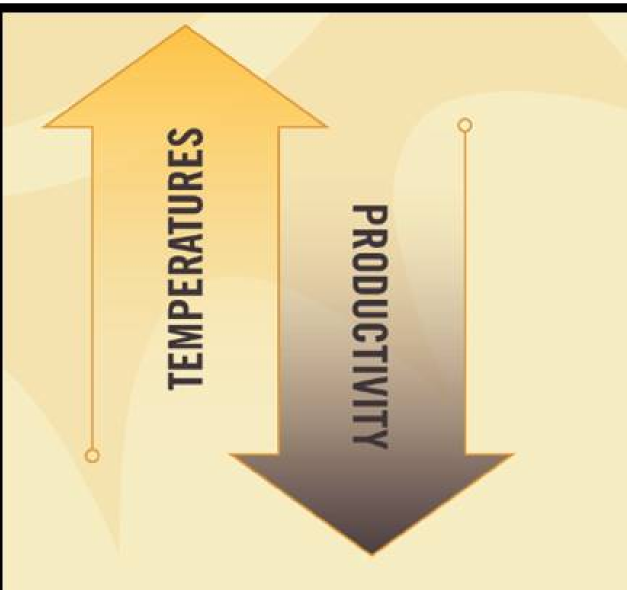
Now that we've discussed the benefits of using fans in conjunction with traditional air conditioning to offset materials and energy usage, we will address a few other benefits of using elevated air speed in a design. One of these benefits relates to productivity. As perceived air temperature rises, research has shown that productivity decreases dramatically.

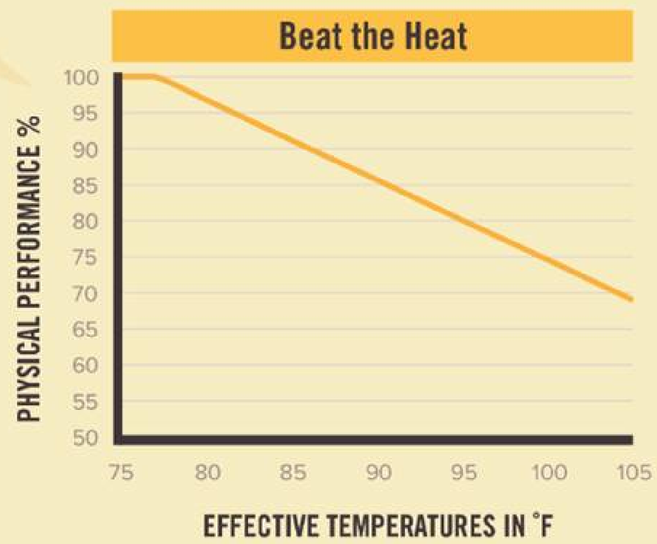
TEMPERATURE	PRODUCTIVITY LOSS
77°F	0.0%
80°F	-3.2%
85°F	-8.8%
90°F	-14.3%
95°F	-19.9%
100°F	-25.4%
105°F	-31.0%

** Source: Seppänen, O., Fisk, W. J. and Lei, Q. H. (2006)*

Comfort vs. Productivity & Accuracy

For example, in a space without air conditioning, if air temperatures were to rise to 85°F, productivity losses of almost 9% would be seen. If the increased space temperatures are offset by elevated air speed, those productivity losses can be regained. As you can see in the chart below, if the air temperature is 85°F, but elevated air speed creates a five-degree cooling effect so that the perceived temperature of the space is 80°F, a majority of the productivity losses will be regained. This results in not just a more comfortable environment for employees, but employers can avoid the losses associated with decreased productivity and heat stress incidents.





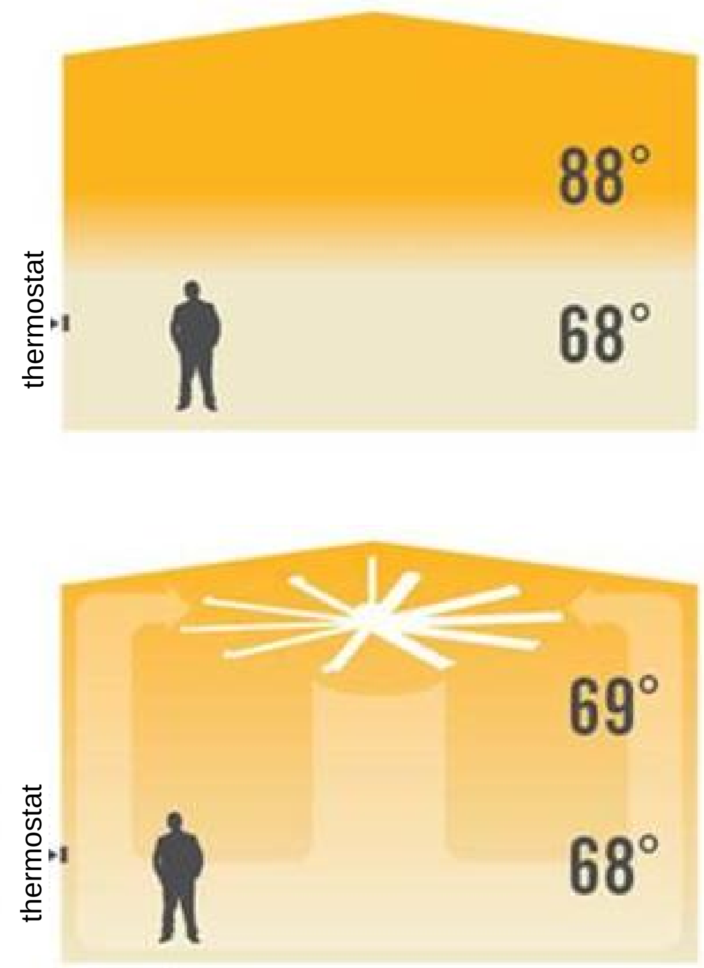
Temperature	Productivity Loss
77°F	0.0%
80°F	-3.2%
85°F	-8.8%
90°F	-14.3%
95°F	-19.9%
100°F	-25.4%
105°F	-31.0%

Source: Seppänen, O., Fisk, W. J. and Lei, Q. H. (2006)

Stratification in Heating Mode

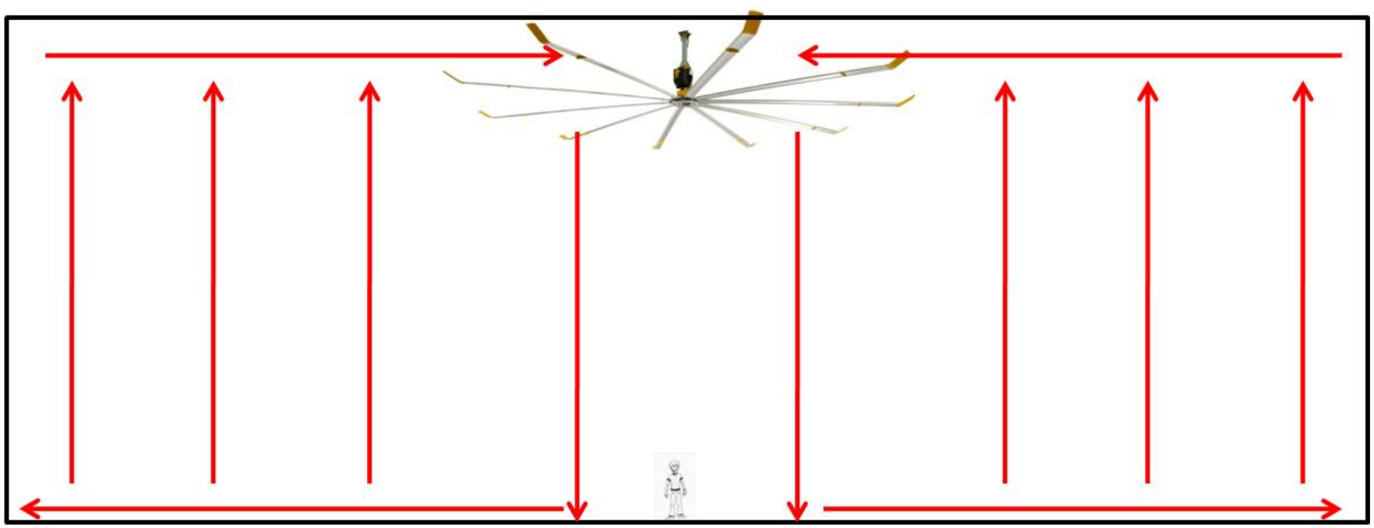
A second ancillary benefit pertains to cold weather seasons. During the heating season, an HVAC system typically supplies air at 20°F to 30°F above the ambient space temperature. Since hot air is less dense, it tends to rise to the top of the space, and stratification occurs. This non-uniformity of air temperature leads to increased envelope losses, meaning more heat transfer through the walls and roof, which results in an increased equipment run time and higher operating costs.

A properly sized and located circulator fan, running slowly in the forward direction, can be used to push the hot air down from the ceiling to the occupant and thermostat level. This process recaptures the lost heat before it has a chance to transfer through the envelope, resulting in decreased equipment run time and a reduction in operating costs.



Fan Jet Requirement

The key to destratification is selecting a fan that is large enough to push a jet of air from the ceiling down to the occupant level. This air must then be allowed to spread out in the space to impact an open area beneath the fan.



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Standard 62.1 & Overhead Heating

Another benefit of destratification is the potential reduction of outdoor air that must be brought into a building. To illustrate this, ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, will be used to calculate the outdoor air intake flow required for two different scenarios.

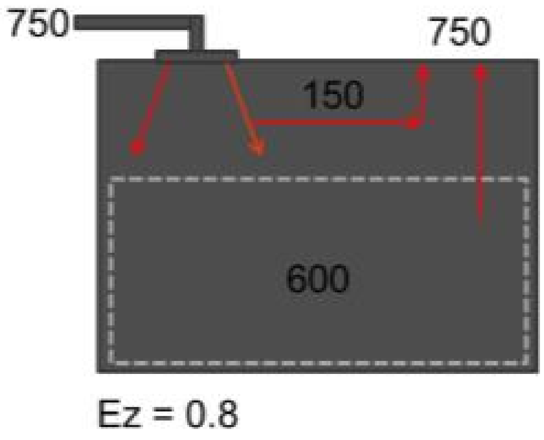
In the first scenario, a 10,000 sq. ft. warehouse area with ten people is served by a single zone system. The people outdoor air rate and area outdoor air rates from Table 6-1 of Standard 62.1 can be used to calculate the breathing zone outdoor airflow. The required cfm (cubic feet per minute) rating for this system design (per the table) is 600 cfm of fresh air into the breathing zone.

	Warehouse
Zone Floor Area - (ft2)	**10,000**
Zone Population - (people)	**10**
Breathing Zone Outdoor Airflow (cfm)	**600**
Typical Zone Air Distribution Effectiveness (Ez)	**0.8**
Outdoor Air Intake Flow (cfm)	**750**

Standard 62.1 & Overhead Heating

Per Table 6-2 of Standard 62.1, an overhead supply and overhead single zone heating system with a supply air temperature of 15°F or more above the ambient space temperature has a zone air distribution reduced effectiveness of 0.8. Said another way, 20% of this system's outdoor air bypasses the breathing zone and never reaches the occupant level.

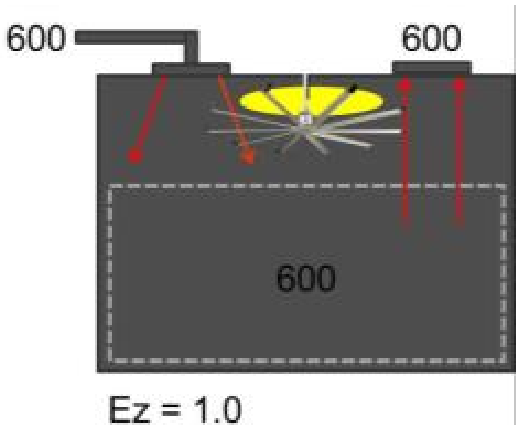
To compensate for the short circuiting in this scenario, the outdoor air intake flow, or the outdoor air taken in through the HVAC unit, must be increased to 750 cfm to ensure that 600 cfm reaches the occupants in the breathing zone.



	Warehouse
Zone Floor Area - (ft2)	10,000
Zone Population - (people)	10
Breathing Zone Outdoor Airflow (cfm)	600
Typical Zone Air Distribution Effectiveness (Ez)	0.8
Outdoor Air Intake Flow (cfm)	750

Improved Air Distribution

In the second scenario, a circulator fan is placed between the supply and the return. If the fan is properly sized, the air that would normally bypass the breathing zone is pushed down to the occupant level, creating a well-mixed space. A zone air distribution effectiveness of 1.0 would be achieved, and the outdoor air intake flow can be decreased to 600 cfm, as all of the air brought in through the HVAC unit is being pushed down to the occupant level. In both scenarios, indoor air quality would be approximately the same, as 600 cfm of outside air would be reaching the breathing zone in either case. However, in the second scenario, only 600 cfm of outside air must be heated and cooled, and energy savings and a potential reduction in HVAC capacity could be achieved.



	Warehouse
Zone Floor Area - (ft2)	10,000
Zone Population - (people)	10
Breathing Zone Outdoor Airflow (cfm)	600
Typical Zone Air Distribution Effectiveness (Ez)	1.0
Outdoor Air Intake Flow (cfm)	600

British Airways Hangar 6

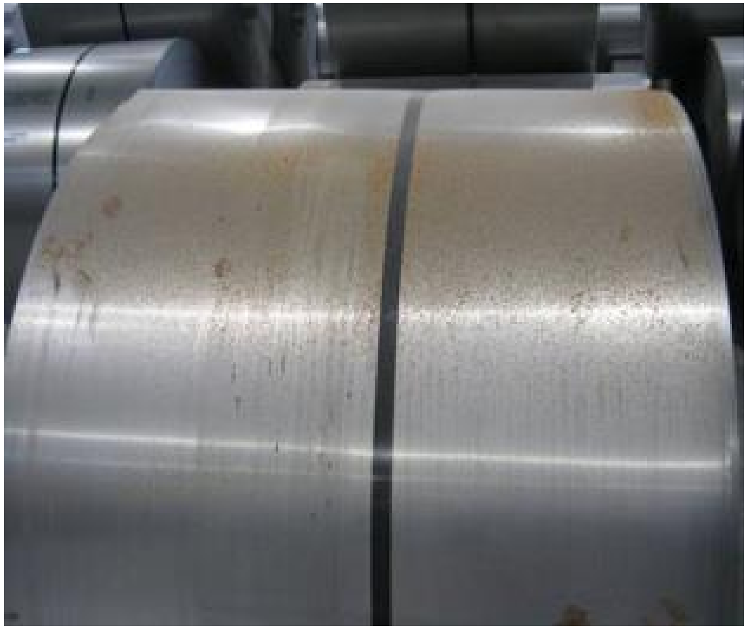
British Airways Hangar 6 in London is an example of a stratified space. The temperature difference between the floor and the ceiling was measured at 18°F to 20°F during the heating season, creating uncomfortable and inconsistent temperatures at each level. Through a corporate initiative to address working environments and sustainability, British Airways teamed with their facility management group, Emcor UK, to explore solutions for Hangar 6.

The installation of five, 24-ft. diameter HVLS (high-volume, low-speed) fans resulted in an energy savings of over two million kilowatt hours and an operating cost reduction of over USD $114,000 during the first four months of operation, as heated air was pushed down to occupant level and run time was reduced.

Condensation Mitigation

Another benefit of elevated air speed is condensation mitigation. During the spring and fall, air temperature and humidity levels tend to vary widely. Warm, humid air can come in contact with cold, thermally massive surfaces, resulting in condensation. Condensation can lead to mold growth, corrosion, product losses, and safety hazards.

By increasing the air speed across the cold surface, the stagnant layer of air is disturbed, which increases the surface temperature as well as the temperature of the air that comes in contact with that surface. This phenomenon can lead to a dramatic reduction in the amount of time in which condensation is seen in a space, resulting in improved safety and decreased product loss.



O’Neal Flat Rolled Metals

Problems with condensation at O’Neal Flat Rolled Metals in Garlands, TX, came into play every spring and fall. The high thermal mass coils changed temperature rather slowly, while air temperature and humidity levels fluctuated more rapidly. The combination of a cold roll of steel coming in contact with warm, humid air resulted in condensation on the surface of the coil.

This condensation had a costly side effect. In aluminum alone, the company wrote off $28,000 per year in product loss due to condensation. When considering all of their flat roll metals, their annual product loss due to condensation totaled hundreds of thousands of dollars.

O’Neal Flat Rolled Metals

The use of elevated air speed to eliminate the stagnant film of air across the metal surface and increase the surface temperature of the metal coils led to a substantial decrease in product loss, saving the company approximately $300,000 in devalued inventory in a year.

The elevated air speed also prevents mold growth and helps improve worker safety.

Improving IAQ

Air movement can also be used to improve IAQ.

At the Lee and Joe Jamail Natatorium at the University of Texas, Austin, HVLS fans are used to strip heavy weight trichloramine (a chemical compound formed in the chlorination of swimming pools) off the pool surface and direct it into the exhaust air path. This increases IAQ at the occupant level, particularly for swimmers breathing air at the pool surface.

Conclusion

2030 Commitment

The strategies and benefits described in this presentation can help to dramatically reduce the predicted energy use intensity (pEUI) of a building. Cooling and heating energy costs can be reduced by 15% or more by offsetting traditional air conditioning with elevated air speed.

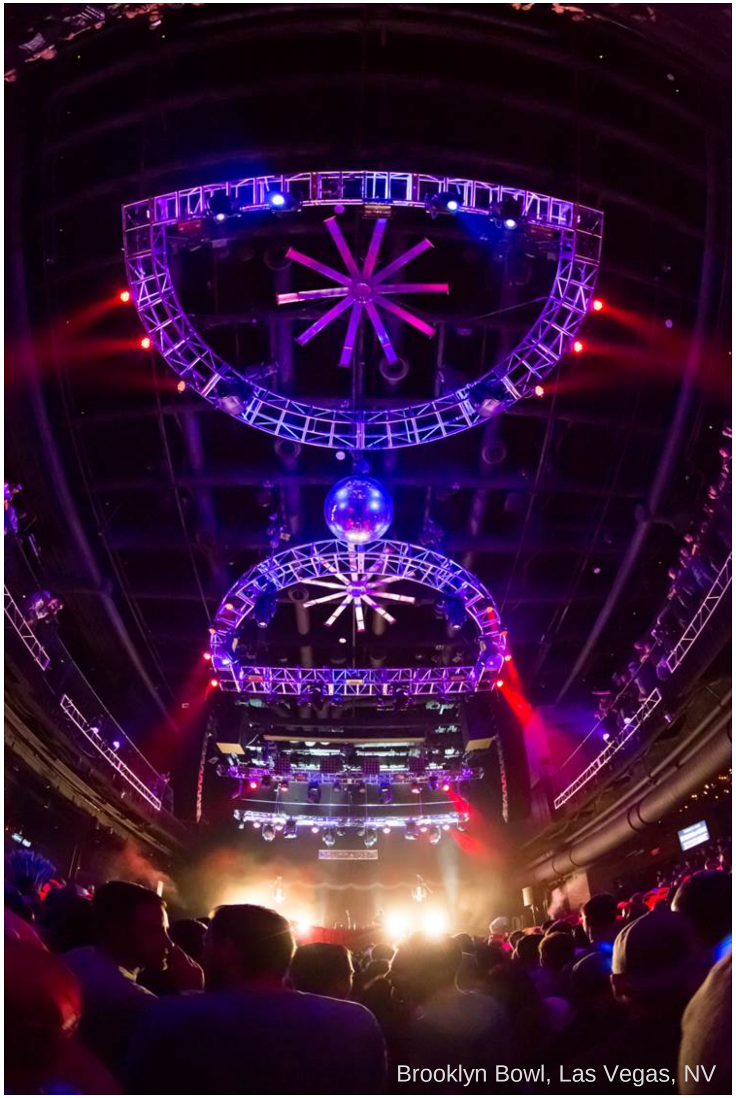
By reconsidering the relationship between air conditioning and elevated air speed, design professionals can affect meaningful change in building sustainability and comfort. These innovative strategies can help the industry as progress is made toward the goals of the AIA 2030 Commitment.


Corvallis Waldorf School, Corvallis, OR

Takeaways…

Takeaways from this presentation include:

- the definition of thermal comfort as specified by the requirements of ANSI/ASHRAE Standard 55
- the methods of heat transfer and the body's goal of heat balance
- how fans and an A/C system together can provide equivalent thermal comfort as an A/C only design, while using significantly less energy, and
- the additional benefits of elevated air speeds, which include improved air distribution, condensation abatement, destratification, increased ventilation effectiveness, and improved IAQ.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Conclusion

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