Basics of Large-Diameter Ceiling Fans

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Christian Taber

Principal Engineer- Codes & Standards, AMCA Member Company

- M.S. in mechanical engineering & biosystems engineering; B.S. in chemical engineering
- ASHRAE certified High-Performance Building Design Professional and Certified Energy Manager
- Developed a LEED-specific energy modeling course for national instruction
- Served on AMCA committees 230, 214, 211, 208 and 11

Basics of Large-Diameter Ceiling Fans

Purpose and Learning Objectives

The purpose of this presentation is to inform industry professionals about basic components, applications examples, and performance/selection metrics of large-diameter ceiling fans (LDCF).

At the end of this presentation you will be able to:

1. Identify a LDCF and the major components.
2. Explain how LDCF work in three different applications.
3. Identify if a LDCF is compliant with US DOE efficiency regulations.
4. Describe the differences between methods of test for LDCF.

Webinar Outline

- What is a large-diameter ceiling fan?
- Available applications
- Performance & selection metrics
- Review
- Q&A

What is a Large-Diameter Ceiling Fan?

http://www.ox.ac.uk/research/research-in-conversation/acquiring-language/professor-charlotte-brewer

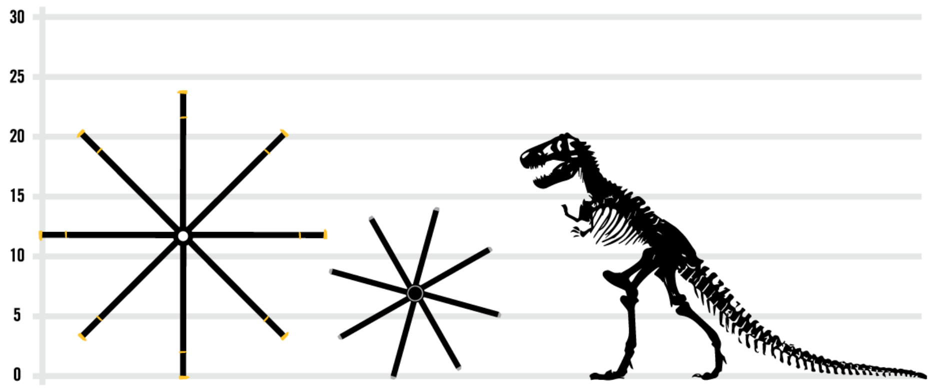
Defining Large-Diameter Ceiling Fans (LDCF)

- Ceiling fan - “a nonportable device that is suspended from a ceiling for circulating air via the rotation of fan blades.”

  - 42 U.S.C § 6291.Definitions

- Large-diameter ceiling fan – “a ceiling fan that is greater than seven feet in diameter.”

  - 10 CFR 430, Appendix U to Subpart B



Design Standards / Typical Characteristics

- 42 U.S. Code § 6295.Energy conservation standards (ff)
  - Fan speed control separate from lighting control
  - Adjustable speed control
  - Capability of reversible fan action*

- Typical Characteristics
  - Impeller diameter 7-24 ft (2.1-7.3m)
  - Airfoil shaped blades
  - 2 to 8 blades
  - Tip speeds 1100-5500 fpm (5-28m/s)

A	Impeller Diameter
H	Hub Diameter
G	Blade Width at Tip
α	Pitch Angle at Tip or at a Designated Radius
N	Number of Blades

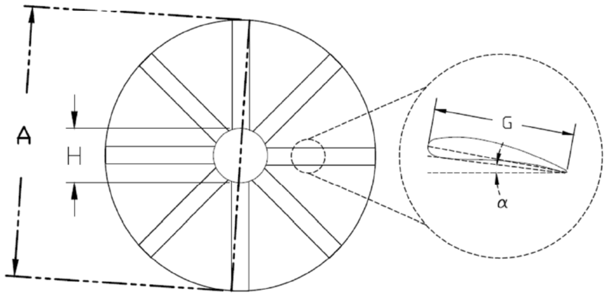
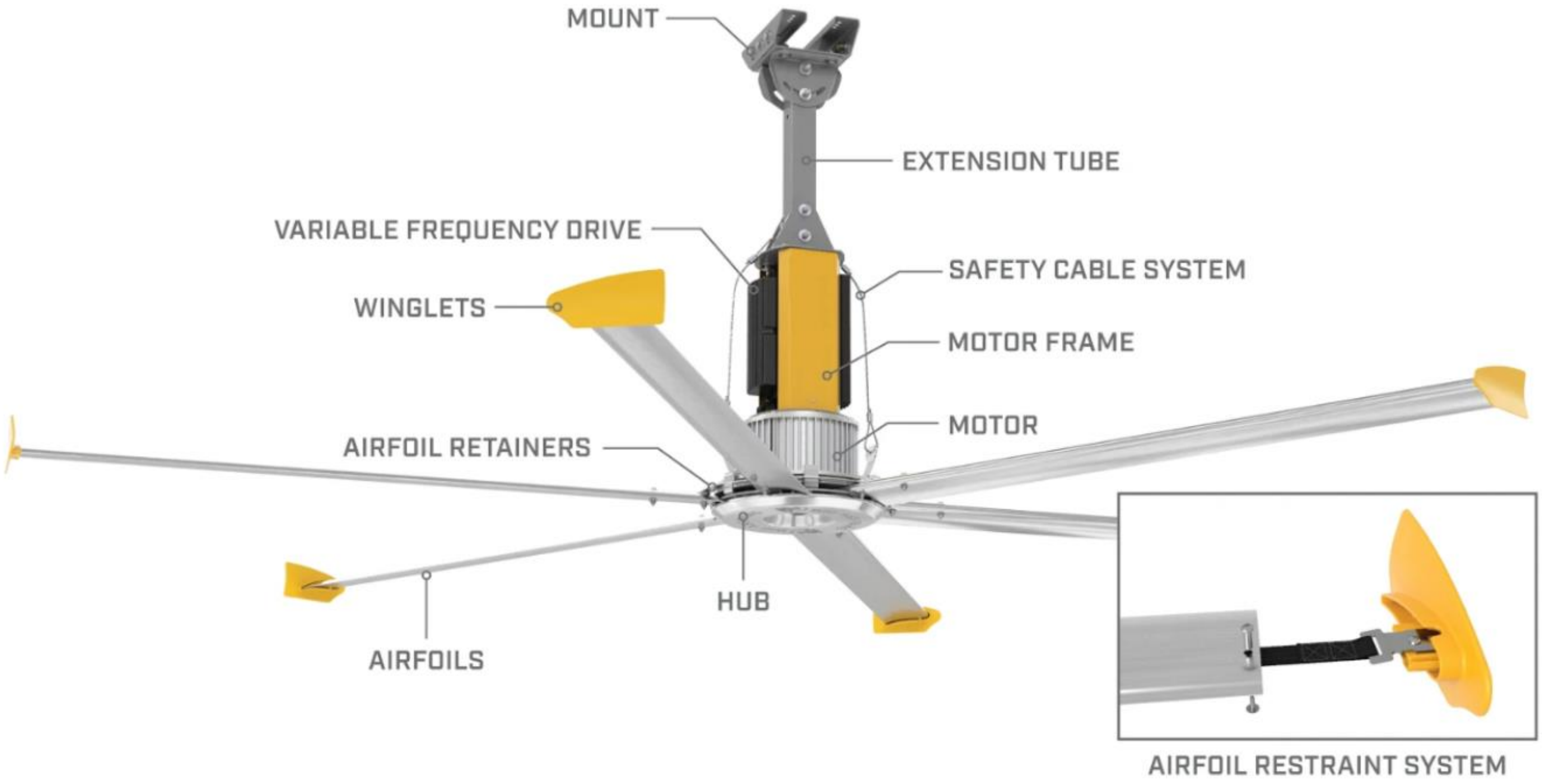


Figure A.37 AMCA 211-13 (Rev. 10-18)

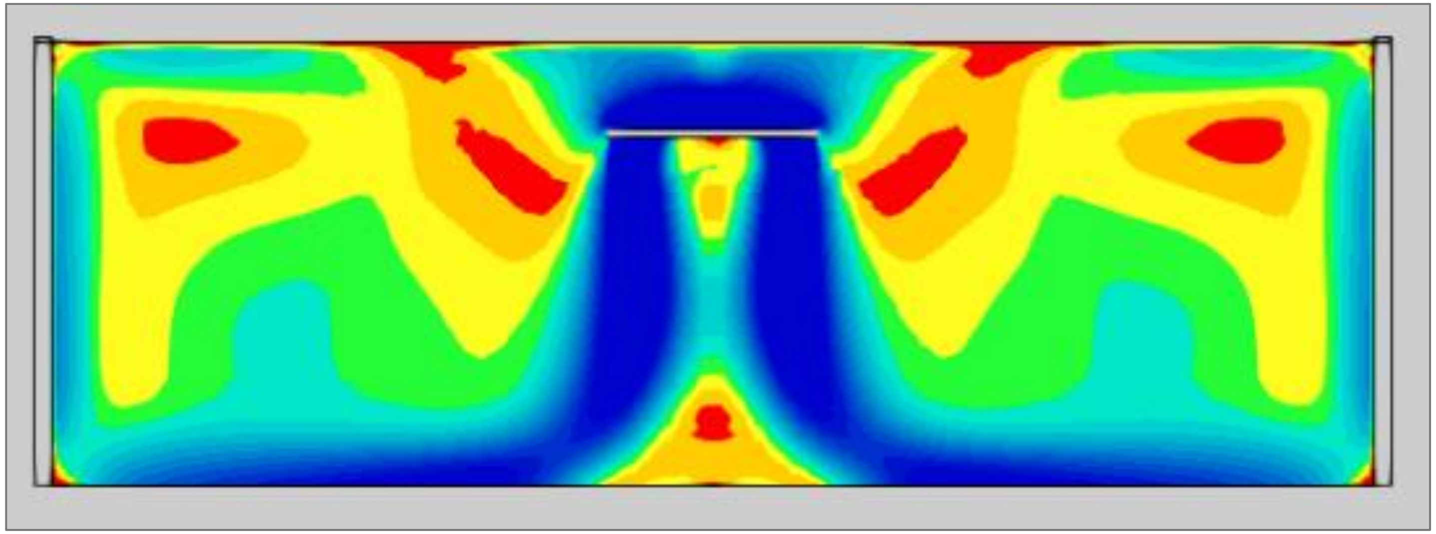
Example Large-Diameter Ceiling Fan

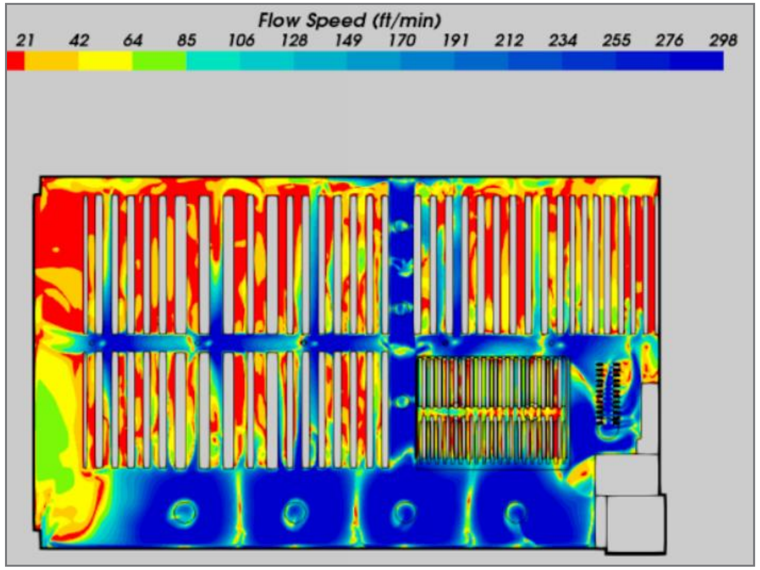


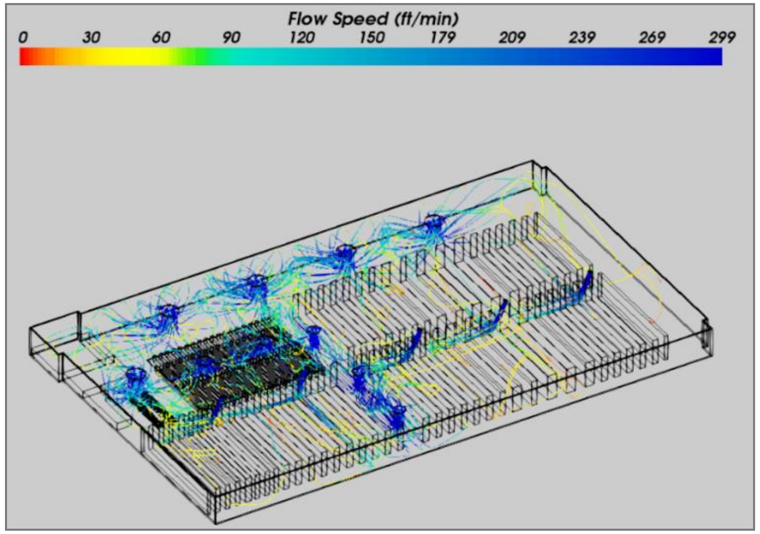
What Does a Large-Diameter Ceiling Fan Do?

What It Do

Visualized Performance





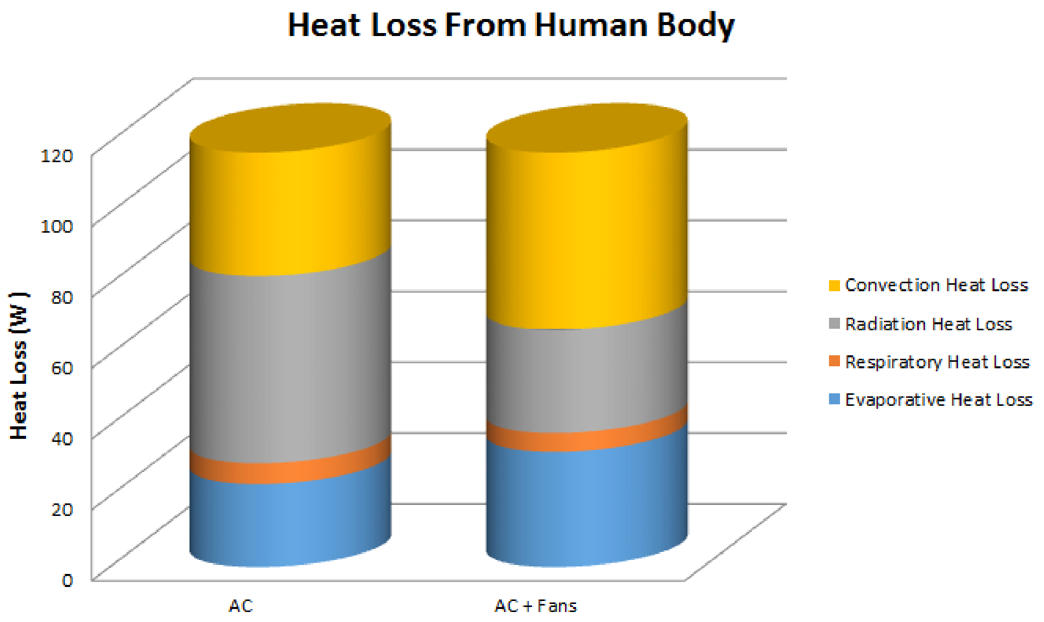


Large-Diameter Ceiling Fan Applications

1. Thermal comfort
2. Thermal mixing
3. Air disinfection

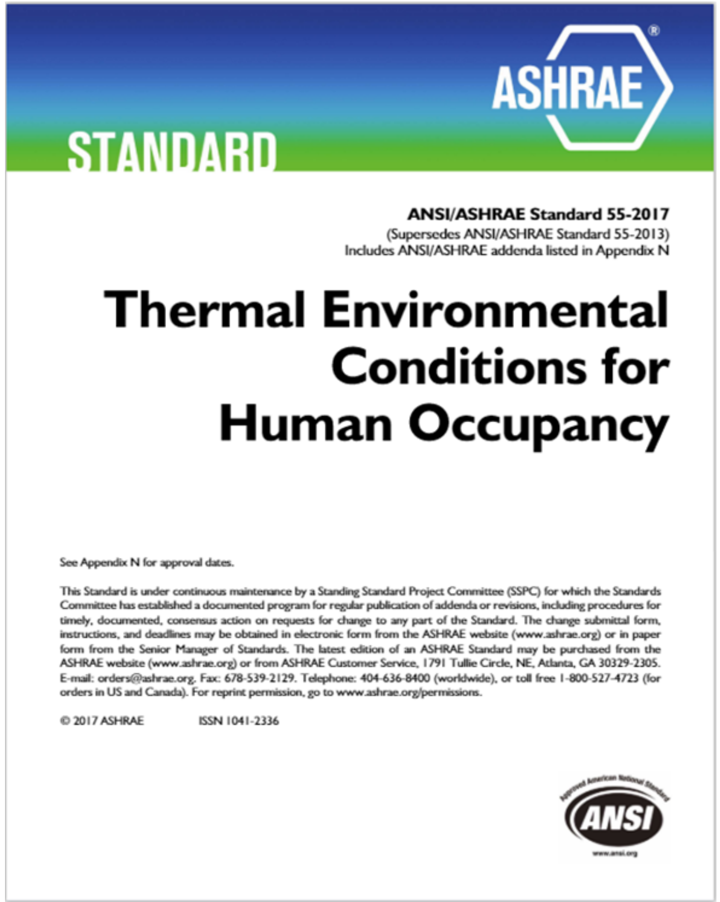
Thermal Comfort - Elevated Air Speed

- Most common comfort application
- Increased heat transfer from the human body
- Sensible & latent heat transfer
  - Sensible at < ~99 °F (37 °C)
  - Latent at < 100% RH



Thermal Comfort - Average Air Speed

- ANSI/ASHRAE Standard 55-2017
  - Average air speed
    - Seated – 4”, 24”, and 43” AFF (0.1, 0.6, and 1.1m)
    - Standing – 4”, 43”, and 67” AFF (0.1, 1.1, and 1.7m)
  - Standard Effective Temperature (SET)
  - Cooling effect calculated using average air speed
  - CBE Thermal Comfort Tool
    - Quantify comfort impact
    - Determine target average air speeds
    - Evaluate different design scenarios



STANDARD

ASHRAE

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

Thermal Environmental Conditions for Human Occupancy

See Appendix N for approval dates.

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. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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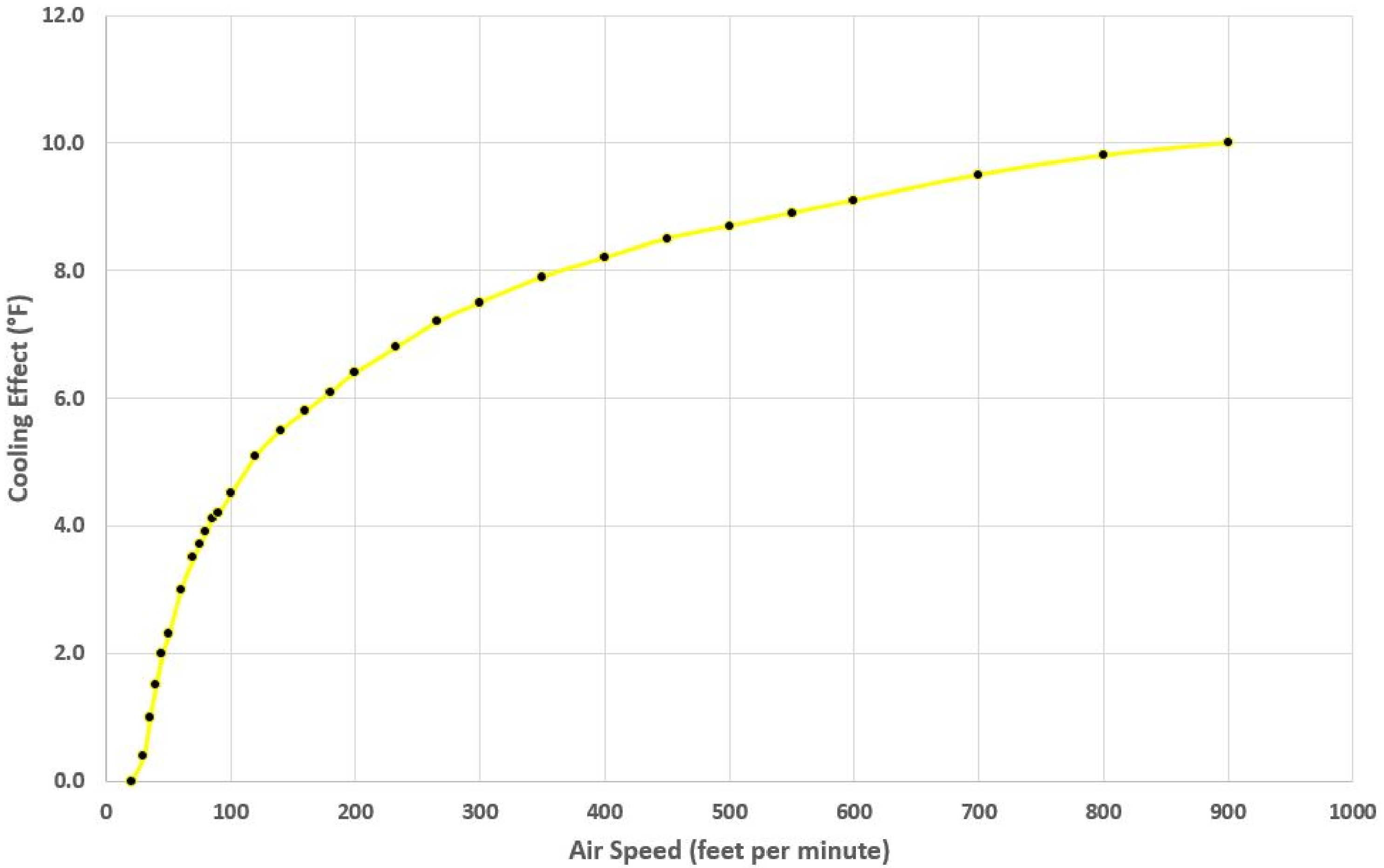
ANSI

Cooling Effect of Elevated Air Speed



Sources: ANSI/ASHRAE Standard 55-2017 & CBE Thermal Comfort Tool. Center for the Built Environment, University of California Berkeley

Standard 55 Definitions

Predicted Mean Vote (PMV)

+ An index that predicts the thermal sensation votes (self-reported perceptions) of a large group of people on a sensation scale.

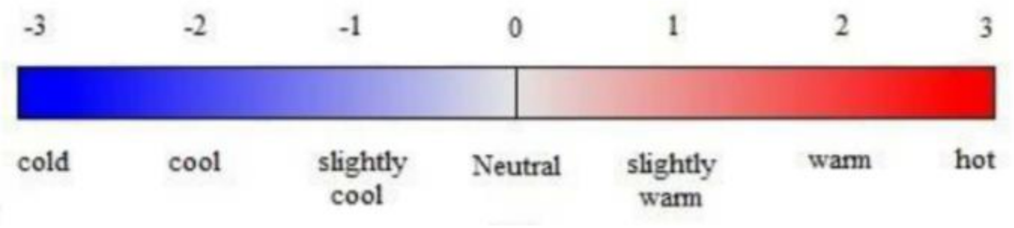
Predicted Percentage of Dissatisfied (PPD)

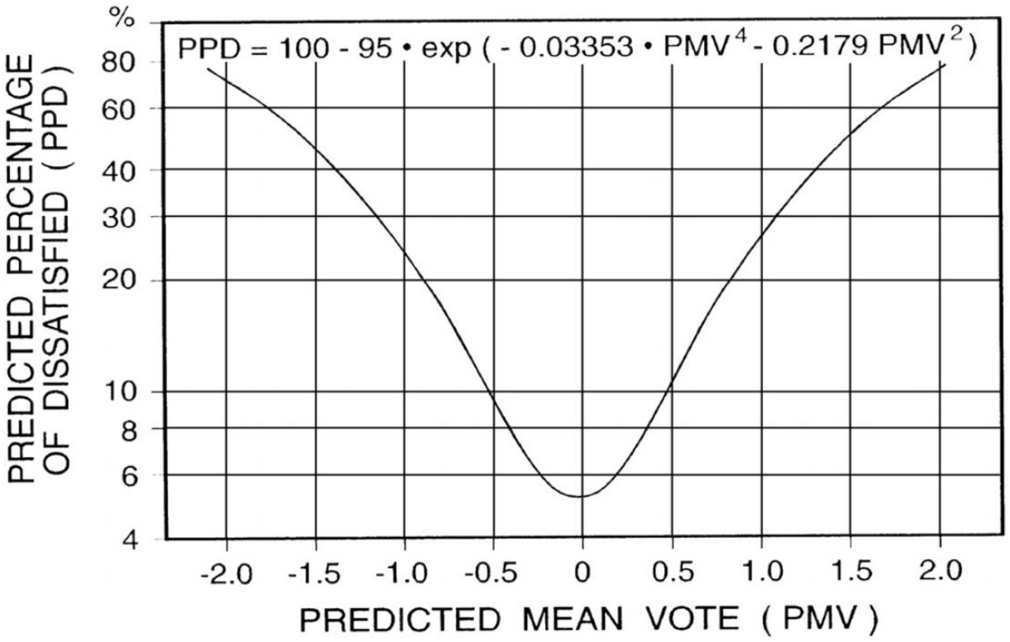
+ An index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV.

Comfort Zone Acceptable Ranges:

+ PMV: -0.5 to +0.5
+ PPD < 10%

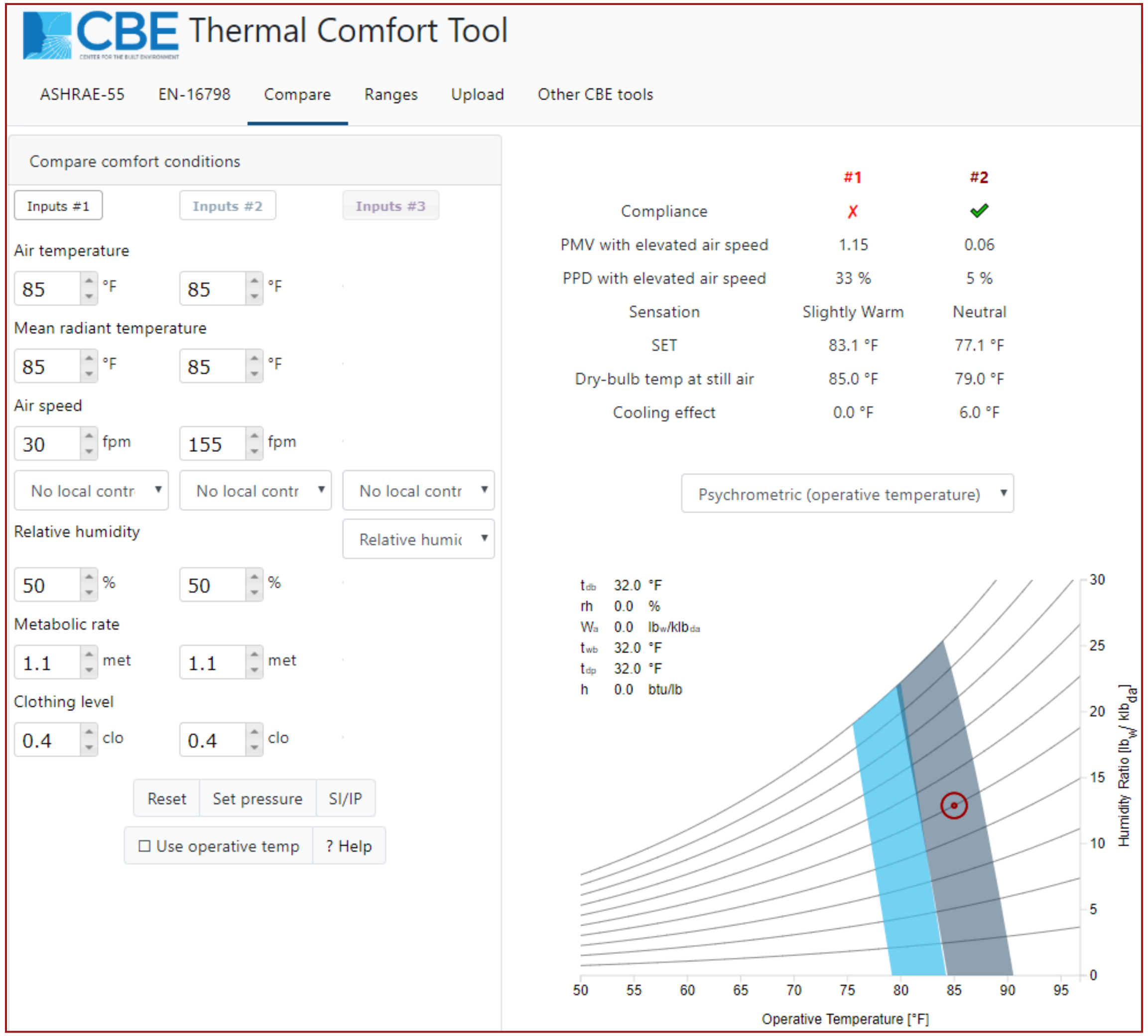
ASHRAE Thermal Sensation Scale





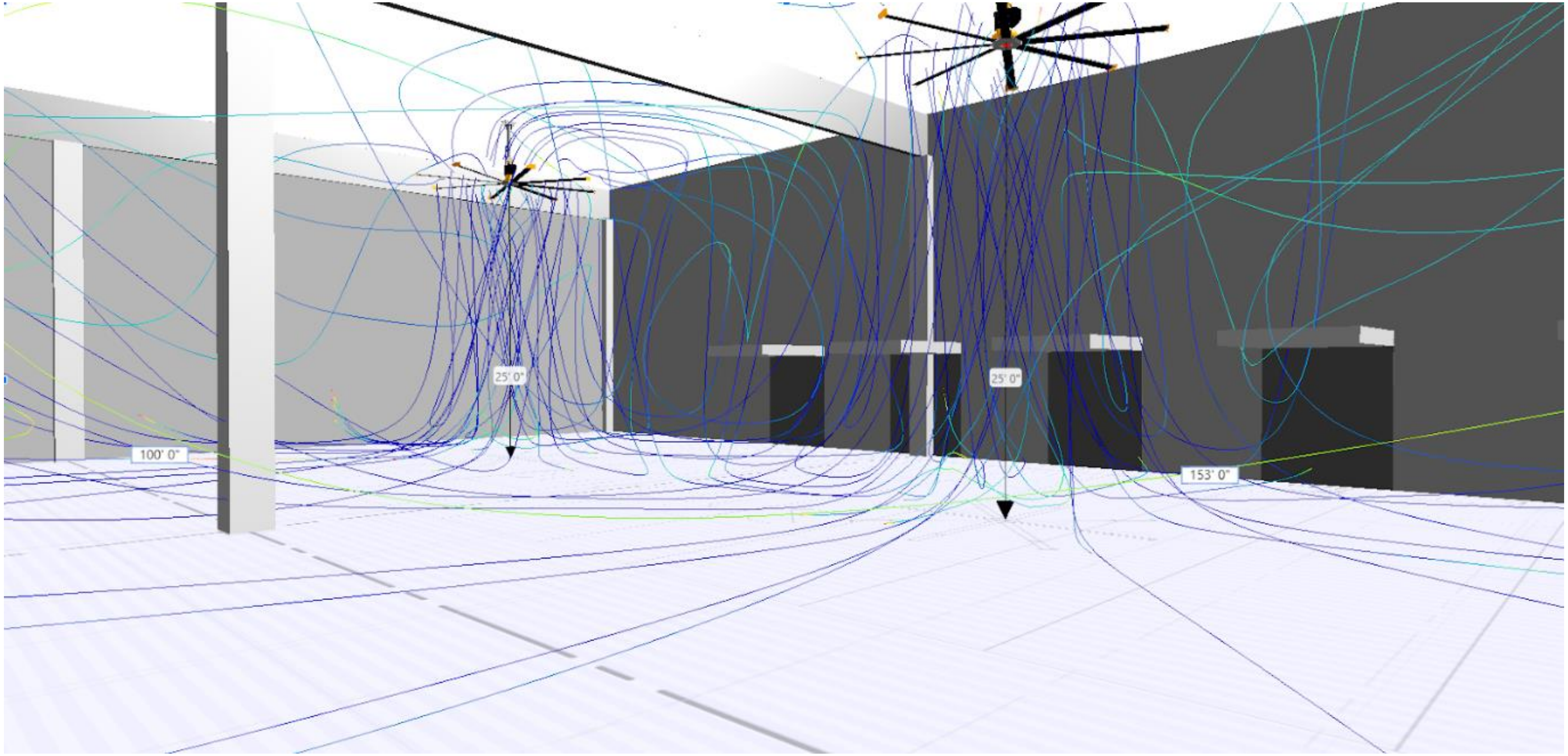
ANSI/ASHRAE Standard 55-2017. Thermal Environmental Conditions for Human Occupancy. 2017

Thermal Comfort Tool Example



Tyler Hoyt, Stefano Schiavon, Federico Tartarini, Toby Cheung, Kyle Steinfeld, Alberto Piccioli, and Dustin Moon, 2019, CBE Thermal Comfort Tool. Center for the Built Environment, University of California Berkeley.

Example CFD Fan Selection



Example Applications

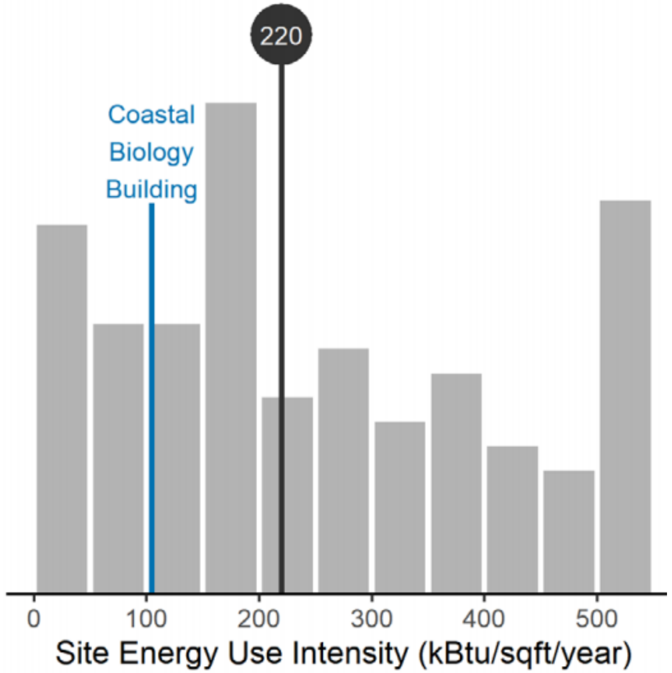
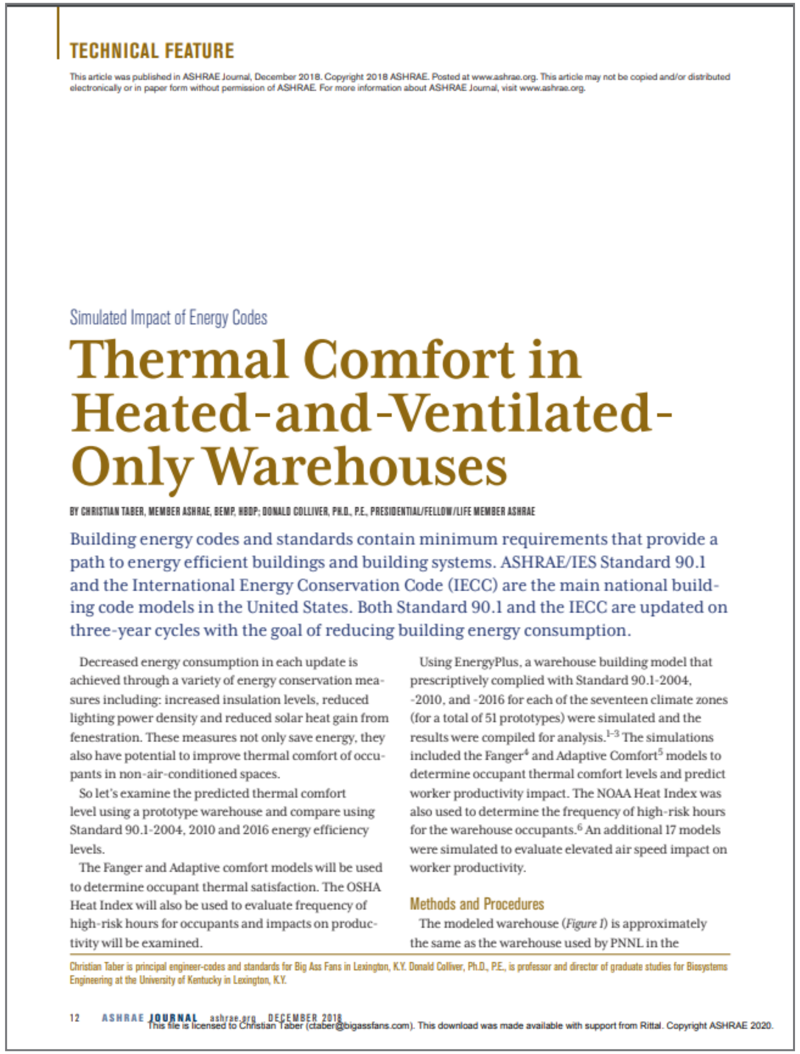


Figure 1. Energy use for both the main building and greenhouse is below 75% of laboratory and college buildings from the same climate zone in the Building Performance Database (BPD). The Site EUI of 105 is over 50% less than the mean EUI of 220.

Integrating Smart Ceiling Fans and Communicating Thermostats to provide Energy-Efficient Comfort, Paul Raftery at UC Berkeley Center for the Built Environment

Additional Information

- ANSI/ASHRAE Standard 55-2017
- Thermal Comfort in Heated-and-Ventilated-Only Warehouses, ASHRAE Journal, Dec 2018
- Center for the Built Environment Case Studies



TECHNICAL FEATURE

Simulated Impact of Energy Codes

Thermal Comfort in Heated-and-Ventilated-Only Warehouses

BY CHRISTIAN TABER, MEMBER ASHRAE, BEMP, HBDP; DONALD COLLIVER, PH.D., P.E., PRESIDENTIAL/FELLOW/LIFE MEMBER ASHRAE

Building energy codes and standards contain minimum requirements that provide a path to energy efficient buildings and building systems. ASHRAE/IES Standard 90.1 and the International Energy Conservation Code (IECC) are the main national building code models in the United States. Both Standard 90.1 and the IECC are updated on three-year cycles with the goal of reducing building energy consumption.

Decreased energy consumption in each update is achieved through a variety of energy conservation measures including: increased insulation levels, reduced lighting power density and reduced solar heat gain from fenestration. These measures not only save energy, they also have potential to improve thermal comfort of occupants in non-air-conditioned spaces.

So let's examine the predicted thermal comfort level using a prototype warehouse and compare using Standard 90.1-2004, 2010 and 2016 energy efficiency levels.

The Fanger and Adaptive comfort models will be used to determine occupant thermal satisfaction. The OSHA Heat Index will also be used to evaluate frequency of high-risk hours for occupants and impacts on productivity will be examined.

Using EnergyPlus, a warehouse building model that prescriptively complied with Standard 90.1-2004, -2010, and -2016 for each of the seventeen climate zones (for a total of 51 prototypes) were simulated and the results were compiled for analysis.[1-3] The simulations included the Fanger[4] and Adaptive Comfort[5] models to determine occupant thermal comfort levels and predict worker productivity impact. The NOAA Heat Index was also used to determine the frequency of high-risk hours for the warehouse occupants.[6] An additional 17 models were simulated to evaluate elevated air speed impact on worker productivity.

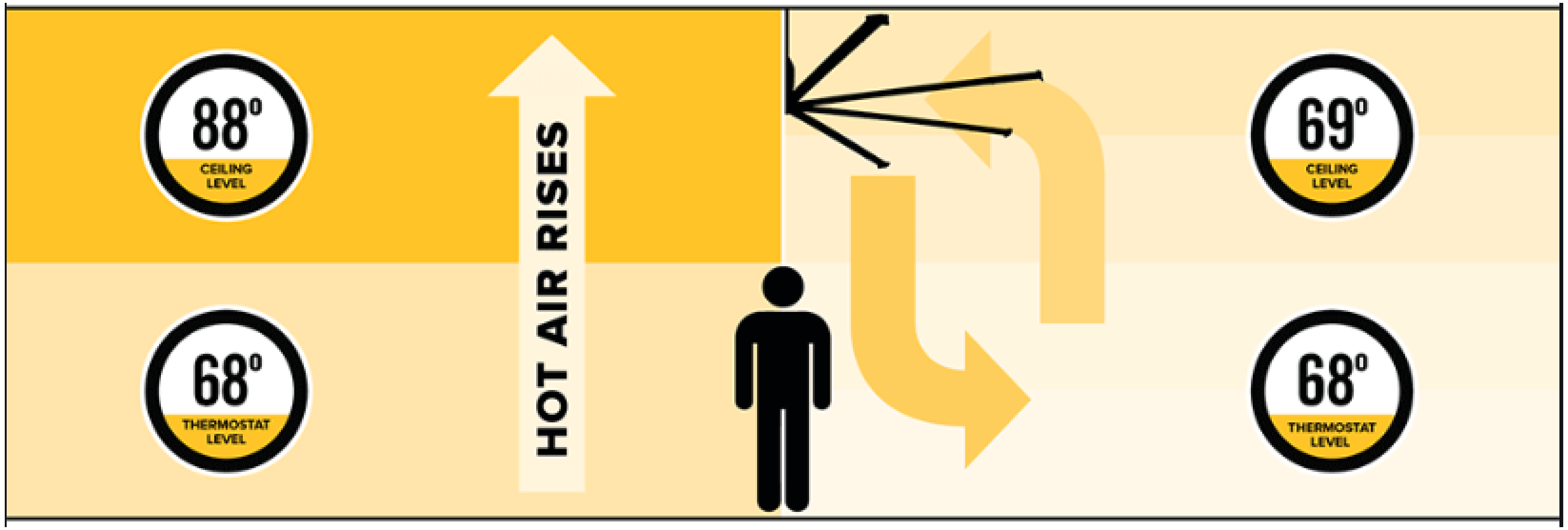
Methods and Procedures

The modeled warehouse (*Figure 1*) is approximately the same as the warehouse used by PNNL in the

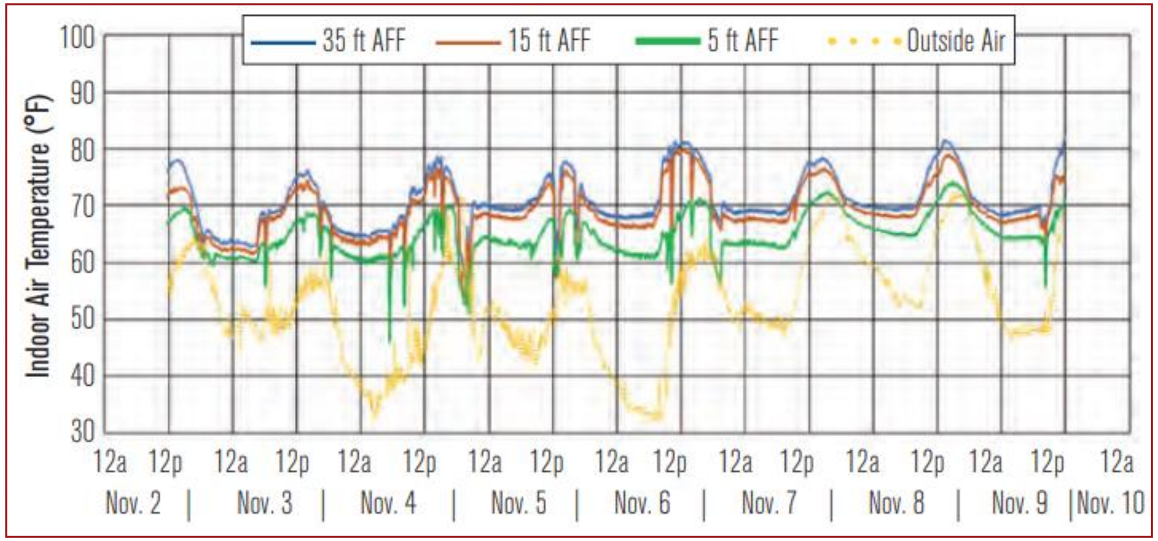
Christian Taber is principal engineer-codes and standards for Big Ass Fans in Lexington, K.Y. Donald Colliver, Ph.D., P.E., is professor and director of graduate studies for Biosystems Engineering at the University of Kentucky in Lexington, K.Y.

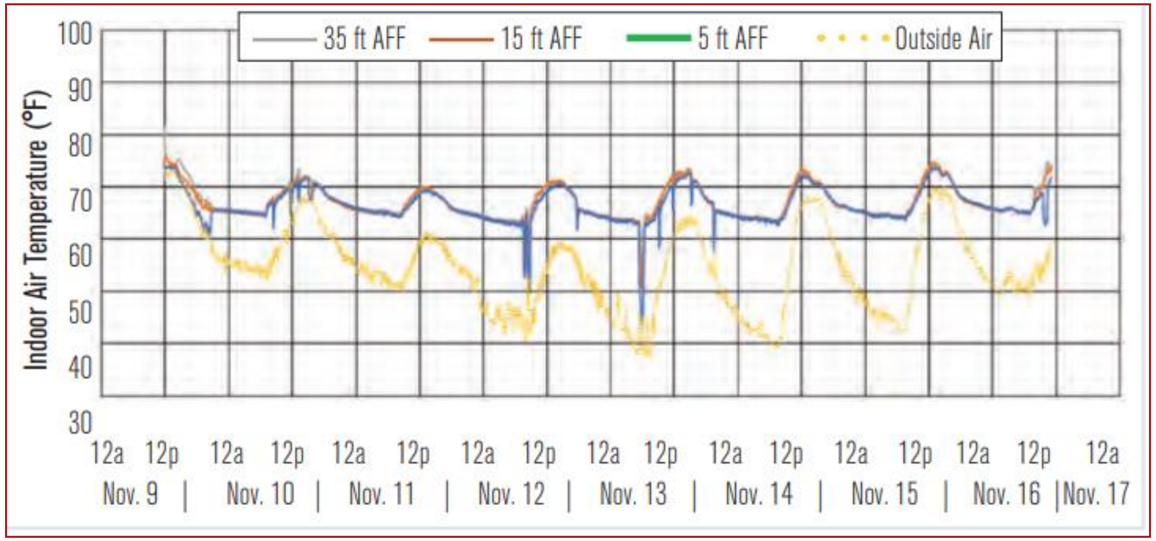
Thermal Mixing

- Most common energy saving application
- Mixing stratified layers of air
- High ceilings, overhead supply/return ideal



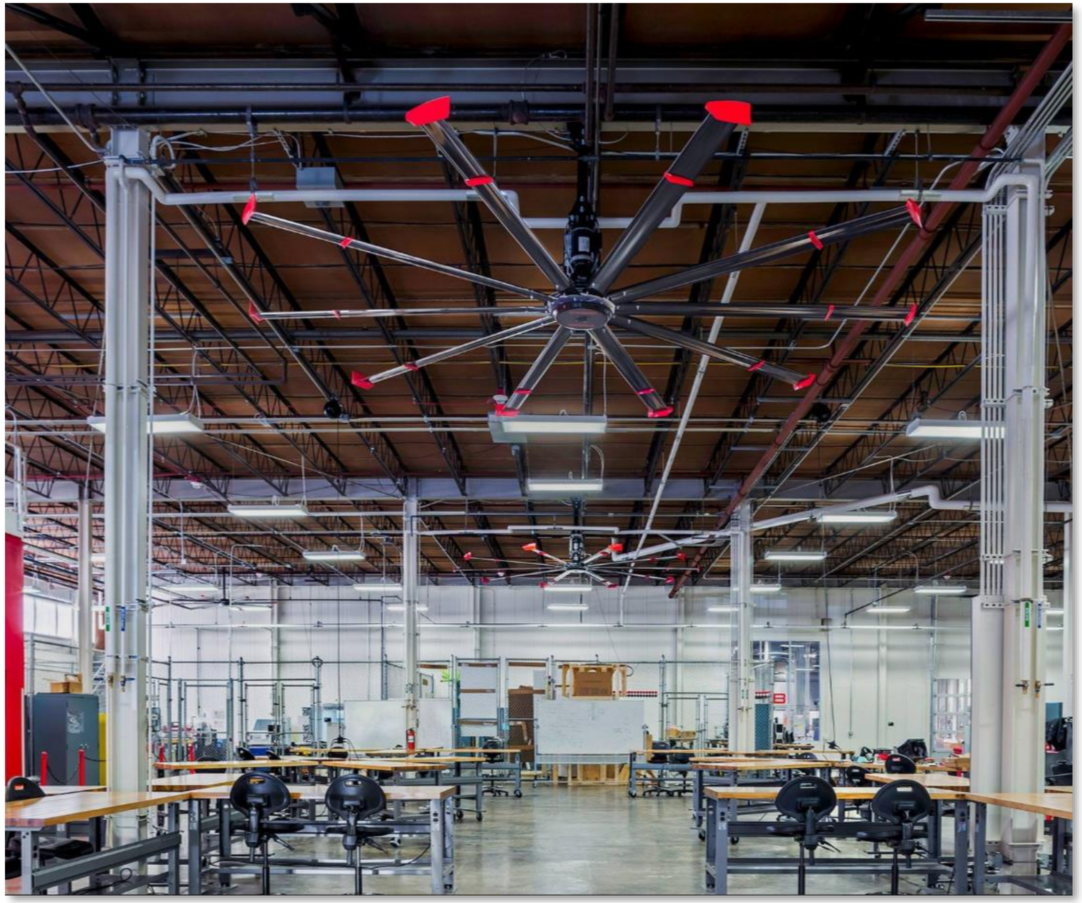
Thermal Mixing – Floor to Ceiling Temps





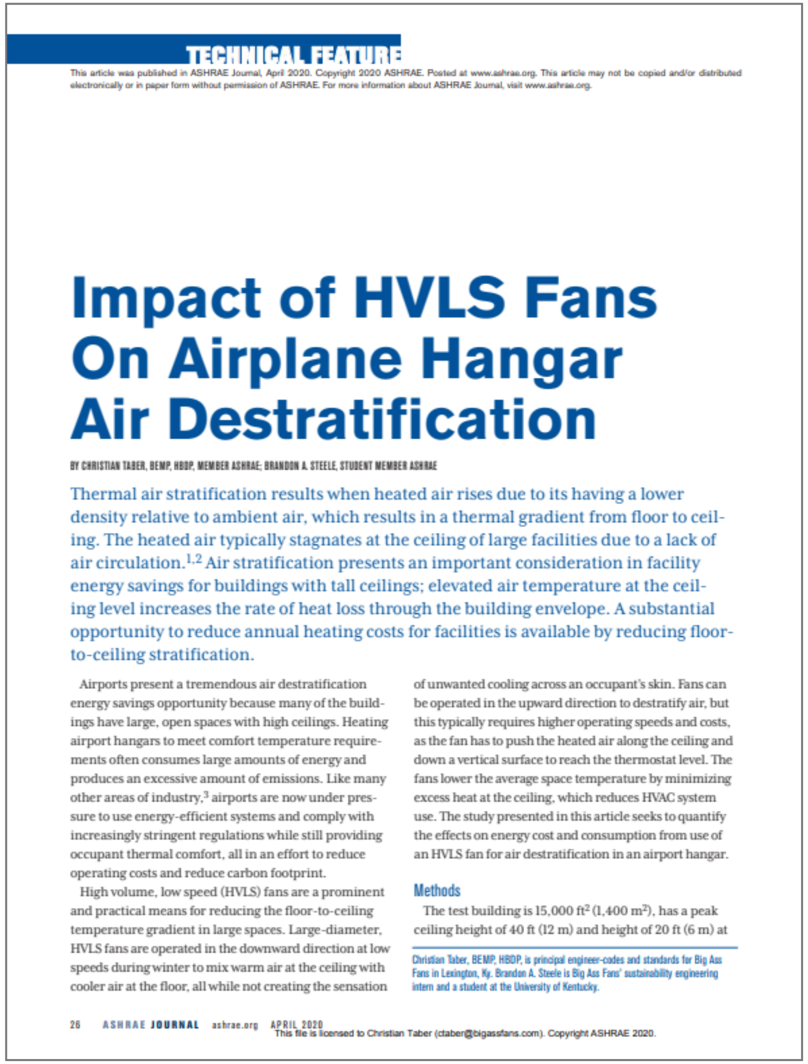
Impact of HVLS Fans on Airplane Hangar Air Destratification, ASHRAE Journal, April 2020

Example Applications



Additional Information

- Impact of HVLS Fans on Airplane Hangar Air Destratification, ASHRAE Journal, April 2020
- Optimizing Winter Heating: Is reversing the direction of your ceiling fan the best way to achieve thermal destratification?, Sonya Milonova, Harvard School of Public Health



TECHNICAL FEATURE

Impact of HVLS Fans On Airplane Hangar Air Destratification

BY CHRISTIAN TABER, BEMP, HBDP, MEMBER ASHRAE; BRANDON A. STEELE, STUDENT MEMBER ASHRAE

Thermal air stratification results when heated air rises due to its having a lower density relative to ambient air, which results in a thermal gradient from floor to ceiling. The heated air typically stagnates at the ceiling of large facilities due to a lack of air circulation.[1,2] Air stratification presents an important consideration in facility energy savings for buildings with tall ceilings; elevated air temperature at the ceiling level increases the rate of heat loss through the building envelope. A substantial opportunity to reduce annual heating costs for facilities is available by reducing floor-to-ceiling stratification.

Airports present a tremendous air destratification energy savings opportunity because many of the buildings have large, open spaces with high ceilings. Heating airport hangars to meet comfort temperature requirements often consumes large amounts of energy and produces an excessive amount of emissions. Like many other areas of industry,[3] airports are now under pressure to use energy-efficient systems and comply with increasingly stringent regulations while still providing occupant thermal comfort, all in an effort to reduce operating costs and reduce carbon footprint.

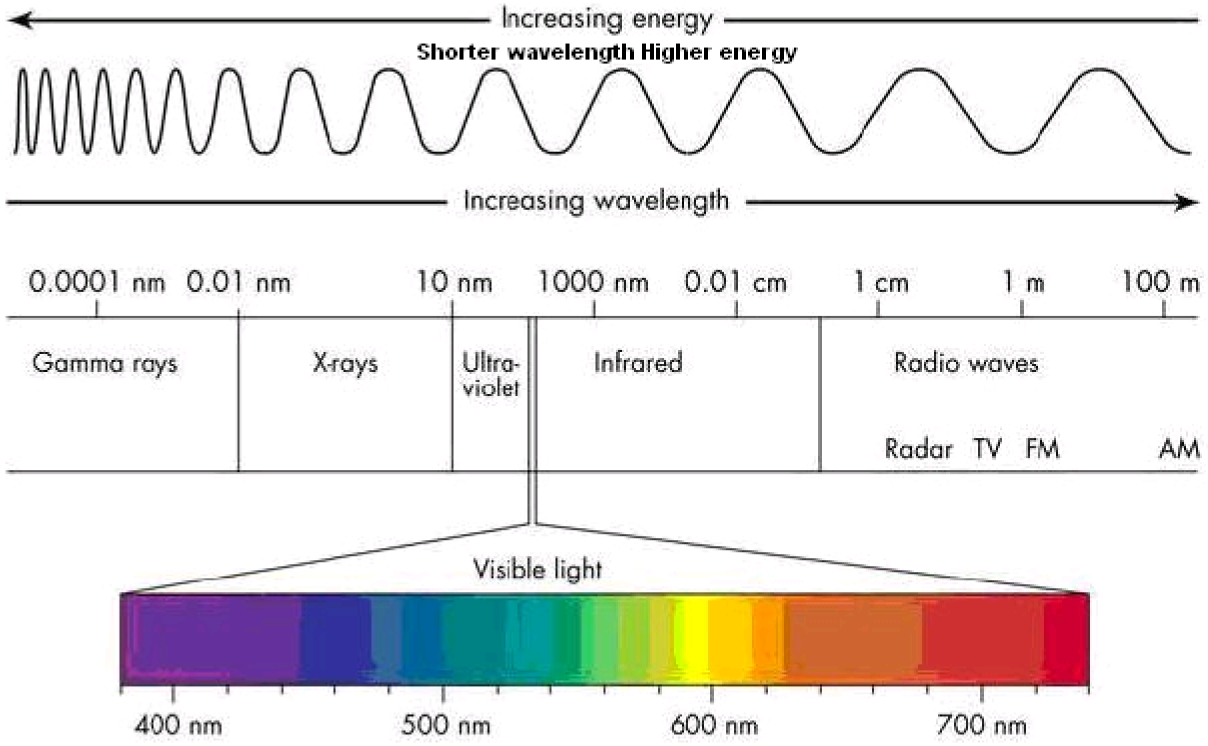
High volume, low speed (HVLS) fans are a prominent and practical means for reducing the floor-to-ceiling temperature gradient in large spaces. Large-diameter, HVLS fans are operated in the downward direction at low speeds during winter to mix warm air at the ceiling with cooler air at the floor, all while not creating the sensation of unwanted cooling across an occupant's skin. Fans can be operated in the upward direction to destratify air, but this typically requires higher operating speeds and costs, as the fan has to push the heated air along the ceiling and down a vertical surface to reach the thermostat level. The fans lower the average space temperature by minimizing excess heat at the ceiling, which reduces HVAC system use. The study presented in this article seeks to quantify the effects on energy cost and consumption from use of an HVLS fan for air destratification in an airport hangar.

Methods

The test building is 15,000 ft^2 (1,400 m^2), has a peak ceiling height of 40 ft (12 m) and height of 20 ft (6 m) at

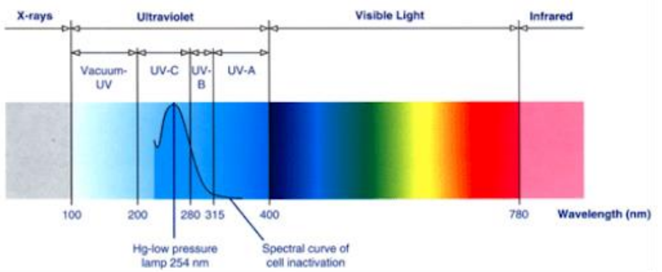
Christian Taber, BEMP, HBDP, is principal engineer-codes and standards for Big Ass Fans in Lexington, Ky. Brandon A. Steele is Big Ass Fans' sustainability engineering intern and a student at the University of Kentucky.

Air Disinfection



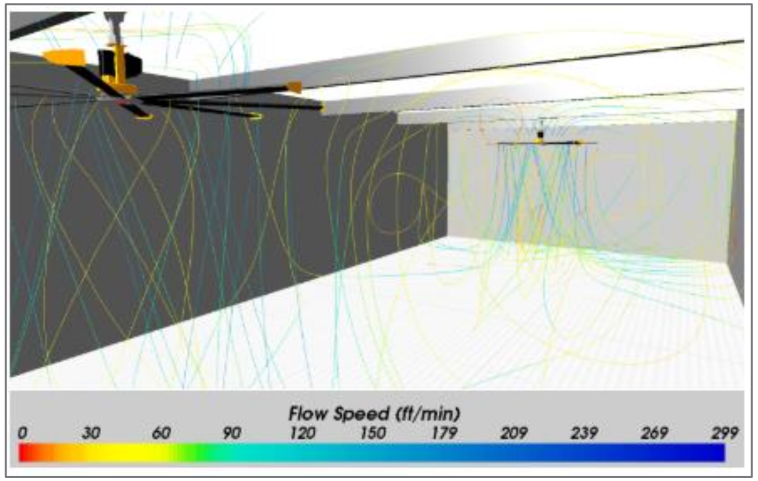
Air Disinfection - UVGI

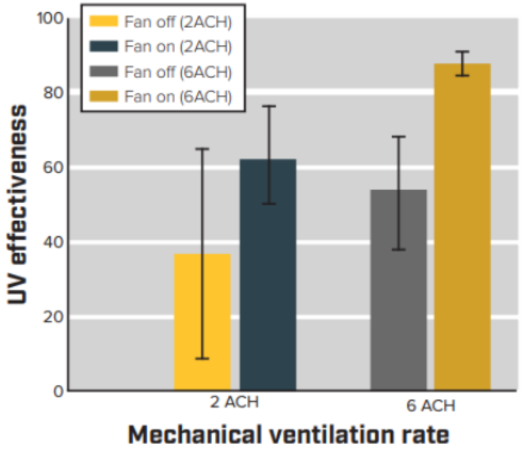
- **What?**
  - UVGI = Ultraviolet Germicidal Irradiation
  - Disinfection method using waveform energy from light fixtures
  - Effective against viruses, bacteria, mold - widely accepted and established technology
- **Why?**
  - Reduction of germ concentrations increases air quality and reduces the risk of disease transmission
- **How?**
  - Exposure to UV radiation damages genetic material (Inactivation)
  - Inactivated microorganisms cannot replicate - no risk to hosts for infection from inactivated pathogens
  - Existing guidelines for irradiation dose inactivation and safety levels
- **When?**
  - Use of UV for disinfection dates to late 1800s
  - In wide use in HVAC industry since 1940

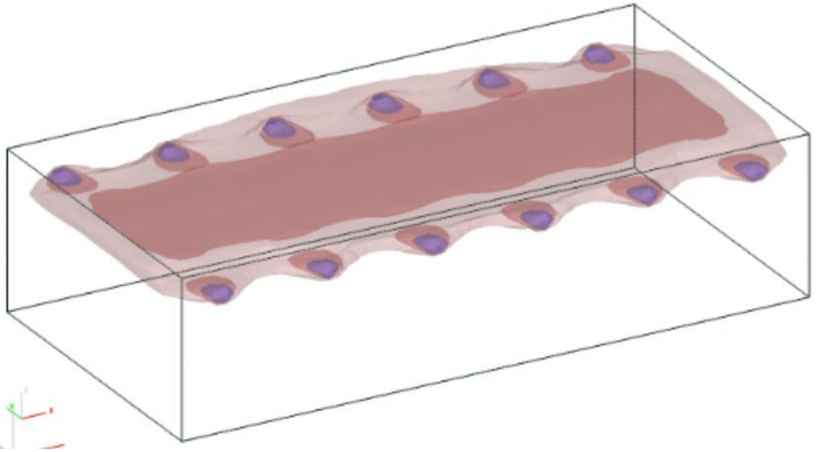


Air Disinfection - UVGI

- UR-UVGI Effectiveness is limited without air circulation (12%).*
  - This is especially true in high volume applications.
- Effectiveness is driven by mixing
  - The replacement of contaminated air in the lower room (occupant breathing zone) with cleaned air from the upper room (disinfected zone).
- Ceiling fans are a widely accepted way to improve effectiveness.
  - Readily retro-fittable
- UR-UVGI effectiveness has been shown to increase by up to 77% when paired with ceiling fans.*





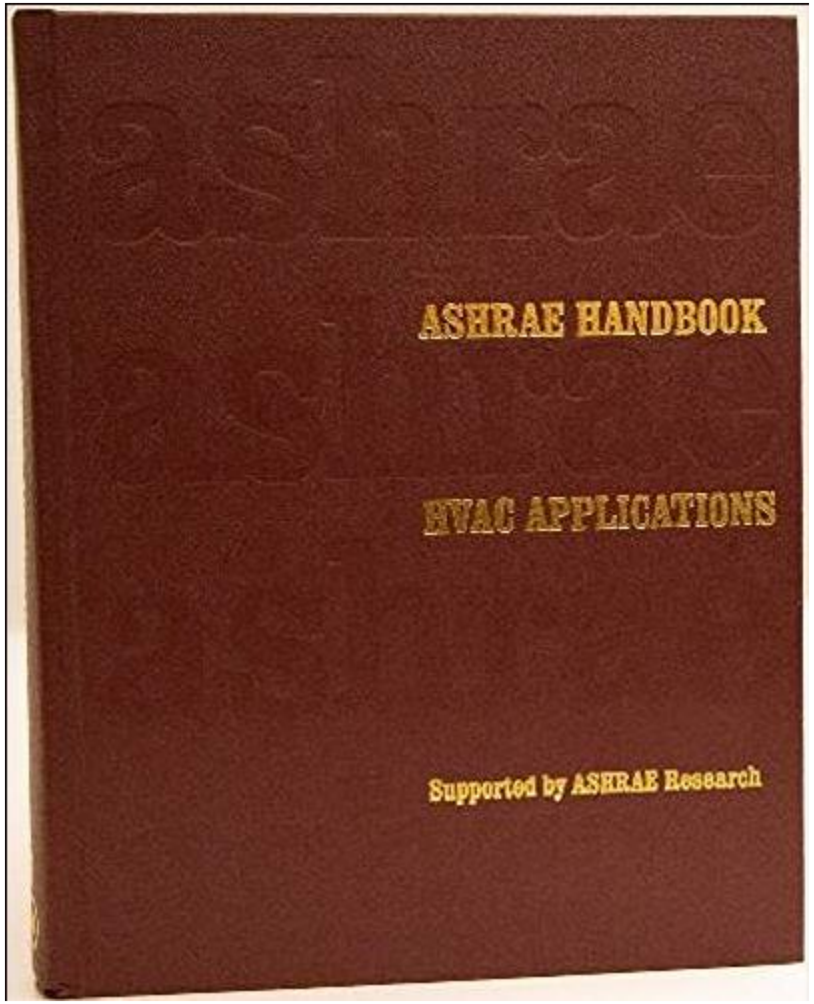


*National Institute for Occupational Safety and Health; 2009. Environmental control of tuberculosis: basic upper-room ultraviolet germicidal irradiation guidelines for healthcare settings.

Example Applications

Additional Information

- ASHRAE Handbook—HVAC Applications
- The History of Ultraviolet Germicidal Irradiation for Air Disinfection, Reed



Published Data - How to Select a LDCF

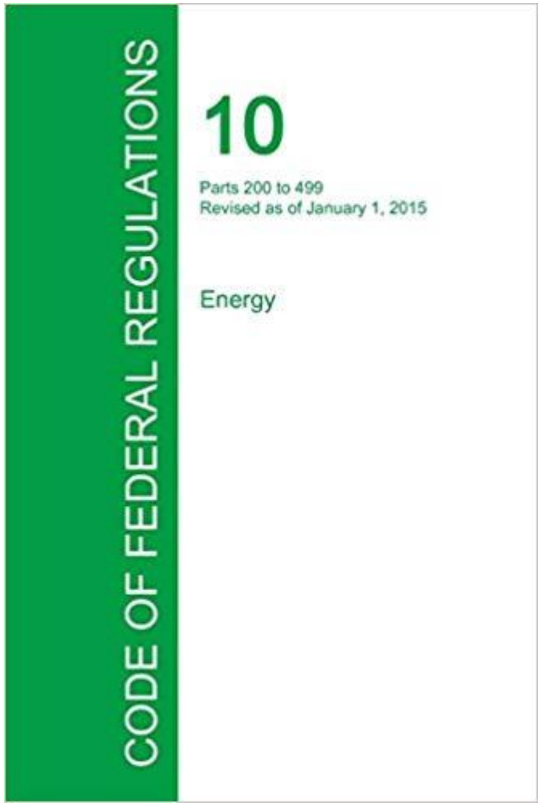
¯_(ツ)_/¯

Performance & Selection Metrics

- US DOE
  - 10 CFR 430 Appendix U
  - 10 CFR 430.32
- ASHRAE
  - ANSI/ASHRAE Standard 55-2017
  - ASHRAE Standard 216P

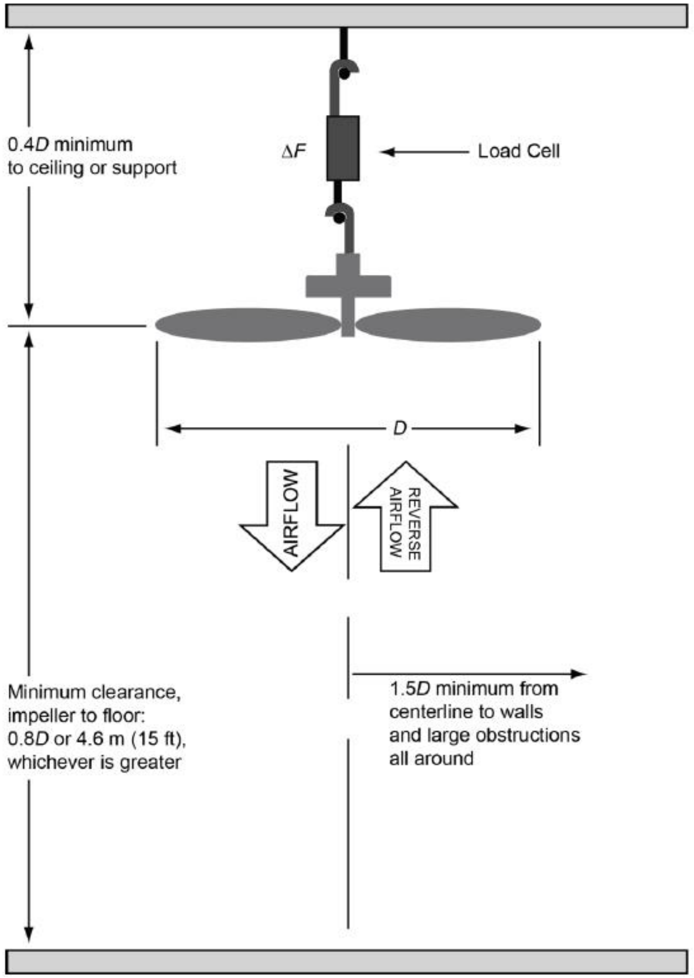
U.S. DOE Ceiling Fan Regulations

- 10 CFR Part 430, Appendix U to Subpart B
  - Product classes
  - Test procedures
  - Efficiency metric
  - Performance representations
  - Effective 1/23/17



- 10 CFR Part 430.32 - Energy and water conservation standards and their compliance dates
  - Minimum efficiency by product class
  - Effective 1/21/20

U.S. DOE – LDCF Method of Test



ANSI/AMCA Standard 230-15

TEST METHOD	POWER (WATTS)	THRUST (POUNDS FORCE)	AIRFLOW (CFM)
AMCA 230-99	750	36.5	113,664
AMCA 230-07	750	37.0	N/A
AMCA 230-12	750	37.0	80,897
AMCA 230-15	750	37.0	80,365
DOE Regulations 2016/17	750	37.0	80,365

New Federal Regulations for Ceiling Fans, ASHRAE Journal

Metrics: 10 CFR 430 - Appendix U

- Airflow (cfm) & power (W) measured
- Ceiling Fan Efficiency (CFE) calculated
- CFE ≈ “Typical” daily airflow / daily energy use (cfm/W)

Large Diameter CFE =

$$\frac{CFM_{20\%} \times Hours_{20\%} + CFM_{40\%} \times Hours_{40\%} + \ \dots + CFM_{100\%} \times Hours_{100\%}}{W_{20\%} \times Hours_{20\%} + W_{40\%} \times Hours_{40\%} + \ \dots \ + W_{100\%} \times Hours_{100\%} + W_{SB} \times Hours_{SB}}$$

Where:

CFM_i = airflow at speed
OH_i = operating hours at speed
W_i = power consumption at speed
OH_{sb} = operating hours in standby mode, and
W_{sb} = power consumption in standby mode.

10 CFR 430 - Appendix U Derived Data

- Advantages
  - Federally regulated
  - AMCA certification available
  - Hurdle to sell products in US
  - Familiar data (other fan types selected on CFM & W)
  - Can be used for mixing applications
- Disadvantages
  - Are not the design criteria for most common applications (fpm at occ level)
  - Easy to game CFE by reducing RPM
  - Limits fan maximum performance

Additional Information

- AMCA 230-15
- 10 CFR Part 430.32
- 10 CFR Part 430, App U Subpart B
- New Federal Regulations for Ceiling Fans, ASHRAE Journal
- Circulator Fan Performance Testing Standards, ASHRAE Journal

TECHNICAL FEATURE

The Thrust of ANSI/AMCA Standard 230-15

Circulator Fan Performance Testing Standards

BY CHRISTIAN TABER, BEMP, HBDP, MEMBER ASHRAE

Inventor Philip Diehl is credited with creating the first electric ceiling fan out of a modified sewing machine motor in the 1880s.[1] The invention led to a manufacturing boom, and fans of different sizes, with varying numbers of blades and blade shapes, soon became available to consumers. Manufacturers sought to stand out from one another, and early 1900s print advertisements show the same selling points we see today—including efficiency claims (*Photo 1*).

However, for more than 100 years after the inception of the electric ceiling fan, there was no widely accepted standard to back up those claims, and fan manufacturers published data based on different assumptions, using disparate conditions and rating methods.

The Journal of the Institution of Electrical Engineers acknowledged the problem as far back as the 1920s:

> "It appears to be the practice to state the volume of air displaced per minute by a ceiling fan without any reference to the conditions under which the measurements are made.... When ceiling fans are being compared on the basis of air displacement, such comparison is useless unless the measurements have been made under similar conditions."
> -E. Hughes, 1926[2]

It wasn't until 1999 that the Air Movement and Control Association (AMCA) introduced ANSI/AMCA Standard 230-99, *Laboratory Methods of Testing Air Circulating Fans for Rating and Certification*, which set uniform requirements for testing the performance of circulating fans. Energy Star created a standard specifically for residential ceiling fans three years later. AMCA Standard 230-99, while widely accepted for nonresidential fans, didn't account for a new type of industrial fan that was invented at roughly the same time: high-volume, large-diameter (HVLD) fans. The primary issue was the standard's requirement that the ceiling height of the test chamber be three times the diameter of the fan; for a 24 ft (7.3 m) industrial fan, this would require a testing facility with a 72 ft (21.9 m) ceiling.

The emerging HVLD fan industry found itself where the residential ceiling fan industry as a whole had been 100 years prior—without a practical standard for measuring performance. Therefore, manufacturers of HVLD ceiling fans used numerous rating methods and test

Christian Taber is a senior research engineer at Big Ass Solutions, Lexington, Ky. He is a member of ASHRAE SSPC 90.1 and SSPC 189.1, and of the AMCA Standard 230 committee.

TECHNICAL FEATURE

What You Need to Know

New Federal Regulations For Ceiling Fans

BY CHRISTIAN TABER, MEMBER ASHRAE, BEMP, HBDP; MICHAEL IVANOVICH, MEMBER ASHRAE

In January 2017, the U.S. Department of Energy (DOE) finalized its first efficiency performance standards for ceiling fans,[1] which included minimum efficiency requirements for large-diameter ceiling fans. The DOE is covering commercial and industrial fans and blowers in a separate rulemaking that has yet to be finalized.[2]

Ratings using the DOE test procedure allow comparisons of products based on electric input power and airflow. Fan companies that fail to use the prescribed DOE test procedure for making representations of ceiling fan performance would be subject to fines.[3] Because the DOE performance metric is not based on a specific airflow point, some additional effort on the part of the designer may be required to evaluate fan performance equitably at a specific airflow point.

Here, then, are four things to know about the DOE's regulation of ceiling fans that will help to ensure a successful and efficient ceiling fan selection.

1. The Test Methods Are Based on Well-Known Industry Standards

The DOE test methods for ceiling fans are defined in the Code of Federal Regulations (CFR).[4]

For small-diameter (7 ft [2.1 m] or less) ceiling fans, performance testing is based on a modified version of *ENERGY STAR® Testing Facility Guidance Manual: The Solid State Test Method for ENERGY STAR Qualified Ceiling Fans*,[5] which has been in use for testing residential ceiling fans since 2002. DOE's final rule incorporates some aspects from version 1.2 of the guidance manual, but is formally an update with respect to DOE's previous test procedure. Effective June 15, 2018, the DOE test method will be used for qualification for ENERGY STAR certification.

For large-diameter (greater than 7 ft [2.1 m]) ceiling fans, performance testing is based on a standard published by Air Movement and Control Association (AMCA) International: ANSI/AMCA Standard 230-15, *Laboratory Methods of Testing Air Circulating Fans for Rating and Certification*. AMCA 230 initially was published in 1999;[6] the most recent revision, published in 2015,[7] was discussed in detail in a previous *ASHRAE Journal* article.[8]

As of July 2017, all temporary testing extensions granted by the DOE are expired; thus, all ceiling-fan manufacturers now are required to use the DOE testing methods as the basis of any published performance data, per DOE's representation requirements at 10 CFR 429.32.[3]

2. Fan Manufacturers' Performance Data Should Not Change Dramatically.

Although the DOE regulations differ slightly from AMCA 230-15, airflow is calculated according to AMCA 230-15, and published performance data should not vary dramatically from those obtained

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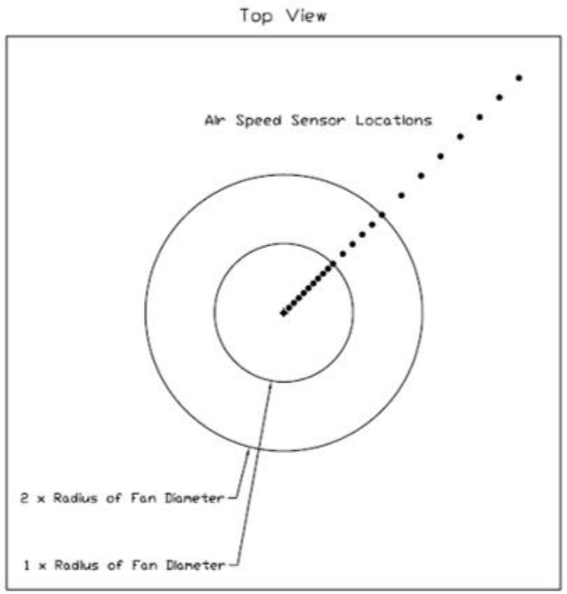
BSR/ASHRAE Standard 216P - Background

- Authorized January 22, 2014 (New York)
- To be published in 2020
- Title: Methods of Test for Determining Application Data of Overhead Circulator Fans
- Purpose: The purpose of this standard is to specify the instrumentation, facilities, test installation methods, and procedures to determine circulator fan application data for occupant thermal comfort in a space.
- Scope: This standard applies to overhead circulator ceiling fans.

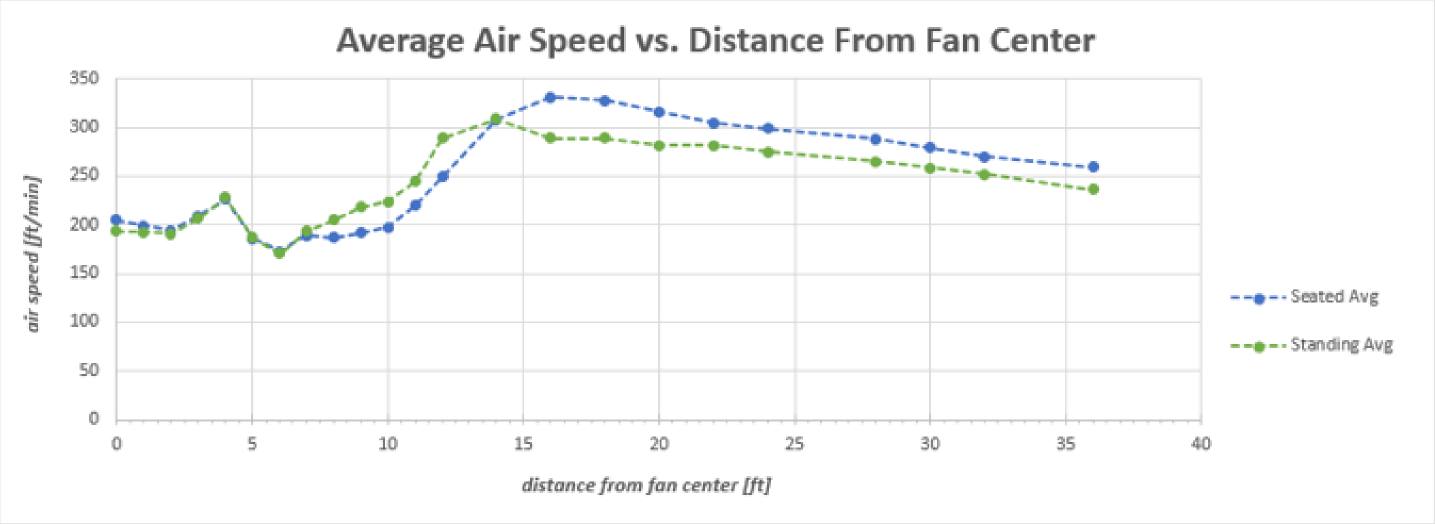
Standard 216: Overview

- Fan mounted in test chamber
  - Small - 20’x20’x11’ (6.1x6.1x3.4m)
  - Medium - 50’x50’x22’ ±1.5 (15.2x15.2x6.7m)
  - Large - 80’x80’x32’ (24.4x24.4x9.8m)
- Air speeds measured at four test points per test position
  - 4”, 24”, 43”, and 67” AFF (0.1, 0.6, 1.1, 1.7m)
- Test positions – center to corner of room
- Power measured per 10 CFR 430
- Air speed + power measurements → Application data & metrics

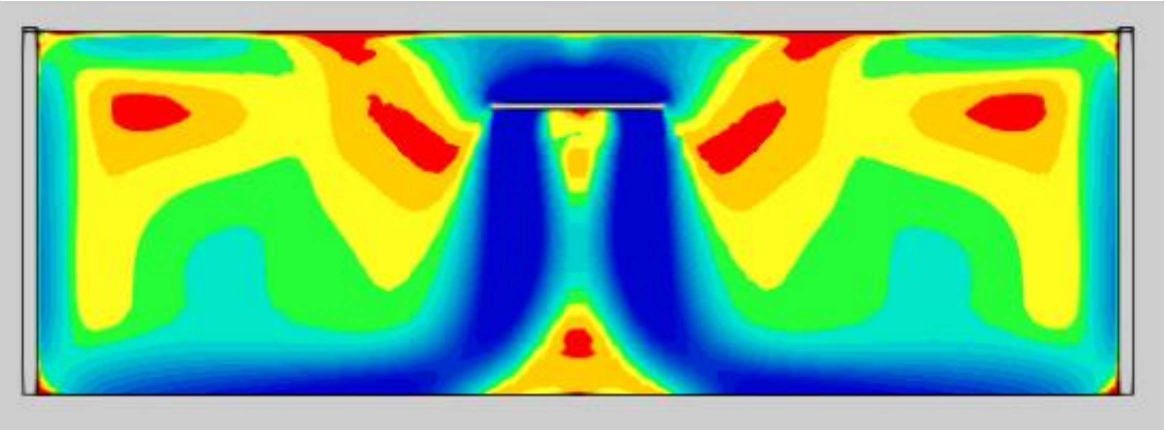


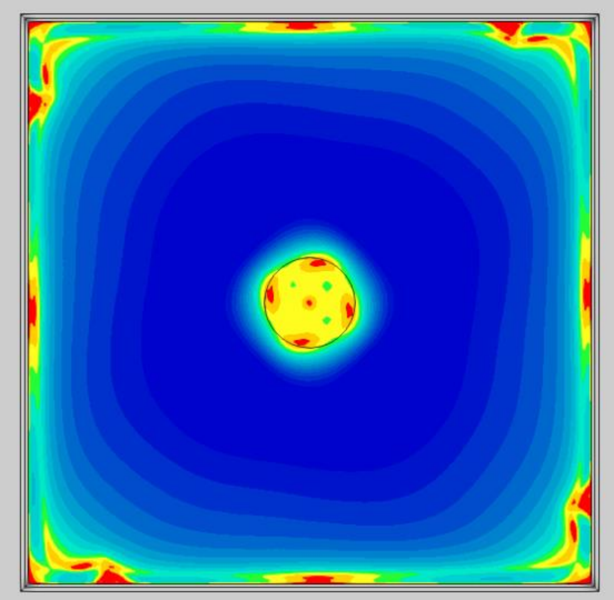
Standard 216 Based Ceiling Fan Selections- Key Criteria

- 8.4 - Average Air Speed – Combined to create average air speed profile
- 8.5 - Maximum Average Air Speed – Too Cold (PMV<-0.5), Paper flutter
- 8.6 - Minimum Average Air Speed – Too Hot (PMV>0.5)
- 8.7 – Uniformity - Spot cooling or numerous occupants
- 8.9 - Room Average Cooling Effect – Estimated thermostat increase
- 8.11 - Cooling Coverage Fraction – High-speed test, does it cover the space
- 8.12 - Heating Draft Risk Fraction – Optional low-speed test, will it draft?



Example CFD Fan Selection





Standing | Seated

	Min	Avg	Max
Air Velocity	191.47 ft/min	211.57 ft/min	238.53 ft/min
Cooling Effect	6.01 °F	6.24 °F	6.52 °F
Cooling Coverage	--	100%	--
Advanced			
PMV	-0.36	-0.4	-0.45
PPD	7.77%	8.38%	9.21%
SET	75.06 °F	74.82 °F	74.53 °F

ASHRAE Standard 55 & 216P Data

- Advantages
  - Design criteria for most applications
  - Aligns with ASHRAE Standard 55

- Disadvantages
  - Requires either CFD simulation or ASHRAE 216P testing

LDCF Test Data Summary

	US DOE	AMCA CRP	ASHRAE 55 & 216P
Primary Purpose	Min Effic to Sell in US & Accurate Published Data	Accurate Data	Selection of Product
Method of Test	Based on AMCA 230-15	AMCA 230-15	ASHRAE 216
Primary Data	Power & Airflow	Power & Airflow (no sound currently)	Air Speed & Cooling Effect
Third Party Verification	Yes	Yes	No
Performs Primary Testing	No	Yes	N/A
Market Surveillance	Yes	Yes	N/A
Periodic Reverification	Annual Resubmission	3 Years	N/A
Penalty for Violations	Fines, Public Announcement	Public Announcement	N/A
Online Verification Database	CCMS	CRP Database	N/A
Valid Internationally	No	Yes	Yes

Review

- LDCF > 7’ in diameter
- Applications - Thermal comfort, thermal mixing, air disinfection
- Federally regulated product
- Performance Data – AMCA 230, ASHRAE 55/216

Resources

- **AMCA International**: *www.amca.org*
- **ANSI/AMCA Standard:** *www.amca.org/store*

  > **230-15:** Laboratory Methods of Testing Air Circulating Fans for Rating and Certification (Available for purchase)

- **AMCA Publication:** *www.amca.org/store*

  > **211-13**: Certified Ratings Program — Product Rating Manual for Fan Air Performance (Free PDF download)

- **AMCA Certified Products:** *www.amca.org/certify*

  > Certified and listed large diameter ceiling fan products by company name

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