Saving Energy and Reducing COVID Exposure Using HVLS Fans

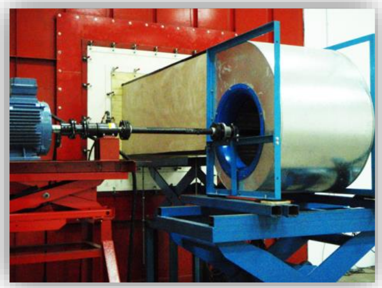
AMCA *insite* Webinar | May 18, 2022

Welcome to Asia AMCA insite Webinar!

amca INTERNATIONAL

ASIA


Asia
amca
Asia AMCASdn.Bhd.1063167-D



amca INTERNATIONAL

Michael Ivanovich

Sr. Director, Global Affairs, AMCA International

Moderator and Presenter

- Joined AMCA July 2011
- Coordinates advocacy in N. America, Asia, Europe, and Middle East
- Leads AMCA energy efficiency initiatives involving codes, standards and regulations
- M.Sc. Civil Engineering (Building Systems)

Introductions & Guidelines

- Participation Guidelines:
  - Audience will be muted during the webinar.
  - Questions can be submitted anytime via the GoToWebinar platform and will be addressed at the end of the presentation.
  - Reminder: This webinar is being recorded!
  - The PowerPoint PDF & resource documents are available in the Handouts section of the control panel.
  - To earn PDH credit for today, please stay clicked onto the webinar **for the entire webinar**.
  - A post-webinar evaluation will be emailed to everyone within one day, and it must be completed to qualify for today's PDH credit.

Q & A

To submit questions:

- From the attendee panel on the side of the screen, select the “Questions” drop down option.

- Type your question in the box, and please include which presenter your question is directed to.

- Click “Send”.

- Questions will be answered at the end of the program.
- Unanswered questions will be responded to via email.

AMCA International has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

Attendance for the entire presentation AND a completed evaluation are required for PDH credit to be issued.

DISCLAIMER

The information contained in this webinar is provided by AMCA International as an educational service and is not intended to serve as professional engineering and/or manufacturing advice. The views and/or opinions expressed in this educational activity are those of the speaker(s) and do not necessarily represent the views of AMCA International. In making this educational activity available to its members and others, AMCA International is not endorsing, sponsoring or recommending a particular company, product or application. Under no circumstances, including negligence, shall AMCA International be liable for any damages arising out of a party's reliance upon or use of the content contained in this webinar.

Saving Energy and Reducing COVID Exposure Using HVLS Fans

Abstract

Part 1 of this webinar will describe a new energy-efficiency metric for high-volume, low-speed (HVLS) ceiling fans that are used in commercial and industrial applications. The metric is called Ceiling Fan Energy Index (CFEI).

Part 2 of this webinar will describe how to operate HVLS ceiling fans in large open spaces with sparse occupancy during heating and cooling seasons to help reduce potential exposure to airborne particles that are contaminated with a virus such as COVID-19.

Saving Energy and Reducing COVID Exporure Using HVLS Fans

Learning Objectives

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

1. Describe how HVLS fans are tested
2. How HVLS fans are rated for energy efficiency using efficiency metric, Ceiling Fan Energy Index (CFEI).
3. How HVLS fans can help reduce potential COVID exposure in warehouses.

Today’s Presenters

- **Michael Ivanovich**:
  HVLS Fan Research Results for Reducing Potential COVID-19 Exposure in Warehouses
- **Christian Taber:**
  New Metric for LDCF Efficiency Regulations: Ceiling Fan Energy Index (CFEI)

Welcome and Thank You!!

- Countries
  - China
  - India
  - Malaysia
  - Philippines
  - Republic of Korea
  - Singapore
  - Taiwan
  - United States
  - Vietnam
- Applications
  - Manufacturers
  - Property Managers
  - Hospitals
  - Government Agencies
  - Education
  - Consulting and Design Engineering
  - Energy – Chemical – Utilities
  - Transportation & Distribution

Handouts for This Webinar

- PDF of the presentation
- AMCA inmotion magazine article on COVID research for HVLS Fans
- AMCA white paper on Ceiling Fan Energy Index

Christian Taber

Principal Engineer - Codes & Standards, AMCA Member Company

Presenter

- M.Sc. in mechanical engineering & biosystems engineering; B.S. in chemical engineering
- ASHRAE-certified High-Performance Building Design Professional and Certified Energy Manager
- Chair, AMCA N.A. Air Movement Advocacy Committee
- Served on AMCA committees 230, 214, 211, 208 and 11 and ASHRAE – Standards Committee, SSPC 90.1

New Metric for LDCF Efficiency Regulations: Ceiling Fan Energy Index (CFEI)

U.S. Large Diameter Ceiling Fan Regulation

- Prior to the U.S. DOE regulation ceiling fan regulations were state-by-state, leading to a variety of efficiency metrics and test standards.
- The DOE regulation preempted state regulations and established uniform test methods, metrics, and requirements
- DOE ”product” regulations are legally enforceable provisions of the U.S. Code of Federal Regulations
- Developed and enforced by the U.S. DOE Appliance and Equipment Standards Program

U.S. Large Diameter Ceiling Fan Regulation

- Basics
  - A federal energy efficiency regulation has two main parts:
    - Test Procedure
    - Energy Conservation Standard
  - Test procedure is *a regulation* that defines
    - Regulatory metric and method(s) of test, including start date
    - Product classes
    - Scope - covered and excluded products
  - Energy conservation standard establishes
    - Design criteria
    - Minimum efficiency performance standard (MEPS) by product class
    - Compliance filing requirements, including start date of enforcement
    - Enforcement provisions (surveillance), including testing, penalties
  - Administrative laws such as these are published in the U.S. Code of Federal Regulations (CFR)

U.S. LDCF Regulation

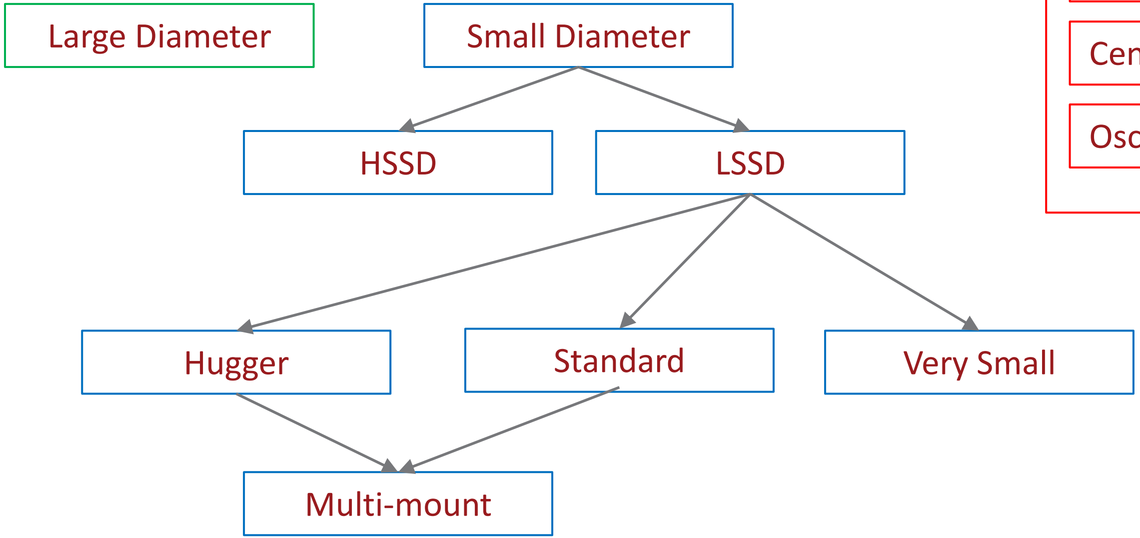
- Basics
  - Test Procedure
    - Use “definitions” to establish product classes and regulatory metrics
    - Establishes a uniform test procedure for all covered products
      - DOE will consider industry test standards and not use, use, or refine
    - Ceiling fan test procedures published July 24, 2016
      - LDCF use ANSI/AMCA 230-15
      - Other product classes use a different procedure
    - “On or after January 23, 2017, manufacturers of ceiling fans…must make any representations with respect to energy use or efficiency in accordance with the results of testing pursuant to this appendix.”

Product Classes

All product classes that are covered or exempt must be explicitly defined.

Exempt Fans

- Highly Decorative
- Belt Driven
- Centrifugal
- Oscillating



U.S. LDCF Regulation

- *Establishment of the LDCF Product Class:*
  - *(10 CFR 430.2 – Definitions). The term "ceiling fan" means a nonportable device that is suspended from a ceiling for circulating air via the rotation of fan blades.*
  - *(10 CFR 430, Appendix U to Subpart B (1.11)). Large-diameter ceiling fan means a ceiling fan that is greater than seven feet in diameter. (2.14m)*
  - …
- Establishment of the LDCF Test Procedure:
  - *(10 CFR 430, Appendix U to Subpart B (3.4)).* The test apparatus and instructions for testing large-diameter ceiling fans must conform to the requirements specified in sections 3 through 7 of AMCA 230-15 …with the following modifications:
    - 3.4.1. The test procedure is applicable to large-diameter ceiling fans up to 24 feet in diameter. (7.32m)
    - Etc.

U.S. Ceiling Fan Regulation

- Basics
  - Energy conservation standard establishes
    - Design criteria
    - Minimum efficiency performance standard (MEPS)
    - Exempt product classes
    - Compliance filing requirements, including start-date of enforcement
    - Enforcement provisions (surveillance), including testing, penalties
  - Final rule published January 19, 2017; effective January 20, 2020
  - Updated May 27, 2021 for Ceiling Fan Energy Index
    - Became immediately enforceable

U.S. LDCF Regulation

- *Establishment of Energy Standard (Efficiency Requirement)*
  - (10 CFR 430.32(s)(2)). Large-diameter ceiling fans manufactured on or after January 21, 2020, shall have a CFEI greater than or equal to

    (A) 1.00 at high speed; and

    (B) 1.31 at 40 percent speed or the nearest speed that is not less than 40 percent speed.

U.S. LDCF Regulation

- *Establishment of Energy Standard (Efficiency Requirement)*

  …

  - 430.32(s)(2)(ii). 5. Calculation of Ceiling Fan Energy Index (CFEI) From the Test Results for Large-Diameter Ceiling Fans:
    - Calculate CFEI, which is the FEI for large-diameter ceiling fans, at the speeds specified in section 3.5 of this appendix according to ANSI/AMCA 208-18, (incorporated by reference, see § 430.3), with the following modifications:
    - (1) Using an Airflow Constant (Q0) of 26,500 cubic feet per minute ($12.507 m^3/s$);
    - (2) Using a Pressure Constant (P0) of 0.0027 inches water gauge (0.6719 Pa); and
    - (3) Using a Fan Efficiency Constant (η0) of 42 percent.

Canada…

- U.S. Dept. of Energy and Natural Resources Canada (NR Canada) have a working relationship formalized in a memorandum of understanding
- Generally, U.S. appliance/equipment efficiency regulations are adopted into Canadian regulations
- As of July 19, 2021, NR Canada specifies “ceiling fan efficiency” for LDCF, and DOE still defines “ceiling fan efficiency” using cfm/w
  - *Ceiling fan efficiency means the ratio of the total airflow to the total power consumption, in units of cubic feet per minute per watt (CFM/W).*
- Therefore, CFEI not yet applicable to Canadian efficiency regulation

Extract From NR Canada Website

Energy efficiency standard

78 (1) The energy efficiency standard for a ceiling fan is the standard as set out in 10 C.F.R. §430.32(s)(2)(i).

Testing standard

(2) A ceiling fan complies with the energy efficiency standard if it meets that standard when tested in accordance with testing procedures established by 10 C.F.R. Appendix U that are applicable to a ceiling fan as defined in section 75.

Information

79 For the purpose of subsection 5(1) of the Act, the following information must be collected in accordance with 10 C.F.I Appendix U and provided to the Minister in respect of a ceiling fan:

- **(a)** its type;
- **(b)** its blade span;
- **(c)** its air flow at high speed;
- **(d)** its ceiling fan efficiency; and
- **(e)** its standby power consumption expressed in watts.

New Metric for LDCF Efficiency Regulations

- Ceiling Fan Energy Index (CFEI)
  - Calculated at two speeds – 100% and 40% of max RPM
  - Intended as a regulatory metric
  - Allows for high utility (airflow) products
  - More difficult to “game” than “airflow rate/power” based metrics
  - Very similar to AMCA 208’s FEI, except different constants

New Metric for LDCF Efficiency Regulations

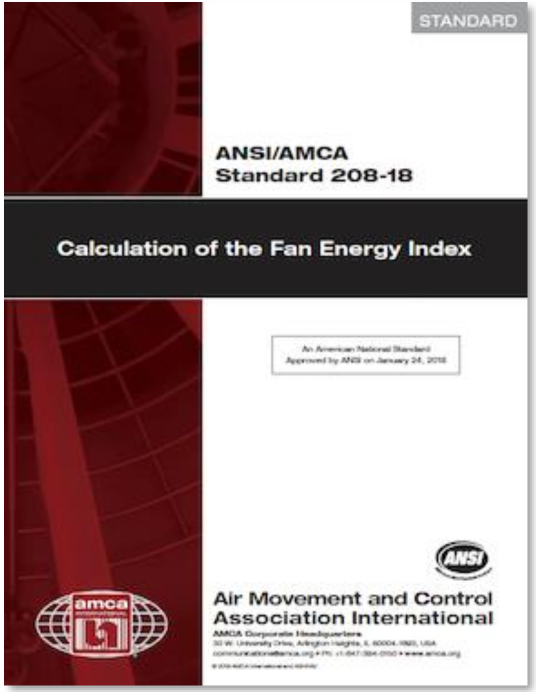
$$\text{FEI} = \frac{\text{Actual Fan Efficiency}}{\text{Reference Fan Efficiency}} = \frac{\dfrac{\cancel{\text{Actual Fan Air Power}}}{\text{Actual Fan Electric Power}}}{\dfrac{\cancel{\text{Reference Fan Air Power}}}{\text{Reference Fan Electric Power}}}$$

$$\text{FEI} = \frac{\text{Reference Fan Electric Power}}{\text{Actual Fan Electric Power}}$$

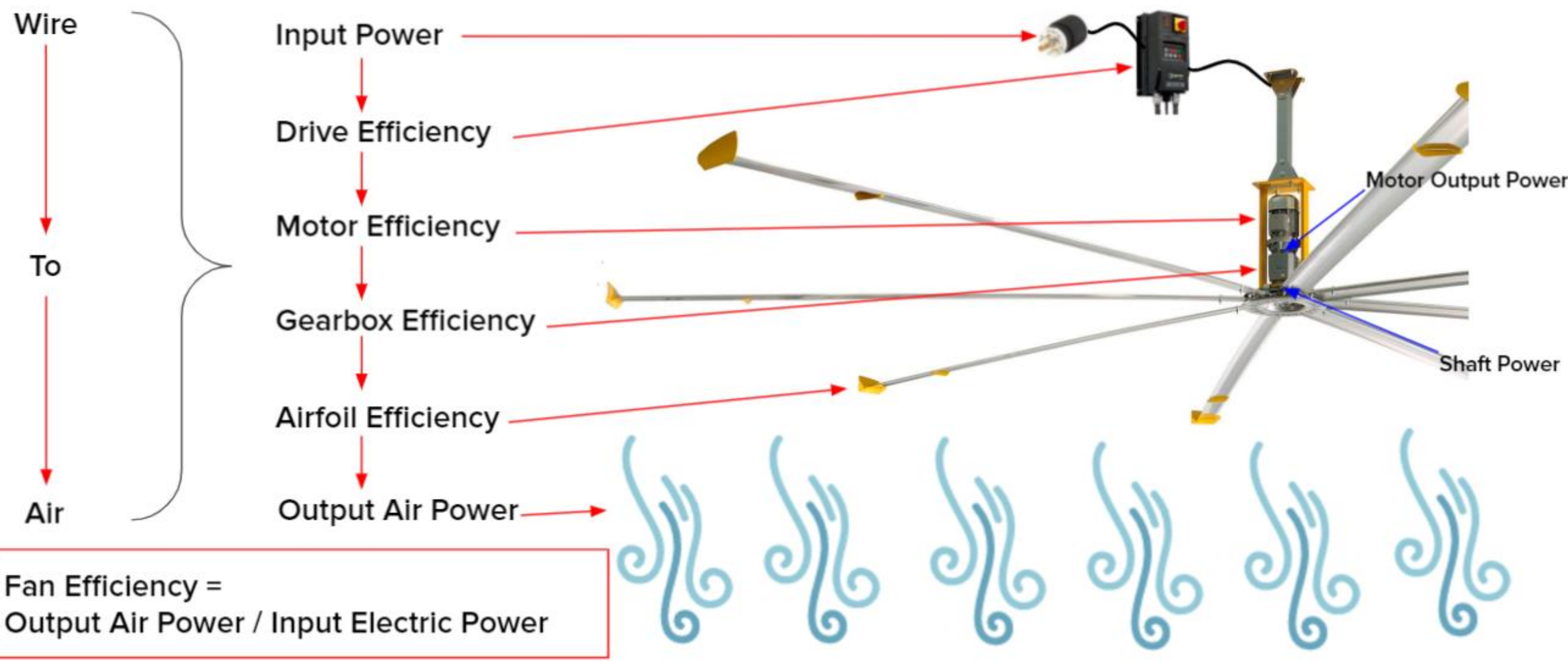
How To Calculate CFEI

- Use AMCA Standard 208-18
  - FEI equation for total pressure
  - Airflow Constant: Q_0 = 26,500 cfm
  - Pressure Constant P_0 = 0.0027 in. WG
  - Fan Efficiency Constant h_0 = 42 percent

  - Metric Equivalents (from AMCA 211 draft)
  - Airflow Constant: Q_0 = 12.507 m^3/s
  - Pressure Constant P_0 = 0.6719 pascals

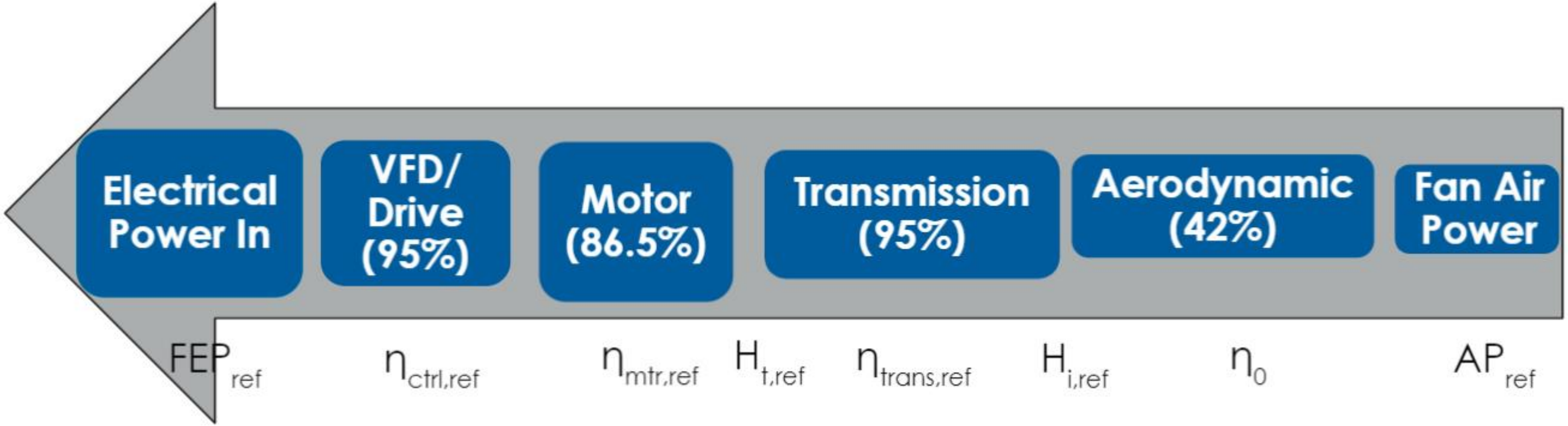


Ceiling Fan Efficiency - Wire-to-Air



Fan Efficiency =
Output Air Power / Input Electric Power

Calculating Reference Fan Electrical Input Power



AP_{ref} = Air power (aka output power)
η_0 = Fan efficiency constant
$H_{i,ref}$ = fan shaft power (ref fan)
$\eta_{trans,ref}$ = transmission efficiency (ref fan)
$H_{t,ref}$ = motor output power (ref fan)
$\eta_{mtr,ref}$ = motor efficiency (ref fan)
$\eta_{ctrl,ref}$ = controller efficiency (ref fan)
FEP_{ref} = Fan electrical input power (ref fan)

Example CFEI – LDCF 100% RPM

- Actual 24’ LDCF
  - 235,000 CFM (110.9m^3/s) (~600W of Air Power)
  - 1,530 W input power
- Reference 24’ LDCF
  - 235,000 CFM (110.9m^3/s)
  - 600W Air Power / 42% / 93% / 87% / 100% ≅ 1,770 W
  - 1,770 W input power

CFEI = 1,770 W / 1,530 W = 1.16

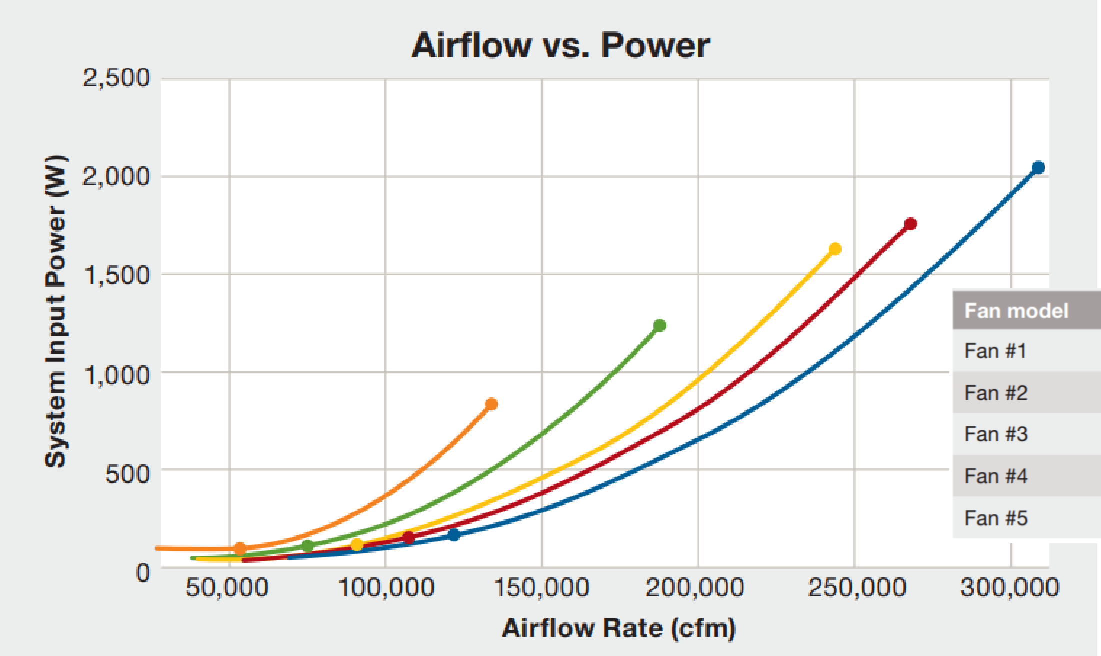
$$CFEI = \frac{FEP_{ref}}{FEP_{actual}}$$

CFEI Calculation – Step by Step

Fan	Fan 1	SI Units	Variable	
Diameter	24-ft (288-in)	7.32m	-	Measured - 10 CFR 430, App U
Airflow (Act)	235,000 CFM	110.9 m^3/s	Q_i	Measured - 10 CFR 430, App U
Input Power (Act)	1,530 W	1,530 W	FEP_{act}	Measured - 10 CFR 430, App U
Total Pressure (Act)	0.0168 in wg	0.0314 mm Hg	$P_{t,i}$	Calculated - AMCA 208, Eq A.1
Shaft Power (Ref)	1.91 hp	1,397 W	$H_{i,ref}$	Calculated - AMCA 208, Eq 5.3
Trans Effic (Ref)	92.40%	92.40%	$\eta_{trans,ref}$	Calculated - AMCA 208, Eq 5.5
Motor Output (Ref)	2.07 hp	1,522 W	$H_{t,ref}$	Calculated - AMCA 208, Eq 5.6
Motor Effic (Ref)	87.16%	87.16%	$\eta_{mtr,ref}$	Calculated - AMCA 208, Eq 5.7
Control Effic (Ref)	100%	100%	$\eta_{ctrl,ref}$	Calculated - AMCA 208, Eq 5.8
Input Power (Ref)	1,772 W	1,772 W	FEP_{ref}	Calculated - AMCA 208, Eq 5.2
$CFEI_{100}$	1.16	1.16	$FEI_{t,i}$	Calculated - AMCA 208, Eq 5.1

CFEI Requirements

- Using DOE test procedure (AMCA 230-15), LDCF tested at 100% and 40% speeds only
  - High Speed: 100%
  - At 40% or speed closest to 40% without going under 40%
- Using “modified” AMCA 208-18, calculate CFEI
  - CFEI ≥ 1.00 at high speed (100%)
  - CFEI ≥ 1.31 at 40% speed or speed closest to 40% without going lower
- Optional measure standby power
  - Not included in CFEI
  - May be required in future DOE regulations



Fan model	Color	$CFEI_{100}$ (≥ 1.00)	DOE cfm/W
Fan #1	Blue	1.72	234
Fan #2	Red	1.38	234
Fan #3	Yellow	1.18	234
Fan #4	Green	0.85	234
Fan #5	Orange	0.63	234

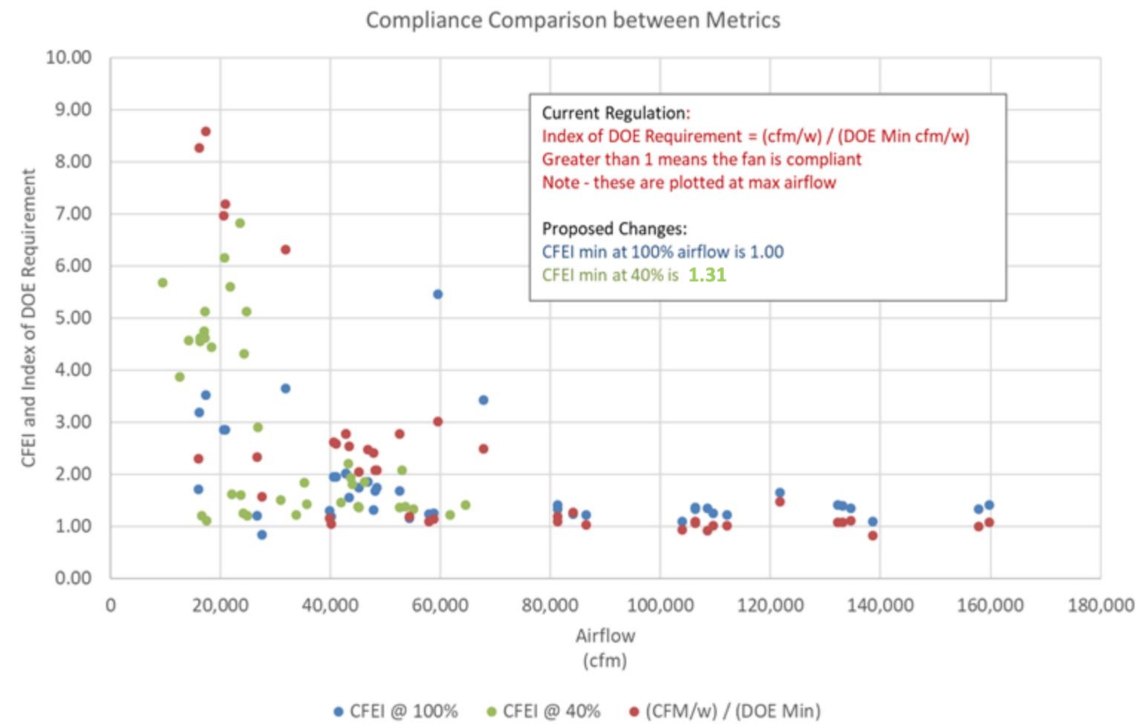
234 cfm/W = 0.11 m^3/s / W

50k CFM = 23.6 m^3/s

Power vs. Airflow and CFEI

- Previous slide shows input power versus airflow for four fans.
- Fans 1-4 all have the same cfm/W.
- For a given airflow, the lower the curve is on the chart, the more efficient the fan.
- Lowest curve: Fan 2 has a CFEI of 1.72 at 100%
- Highest curve: Fan 4 has a CFEI of 0.63 at 100%.
- Illustrates how a bad fan can be pass with cfm/W metric but not with a low CFEI

AMCA Lab Data for LDCF Compliance Rate cfm/Watt vs CFEI



AMCA Lab Data for LDCF Compliance Rate cfm/Watt vs CFEI

- Previous slide shows an index for cfm/W vs. CFEI
- Index (red dots) are very close to 1.00 at highest airflows
  - Below 1.00 is non-compliant
    - Indicates that future fans will have harder time being compliant
  - Blue dots (100% airflow CFEI) at these dots trend higher than 1.00
    - Indicates that CFEI provides cushion for higher-performance/utility fans

HVLS Fan Research Results for Reducing Potential COVID-19 Exposure in Warehouses

AMCA COVID-19 Guidance for Large-Diameter Ceiling Fans

Over a 12-month period, Air Movement and Control Association, in collaboration with an international team of scientists, engineers, and researchers, executed a series of numerical simulations to investigate the impact of large-diameter ceiling fans

BY **MICHAEL IVANOVICH**, **AARON GUNZNER**, AND **SCOTT ARNOLD**, AMCA INTERNATIONAL

Numerous studies of airflow and performance characteristics of circulating fans have been undertaken.[1,2,3,4,5,6] Relatively few, however, are focused on aerosol transmission of airborne pathogens in large industrial spaces, a shortage all the more noticeable during the coronavirus disease 2019 (COVID-19) pandemic.

To contribute to and improve the body of COVID-19-prompted guidance for the operation of circulating fans, Air Movement and Control Association (AMCA) International commissioned numerical-simulation studies of airborne-particle and aerosol transmission with large-diameter (greater than 2.1 m [7 ft]) ceiling fans (LDCF). The focus of the studies was warehouses in the United States, in which LDCF commonly are used for comfort cooling and destratification. The results, however, also are applicable to many manufacturing/industrial facilities.

To promote integrity in the design and execution of staff, the industry team provided expertise in the application and performance of products, while the science team, made up of authorities in infectious diseases, indoor-air quality, fans, and computer modeling, including two leading members of the ASHRAE Epidemic Task Force, advised on the project setup and reviewed the intermediate and final results. Because COVID-19 infection rates are poorly understood and varying with mutations, the study focused on particle concentrations as an indicator of exposure risk.

Following is a high-level summary of the project's findings and resultant guidance. For information on the simulation methodology, setups, assumptions, validations, and results, see the final report, "AMCA COVID Guidance for UNDUCTED Fans – Modeling Ceiling Fans," prepared by Liangzhu (Leon) Wang, PhD, P.Eng.; Senwen Yang; Runzhong (Alvin) Wang; Mohammad Mortezazadeh, PhD; Jiwei Zou; and Chang Shu of Concordia University, at https://bit.ly/COVID_LDCF.

The Building

Based on the U.S. Department of Energy (DOE) commercial

Purpose of Study

- Some COVID-19 guidance includes operation of ceiling fans
  - Guidance does not seem to apply to HVLS fans or warehouses
- **To contribute to the body of COVID-19 guidance for commercial and industrial facilities, with focus on the role of high-volume, low-speed (HVLS) fans without supplemental air treatment**
- U.S. only because of regional construction and occupancy characteristics
  - Some slides to not have metric equivalents
  - Concordia Univ. can replicate study for different climates, warehouse characteristics

Purpose of Study

- Warehouses selected as subject building type/application
- Warehouses are critical to supply chain, and increasingly so
  - Second largest building type in USA based on square footage (office bldg. #1)
- COVID outbreaks happen in warehouses
  - Supply chains have enough problems.

Purpose of Study

- Examples of Current Guidance
  - Centers for Disease Control, USA
  - https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html
    - “Use ceiling fans at low velocity and potentially in the reverse-flow direction (so that air is pulled up toward the ceiling)”
    - **Problem: Running HVLS fans in reverse direction diminishes performance, especially in warmer temperatures**

  - World Health Organization
  - https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-ventilation-and-air-conditioning
    - The use of ceiling fans can improve the circulation of air from outside and avoid pockets of stagnant air forming indoors. However, it is critical to bring in air from outside when using ceiling fans, such as by opening windows
    - **Problem: In warehouses, opening windows and loading-dock doors in winter is not possible in cold-weather climates**

Structure of Study

- Assembled an international team of experts on building science, IAQ science, infectious diseases, modeling
- Assembled an industry team of experts to provide HVLS expertise and funding
- Goal was to peer review the study from start to finish
- Science team governed research design, modeling, interpretation of results, and final report
- Industry team helped tune the fan model and operationalize guidance
- Winter and summer conditions were modeled; emphasis on summer conditions
  - Summer conditions are the focus for this Webinar for Asia

Project Team

Principal Investigator:
- Leon Wang, PhD, Peng

Science Team Leader:
- William P. Bahnfleth, PhD, PE

Project Manager:
- Michael Ivanovich

Project funded by:
AMCA International
- Big Ass Fans
- Greenheck
- Hunter Industrial
- MacroAir

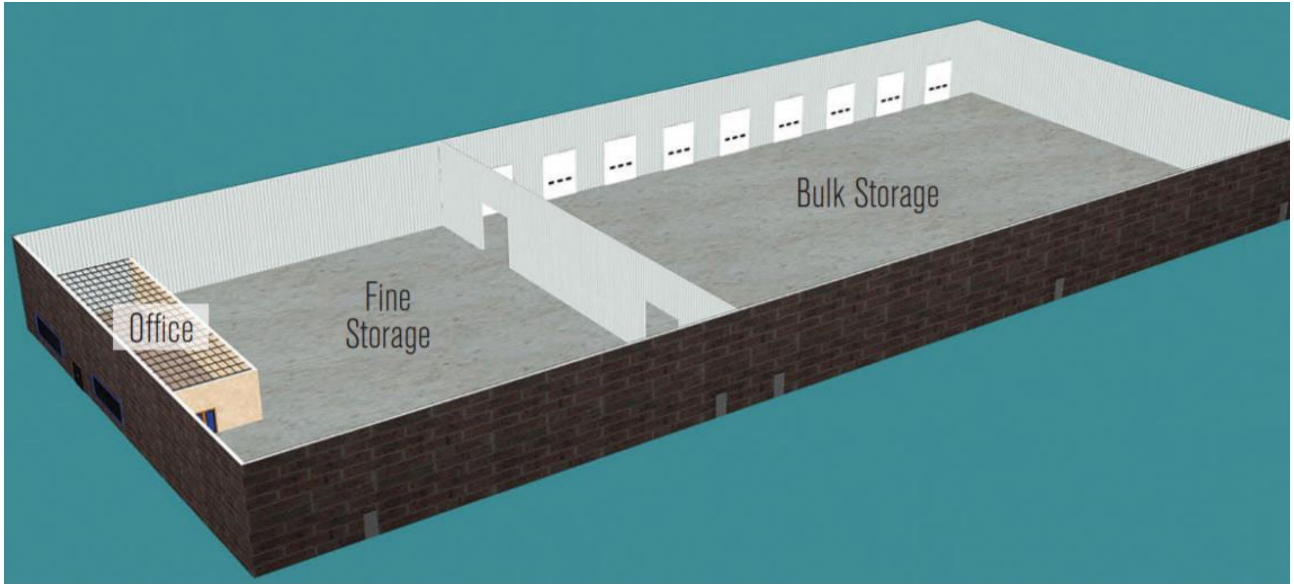
SCIENCE TEAM			
Name	**Title**	**Affiliation**	**Project role/contribution**
Liangzhu (Leon) Wang, PhD, P.Eng.	Associate professor, Department of Building, Civil, and Environmental Engineering	Concordia University	Principal investigator
William P. Bahnfleth, PhD, PE	Professor, architectural engineering Chair, ASHRAE Epidemic Task Force	The Pennsylvania State University	Science-team leader
Edward A. Nardell, MD	Professor, departments of Environmental Health and Immunology and Infectious Diseases	Harvard T.H. Chan School of Public Health	Infectious diseases and study of ceiling fans for control of infectious diseases
Jovan Pantelic, PhD	Research scientist, building science	Well Living Lab Inc.	Infectious diseases
Paul Raftery, PhD	Professional researcher	Center for the Built Environment, University of California, Berkeley	Ceiling-fan modeling
Geoff Sheard, DSc	President	AGS Consulting LLC	Computational-fluid-dynamics modeling and fan engineering
Pawel Wargocki, PhD	Associate professor, departments of Civil Engineering and Indoor Environment Chair, ASHRAE Epidemic Task Force Science Applications Committee	Technical University of Denmark	Indoor-air-quality expertise
INDUSTRY TEAM			
Michael Ivanovich	Senior director, global affairs	AMCA International	Project manager
Eddie Boyd	Chief executive officer	MacroAir Technologies	LDCF performance
Marc Brandt	Director, domestic industrial	Hunter Industrial	LDCF performance
Thomas Catania, Esq.	Board member	Institute for Energy Innovation	Regulatory communications
Aaron Gunzner	Senior manager, advocacy	AMCA International	Staff liaison
Mark Stevens	Executive director	AMCA International	Member relations
Christian Taber	Principal engineer, codes and standards	Big Ass Fans	Warehouse model, LDCF modeling
Mike Wolf, PE	Director, regulatory business development	Greenheck Fan Corp.	Regulatory communications

This is the type of space we modeled

Polling Question #1

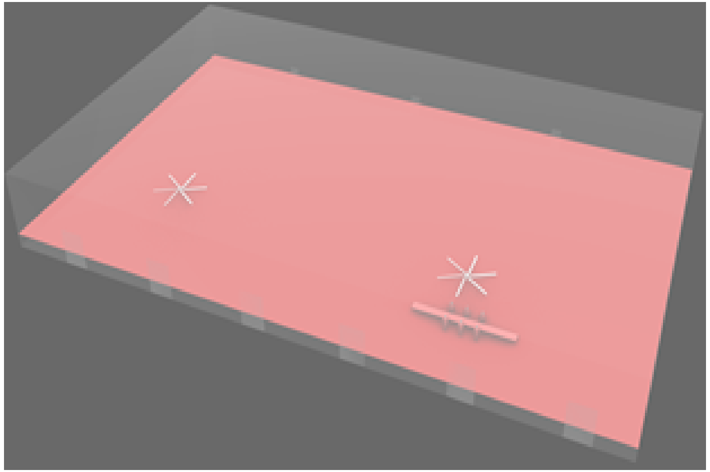
Warehouse - Building Overview

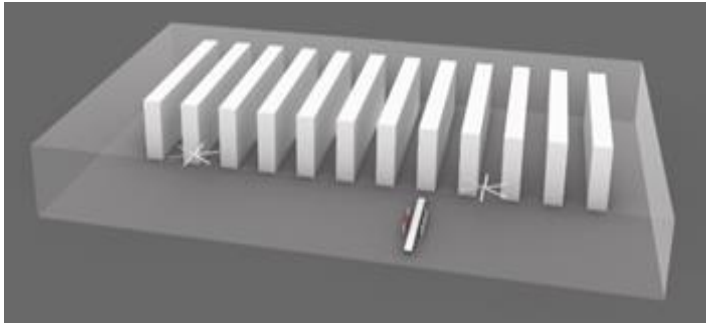
- Based on U.S. Department of Energy commercial reference building for warehouses
- Dimensions - 100m (330 ft) x 46m (150ft) x 8.5m (28ft)
- Chicago, IL USA



Warehouse Bulk Storage

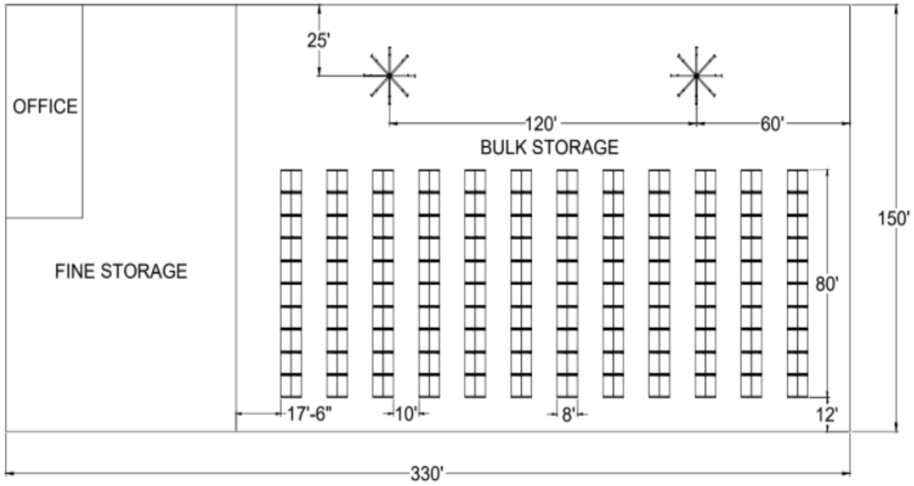
- Dimensions
  - 70-m (230-ft) x 46-m (150-ft) x 8.5-m (28-ft)
- Mechanical System
  - Heating - Unit heaters, constant volume, 55-F setpoint
  - Ventilation - Exhaust fans, 85F on-point
  - Air Conditioning - None
- Envelope
  - Based on ASHRAE 90.1 - 2016
  - Six dock doors, Three standard doors
- Thermal conditions modeled using EnergyPlus
- Occupancy is very low-density





Bulk Storage - Airflows

- Ventilation
  - Minimum = 2,907 cfm
  - Comfort = 24,150 cfm (1.5 ach)
- Infiltration
  - 5,228 cfm
- HVLS Fans
  - Two 6.1-m (20-ft) impeller diameter
  - AMCA-certified performance data
    - 91 m^3/s (192,000 cfm)
    - Test procedure in accordance with U.S. Code of Federal Regulations 10 CFR 430 Appendix U
  - 6.1-m (20-ft) blade height



Comparison of Air Volumes & Dilution Airflow Rates

	Office Space	Breakroom	Warehouse - Winter	Warehouse - Summer
Outdoor Air (cfm/person)	5	5	10	0.7 cfm/ft^2
Outdoor Air (cfm/ft^2)	0.06	0.12	0.06	
Infiltration (cfm/ft^2)	0.054	0.054	0.152	
Occupants (person/1k ft^2)	5	50	0.333	0.333
Room Air Volume (ft^3/person)	2,000	200	84,000	84,000
OA + Infil (cfm/person)	27.8	8.5	646	2,100

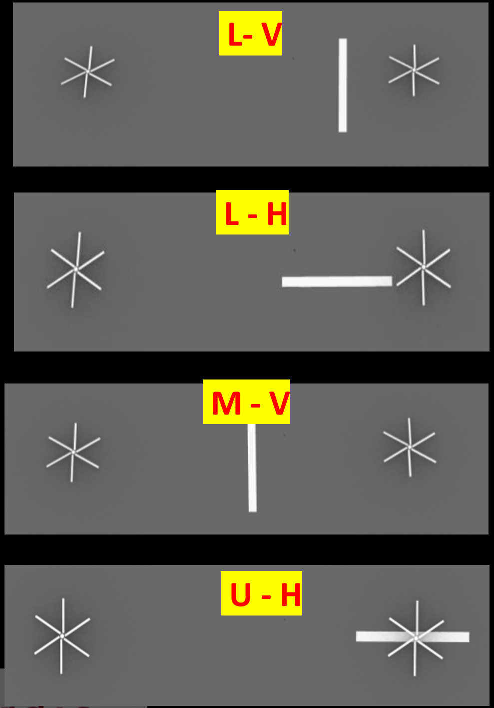
Assumptions: 3,000 ft^2 per space type, 10-ft ceiling in office and breakroom, 28-ft ceiling in warehouse
Source: ASHRAE Standard 62.1-2019 Table 6-1, ASHRAE AEDG Warehouses & Small Office Buildings

Packing Line Scenarios

Fan, Packing Line Location Definitions

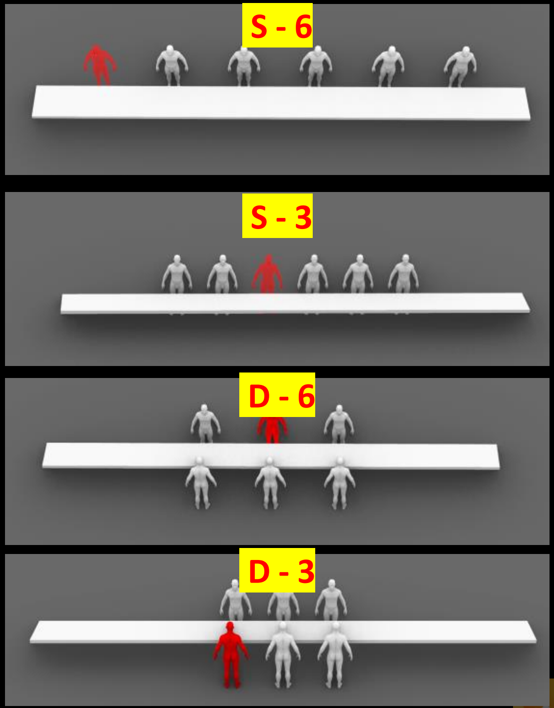
Packing line location

M=Middle L=Left U=under V=Vertical H=Horizontal



Worker location

D=double row S=single row 6=6 ft 3=3 ft



Fan Speeds Nomenclature

Fan-speed label	Fan speed (% max. rpm)	Fan speed rpm	Air speed exiting fan m/s (fpm)
FS-0.6	20	16	0.6 (118)
FS-0.9	30	23	0.9 (177)
FS-1.2	40	31	1.2 (236)
FS-1.5	50	39	1.5 (295)
FS-1.8	60	47	1.8 (354)
FS-2.1	70	55	2.1 (413)
FS-2.4	80	62	2.4 (472)
FS-2.7	90	70	2.7 (531)
FS-3.0	100	78	3.0 (591)

[1]The side of the cylinder of the fan zone colored by yellow in Figure 5c.
[2]A cylinder around the fan center at a height of 1.7 m (5.6 ft).

TABLE 2. Fan air speed and airflow rate in the fan zone for a case of U-H-D-3.

Fan speeds to focus on::

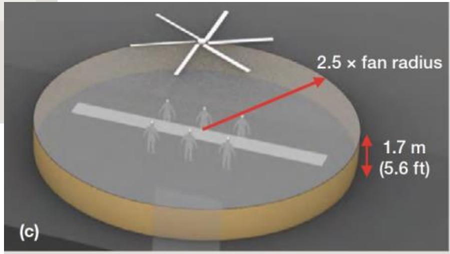
- **FS-0** = Fan Not Running
- **FS-0.6** = 0.6 m/s (118 fpm)
- **FS -3.0** = 3.0 m/s (591 fpm)

Fan Parameters for Design Guidance

Fan-speed label	Fan speed	Fan speed	Air speed exiting fan	Airflow exiting fan	Average air speed at side surface[1]	Average fan-zone[2] air speed	Maximum air speed in fan zone
	(% max. rpm)	rpm	m/s (fpm)	m^3/s (cfm)	m/s (fpm)	m/s (fpm)	m/s (fpm)
FS-0.6	20	16	0.6 (118)	18 (38,400)	0.2 (39)	0.4 (79)	1.0 (197)
FS-0.9	30	23	0.9 (177)	27 (57,600)	0.3 (59)	0.6 (118)	1.3 (256)
FS-1.2	40	31	1.2 (236)	36 (76,800)	0.4 (79)	0.8 (157)	1.7 (335)
FS-1.5	50	39	1.5 (295)	45 (96,000)	0.5 (98)	1.0 (197)	2.2 (433)
FS-1.8	60	47	1.8 (354)	54 (115,200)	0.6 (118)	1.2 (236)	2.5 (492)
FS-2.1	70	55	2.1 (413)	63 (134,400)	0.7 (138)	1.4 (276)	2.9 (571)
FS-2.4	80	62	2.4 (472)	72 (153,600)	0.8 (157)	1.7 (335)	3.4 (669)
FS-2.7	90	70	2.7 (531)	82 (172,800)	0.9 (177)	1.9 (374)	3.8 (748)
FS-3.0	100	78	3.0 (591)	91 (192,000)	1.0 (197)	2.1 (413)	4.4 (866)

[1]The side of the cylinder of the fan zone colored by yellow in Figure 5c.
[2]A cylinder around the fan center at a height of 1.7 m (5.6 ft).

TABLE 2. Fan air speed and airflow rate in the fan zone for a case of U-H-D-3.

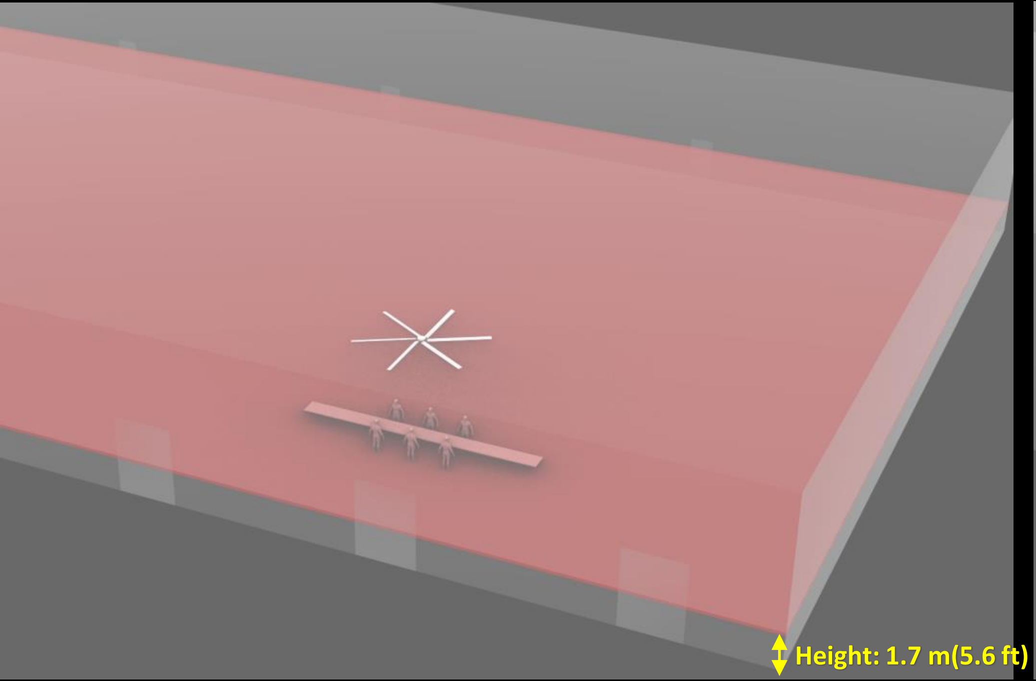


Note: Figure from AMCA inmotion article at www.amca.org/inmotion

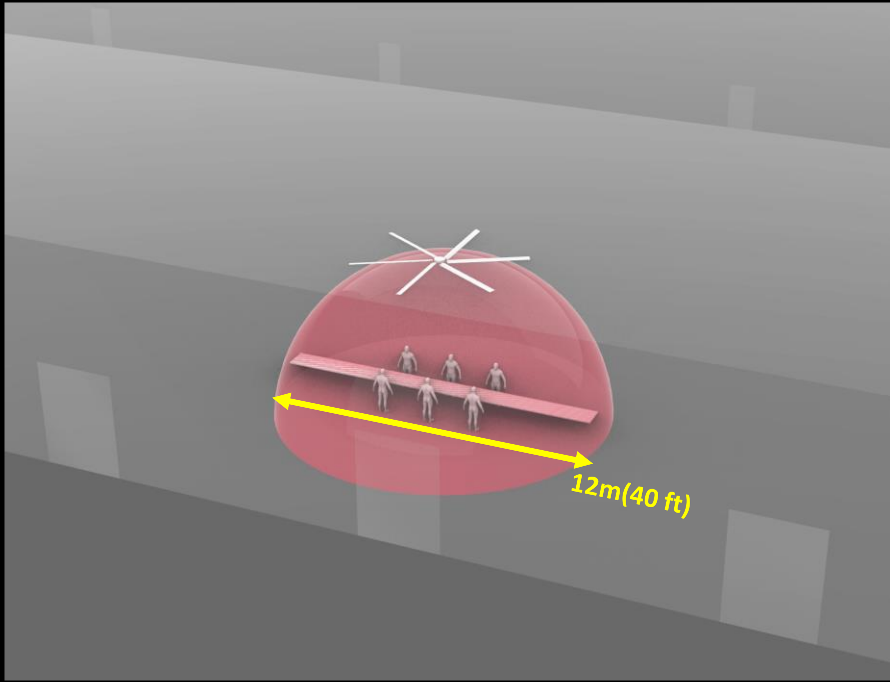
Polling Question #2

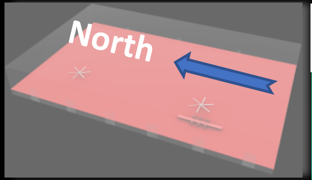
Result Zone Definitions

Whole-warehouse Breathing Zone



Working Zone





Whole-warehouse breathing zone concentration, FS-0, counts/m^3 (8 hr)

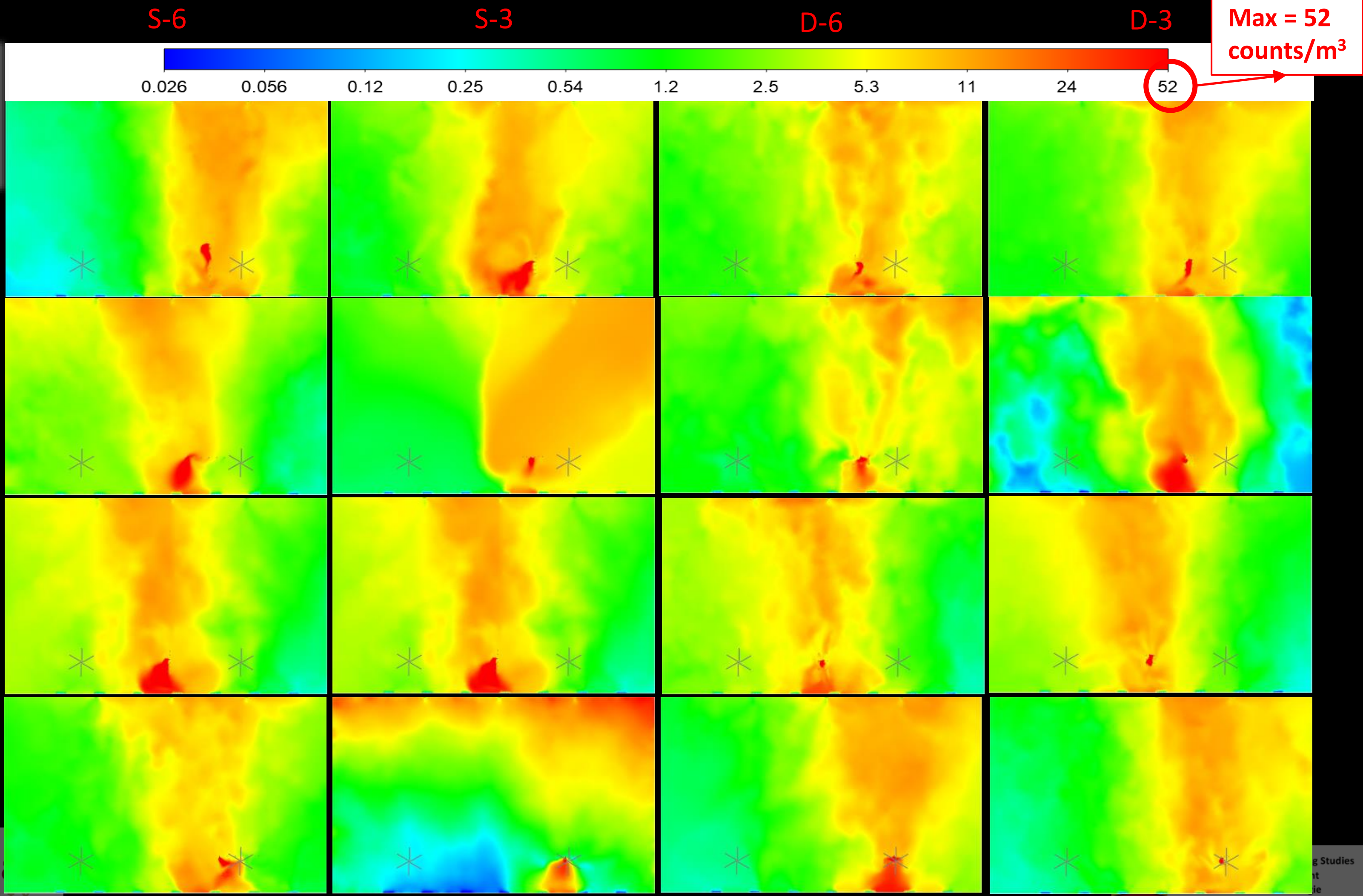
Airflow/particle moving West to East

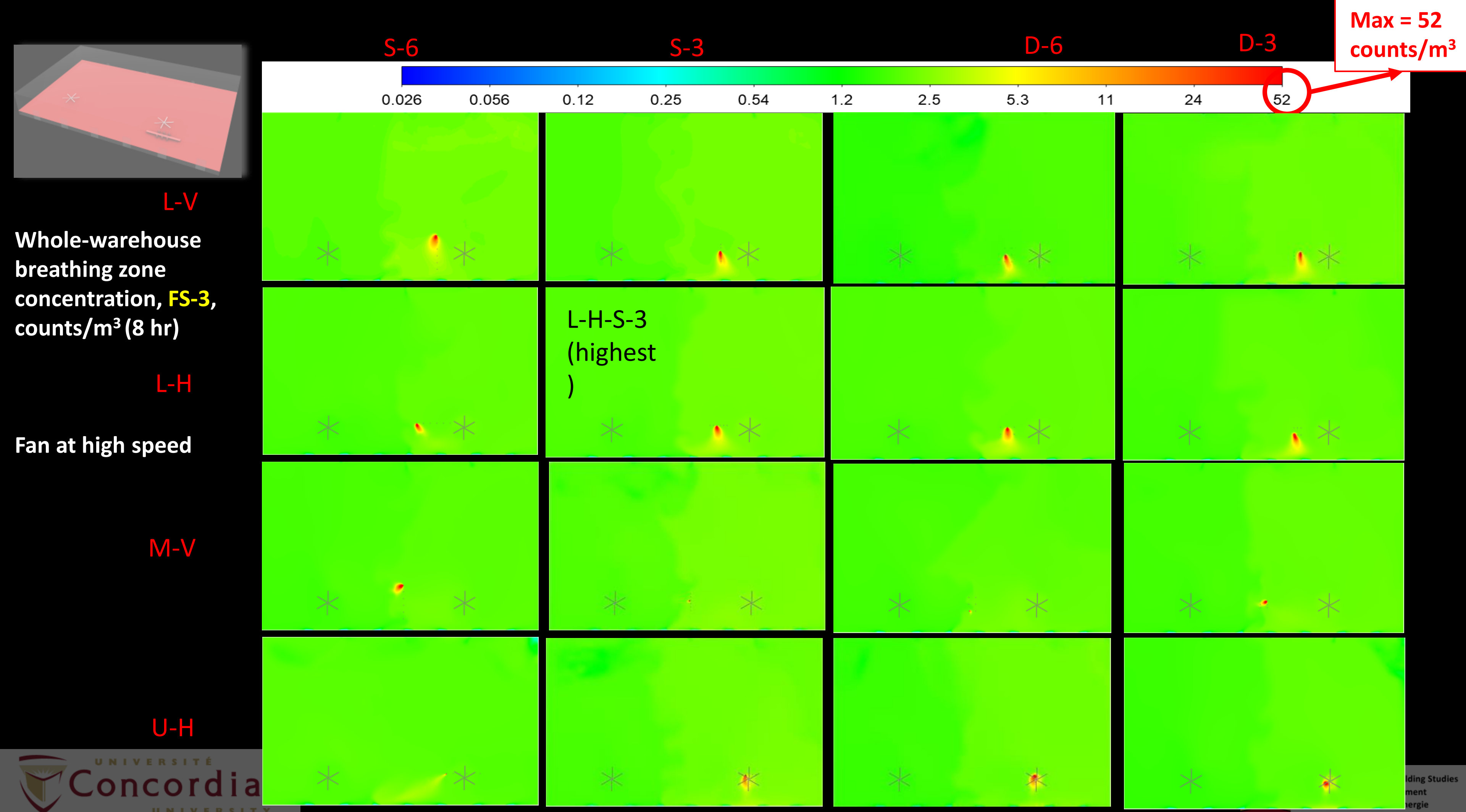
L-V

L-H

M-V

U-H

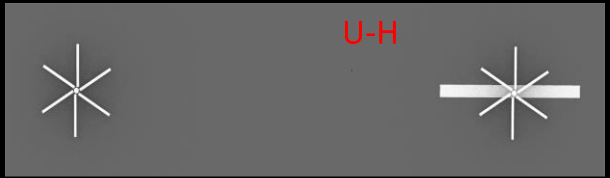




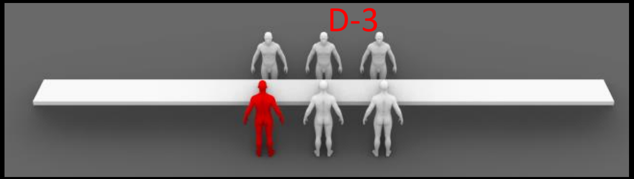
Whole-warehouse breathing zone concentration, FS-3, counts/m³ (8 hr)

Fan at high speed

Investigate the Case (U-H-D-3) Summer Conditions



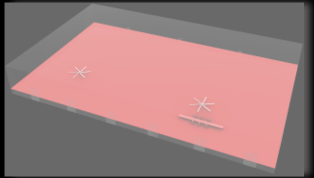
Packing line **U**nder the fan
Horizontal placement

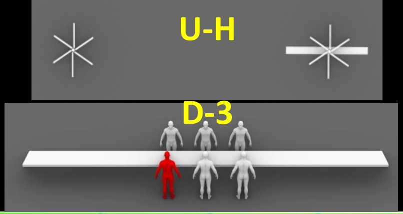


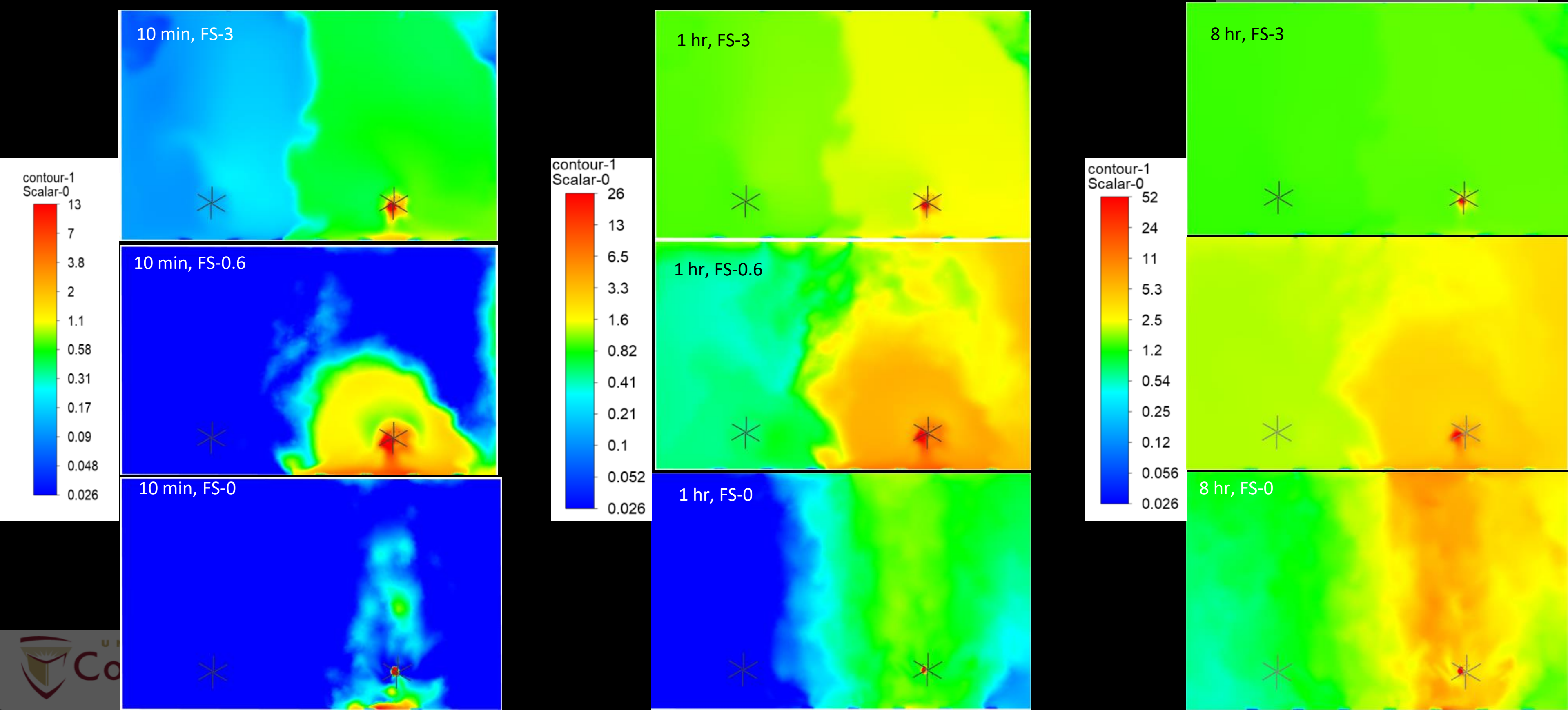
Double line workers with **3** feet apart

because it results in lowest whole-warehouse beathing zone concentration

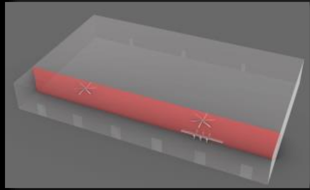
Compare Fan Operations (U-H-D-3) – Horizonal Plane



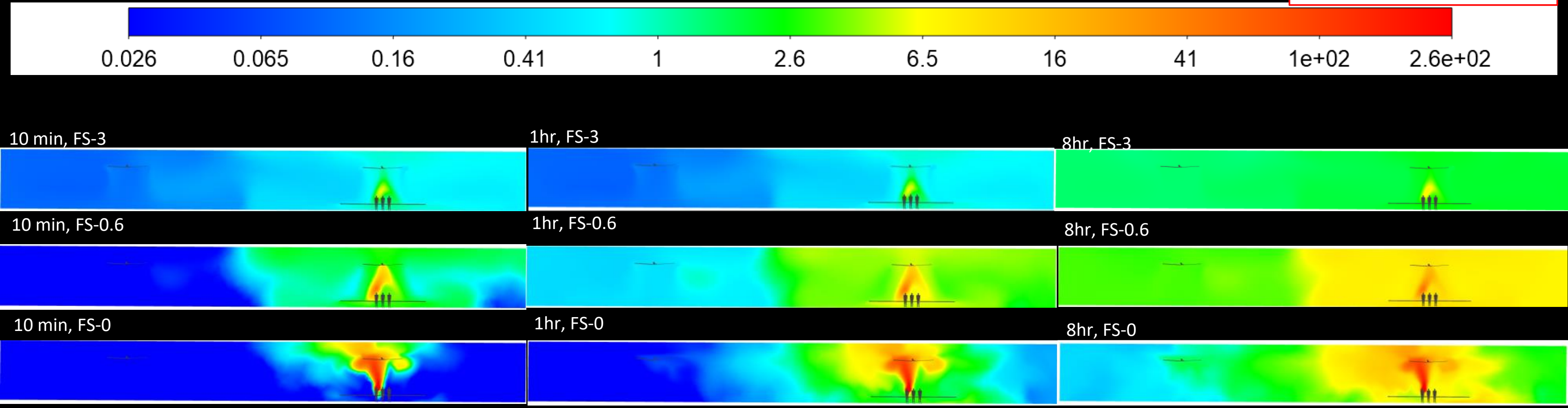




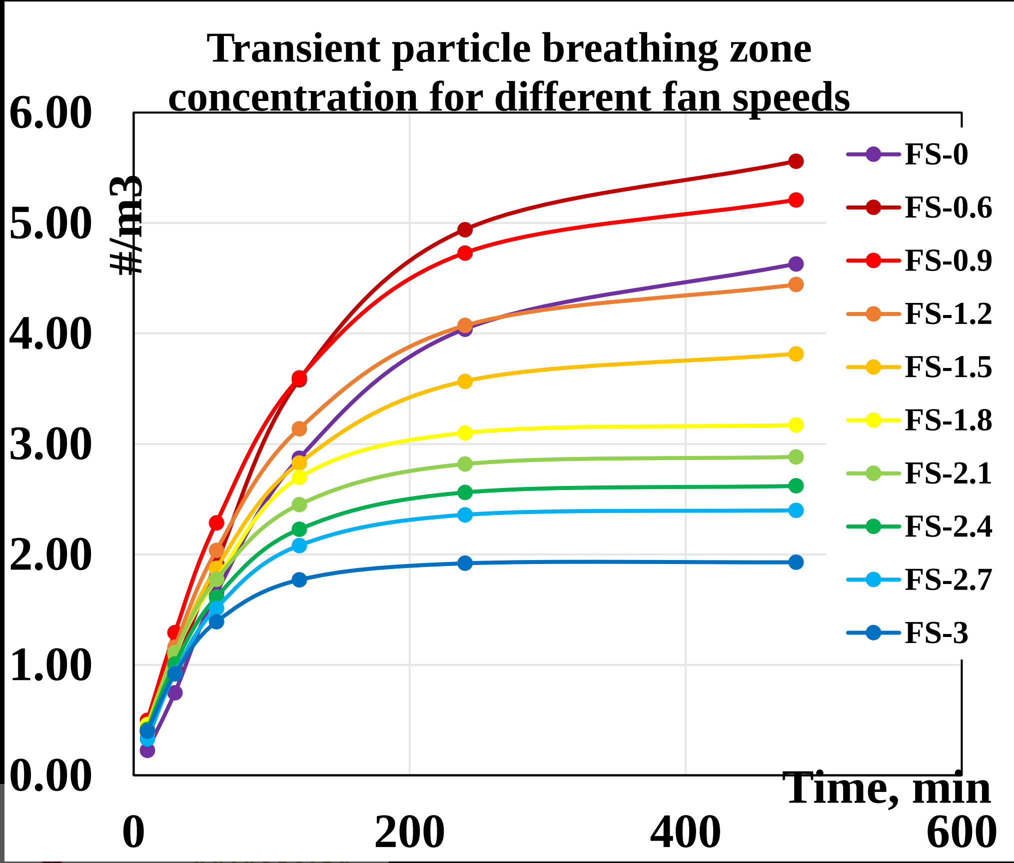
Compare Fan Operations (U-H-D-3) – Vertical Plane



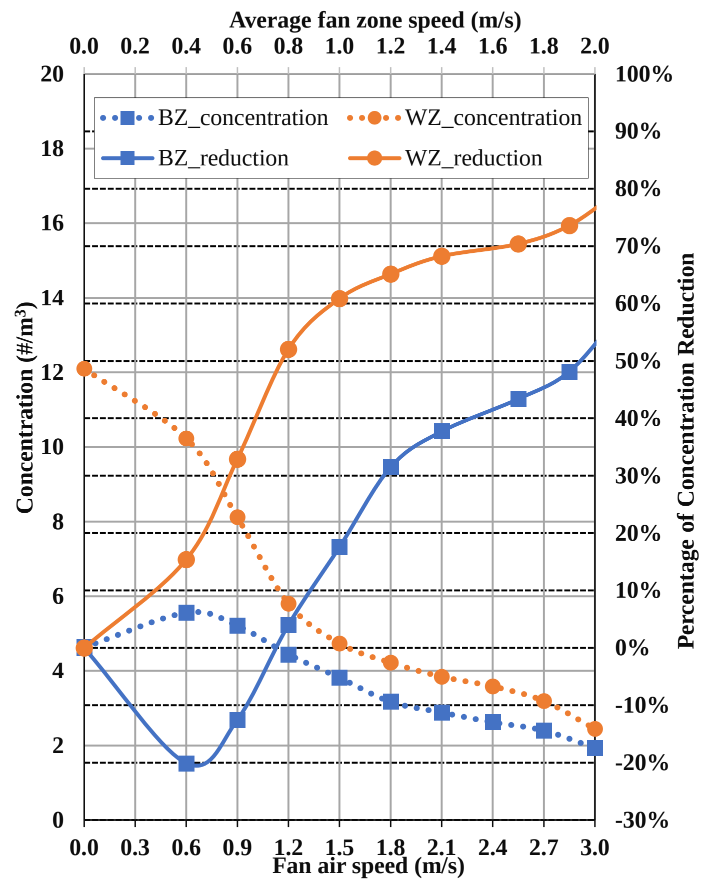
Max = 260 counts/m^3



U-H-D-3 – Whole warehouse breathing zone and working zone concentration at different fan speeds



0%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% 100% fan speeds



Results: Simplified guidance

- Guidance based on season and worker-location with respect to fans:
  - Operate fans at the highest feasible speed while maintaining occupant comfort in the space.
  - Where possible, avoid locating occupants immediately downstream of each other for extended periods of time.
  - At high fan speeds (e.g. warm-temperature conditions) the simulations show a notable reduction in concentrations.
  - At low fan speeds (e.g. cold-temperature conditions) the simulations show a slight reduction in concentration in the region close to the fan (e.g. within three fan diameters), and no practical difference outside that region.

Results: Logic behind the guidance

Where are most occupants located?	Summer conditions	Winter conditions
Close to the fan(s)	Operate fans downwards, at high speed	Operate fans at highest feasible speed that does not cause discomfort in either forward or reverse direction, whichever approach was used pre-pandemic[1]
Far from the fan(s)[3]	Operate fans downwards, at high speed	Operate fans at highest speed in either forward or reverse, whichever approach was used pre-pandemic[2]

Notes: Green/yellow/red color coding is an approximate indicator of how clear the effect was in the scenarios we simulated.
1: Simulations show slightly lower concentrations with reverse flow than with forward flow at a given low speed, but this is based on a much smaller number of simulated scenarios (two as opposed to the 16 for a typical forward-direction scenario) and is a small effect given simplifications and assumptions in the model. For simplicity, retaining the pre-pandemic direction is advised—unless reversing the fan allows for substantially higher fan speeds while avoiding draft at the occupied level.
2: Although simulations show a slight *increase* in average warehouse breathing concentration for fans at low-speed vs off, the distribution is far more uniform across the entire warehouse (i.e. no 'hot spots'). Based on feedback from the science team, overall this homogeneity is a net advantage as more mixing (i.e., dilution) is beneficial for times when workers who may be far apart for much of the workday meet and interact more closely. Lastly, the still-air results depend highly on model assumptions and simplifications (e.g., plume effectiveness, lack of local mixing, the presence of racks, etc.), and this small difference could be an artifact of those.
3: e.g. Most occupants located more than 3 fan diameters from the center of a fan for the majority of the day.

Resources and Hyperlinks

- Project Final Report:
  - AMCA COVID Guidance for Unducted Fans – Modeling Ceiling Fans, https://bit.ly/COVID_LDCF

- *AMCA inmotion magazine* article https://tinyurl.com/yc3ubhzy

- AMCA Web Page for HVLS fans
  - www.amca.org/LDCF

Thank you for your time!

*To receive PDH credit for today's program, you **must** complete the online evaluation, which will be sent via email 1 hour after this webinar.*

PDH credits and participation certificates will be issued electronically within 30 days, once all attendance records are checked and online evaluations are received.

Attendees will receive an email at the address provided on your registration, listing the credit hours awarded and a link to a printable certificate of completion.

Questions?

Presenters

Michael Ivanovich

Christian Taber