Pressurization & Outdoor Air Measurement and Control Solutions for Optimizing High Performance Bldgs.

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EBTRON, Inc.
Why Measure Airflow Rates for Pressurization and Intake control?

Challenges in Measurement and Issues with Indirect Estimates

There are Significant Performance Differences between Instrument Designs and Technologies

Performance Comparison between one Thermal Dispersion device and NEBB Requirements for Instruments

Presentation Objectives
Building Pressurization
ASHRAE 62.1

- Specifies outdoor airflow rates and requires neutral or positive exfiltration (pressure flow).
- Healthcare space type dictates pressure relationships and air change rates.

ASHRAE 170

ASHRAE 189.1

- Mandates outdoor airflow measurement on VAV systems.
- Requires quarterly verification of outside airflow rates.
- 62.1 is a prerequisite

LEED

IAQ Related Industry Standards, Rating Systems & Codes

- Currently awards 1 point for outdoor airflow measurement. LEED does not address pressure relationships in the rating system.

IMC

- Strict interpretation of ASHRAE 62.1 VRP requires specified outdoor airflow rates and positive exfiltration or net neutral pressure requirement similar to 62.1. Special provisions for smoke control and hazardous gases exhaust.
5.9.2 Exfiltration. For a building, the ventilation system(s) shall be designed to ensure that the minimum outdoor air intake equals or exceeds the maximum exhaust airflow.

*Note:* Although individual zones within a building may be neutral or negative with respect to outdoors or to other zones, net positive mechanical intake airflow for the building as a whole reduces infiltration of untreated outdoor air.

**IMC (2012) §4 Ventilation**

403.1 Ventilation system. Mechanical ventilation shall be provided by a method of supply air and return or exhaust air. The amount of supply air shall be approximately equal to the amount of return and exhaust air. The OA intake airflow shall exceed the exhaust airflow to maintain a net neutral or net positive mechanical intake airflow to limit dirt/moisture migration.
5.3.1 All systems shall be provided with manual or automatic controls to maintain no less than the outdoor air intake flow (Vot) required by Section 6, under all load conditions or dynamic reset conditions.

5.3.2 Systems with fans supplying variable primary-air ($V_{ps}$), including single-zone VAV and multiple-zone-recirculating VAV systems shall be provided with one or more of the following:

a. Outdoor air-intake, return air dampers or a combination thereof that modulate to maintain no less than the outdoor air intake flow ($V_{ot}$)

b. Outdoor-air injection fans that modulate to maintain no less than the outdoor air intake flow ($V_{ot}$)

provide controls to maintain the outdoor air intake flow $V_{ot}$ on all VAV systems
6.7 Air Distribution Systems

6.7.1 General. Maintain the pressure relationships required in Table 7-1 in all modes of HVAC system operation, except as noted in the table. Spaces listed in Table 7-1 that have required pressure relationships shall be served by fully ducted returns. The air-distribution design shall maintain the required space pressure relationships, taking into account recommended maximum filter loading, heating-season lowered airflow operation, and cooling-season higher airflow operation.

**TABLE 7-1 Design Parameters** describes specifics that vary by the function of the space: Pressure Relationship to Adjacent Areas; Minimum Outdoor (ach); Minimum Total (ach); All Room Air Exhausted Directly to Outdoors; Air Recirculated [Y/N]; Design RH (%); Design Temperature (F/C).
Negative pressure is an IEQ nightmare!
Mechanical Cooling
Avg. Daily Gallons of Water Transported Across the Building
Envelope for every 1,000 CFM of Negative Airflow
(when outdoor conditions specified exist)
Free Cooling
Mechanical Heating
Positive pressure is costly!
Excess or Uncontrolled Pressurization Flow
Static Pressure Control

Static Pressure = Net $\Delta$ Airflow

when ...

Wind speed = 0

All interior doors are open

Pressure in w.g.
Static Pressure Control

Static Pressure ≠ Net Δ Airflow

when ...

Wind speed > 0

Pressure
in.w.g.
Static Pressure ≠ Net Δ Airflow

when ...

Wind speed > 0
Static Pressure Control

Wind Pressure on Exterior Reference Tap

Target: 0.03 – 0.05”WG (7.5 – 12.5 Pa)

Cross Wind | Direct Wind
Static Pressure Control

Static Pressure ≠ Net Δ Airflow

*when...*

All (or some) interior doors are closed
(common return in open area)
Pressure Drop Under Closed Doors

Flow Coefficient = 0.6, Opening 36 in. x 0.5 in.
Static Pressure Control

Pressure Interaction

AHU-1 responds to zone 1 pressure and affects zone 2 pressure.

AHU-2 affects zone 2 pressure.
It’s all about a building’s MECHANICAL Pressurization Airflow

Building Pressure Model: \( Q_P = Q_{OA} - (Q_{RE} + Q_{EX}) \)
Systems with Relief Fans

Building Pressure Model: $Q_P = Q_{OA} - Q_{RE}$
Systems with Relief at the AHU (relief inactive)

Building Pressure Model: $Q_P = Q_{OA}$
Systems with Relief at the AHU (relief active)

Building Pressure Model: \( Q_P = Q_{OA} - Q_{RE} \)
**Systems with Relief at the AHU (relief active)**

Mathematical Equivalent:
\[
\begin{align*}
Q_{Rec} + Q_{OA} &= Q_{SA} \\
Q_{Rec} + Q_{RE} &= Q_{RA} \\
Q_{OA} - Q_{RE} &= Q_{SA} - Q_{RA}
\end{align*}
\]
Systems with Relief at the AHU (relief active)

Building Pressure Model: \( Q_P = Q_{SA} - Q_{RA} \)
Systems with Relief at the AHU (relief active)

Building Pressure Model: $Q_P = Q_{SA} - Q_{RA}$
Supply/Return Air at each AHU (single pressure zone systems - duct measurement preferred)

Outside Air Intakes

Supply/Return Air at each Floor (multi-floor systems)

Supply/Return (or Exhaust) Air at each Room (room pressurization)
Intake Measurement/Control Challenges

- Intake systems are **dynamic**, and change continuously.

- Airflow rates are typically **very low velocity** (50 – 250 fpm and rarely as high as 500 - 1200 fpm).

- There is **very little distance** for a pressure or velocity profile to develop for measurement, between the louver/hood and intake damper (You can’t measure downstream of a modulating damper).
Did I mention that these factors were inter-related and *dynamic*?

Intake Flow Rates Change Continuously

- Damper/Actuator Issues
- Hysteresis
- Binding / Slippage
- Age / Corrosion

Pressure Variations

- Supply Fan Speed
- Wind
- Stack Effect
Dynamic Variables that Affect OA and Pressurization Control Precision

- Damper Issues
  - ± 25%

- Fan Speed Changes
  - Proportional to Fan Speed Reduction

- Wind & Stack Pressure
  - ± 50% or more

Cumulative Uncertainty on Uncontrolled Intake Flow Rates During Minimum or DCV* Operation

* DCV Uncertainty is most critical at minimum and maximum expected populations and CO₂ has no relationship with pressurization flow.
How should airflow rates be controlled?
Here are the most common options...

A. **Fixed damper positions** using field measurements

B. **Temperature (or Mass) Balance methods** to estimate the percentage of outside air in the mixed air or supply air

C. **Difference between the Supply and Return airflow rates** if there is no exhaust at the air handler

D. **Traceable gas (CO₂) or measurable contaminant (VOCs)** to estimate the outdoor airflow rate based on a mass balance equation or metabolic activity of the occupants, then using the calculated OA or contaminant value to reset the intake flow rate

E. **Directly measure and control airflow rates** with a permanently mounted airflow measuring device and use the actual value to reset the intake flow rate
Uncontrolled Outdoor Air ($Q_p$)

Typical system, without airflow measurement

» Damper is set to a fixed minimum position, multiple predetermined positions or damper linearity is assumed for reset
  > Alternate: $\Delta P$ across damper is maintained by modulating the return air damper and/or return fan (to fixed MA plenum pressure set point)

» Positions are setup by TAB or facility technician

» Operating performance generally deteriorates over time and operating control errors can be very large
Fixed Minimum Position Damper

Linkage and Actuator Hysteresis will result in airflow variations

Where do you measure intake flow rate with this common damper configuration?
Fixed Minimum Position Damper

Hysteresis - No Wind
15% Damper Open

Actual Test Data

V_{ot} Setpoint

% of Minimum Setpoint

Sample Number

From Closed

From Open

Average

Average
Supply Fan Speed Changes
(VAV and multi-speed)

Std. 90.1 and CA Title 24 require multi-speed or variable speed supply fan motors for ALL air systems when load varies, making both CAV and VAV intakes see similar speed-proportional declines in intake rates.
VAV Mixed Air Pressure Effect on OA Intakes

Fixed Minimum Position Intake Damper

0.2 in.w.g. $\Delta = 40\%$ reduction in CFM

Measurement for Control of Fresh Air Intakes - Solberg, Dougan & Damiano - ASHRAE Journal, January 1990
Wind & Stack Pressure
Wind Pressure on Intake System

18 mph direct to cross wind ≈ 0.2 in.w.g. Δ = 40% reduction

Flow coefficients for conversion of velocity pressure to static pressure
Hysteresis + 15 mph Cross Wind
15% Damper Open

Actual Test Data

% of Minimum Setpoint

Sample Number

V_0t Setpoint

From Closed
From Open
Average
Average
No Stack Effect

No difference in the pressures, air densities or temperatures – inside to outside.
Wind & Stack Pressure

Outside Air Column (more dense)

Winter Stack Effect
w/o active intake control
Wind & Stack Pressure

Outside Air Column (less dense)

Summer Stack Effect
w/o active intake control
Stack Pressure on Intake System
70 ft. (First Floor to Roof)

100 F Temperature Drop ≈ 0.2 in.w.g. \( \Delta = 40\% \)
reduction in intake flow rates
Combined Impact on Fixed Position Dampers

Proportional reset is not acceptable for VAV because of MA plenum pressure variations

Errors DO NOT include field measurement uncertainties!

Proportional reset strategy was shown not to be significantly better than a fixed intake damper.

This 35% deficit / excess is the same for a CAV system (= VAV@100% supply).

Wouldn’t this also happen on a constant volume system?

At 70% supply this system’s intake was an exhaust!!!

Figure 8. Stack and wind effects, comparing intake flow and supply flow.

Measurement for the control of fresh air intake By Solberg, P.E., Dougan and Damiano; ASHRAE Journal, Oct 1990
Temperature Balance methods

Air Balance Report
SA: 100,000 cfm
OA%: 10%
OA: 10,000 cfm

RA Temp
75°F (no error)

MA Temp
71.5°F (-2°F error)

T_{MA} - T_{RA}
\frac{\text{T}_{OA} - T_{RA} \times \text{SA cfm}}{\text{OA}} = \text{OA}

Monitor Only
No Control

>60% uncertainty

4,286 CFM
OA Temp
40°F (no error)

DETERMINATION OF OUTSIDE AIR INTAKE FLOWS
Temperature Balance methods

Uncertainty at OA Intake
OA=10% max. supply, -2°F MA temp. uncertainty

If TAB uses this technique to evaluate a system or an airflow measurement device, there will be a discrepancy in readings!
5.3 Remove the energy balance and return fan tracking methods from the allowed list of dynamic ventilation controls.

5.3.1 Description

Currently, the Nonresidential Compliance Manual states that energy balance and return fan tracking methods are both approved methods of implementing dynamic ventilation. The energy balance method, however, is prone to error due to inaccuracies in temperature and air flow measurements, especially where temperature differences are small.

Consider removing both of these control methods from the approved list of dynamic controls.

Temperature Balance

“...also discouraged by ASHRAE Research...”

RP-980, ASHRAE TRANSACTIONS 2000, V. 106, Pt. 2

CASE Study for CA Energy Commission, March 2011

CA Title 24, Part 6 Code of Regulations Energy Efficiency Standards
Supply - Return $\Delta$ airflow rates

Actual is 3% Less

SA: 100,000 cfm
RA: 90,000 cfm
OA: 10,000 cfm

Actual is 3% More

$\pm 5\% \frac{S}{R} = \pm 95\% V_{ot}$
Comments on determining intake flow rate (relates directly to pressurization control)

Air intake measuring devices include those that measure intake volume directly by measuring air velocity, area, and velocity. The velocity and area can be measured directly. The velocity can be determined from pressure drops across the fan or the flow rate and pressure drop across the fan. If the system includes an outdoor air economizer, a separate minimum outdoor air damper may also be required to ensure adequate velocity across the outdoor air intake for an accurate measurement (see Figure 5-J). Note that a fixed-speed, outdoor-air fan without control devices will not maintain rates within the required accuracy.

Using return air, outdoor air and mixed air temperatures or CO₂ concentrations to measure intake percentage is usually inaccurate. Taking the difference between supply- and return-airflow measurements will also seldom meet reasonable accuracy requirements.
Fixed Minimum Position Damper
Temperature Balance methods
Supply - Return $\Delta$ airflow rates

1. These are all INDIRECT methods of flow rate determination or control.

2. All INDIRECT methods require acceptance of assumptions.

3. All assumptions carry very large portions of uncertainty.

4. Therefore, all INDIRECT methods include large uncertainties.
Common Direct Airflow Measurement Devices

**Hand-held and Terminal Devices**

- **Differential Pressure**
  - Pitot-static tubes
  - Pitot-static grids
  - Flow Capture Hoods

- **Thermal velocity meters**
  - Single-point Thermal
  - Anemometers and
  - Flow Capture Hoods

- **Vane Anemometers**

**Permanent Averaging Instruments**

- **Differential Pressure**
  - Pitot-static tubes and arrays
  - Piezo Rings
  - $\Delta P$ Across a Louver
  - $\Delta P$ Across a Fixed Obstruction

- **Thermal velocity meters**
  - Thermal Dispersion
  - other thermal velocity meters

- **Vortex Shedders**

- **Combination Damper/AFMS**
Thermal Dispersion (not all thermal devices)

Outside Air Intakes

Ducted

Fan Inlets

Min. OA

Very High Uncertainty

Pitot Tubes and Arrays

Vortex Shedding

Piezo Rings

OA Intakes w/Economizer

Airflow Rate (FPM)
Why are the Limitations of Measurement Technologies Different?

**Signal Comparison**
Unprocessed Signal to Transmitter

- **Raw**
- **Vortex Shedding**
- **Thermal Dispersion**

![Graph showing sensor output in volts and airflow in fpm]
# What is NIST Traceability? And What does it Mean?

## Sensor Uncertainty: Calibration

### Factory Cal. Standard

<table>
<thead>
<tr>
<th>NIST Airspeed (VNIST), [fpm]</th>
<th>IUT Output (VIUT), [fpm]</th>
<th>Expanded Uncertainty, [%]</th>
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### Production Unit Calibration Report (typ.)

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<th>Error%</th>
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</table>
Procedure for Using Factory-calibrated Permanent Instruments to meet NEBB Requirements

Evaluate
- Technology
- Flow rates (capability)
- Manufacturer
- Reliability

Inspect
- Placement (susceptibility)
- Wiring

Verify
- Apply YOUR equipment properly
- Understand its limitations

NOTE: With proven stability, superior factory calibration standards and measurement conditions better than found on site; field adjustment will generally hinder the performance of factory calibrated products. However, ...

Adjust output to match TAB? (not always)
Validation: ADJUST DUCTED SENSORS ONLY WHEN NECESSARY

- PROPER ADJUSTMENT
  - Gain Only
Validation: ADJUST DUCTED SENSORS ONLY WHEN NECESSARY
Validation: ADJUST DUCTED SENSORS ONLY WHEN NECESSARY
Connectivity Solutions can Provide TAB with a “force multiplier”

- Two field selectable 0-5, 0-10 VDC or 4-20 mA isolated outputs
- One RS-485 BACnet MS/TP or Modbus output

- Two field selectable 0-5, 0-10 VDC or 4-20 mA isolated outputs
- One Ethernet BACnet or Modbus output

- LonWorks

- USB thumb-drive data logger, logs average airflow and temperature plus airflow and temperature readings of individual sensors with time stamp

- IR Option
  - Add to any GTx116 transmitter to interface with infra-red Reader/PDA
TAB Solutions

IR Reader and Download software
Permanently Installed Instruments Can Satisfy NEBB Procedural Standards for Certified TAB Airside Activities

SECTION 4 STANDARDS FOR INSTRUMENTATION AND CALIBRATION

4.1 MINIMUM INSTRUMENTATION

A NEBB Certified TAB Firm will use a variety of instrumentation to perform the specified TAB procedures on a project. It is the responsibility of the NEBB Certified TAB Firm to provide appropriate instrumentation that meets the minimum requirements of TABLE 4-1 (US or SI) for use on a project. Instrumentation used on a NEBB project shall be in proper operating condition and shall be applied in accordance with the manufacturer’s recommendations. TABLE 4-1 (US or SI) lists the minimum instrumentation that a NEBB Certified TAB Firm shall own and maintain.

Section 4.1 is consistent with the use of ANY instrument that conforms to the minimum performance requirements of Table 4-1 (below) and operating in accordance with the manufacturer’s recommendations. The comment on the list of instruments required is very specific that the Certified TAB firm shall “own and maintain” those on the list, but does not limit TAB activities to only those instruments on the list. It is a measurement performance requirement and not a hardware restriction. The conclusion being any instrument equal to or exceeding the minimum requirements would be acceptable for use by Certified TAB firms for system balance and any appropriate TAB activity.
4.2 RANGE AND ACCURACY

The accuracy and range as reported by the instrument manufacturer shall be verified by a testing laboratory traceable to the National Institute of Standards and Technology or equivalent institute in countries other than the United States.

Calibration requirements for each function are specified and shall be met. Some instruments such as U-tube manometers and inclined manometers may not require calibration. However, if a "mechanical / electrical" device is substituted or employed in place of these types of instruments, the indicated calibration requirements noted shall apply. ....... Instruments shall be used in accordance with manufacturer’s recommendations. The most suitable instrument, or combination of instruments, should be employed for a particular measurement or reading. For example, a traverse may be accomplished with a Pitot tube and manometer (digital, analog, or incline); it is not acceptable to use a Pitot tube with another device that does not provide the same overall accuracy.

### PARTIAL TABLE 5-1 NEBB MINIMUM INSTRUMENTATION REQUIREMENTS (U.S. UNITS)

(Note: Direct Reading Hood is included for comparison only.)
Calibrations of all instrumentation requiring calibration shall be traceable to current NIST Standards for US firms, or equivalent organizations in other countries.

<table>
<thead>
<tr>
<th>Function</th>
<th>Minimum Range</th>
<th>Accuracy</th>
<th>(Display?) Resolution</th>
<th>Calibration Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Temperature Measurement Air</td>
<td>-40 to 240 °F</td>
<td>± 1% of reading*</td>
<td>0.2 °F</td>
<td>12 Months</td>
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<tr>
<td>A Air Velocity Measurement</td>
<td>50 to 2500 fpm</td>
<td>± 5% of reading</td>
<td>20 fpm</td>
<td>12 Months</td>
</tr>
<tr>
<td>(Not for Pitot tube traverses)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Direct Reading Hood / Digital</td>
<td>100 to 2000 cfm</td>
<td>± 5% of reading,</td>
<td>Digital – 1 cfm</td>
<td>12 Months</td>
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<tr>
<td>A Airflow Multimeter</td>
<td></td>
<td>± 5 cfm</td>
<td>Analog-NA</td>
<td></td>
</tr>
</tbody>
</table>
6.1 INTRODUCTION
These recommended procedures are to be followed for all TAB measurements so that the reported data is accurate and repeatable. ... The ability to take accurate and repeatable measurements may depend on the skill of the technicians and measurement locations.

6.3 AIR VELOCITY PROCEDURES
The following procedures describe the methods to be used when making air velocity measurements....While the procedures outlined here are prescriptive, instrumentation use should always be in accordance with the manufacturer’s recommendation. All instrumentation used for air velocity measurements shall conform to the requirements of Table 4-1 for function, range, accuracy, and resolution.

6.3.2 GENERAL MEASUREMENT TECHNIQUES
... Duct air velocity measurements typically are performed to determine air volume in a duct by Pitot tube traverses. The Pitot tube traverse, properly conducted, is the basis for all other airflow measurements performed by a NEBB Certified TAB Firm. Other instruments used for air velocity measurements are rotating vane anemometers, swinging vane anemometers, bridled vane anemometers, thermal anemometers, velocity grids, etc. These devices are typically used for measurements where flow hoods are not appropriate, or where the air velocities are too low for accurate measurement by a Pitot tube traverse. In all cases the instrument manufacturer’s application recommendations shall be followed.

6.3.3 SPECIFIC MEASUREMENT TECHNIQUES
h) The accuracy of a Pitot tube traverse is determined by the availability of a suitable location to perform the traverse. Suitability of the location is determined by the quality of the data measured.
10.2 MEASUREMENT OPTIONS

10.2.1 DIRECT MEASUREMENT METHOD

The preferred method of outdoor air measurement is direct, which may include but is not limited to, Pitot tube traverse, velocity averaging grid, and airflow measuring station. When direct measurement of the outdoor air path is not an option, then a Pitot tube traverse of the total supply minus the total return air quantities is deemed acceptable.

Supply – Return calculation is not a “direct” measurement method for determining Outdoor Air. Additional information on velocity measurement instruments for HVAC and their general performance limitations can be found in the ASHRAE 2009 Handbook - Fundamentals, p. 36.16.

10.2.2 MIXED AIR TEMPERATURE METHOD

The mixed air temperature method may be used for setting outdoor air dampers to yield the specified percentage of outdoor air. Quite often, the mixed air temperature is very difficult to measure accurately. With regard to this method, it is important to note that air stratification within HVAC units may inhibit accurate airflow temperature measurement, which may prevent its use. Mixed air temperatures may vary considerably depending on where the readings are taken. If it is determined that air stratification is present, it will be necessary to take several temperature readings by performing a weighted average temperature traverse. This can be a time consuming process and a quick reading digital thermometer may speed up the process. Accurate readings and large differentials between outdoor air and return air temperatures [over 20°F (12°C) Δt] are essential to this method.
EBTRON’s published performance dramatically exceed the requirements of Table 4-1 (2005) & 5-1 (2012) in all but one item – temperature measurement range extremes.

I would argue that their operating temperature range is more than acceptable for the locations where these products would normally be found and in use.

<table>
<thead>
<tr>
<th>EBTRON Performance vs NEBB Table 5-1 Min Reqts</th>
<th>Velocity</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>range</td>
<td>100% greater,</td>
<td>Products are designed and tested to operate between -20 to +160 °F—in excess of operating requirements.</td>
</tr>
<tr>
<td>accuracy</td>
<td>250% greater</td>
<td>approx. 550% greater</td>
</tr>
<tr>
<td>output resolution</td>
<td>&gt; 14 times greater</td>
<td>&gt; 4 times greater</td>
</tr>
<tr>
<td>output average</td>
<td>velocity or volume – fpm or cfm (m/s or L/s)</td>
<td>arithmetic or velocity-weighted, field selectable</td>
</tr>
<tr>
<td>repeatability</td>
<td>0.25% of reading</td>
<td>0.25% of reading</td>
</tr>
<tr>
<td>stability / zero drift</td>
<td>max uncertainty +0.41 to -0.75% @100 fpm, 10 years</td>
<td>max drift 0.015°F, 10 years</td>
</tr>
<tr>
<td>calibration interval</td>
<td>not recommended vs every 12 mos.</td>
<td>not recommended vs every 12 mos.</td>
</tr>
</tbody>
</table>
CONCLUSIONS

• Many valid reasons and requirements exist to measure airflow and the number is growing
• Pressurization airflow control is more precise and more stable than static pressure control
• Volumetric flow tracking requires highly repeatable and precise measurements to be reliable
• Outdoor air measurement conditions are difficult and requires instruments with suitable capabilities
• Direct outdoor air measurement has significantly less uncertainty than Indirect methods
• Airflow Measurement performance is determined by:
  Basic range and nature of the technology used
  Repeatability of the method and product design
  Calibration method and strength of calibration reference
  Sensor stability and maintenance requirements
• NEBB sensor minimum requirements are performance-based, and are not limited to specific types
Seminar presented by
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