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Field measurement of air velocity: pitot traverse or vane anemometer?

A rotating vane anemometer at a downstream coil face can provide the same accuracy as an in-duct pitot tube traverse

By Ronald H. Howell and Harry J. Sauer, Jr.
Fellow ASHRAE *Fellow ASHRAE*

ASHRAE Research

When making testing and balancing measurements in heating, ventilating and air-conditioning systems, it is necessary to obtain field measurements of airflow rates in duct systems. The accurate measurement of airflow in an existing duct system or at a coil is a very important measurement and yet very difficult to obtain.

In most existing duct/coil situations, there is not sufficient straight duct length or even access to the duct in order to make pitot tube measurements. Sometimes, the only possibility is to take velocity measurements at the coil face, where there is usually access in large cabinets or built-up units, using a hand-held anemometer such as the rotating vane.

Pitot tube measurements

When the pitot traverse is used in round duct, 24 total and 24 static pressure measurements are taken at specified locations along three defined diameters across the duct. Specifications for how and where these measurements are to be made are given in ASHRAE *Standard 41.2* (ASHRAE 1987). Specific details concerning the calculation procedure for airflow rate are also outlined in *Standard 41.2*.

To have airflow measurements at standard density, it is necessary to take dry-bulb and wet-bulb temperature measurements and barometric pressure. It is also specified that the pitot tube traverse measurements are to be taken a minimum of 8-1/2 duct diameters downstream from the last fitting and that a straightener needs to be installed five duct diameters upstream of the traverse. Additional details concerning pitot tube traverses, tube construction and applications of tube traverses are given by Streeter (1961) and Dean (1953).

Several sources, including Considine (1976), also indicate that pitot tube measurements are not practical below a velocity of about 600 fpm. At this air speed, the velocity pressure would be 0.0037 in. of water. It is impractical to obtain reasonable accuracy at a pressure this low during field measurements.

Several investigations (Dean 1953; Sauer and Howell 1990) report that the uncertainty (difference between the true value of the quantity measured and the observed value) in the pitot tube traverse method is between 5 to 10 percent for field measurement conditions. Combining these facts with the necessity for having at least 8-1/2 duct diameters available for pitot tube traverses, there are many field measurement situations where a traverse cannot be used.

Anemometer procedures

Recently, ASHRAE Research Project RP-451 (Howell and Sauer 1986, 1987, 1989) addressed the problem of measuring airflow rates at coil faces using the rotating vane anemometer. An illustration of this technique is shown in *Figure 1*. In a paper resulting from that research (Sauer and Howell 1990), a measurement and calculation procedure was developed (see *Table 1*).

In *Table 1*, all of the corrections for anemometer calibration density and actual air density are taken into account. In Step 8, the volume flow rate through the coil for standard density (0.075 lb/ft^3) is calculated. In Step 9, the volume flow rate for the actual air density is calculated. The procedures for anemometer calibration density corrections and airflow density corrections are given by ASME (1959) and Ower and Pankhurst (1960).

In the technical papers prepared from the results of ASHRAE RP-451, it is shown that the use of the k-factor concept and the above measurement and calculation procedure using the 4-in. rotating vane anemometer provides volume flow rates at coil faces to an accuracy of ±7 percent, which is similar to the accuracy obtained using pitot tube traverses (Sauer and Howell 1990; Howell and Sauer 1990). The procedure is valid in a velocity range of 100 to 1,500 fpm. Upstream disturbances such as elbows, partially blocked coils, dampers and fan blasts had virtually no effect on the accuracy of using the k-factor concept and procedure as long as the measured velocities are positive and relatively uniform.

Unfortunately, the complete methodology requires values of tube dia

About the authors

Ronald Howell is a professor of mechanical engineering at the University of Missouri-Rolla. He received B.S., M.S. and Ph.D. degrees in mechanical engineering from the University of Illinois-Urbana, Champaign. He is currently a member of the ASHRAE R&T Committee, chairman of the R&T Project Activities Subcommittee, and chairman of the ABET Participation Committee. He is a past member of Technical Committees 1.1, 1.5 and 4.7 as well as a former chairman of SPC 41.6, TC 1.3. Howell is the recipient of the ASHRAE Distinguished Service Award and Best Technical Paper Award (1986).

Harry J. Sauer, Jr. is the dean of graduate study and professor of mechanical and aerospace engineering at the University of Missouri-Rolla. He received B.S. and M.S. degrees from the Missouri School of Mines and Metallurgy and a Ph.D. degree from Kansas State University, all in mechanical engineering. Sauer is currently a member of the ASHRAE *Journal/Insights* Committee, Technical Committees 1.6 and 7.6, and SPC-116R. Previously, he served on the Technology Council and other standing, technical and standards committees.

meter, tube spacing, fins per inch, number of tube rows, and actual air density. Of interest is the loss in accuracy if these factors are not known. Two specific cases of proceeding with less than complete input were evaluated: density correction neglected; and correlation of k-factor with face velocity only.

A modified procedure without density correction is identical to the previous procedure except that the velocity readings obtained in Step 4 are not corrected to standard density at which the anemometer was calibrated as indicated in Step 5. The modified procedure is given in *Table 2*.

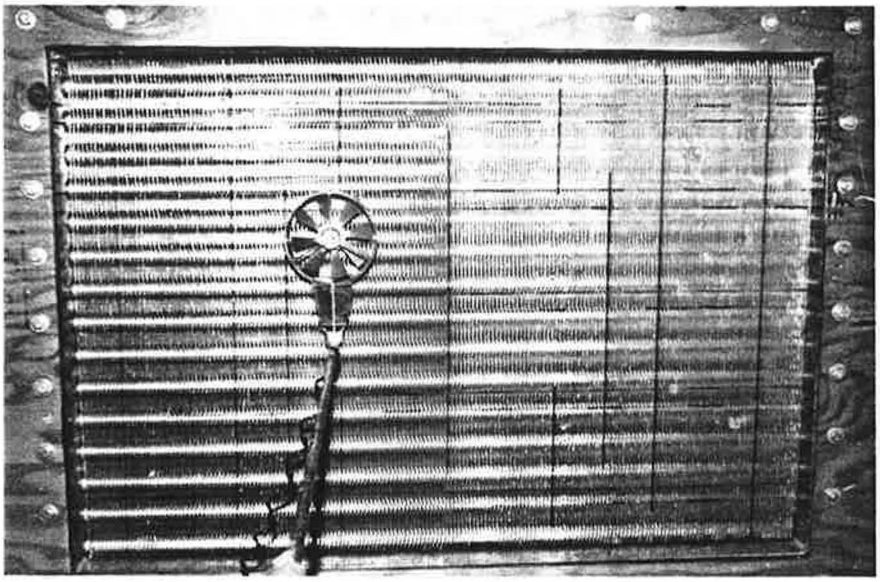

Figure 1. Positioning of rotating vane anemometer on the downstream side of dry coil at the face.

Simplified procedure

In this procedure, the k-factor is correlated only to face velocity and neglects the separate effects of all other coil parameters, including air density. *Figure 2* shows all of the k-factor data for the 4-in. anemometer at all of the coil faces tested in ASHRAE RP-451. The best fit curve has been put through the data and the ±10 percent deviation lines are also shown. Virtually all of the results lie within the ±10 percent accuracy limits.

In *Figure 2*, the k-factor is plotted versus the average anemometer velocity of the traverse. By using the equation given in *Figure 2*, the user does not need to know number of rows, fins per inch, tube spacing or tube diameter for the coil. This simplified procedure is given in *Table 3*.

Comparison of the procedures

Calculations were made for various

rows of tubes, tube diameters, tube spacing and fins per inch on coils with various values of air density. In these calculations, the average velocity reading for the anemometer is varied from 100 to 1,400 fpm. For all of these conditions, the actual volume flow rates are determined using the three measurement techniques described in the three tables.

The volume determined using the technique without density correction (*Table 2*) is compared to the RP-451 technique (*Table 1*). The simplified procedure in Table 3 is also compared to the RP-451 technique. The maximum error at 600 fpm in reference to the RP-451 technique is computed for density variation between ±10 percent of standard density.

In *Figure 3*, the error in the airflow measured quantity in percent is plotted for variations in the air density of plus to minus 10 percent from standard density of 0.075 lb/ft^3. One bar graph is for the Modified Procedure Without Density Correction (*Table 2*). The maximum error found there was about ±5 percent for a ±10 percent departure in the air density from standard density.

The other bar graph is for the Simplified Procedure (*Table 3*). The maximum error for this procedure was plus 17 percent to minus 19 percent for a density departure of ±10 percent. However, observe that at standard density (0 percent departure from standard density in *Figure 3*), the error due to not considering rows of tubes, tube diameter, tube spacing and fins per inch was ±13 percent. This means that there is still about a ±5 percent deviation due to ignoring density corrections with a ±10 percent density variation in this technique.

Conclusions

For the greatest precision in using a rotating vane anemometer at a coil face, the RP-451 Measurement and Calculation Procedure shown in *Table 1* should be used. This technique yields volume flow measurements accurate to within ±7 percent, similar to the accuracy expected from pitot tube measurements.

If the Modified Procedure Without Density Correction shown in *Table 2* is used, up to an additional ±5 percent error could occur if the density is different from standard air density by ±10 percent.

If the Simplified Procedure shown in *Table 3* is used, an additional error of up to 19 percent in comparison to the RP-451 Measurement and Calculation Procedure could occur, with a density departure from standard air density of ±10 percent.

The user would have to decide how much error can be tolerated in trade-off for the simpler procedure in taking measurements. In general, it appears that the additional accuracy is well worth the effort required in measuring the air density and determining the number of rows, tube diameter, tube spacing and fins per inch.

Table 1. RP-451 Measurement and Calculation Procedure

Step 1. Mark the coil so that standard and offset location readings can be taken on a dry coil on the downstream side. This should all be done according to the pattern indicated in *Figure 4*.

Step 2. Measure the coil height and width, and calculate the coil face area from

$$A = H \times L/144$$

where:

A = coil face area, ft^2
H = height of coil, in.
L = length of coil, in.

Step 3. With the air flowing through the coil, measure the air dry-bulb temperature, the wet-bulb temperature, and the barometric pressure. Calculate the specific volume of the air flowing through the coil from

$$v = R_a T/P\,(1 + 1.6078\,W)$$

where:
v = specific volume, ft^3/lb
R_a = gas constant for air, 53.35 ft-lb_f/lb_m °R
T = absolute temperature, °R
P = total pressure, lb_f/ft^2
W = humidity ratio, lb_v/lb_a

and

$$W = \frac{(1093 - 0.556\,t^*)\,W_s^* - 0.24\,(t - t^*)}{1093 + 0.444\,t - t^*}$$

where:
t = air dry-bulb temperature, °F
t^* = air wet-bulb temperature, °F
W_s = humidity ratio of saturated air at the wet-bulb temperature

$$W_s = 0.62198\,\frac{P_w^*}{P - P_w^*}$$

P_w^* = saturation pressure for water vapor at the wet-bulb temperature

Step 4. Using a calibrated 4-inch rotating vane anemometer (calibrated to standard density air), take 19 velocity readings at the standard location and 19 readings at the offset location (*Figure 4*). These are to be fixed location readings allowing a reasonable time for the anemometer to respond to the velocity at that location (5-15 seconds).

Step 5. Correct the measured velocity readings from Step 4 to standard density air at which the anemometer was calibrated according to

$$MVSTD = V \times (13.33/v)^{1/2}$$

where:
V = measured velocity, fpm
v = specific volume of air, ft^3/lb
MVSTD = corrected velocity for calibration density, fpm

Step 6. Determine the average velocity reading at the coil face using

$$MVSTDAV = \frac{\sum_{i=1}^{38} MVSTD_i}{38}$$

where:
MVSTDAV = average air velocity for the 38 measured coil velocities, fpm

Step 7. Determine the K-factor for this coil from the following equation.

$$KSTD = a_0 + a_1 \times MVSTDAV + a_2 \times ROWS + a_3 \times FPI + a_4 \times SP + a_5 \times D + a_6 \times MVSTDAV^2$$

where:
MVSTDAV = average air velocity for the 38 measured coil velocities, fpm
ROWS = number of rows deep of tubes in coil
FPI = fins per inch for the coil
SP = tube spacing at the coil face, in.
D = tube outside diameter, in.
KSTD = k-factor for coil

and for 4-in. anemometers

a_0 = 0.65204515
a_1 = 0.000176163
a_2 = 0.000971875
a_3 = −0.006745072
a_4 = 0.04736985
a_5 = −0.09111685
a_6 = −8.68316 E−08

Step 8. Calculate the volume flow rate through the coil from

$$QSTD = A \times MVSTDAV \times KSTD$$

where:
QSTD = volume flow rate at standard density air, scfm

Step 9. If the actual flow rate is desired, calculate this from

$$QACT = QSTD \times v/13.33$$

where:
QACT = volume flow rate at actual density air through the coil, fpm

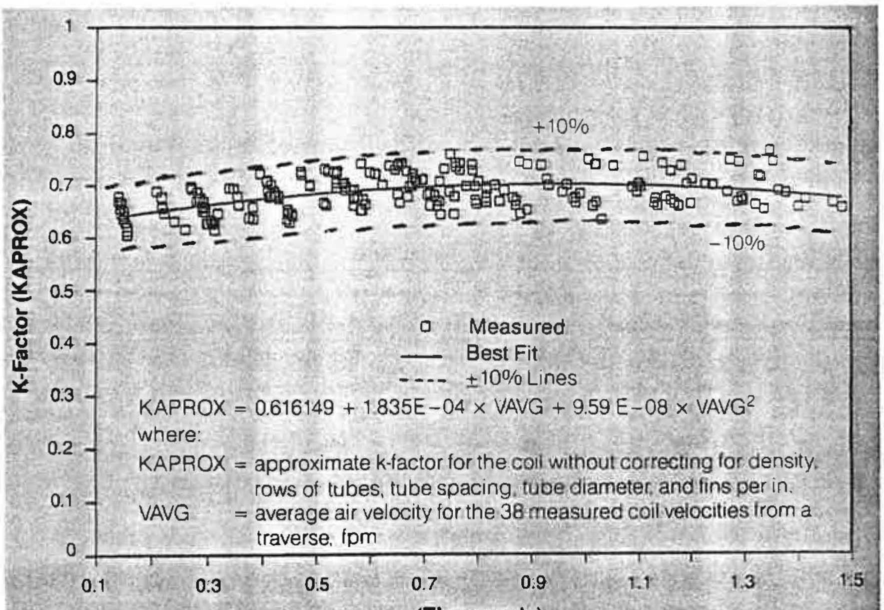

Figure 2. K-factor variation with velocity only.

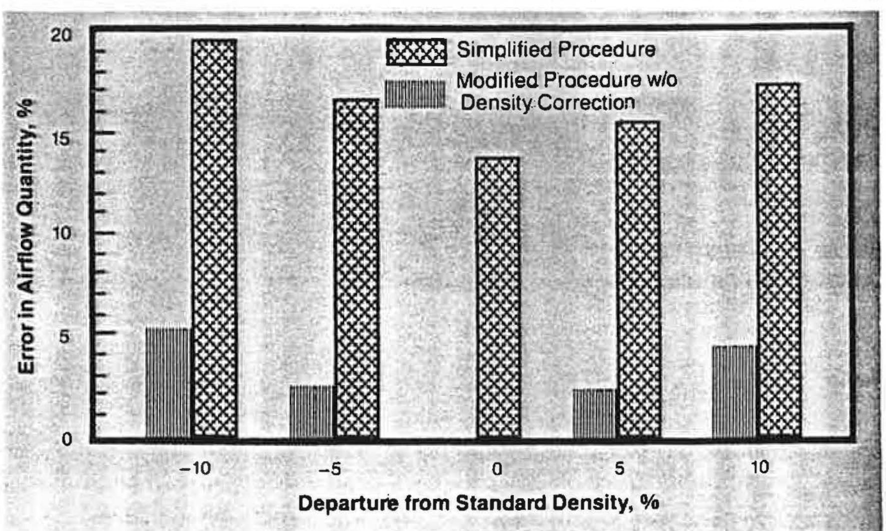

Figure 3. Comparison of the technique accuracy evaluated at 600 fpm face velocity.

Table 2. Modified Procedure Without Density Correction

Step 1. Mark the coil so that standard and offset location readings can be taken on a dry coil on the downstream side. This should be done according to the pattern indicated in *Figure 4*.

Step 2. Measure the coil height and width, and calculate the coil face area from

$$A = H \times L/144$$

where:

A = coil face area, ft²
H = height of coil, in.
L = length of coil, in.

Step 3. Using a calibrate 4-in. rotating vane anemometer, take 19 velocity readings at the standard location and 19 readings at the offset location (*Figure 4*). These are to be fixed location readings allowing a reasonable time for the anemometer to respond to the velocity at that location (5-15 seconds).

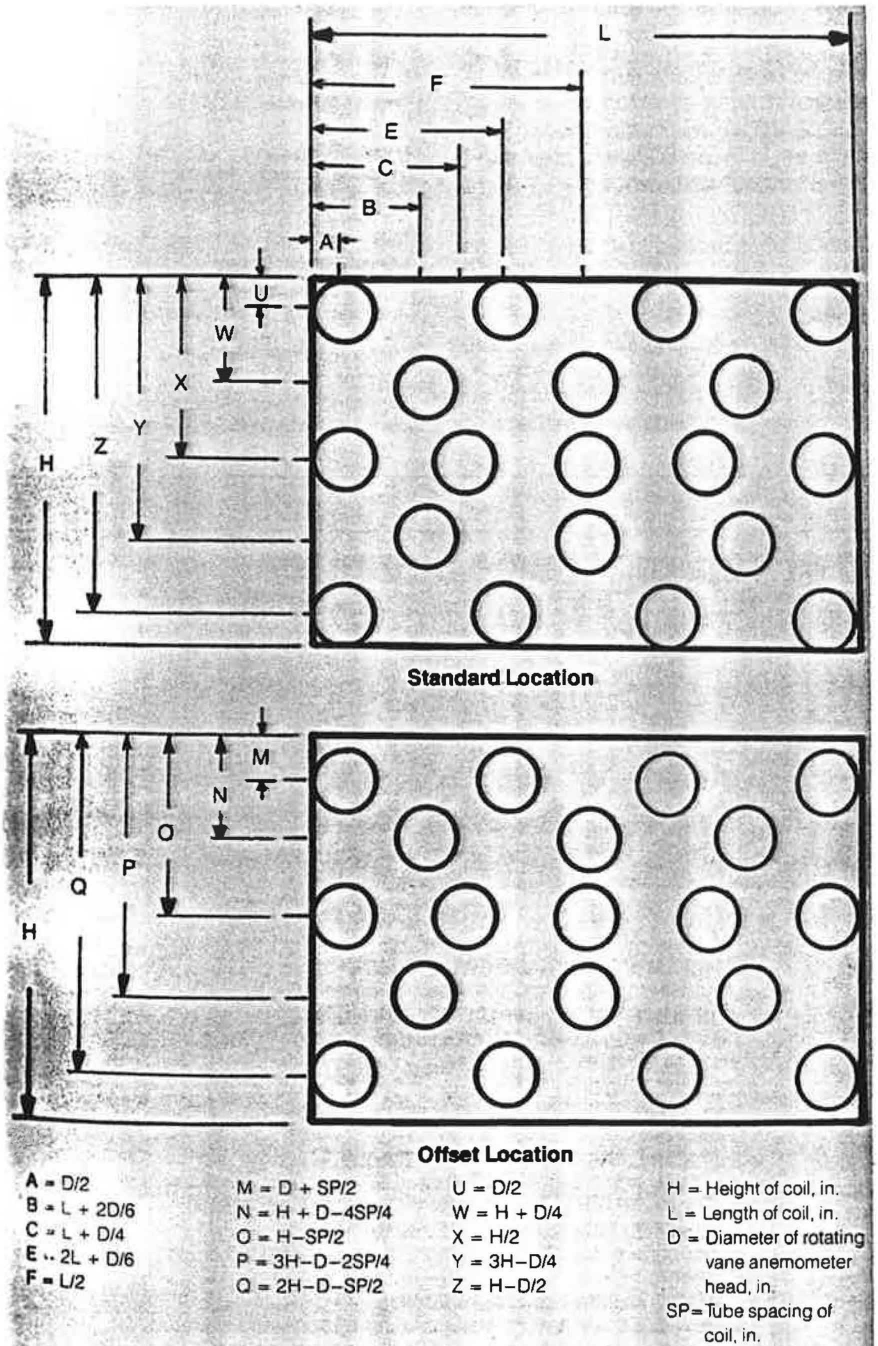

Figure 4. Location of anemometer readings taken on a dry coil on the downstream side for the k-factor procedure.

Step 4. Determine the average velocity reading at the coil face using

$$VAVG = \frac{\sum_{i=1}^{38} V_i}{38}$$

where:

V_i = measured velocity at the ith location on the coil face, fpm
$VAVG$ = average air velocity for the 38 measured coil velocities, fpm

Step 5. Determine the K-factor for this coil from the following equation.

$$KA = a_0 + a_1 \times VAVG + a_2 \times ROWS + a_3 \times FPI + a_4 \times SP + a_5 \times D + a_6 \times VAVG^2$$

where:

KA = K-factor for this coil without any density correction factor
$VAVG$ = average air velocity for the 38 measured coil velocities, fpm
$ROWS$ = number of rows deep of tubes in coil
FPI = fins per in. for the coil
SP = tube spacing at the coil face, in.
D = tube outside diameter, in.

and for 4-in. anemometers

a_0 = 0.65204515
a_1 = 0.000176163
a_2 = 0.000971875
a_3 = −0.006745072
a_4 = 0.04736985
a_5 = −0.09111685
a_6 = −8.68316 E−08

Step 6. Calculate the actual volume flow rate through the coil from

$$QACT = A \times VAVG \times KA$$

where:

$QACT$ = volume flow rate at actual density air through the coil, cfm

Step 7. If the volume flow rate of standard density air is desired, calculate this from

$$QSTD = QACT \times 13.33/v$$

where:

$QSTD$ = volume flow rate at standard density air, scfm
v = specific volume of the air flowing through the coil. This can be determined from *Table 1*, Step 3.

Table 3. Simplified Procedure

Step 1. Mark the coil so that standard and offset location readings can be taken on a dry coil on the downstream side. This should be done according to the pattern indicated in *Figure 4*.

Step 2. Measure the coil height and width, and calculate the coil face area from

$$A = H \times L$$

where:

A = coil face area, ft^2
H = height of coil, in.
L = length of coil, in.

Step 3. Using a calibrated 4-in. rotating vane anemometer, take 19 velocity readings at the standard location and 19 readings at the offset location (*Figure 4*). These are to be fixed location readings allowing a reasonable time for the anemometer to respond to the velocity at that location (5-15 seconds).

Step 4. Determine the average velocity reading at the coil face using

$$VAVG = \frac{\sum_{i=1}^{38} V_i}{38}$$

where:

V_i = measured velocity at the ith location on the coil face, fpm
VAVG = average air velocity for the 38 measured coil velocities, fpm

Step 5. Determine the K-factor for this coil from the following equation from *Figure 2*.

$$KAPROX = 0.616149 + 1.835E{-}04 \times VAVG + 9.59E{-}08\ VAVG^2$$

where:

KAPROX = approximate K-factor for the coil without correcting for density, rows of tubes, tube spacing, tube diameter, and fins per in.

Step 6. Calculate the actual volume flow rate through the coil from

$$QACT = A \times VAVG \times KAPROX$$

where:

QACT = volume flow rate at actual density air through the coil, cfm

Step 7. If the volume flow rate of standard density air is desired, calculate this from

$$QSTD = QACT \times 13.33/v$$

where:

QSTD = volume flow rate at standard density air, scfm
v = specific volume of the air flowing through the coil. This can be determined from *Table 1*, Step 3.

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