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Air Flow Calibration of Building Pressurization Devices

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Abstract

Whole building pressurization devices, or blower doors, have been used to quantify building airtightness and to determine compliance with airtightness standards. Using pressurization testing in airtightness standards requires knowledge of the accuracy of the air flow rate measurement techniques employed by blower doors. The quantitative accuracy of existing air flow calibrations are not known and have been questioned. The blower doors considered in this report employ calibration formula relating the air flow rate through the door to the fan speed and the pressure difference across the door. Such fan speed calibrations must be done accurately over wide a range of fan speed/pressure difference combinations and in a physical setting that closely approximates the manner in which the blower doors are used in the field.

In order to obtain an accurate and well-documented calibration of pressurization devices, a facility was designed and constructed at the U.S. National Bureau of Standards. The calibration facility discussed in this work was built to accurately determine the flow rate through the fan as a function of fan speed, air density and pressure difference across the fan. This report describes the calibration facility and the rationale for its particular design. Results from the calibration of one blower door are presented. The effect of the form of the calibration equation on the accuracy of the air flow rate determination is also discussed.

Key Words: air flow measurement; air tightness evaluation; blower doors; building tightness; calibration; fan pressurization; pressure testing.

Preface

This study of pressurization devices was conducted for research purposes and is not an NBS report of calibration. The work was conducted while the author held a National Research Council Postdoctoral Research Associateship at the National Bureau of Standards.

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1. Introduction

There are two basic uses of whole-house pressurization devices, diagnostics for the location of air leakage paths and quantification of the airtightness of buildings. When used as a diagnostic tool, the pressure difference induced by blower doors accentuates the air flow through leakage paths, thereby making their detection easier [1]. Such leakage detection is further enhanced by using smoke and/or infrared thermography in conjunction with pressurization. Blower doors can also be used to quantify the airtightness of buildings by measuring the air flow rate required to induce and sustain a given inside-outside pressure difference [2,3]. It is this second use of pressurization which concerns us here.

Quantification of building airtightness is useful for the determination of space conditioning loads and the maintainance of indoor air quality. While actual infiltration measurement can fulfill these needs as well as, or perhaps better than, pressurization testing, the characterization of a building's airtightness requires infiltration measurements over a wide range of weather conditions, and is an expensive and time consuming procedure. Pressurization testing requires only a single measurement which takes roughly one hour and is relatively inexpensive. Airtightness measurement through pressurization can be used for measuring the effectiveness of shell tightening retrofits, comparing homes to each other and determining compliance with building tightness standards. Sweden, in fact, requires new homes to achieve a specific tightness level as measured by pressurization [3], and the American Society of Heating, Refrigerating and Air Conditioning Engineers is formulating an airtightness standard for U.S. homes. The use of pressurization testing for airtightness evaluation implies a relation between pressurization and weather induced infiltration. This relation has been studied extensively [4-10], however the ability to predict infiltration from pressurization is limited.

In order to use blower doors as quantitative tools, one must know the accuracy of the measurements. Previous work has shown pressurization test results to be reproducible within about 2% over periods of a few weeks [11]. The absolute accuracy of air flow rate measurement of many pressurization devices has not been well established, especially for devices which employ fan speed calibrations for determining the air flow rate. Some devices have been calibrated by their manufacturers and other researchers [12], but the accuracy of these calibrations has not been carefully examined. In this report, pressurization equipment is discussed briefly, along with general calibration requirements. Several calibration strategies are reviewed and the particular technique used at NBS is described in detail. The formulation and presentation of these flow calibrations are also discussed. Finally, preliminary results obtained at the NBS facility are presented.

2. Pressurization Equipment

There are basically two types of blower doors, those which measure air flow directly using nozzle or orifice meters, and those which use a calibration formula to relate the air flow rate to the fan speed and the inside-outside pressure difference. Direct flow measurement techniques are based on relations between the air flow rate through a nozzle or orifice and the pressure drop across such a constriction. Flow rate measurement with orifices and nozzles is a well documented technique [14-19], but the existence of these constrictions decreases the flow capacity of a fan. In addition, orifice and nozzle meters require ducting and flow straighteners to condition the flow before it passes through the constriction, and this further decreases the flow capacity and makes the device more bulky. For reasons of portability and expense, many designers have developed "calibrated" blower doors in which the air flow rate is given by a general function

$$q = f(\omega,\Delta p) \tag{1}$$

where

q = air flow rate, m^3/s
ω = fan speed, s^{-1}
Δp = inside-outside pressure difference, Pa.

The fan speed ω is the number of revolutions per second of the fan blade and not the blade tip speed. Calibrated blower doors will be the topic of discussion in the remainder of this report, however the material on calibration also applies to blower doors which employ direct air flow rate measurement.

3. Calibration Techniques and Formulations

3.1 Calibration Requirements

The technique of pressurization testing presents specific requirements on the calibration of blower doors. When pressure testing a building, one induces several inside-outside pressure differences generally ranging from 10 to 70 Pa in increments of about 10 Pa [13]. One notes the fan speed required to induce each pressure difference, and using calibration formula, calculates the air flow rate at that pressure difference.

Blower doors must be able to induce a wide range of air flow rates to enable testing of homes ranging from small and tight to large and leaky. At each pressure difference, one must be able to induce and measure reliably a wide range of air flow rates. One may determine a desirable range of air flow rates for a blower door by considering a small, tight house (180 m^3, 2.5 exchanges/hr at 50 Pa) and a large, leaky house (600 m^3, 15 exchanges/hr at 50 Pa). By considering pressurization test data that would correspond to these limiting cases, we calculated the maximum and minimum air flow rates for several pressure differences. Table 1 shows the results of these calculations. At each pressure difference the maximum flow rate is twenty times the minimum, with the maximum flow rate at 75 Pa about 64 times the minimum flow rate at 12.5 Pa. This table gives desirable air flow rate capacities for a blower door, however not all doors are able to cover this range of flow rates.

Table 1. Range of Blower Door Flow Rates

Inside-Outside Pressure Difference (Pa)	Small, Tight House* Flow Rate (m^3/s)	Large, Leaky House* Flow Rate (m^3/s)
12.5	0.051	1.015
25.0	0.080	1.593
37.5	0.104	2.074
50.0	0.125	2.500
62.5	0.145	2.890
75.0	0.163	3.254

* The small, tight house has a volume of 180 m^3 and a 50 Pa flow rate of 2.5 exchanges/hr. The large, leaky house has a volume of 600 m^3 and a 50 Pa flow rate of 15 exchanges/hr. The flow exponent for both houses is assumed to be 0.65. The data in this table is ficitious and is used only to calculate a desirable range of air flow rates for blower doors.

In addition, blower door calibration formulas must deal with the effects of air density on the air flow rate. Air density varies with air pressure, temperature and relative humidity, and therefore blower door tests are conducted at different air densities, depending on the ambient conditions. At constant air pressure and relative humidity, air density changes by about 7% for a 20°C change in temperature. A change in air pressure corresponding to a 500 m change in altitude changes the air density by about 6%. Changes in air temperature and pressure can combine to cause 10% variations in air density. Blower doors are generally calibrated at a single air density of about 1.2 kg/m^3 (corresponding to an air temperature of 20°C and atmospheric air pressure), and the question exists of how to adjust the calibration to account for measurements at other air densities. We know the air flow rate for a given density, fan speed and pressure difference, and want to know the air flow rate for the same values of fan speed and pressure difference but different air density. While fan laws exist to deal with some analogous situations, these particular circumstances are not amenable to fan laws [14].

Standards exist for testing the performance of fans [15-16]. ASHRAE standard 51-75 describes several physical arrangements for the fans and flow rate measuring equipment [15]. In general, the fans are either mounted in a duct of a diameter similar to that of the fan or installed in a large plenum (see fig. 1). In most cases an exhaust system is required to control the back pressure against which the fan blows. The calibration of blower doors should be carried out in a physical setting that closely approximates the manner in which such devices are used in the field. When blower doors are used to test a house, they are installed in a doorway. The fan, in effect, is mounted in a vertical plane. Having a fan mounted in a duct will affect the characteristics of the air flow through it, and therefore a calibration obtained with a fan in a duct will not apply to the same fan used in a blower door. Thus, blower doors should be calibrated with the device mounted in a large chamber into which the fan blows air. Such a chamber allows the air to "settle" or reach an approximately static condition. A simple schematic of such a chamber is shown in figure 1. The air flow rate measurement device must be appropriate to the magnitude of the air flow rates and the air flow/pressure difference combinations in table 1. Several measurement techniques are discussed in the following section.

3.2 Air Flow Rate Measurement

There are several options for measuring the air flow rate out of the calibration chamber including devices such as orifice plates, nozzles, and pitot tube arrays. Each alternative has advantages and disadvantages, and several options are discussed below, concluding with the flow rate measurement technique used in the NBS calibration facility. The use of orifice plates and nozzles installed in pipes is a well documented procedure for measuring fluid flow rates [17-19]. The references listed provide specifications for orifice design, lengths of pipe upstream and downstream from the metering section, flow straighteners and other aspects of design, installation and use. When the appropriate specifications are followed, the uncertainty of the air flow rate measurement is well determined. The basic problem with such meters is the significant pressure drop caused by the pipe lengths, flow straighteners and the orifice or nozzle. The pressure drop is generally too large to obtain the air flow/pressure difference combinations in table 1. Therefore, one requires a large capacity, variable exhaust system to control the back pressure. Such an exhaust system complicates and increases the cost of the calibration facility. Also, several different sized orifices and nozzles are required to cover the wide range of flow rates of interest.

To avoid the large pressure drops associated with orifices in pipes, several researchers have used orifices mounted in the walls of plenums or settling chambers [12,13]. This technique is indeed much simpler than using orifices in pipes, but it is not well documented, nor is there a statement of uncertainty associated with the measurements. No discussion of this technique is found in the three basic handbooks of orifice metering referred to earlier [17-19]. A text on air flow measurement by Ower and Pankhurst [20] does mention the technique, but not in detail. The authors refer to reference 18 as a source of discharge coefficients for such orifices, but Ower and Pankhurst appear to have derived these coefficients from extrapolating data for orifices in large pipes. A practical handbook of fan engineering [21] also provides discharge coefficients for such a situation but does not provide the source of the values. This lack of documentation of discharge coefficients is one problem with this technique. The value of the discharge coefficient is probably not as significant a source of error as the characteristics of the flow impinging on the orifice. The theory of orifice meters is based on conditions of fully developed, turbulent flow upstream of the constriction. Ower and Pankhurst [20] mention that these conditions may not be met for flow discharging from a chamber through an orifice and refer to the need to eliminate flow disturbances such as drafts. The existence of such drafts and the lack of fully developed flow impinging on the constriction may induce unknown measurement errors when using this flow measurement technique. The indeterminant accuracy and the lack of documentation of the technique lead us not to use it nor to recommend its use.

Several commercial flow measurement devices exist, such as a multi-point pitot tube traverse station combined with a flow straightener. The flow measurement is based on the difference between the total and static pressures of the flow. Based on the magnitude of the flow rates of interest and the size of the devices, the pressure differences (total minus static) which must be measured are quite small, in some cases on the order of 1 Pa. It is difficult and expensive to measure such small pressure differences accurately. Also, pitot tubes are generally inaccurate for the small flow rates of interest here. In addition, these pitot tube arrays should be calibrated, and this presents the same problem we are trying to solve. Another commercially available device is referred to as a laminar flow element which channels the air flow through a large number of narrow, parallel passages. These channels are sufficiently narrow that the flow through them is laminar, and the magnitude of the air flow rate is related straightforwardly to the pressure drop across the channels. These devices are expensive and several would be required to cover the range of flow rates of interest. In addition, the pressure drop through the devices is extremely large. Other devices exist but none satisfactorily combine cost, minimal pressure drop and accuracy.

The flow measurement technique used in the NBS calibration facility is a constant flow, tracer gas injection scheme [22]. Tracer gas (sulfur hexafluoride, SF_6) is injected at a constant and known rate into the air stream, and the concentration is measured as far downstream from the injection point as possible (see fig. 2). Under conditions of good mixing of the tracer and the air flow, the air flow rate can be determined from the SF_6 injection rate and the measured concentration according to

$$q = i/c, \tag{2}$$

where

i = SF_6 injection rate, m^3/s
c = SF_6 concentration, ppm.

The SF_6 injection rate is measured and controlled with individually calibrated rotameters. The accuracy of these devices is $\pm 1\%$ of full scale and four different meters are used, providing injection flow rates from 10 to 2500 ml/min. The SF_6 concentration downstream of the injection is measured with an infrared gas analyzer with a 1.5 m path length operating at 10.7 μm. The tracer gas injection rate is adjusted such that the downstream concentration is 25 ppm. The gas analyzer is calibrated with a 25 ppm gas mixture prepared by a gas distributor to an accuracy of $\pm 1\%$. This air flow rate measurement system has a minimal pressure drop through it. To obtain the desired air flow/pressure difference combinations, we still must use constrictions and a variable exhaust fan in the exit duct.

A schematic of the NBS calibration chamber is shown in figure 2. The chamber is used in the large environmental test facility at the Center for Building Technology at NBS, which enables control of air temperature and humidity, and therefore air density. The calibration chamber has a square base with 3.66 m sides and is 1.83 m high. Air is drawn into the calibration chamber from the larger environmental enclosure through the blower door being tested. The air is exhausted to the outside of the large enclosure through a 4.88 m long exit duct. The SF_6 is injected at the upstream end of the exit duct and the concentration measured at the downstream end. The exhaust fan and constriction locations are shown in figure 2. The details of data recording and preliminary results are discussed later in this report.

3.3 Calibration Formulation

Calibrations of blower doors have generally been expressed as linear relations between air flow rate and fan speed for each inside-outside pressure difference [12,13]. These linear relations are the result of applying linear regressions to the calibration data. While such a formula is straightforward to use, it is not physically correct and no indication is given of how to account for density effects. In addition, as will be shown later, such a linear approximation breaks down at low fan speeds. A physically correct calibration formulation has been presented previously which involves nondimensionalization of the air flow rate q and the pressure difference Δp [4,11]. The nondimensional air flow rate is expressed as

$$\alpha = q/\omega d^3, \tag{3}$$

and the nondimensional pressure difference as

$$\beta = \Delta p/\rho(\omega d)^2, \tag{4}$$

where

ρ = air density, kg/m^3
d = fan diameter, m.

A fan's characteristics are described by a relation between α and β, expressed in general as

$$\alpha = g(\beta). \tag{5}$$

The data we collected, and the values of α and β derived from other calibration formulas [4,11], fit well to an equation of the form

$$\alpha = A_1 \exp(A_2 \beta), \tag{6}$$

where A_1 and A_2 are constants. By substituting eq (3) and (4) into eq (6) one obtains the following expression for q,

$$q = A_1' \omega \exp(A_2' \Delta p / \rho \omega^2), \tag{7}$$

where A_1' and A_2' are constants obtained by absorbing the constant fan diameter d into A_1 and A_2. Thus, for $\Delta p=0$ a linear relationship between q and ω is appropriate. For nonzero pressure differences, the exponential factor causes a deviation from a straight line, particularly at low fan speeds. This deviation from linearity and its significance will be discussed in the next section.

This nondimensional calibration formulation leads to a straightforward correction for air density, and explains the inappropriateness of fan laws for such a correction [14]. Fan laws are obtained by holding β, and therefore α, constant. A constant value of these nondimensional quantities implies certain relations between the physical quantities from which they are constituted. For our situation in which Δp and ω are constant, but the density ρ is variable, one sees that α and β change and therefore the fan laws are not appropriate.

4. Test Results

This section describes preliminary results obtained in the NBS blower door calibration facility. Only one door, referred to as Blower Door A, was tested in the counter-clockwise direction of fan rotation. Blower Door A consists of a 0.46 m diameter axial fan coupled by a belt drive system to an electrically reversible, variable speed constant-torque DC motor.

4.1 Experimental Procedure

The most important factor in the tracer gas flow rate measurement technique is the mixing of the tracer gas with the air in the exit duct. The tracer gas must be well-mixed for eq (2) to apply. Good mixing is obtained by injecting SF_6 at several vertically coplanar points immediately upstream of the exhaust fan shown in figure 2. Under this injection scheme the downstream SF_6 concentration is constant in time and location in the duct within about ± 0.25 ppm of the 25 ppm concentration setting. In addition to good mixing, this flow rate measurement technique assumes that the SF_6 concentration in the air flowing through the blower door into the calibration chamber is 0 ppm. This assumption is checked after every other flow rate measurement by turning off the SF_6 injection and making sure the SF_6 concentration in the exit duct returns to 0 ppm. If the SF_6 concentration in the outgoing flow returns to 0 ppm, then there is no SF_6 in the air flowing through the blower door into the calibration chamber.

The desired air flow/pressure difference combinations are obtained by using the exhaust fan and by installing constrictions in the exit duct. A high speed setting on the exhaust fan corresponds to testing large, leaky homes, i.e. low resistance to air flow. Constrictions in the exit duct correspond to smaller, tighter homes with a higher resistance to air flow. The measured ranges of fan speed and air flow rate for each pressure difference are given in table 2. The air flow rates range from about 0.05 to 1.10 m^3/s. This is not as large as the maximum range of interest given in table 1, due primarily to the limited flow capacity of the exhaust fan used.

Table 2. Range of NBS Calibration

Inside-Outside Pressure Difference (Pa)	Fan Speed (s^{-1})	Air Flow (m^3/s)
12.5	7.50-23.33	0.050-0.725
25.0	10.83-30.00	0.075-0.950
37.5	12.50-35.83	0.075-1.050
50.0	14.17-38.33	0.075-1.050
62.5	15.83-38.33	0.075-0.975

For each calibration point, the fan speed, pressure difference across the chamber wall and the air density are also measured. The fan speed for this blower door is measured in the field with a digital tachometer employing a magnetic transducer and a toothed gear interrupter which was found to agree within 0.02 s^{-1} with a digital stroboscope/tachometer with an accuracy of ± 0.02 s^{-1}. The pressure difference across the calibration chamber wall was measured in four locations with magnehelic pressure gauges individually calibrated against an inclined manometer. The four measured pressure differences agree within the range of uncertainty of the pressure gauge calibration, $\pm$ 0.6 Pa. The air density was determined by measuring the air temperature, relative humidity and barometric pressure, and calculating the density using the appropriate formulas. Based on the uncertainties in the measurements of temperature, humidity and pressure, the air density determination has an uncertainty of $\pm$ 0.02 kg/m^3. We then calculated α and β using eq (3) and (4). Based on the uncertainties in q, Δp, ω, and ρ, α and β are determined within about $\pm 6\%$.

4.2 Presentation of Results

Figure 3 is a plot of α versus β for counter-clockwise fan rotation for Blower Door A as determined in the NBS calibration facility. Fitting a curve of the form of eq (6) to the data yields

$$\alpha = 0.368 \exp(-1.72\beta). \tag{8}$$

The coefficient of determination r^2 has a value of 0.9928, and the standard error of the estimate of α is roughly $\pm 4\%$ of its mean value.

Equation (8) can be expressed as a relation between flow rate q and fan speed ω, pressure difference Δp and air density ρ as

$$q = \omega(3.52 \times 10^{-2}) \exp(-8.23\, \Delta p/\rho\omega^2). \tag{9}$$

As discussed earlier, eq (9) is not a linear relation between flow rate and fan speed, however the deviation from linearity is small except at low fan speeds. Figure 4 shows several lines relating flow rate to fan speed derived from eq (9), each for a different pressure difference. The solid portion of each line corresponds to the fan speed range for which calibration data was actually collected. The dashed portions extend beyond the measured range. The measured range of fan speed for each value of pressure difference are given in table 2. The dotted lines extending to the lower left in figure 4 are straight line fits to the calibration data. The straight line fits are indistinguishable from the actual calibration lines except at low fan speeds where the deviation can be significant. Past calibration formulations have employed straight lines, corresponding to these dotted lines [12,13]. We see that the use of such straight lines will lead to erroneously low estimates of air flow rates at low fan speeds. Table 3 shows air flow rates at Δp = 50 Pa for a range of fan speeds derived from eq (9) and from a straight line fit to the calibration data. The errors are large for the lower fan speeds, which implies that if straight line fits are used, then tight or small houses will be reported as tighter than they actually are.

Table 3. Comparison of 50 Pa Flows from Equation (9) and a Straight Line Fit to the Calibration Data

Fan Speed (s^{-1})	Air Flow Rate (m^3/s) Eq (9)	Air Flow Rate (m^3/s) Straight Line	% Error of Straight Line
13.33	0.068	0.031	-54%
14.17	0.090	0.065	-28%
15.00	0.115	0.099	-14%
15.83	0.142	0.134	- 6%
16.67	0.171	0.169	- 1%
17.50	0.201	0.203	+ 1%
18.33	0.233	0.238	+ 2%

Table 4 shows the results of applying both eq (9) and straight line calibration formulas to a sample of pressurization data for a small, tight house. The fan speed is given for each pressure difference, along with the corresponding air flow rates as calculated using eq (9) and a straight line fit to the calibration data. The air flow rates determined using the straight line are all lower than the flow rates calculated from eq (9). Curves are fit to the data, as is often done in analyzing pressurization test results from the field, and two common building tightness measures are calculated, the flow rates at 4 and 50 Pa. The 4 Pa air flow rate from the straight line fit is 24% lower than the 4 Pa rate from eq (9). The 50 Pa flow rate from the straight lines is 10% lower. Thus, we see the potential for error when using straight line calibration formulas to analyze blower door data.

Table 4. Comparison of Pressurization Test Results Using Equation (9) and Straight Line Fits to Calibration Data

Pressure Difference (Pa)	Fan Speed (s^{-1})	Air Flow Rate (m^3/s) Eq (9)	Air Flow Rate (m^3/s) Straight Line	% Error of Straight Line
12.5	7.33	0.053	0.043	-19%
25.0	10.50	0.078	0.066	-15%
37.5	13.17	0.105	0.093	-11%
50.0	15.33	0.126	0.113	-10%
62.5	17.33	0.146	0.135	-8%
75.0	19.00	0.161	0.148	-8%

Curve Fits

Equation (9)	$Q = 0.0104\ \Delta p^{0.637}$	Q(4) = 0.025	Q(50) = 0.126
Straight Line	$Q = 0.0070\ \Delta p^{0.712}$	Q(4) = 0.019	Q(50) = 0.113
% Error of Straight Line		Q(4): -24%	Q(50): -10%

4.3 Comparison to Other Calibrations and Discussion

Figures 5 and 6 show calibration data for Blower Door B, which was built by the same manufacturer as the door tested in the NBS facility. The data on Blower Door B were obtained by the manufacturer by measuring air flow rates with an orifice plate in the wall of a settling chamber as described earlier. The individual "bunches" of points correspond to the different orifices used in the air flow rate measurements. There are fewer data points and more scatter than in the NBS calibrations shown in figure 3. The manufacturer fit the counter-clockwise fan rotation calibration data to the following expression

$$Q = 234 - 355\sqrt{\Delta p} + 178\ \omega. \tag{10}$$

Q is air flow in m^3/hr. Besides being physically incorrect, eq (10) predicts a nonzero air flow rate for zero Δp and ω. Fitting the NBS calibration data to a curve of the same form yields

$$Q = -1 - 265\sqrt{\Delta p} + 149\ \omega. \tag{11}$$

While eq (11) still leads to errors at low fan speeds, it does predict essentially zero air flow for Δp and ω equal to zero. While eq (9) is physically correct and more accurate than the linear formulations in eq (10) and (11), it is also more complex and questions have been raised concerning misuse by field personnel [23]. Equation (11) could be used as a substitute without much loss of accuracy, but only for a limited range of fan speed.

Figure 7 shows a comparison of the curve fit to our calibration of Blower Door A and the measurements made on Blower Door A by the manufacturer (counter-clockwise fan rotation). The manufacturer's calibration data for Blower Door B are also included in the figure. The manufacturer tested Blower Door A using only a single orifice, and therefore all the points are close together. These data are about 25% greater than the curve fit to our calibration of the same door. The manufacturer obtained more data on Blower Door B, and these data are above our curve fit to Blower Door A, about 0.02 higher on the α scale. This difference corresponds to about 50% of α for high values of β and 6% for low values. There are a few manufacturer's points, with α equal to about 0.45, which lie much farther from our line. These points are very different from a curve fit to the other manufacturer's points, and this difference is obvious in the nondimensional presentation of the data. The reason for the otherwise consistant difference between the manufacturer's calibration of Blower Door B and our calibration of Blower Door A is not clear. The difference could be due to imperceptible differences in the doors.

5. Conclusions

This report has presented the problem of calibrating blower doors and the techniques used in the NBS calibration facility. The NBS facility was used to calibrate one blower door and a physically appropriate calibration formulation was applied to the data. Previous calibrations have used linear relations between air flow rate and fan speed which can lead to errors in flow determination at low fan speeds. It is pointed out that such errors can lead to tight or small houses being reported as more airtight than they actually are if the straight line fits are used. Such straight line calibrations can be used if the range of fan speed is appropriately limited. In addition, our calibration formulation allows for straightforward density corrections. Other blower doors, including those which employ direct air flow rate measurement, may be tested in the facility in the future.

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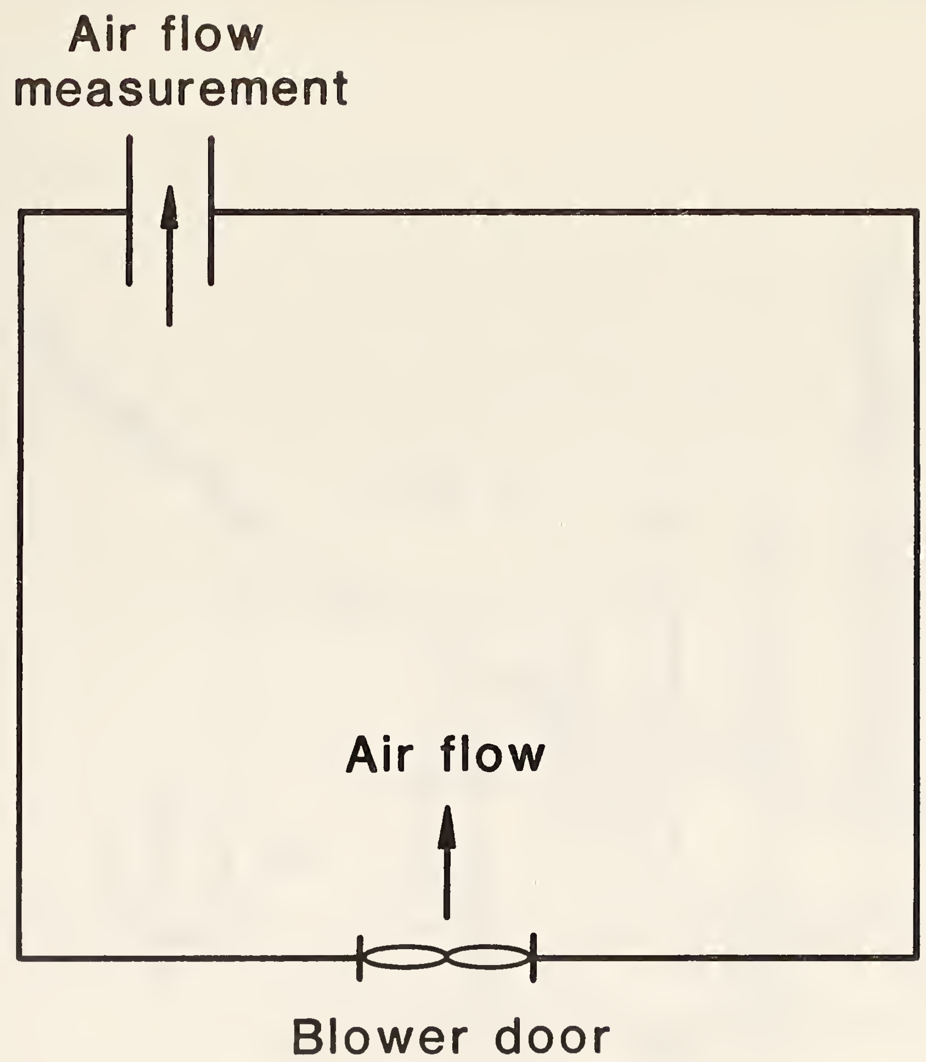

Figure 1 Simple Schematic of General Calibration Chamber

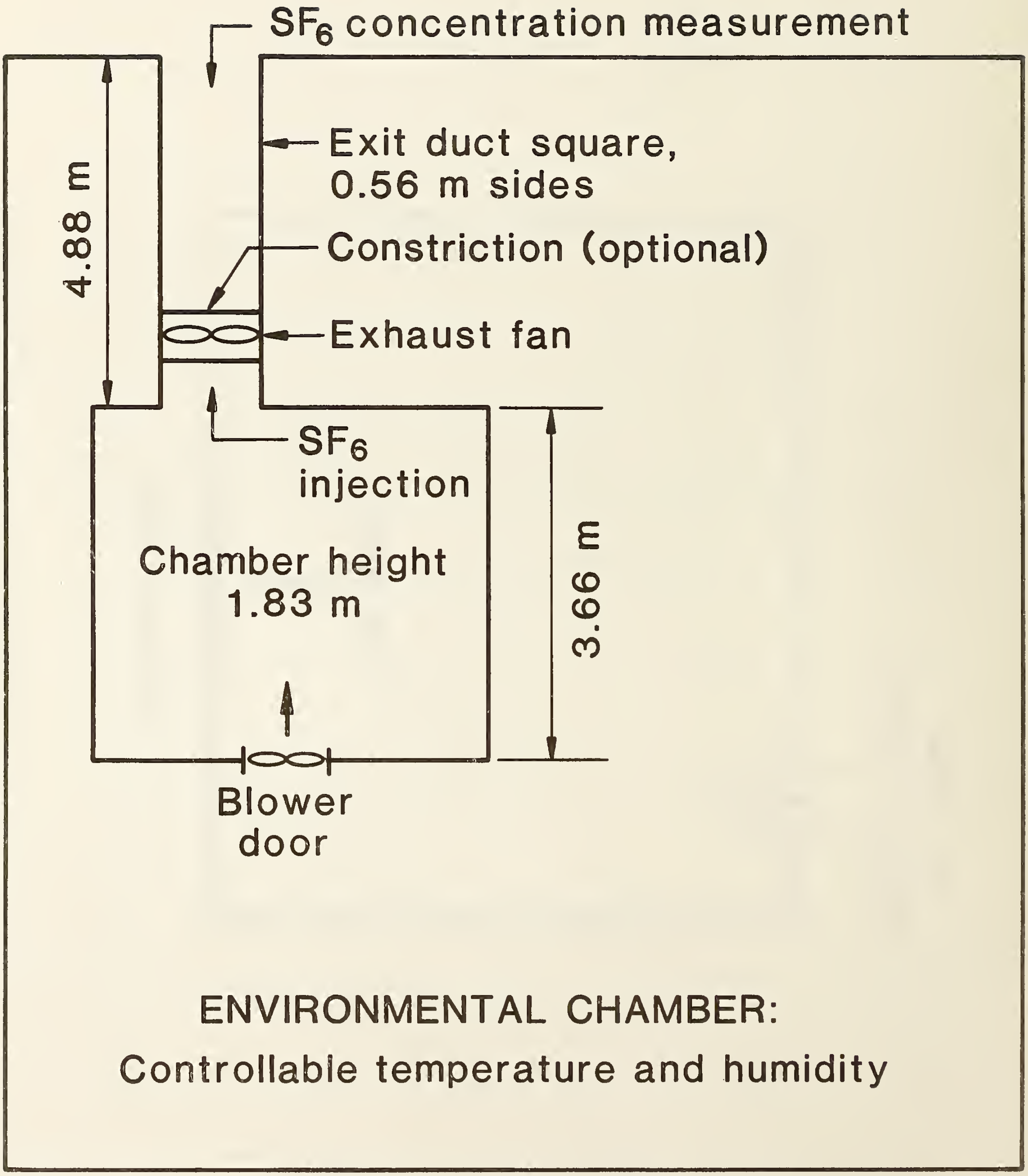

Figure 2 Schematic of NBS Calibration Facility

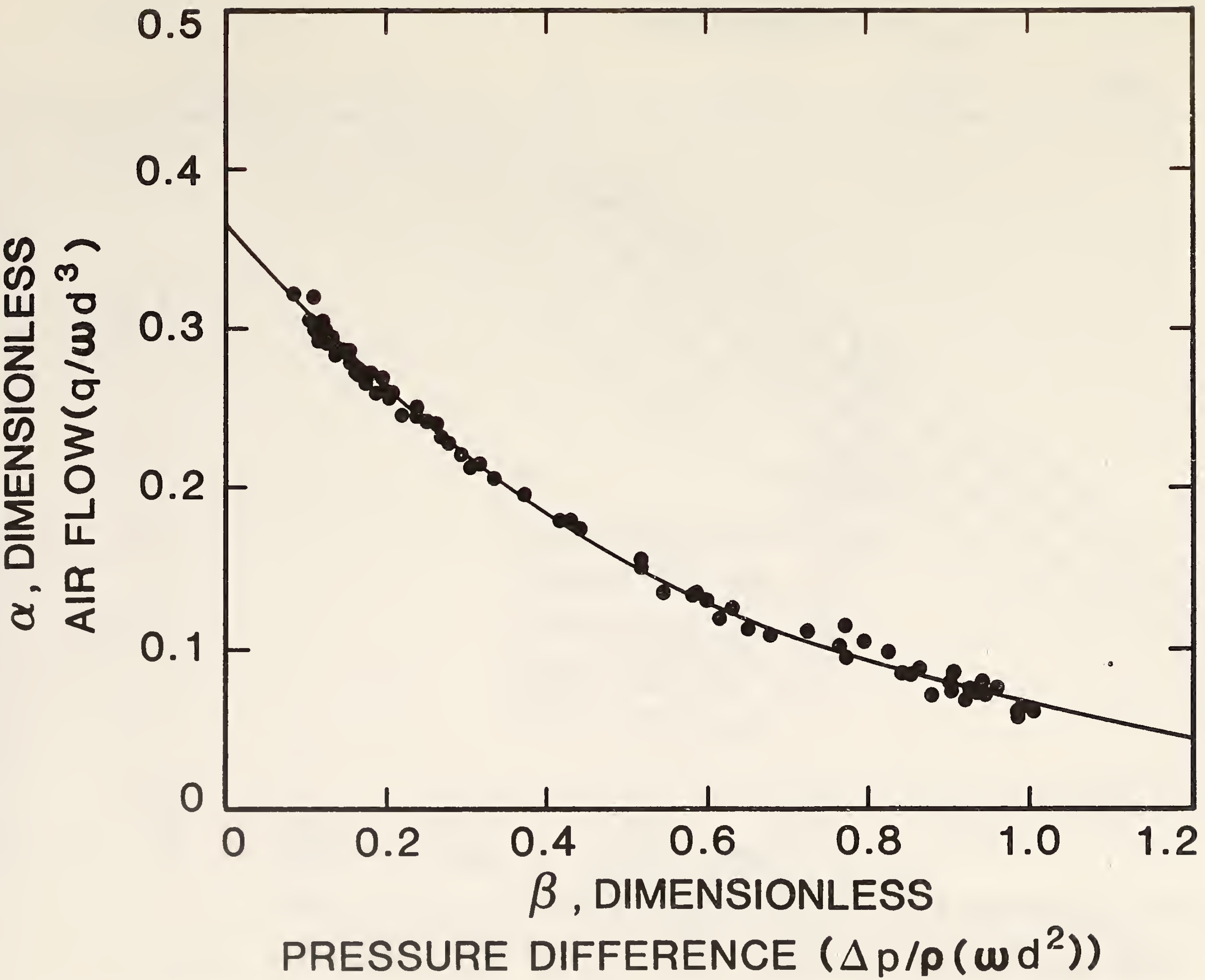

Figure 3 Dimensionless Flow Rate vs Dimensionless Pressure Difference, Counter-Clockwise Fan Rotation, NBS Calibration of Blower Door A

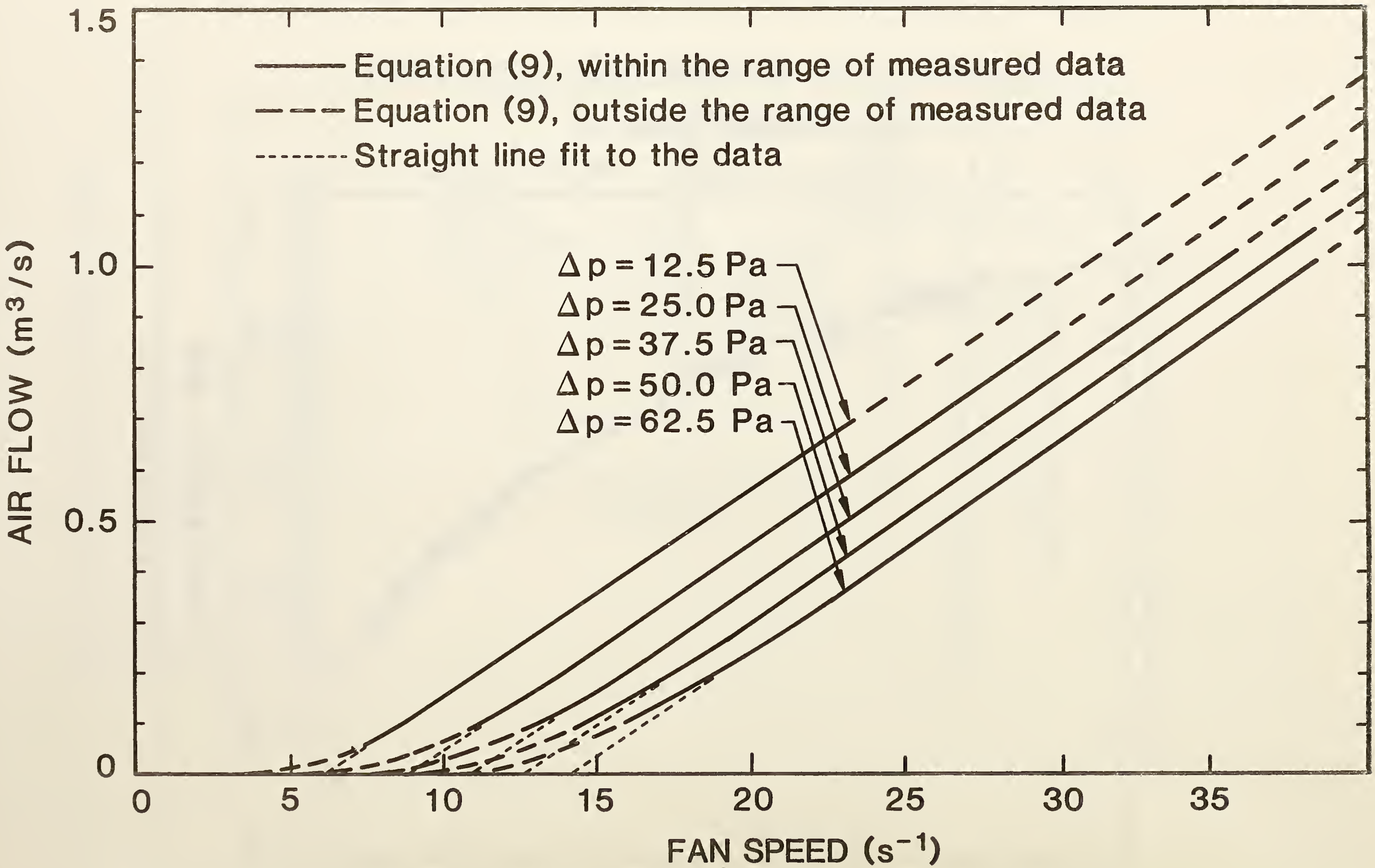

Figure 4 Air Flow Rate vs Fan Speed at Several Pressure Differences

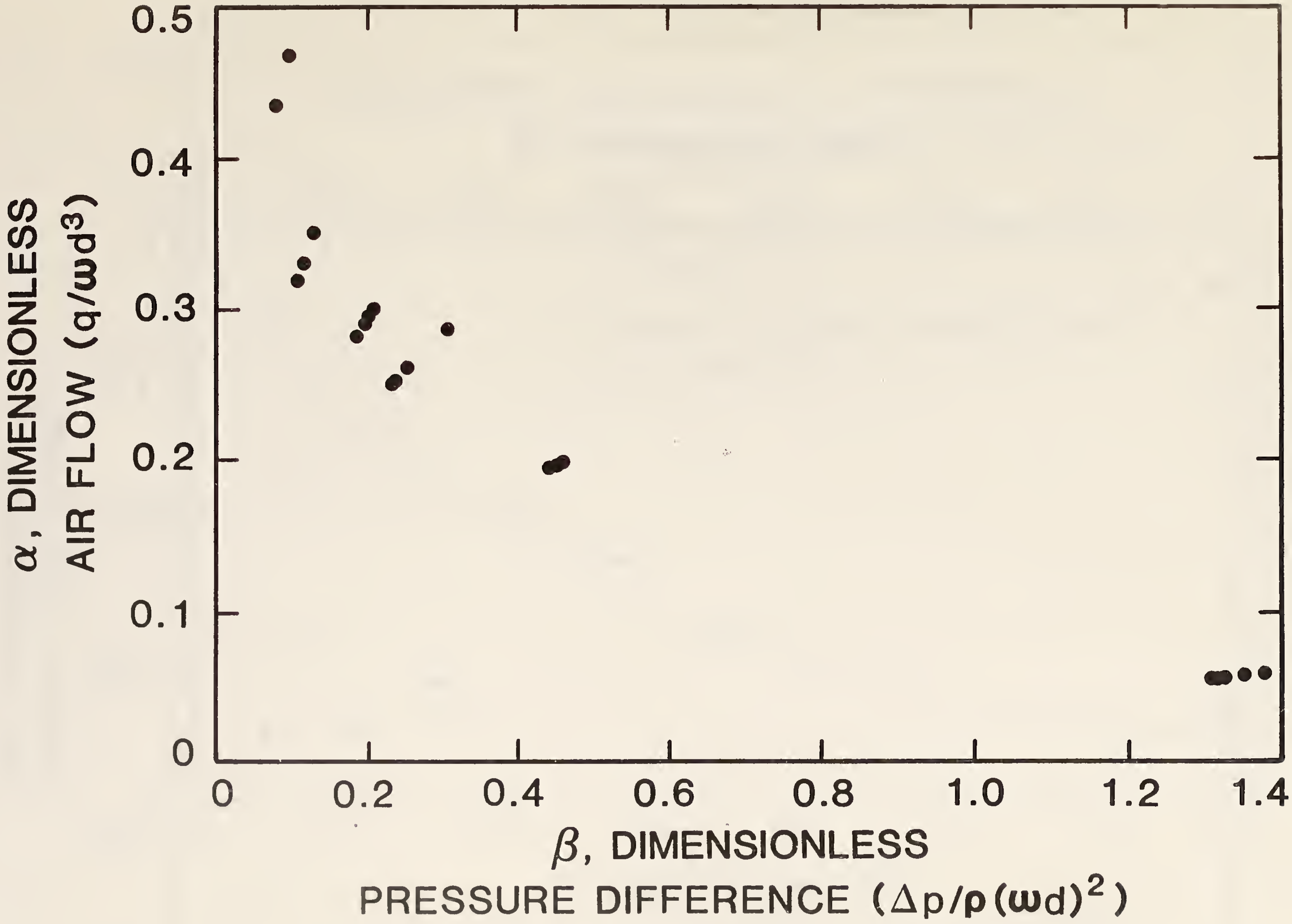

Figure 5 Dimemsionless Flow Rate vs Dimensionless Pressure Difference, Counter-Clockwise Fan Rotation, Manufacturer's Calibration of Blower Door B

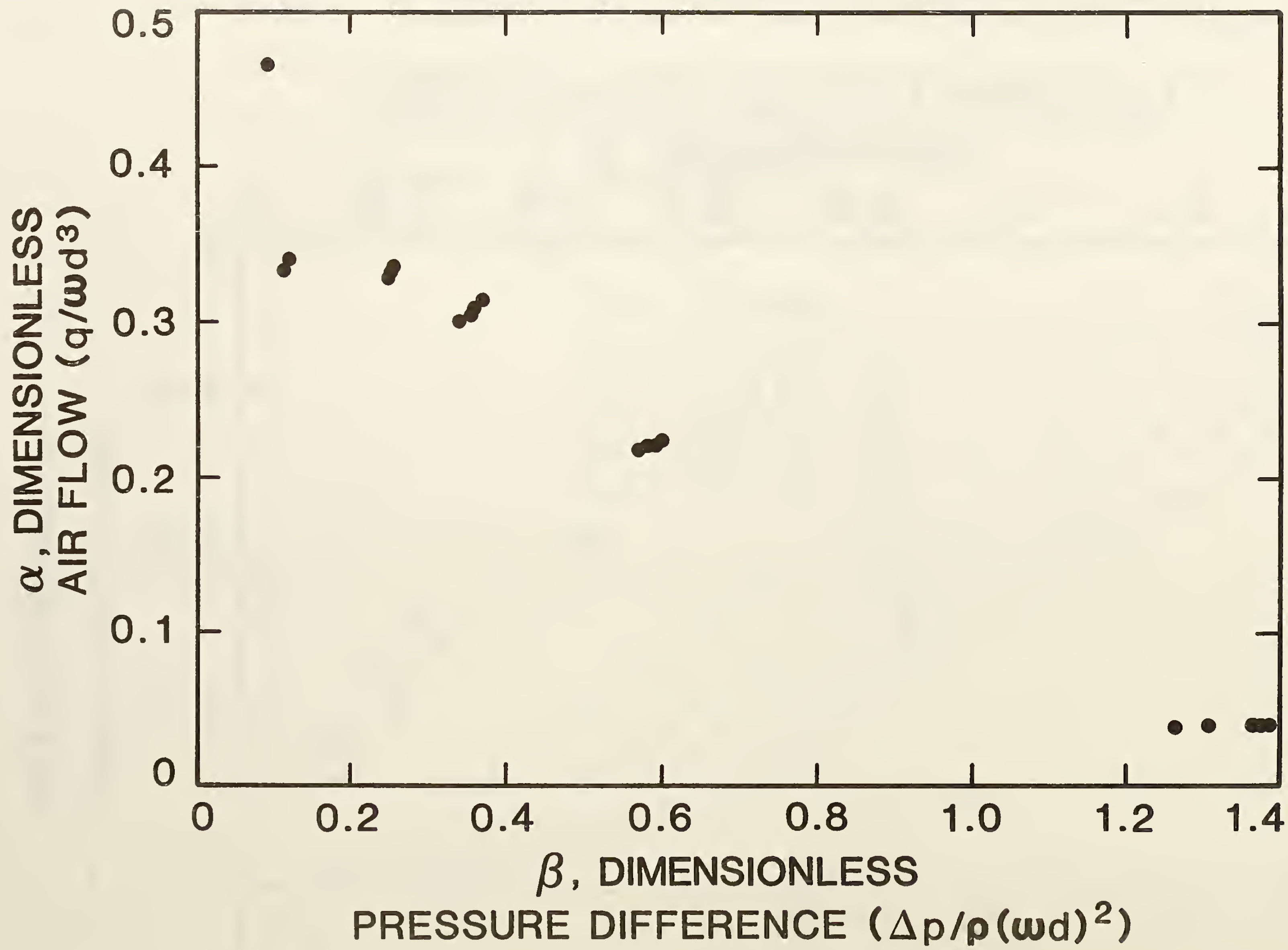

Figure 6 Dimensionless Flow Rate vs Dimensionless Pressure Difference, Clockwise Fan Rotation, Manufacturer's Calibration of Blower Door B

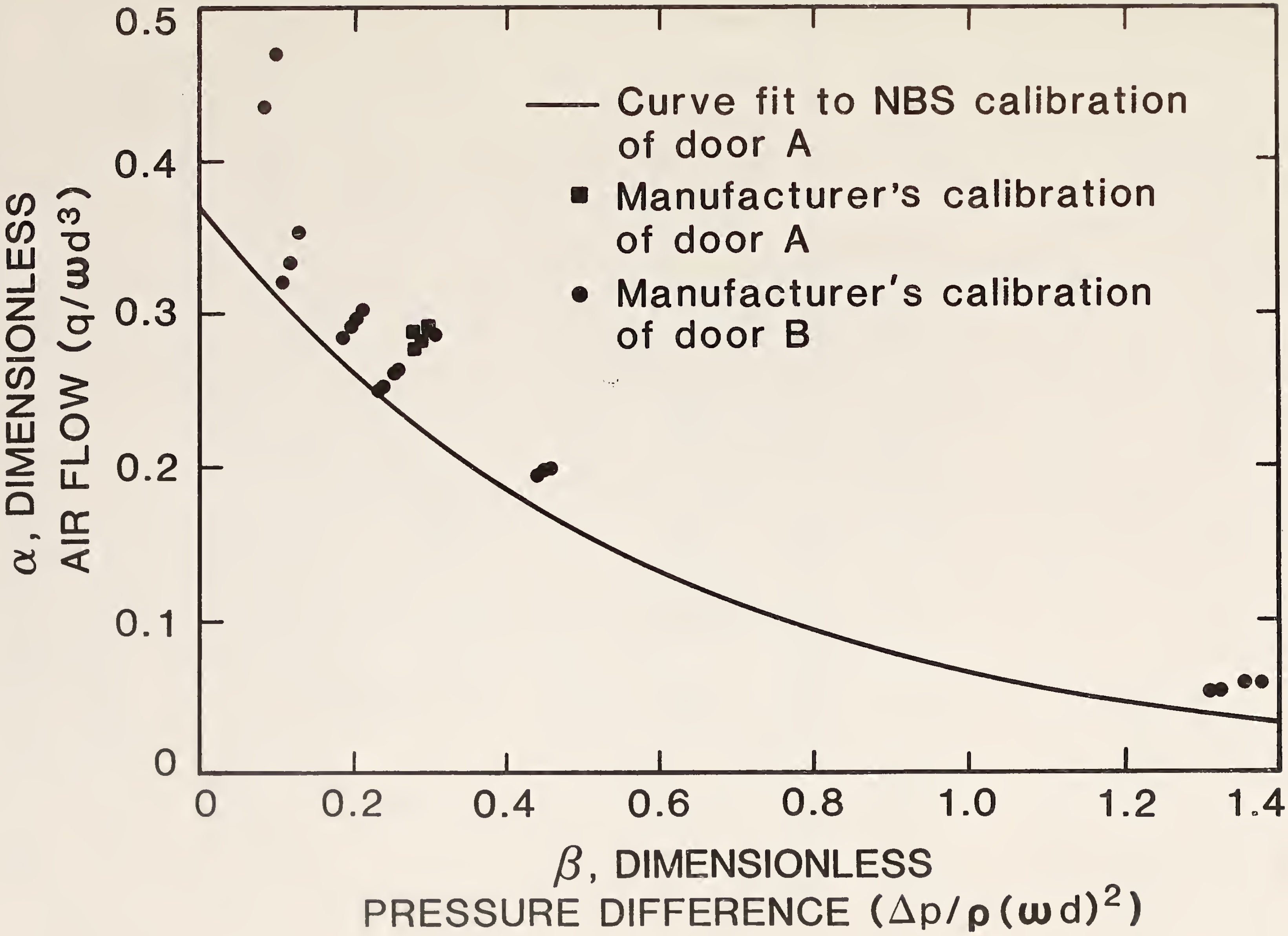

Figure 7 Comparison of Calibrations of Blower Doors A and B

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Research conducted while author held a National Research Council Postdoctoral Research Associateship at the National Bureau of Standards.

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Whole building pressurization devices, or blower doors, have been used to quantify building air-tightness and to determine compliance with air tightness standards. Using pressurization testing in air-tightness standards requires knowledge of the accuracy of the air flow rate measurement techniques employed by blower doors. The quantitative accuracy of existing air flow calibrations are not known and have been questioned. The blower doors considered in this report employ calibration formula relating the air flow rate through the door to the fan speed and the pressure difference across the door. Such fan speed calibrations must be done accurately over wide a range of fan speed/pressure difference combinations and in a physical setting that closely approximates the manner in which the blower doors are used in the field.

In order to obtain an accurate and well-documented calibration of pressurization devices, a facility was designed and constructed at the U.S. National Bureau of Standards. The calibration facility discussed in this work was built to accurately determine the flow rate through the fan as a function of fan speed, air density and pressure difference across the fan. This reports describes the calibration facility and the rationale for its particular design. Results from the calibration of one blower door are presented. The effect of the form of the calibration equation on the accuracy of the air flow rate determination is also discussed.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Air flow measurement; air tightness evaluation; blower doors; building tightness; calibration; fan pressurization; pressure testing.

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