Empirical Determination of the Error in the ACGIH
Method of Predicting Airflow Distribution
in Two Industrial Ventilation Systems

by

Jeanne Schlichtman Hoppe

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Science

University of Washington

1995

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(Chairperson of Supervisory Committee)

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Program Authorized to Offer Degree: School of Public Health and Community Medicine, Department of Environmental Health

Date 6/23/95

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Empirical Determination of the Error in the
ACGIH Method of Predicting Airflow Distribution
in Two Ventilation Systems

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Ventilation systems are important in reducing worker exposure to airborne contaminants. To do this job sufficiently, ventilation systems must deliver the correct airflow to each hood according to its requirements. Proper airflow distribution is achieved through proper design, installation and maintenance. Proper design requires an accurate predictive model of the system. The most commonly used model is that described by the American Conference of Governmental Industrial Hygienists (ACGIH) in Industrial Ventilation: A Manual of Recommended Practice. The efficacy of this predictive model, which is based on published loss coefficients, has not been documented in the field and published literature.

It is the purpose of this field study to compare the observed loss coefficients to those published by the ACGIH in the Industrial Ventilation manual. In this study, the error is determined by analyzing the differences between the observed sum of loss coefficients and the sum of published loss coefficients for each branch. Error in the loss coefficients is important because it results in a proportional error in airflow distribution.

The data analysis for this work focused on the coefficients for different components (e.g. hoods, elbows) in an effort to identify the sources of deviation from the predicted sum of coefficients. That analysis indicated substantial discrepancies between the predicted and observed sums of loss coefficients which may translate into unacceptable shifts in airflow distribution.

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List of Abbreviations

Q	airflow (cubic feet per minute: cfm)
V	velocity (feet per minute: ft/min, fpm)
VP	velocity pressure (inches water gauge: "w.g.)
df	density factor: ratio of actual density to standard density (also ρ)
SP	static pressure (inches water gauge: "w.g.)
SPH	static pressure just downstream of a hood
SPend	static pressure at the most downstream point of a run
TP	total pressure = SP + VP
F	dimensionless pressure loss coefficient
Fobs	observed loss coefficient $\left(\frac{(SPin\text{-}SPout)VPduct}{VPduct}\right)$
Fest	estimated loss coefficient = published value + contributions from short length of duct, elbows (if present)
F_h	hood entry loss coefficient
Fen	entry loss coefficient at a junction due to mixing of air
F_{el}	elbow loss coefficient
Nel	number of elbows in a run
F_f	loss coefficient due to flow along surface of duct
L	length of duct in feet
Diam	diameter of duct in inches
A	area of duct (square feet: ft^2)
θ	angle of entry of a branch at the junction
ID	identification number assigned to a given duct
Type	type of run (i.e. branch, submain)

Acknowledgments

Thanks to my committee members– my preceptor, Dr. Steven Guffey, for his tireless instruction and Dr. Michael Yost for his insight. Thanks to Dr. Gerald van Belle for his statistical input and time when I really needed it.

I would like to thank the staff at the Seattle Central Community College Wood Technology Center for their cooperation with this project: Don Khile and John Harvey for opening up their shop to me; Delores Toycen, for opening the door those early Friday mornings; Tim Watson, who truly believes that I work banker's hours; Roger Webster, for finding me the wrench that I forgot, chatting to keep me from talking to myself, and locking the gate behind me; and finally to all the students who helped me define what it is I was doing by asking me.

Thanks to my friends and family who supported me. Special thanks to my sister Suzanne, for her inspiration. Most of all, thanks to David.

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I. INTRODUCTION

Ventilation is essential in reducing occupational exposures to airborne contaminants. To perform adequately, each hood must obtain its proper share of the total airflow provided by the fan. Appropriate distribution is achieved with judicious selection of components and duct sizes. Thus, proper design decisions are critical to contain workplace contaminants and thus minimize exposures. "The ability of a local exhaust ventilation system to remove contaminants at the point of release is dependent on proper design, construction, operation and maintenance."[8] Since the goal of the latter three is to maintain the flows determined for the design, proper design is prerequisite to continued successful operation.

To achieve the optimum distribution, the engineer designs a system by employing a model which predicts pressures and flows throughout the system. After a system is installed, changes to the system are often made to keep apace with the industrial process it ventilates. The effects of those changes should be predicted as well. Thus, a robust model must be able to predict airflow distribution both for initial design and for subsequent modifications

This field study attempts to empirically determine the error of the American Conference of Governmental Industrial Hygienists (ACGIH) model for two installed systems by comparing the sum of loss coefficients estimated using the values published by ACGIH to those observed in actual operation. In addition, the sources of deviation between these observed and estimated values are assessed.

II. BACKGROUND

Industrial exhaust systems are designed using a mathematical model which predicts pressures and flows throughout the system. The model is used to guide selection of duct size, volumetric flow rate and, ultimately, the fan and power requirements. The goals when selecting duct sizes are to obtain proper airflows and to maintain high enough duct velocities to carry particulates in the ducts without the settling of particulates. An error in the model could result in poor selection of duct sizes, leading to poor system performance, including unnecessary exposures to workers and costly rework.

The model most commonly used in designing industrial exhaust systems is that described by the ACGIH in Industrial Ventilation: A Manual of Recommended Practice (IVM). The IVM utilizes velocity pressure loss coefficients for all system components to model and predict static pressures and airflow distribution throughout the system. Another group, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) use a design method that differs only in the values of coefficients and their treatment of junctions. However, this study focuses on the IVM method and coefficients.

The Predictive Model

Industrial ventilation theory is rooted in fluid mechanics. As in hydraulics, the flows can be treated as incompressible and adiabatic with negligible error. As in hydraulics, the primary source of pressure loss in exhaust systems is the separation of flow and the resulting eddy currents caused by entry into ducts, friction, bends and obstructions.[25,32] Except for friction losses due to flow along surfaces, these losses are assumed to be proportional to the velocity pressure at those fittings. Hence the name "velocity pressure" method given to the approach described in the IVM.

The IVM employs the velocity pressure method to calculate the pressures throughout an exhaust ventilation system. The method assumes that the pressure differential across each component is proportional to the velocity pressure :

$$SP_{component} \propto VP \qquad \text{.......(1)}$$

Where: SP = static pressure, inches water gauge

VP = velocity pressure, " w.g.

$$VP = df\left(\frac{V}{4004.68}\right)^2 \qquad \text{.......(2)}$$

Where: df = density factor

V = velocity, ft/min

The loss coefficient (F) characteristic of a given component (e.g. elbow, hood, etc.) is the proportionality constant relating observed static pressures and velocity pressures for that component:

$$F = \left(\frac{(SP_{in} + VP_{in}) - (SP_{exit} + VP_{exit})}{VP_{exit}}\right) \qquad \text{.......(3)}$$

Where: "in" is upstream of component
"exit" is downstream of component

Thus, one can empirically determine loss coefficients associated with a given type of elbow (F_{el}), hood (F_H), length of straight duct (F_f), and any other component that is used in the system. The values of F varies with the method of construction and the geometric parameters for that component.

The IVM model also assumes for serial flow along a given duct that the downstream pressure is equal to the sum of all the pressures due to the upstream components. Thus, for any cross-section, the static pressure at any point can be determined from the sum of the static pressures upstream of that point. As an example, for cross-section Z in Figure 1 below, the static pressure at Z can be determined from the sum of the static pressures due to the hood (SP_H), friction (SP_f), elbow (SP_{el}):

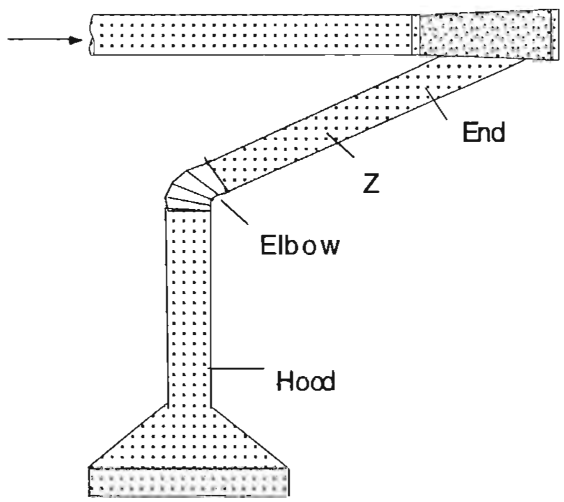

Figure 1: Elements Contributing to Static Pressure Within a Run

$$SP_Z = SP_H + SP_{el} + SP_f \qquad ....(4)$$

$$= (1 + F_H)VP + N_{el}F_{el}VP + \left(\frac{F_fL}{100'}\right)VP \qquad ....(5)$$

$$= -VP\ [\ (1+ F_H) + N_{el}F_{el} + \left(\frac{F_fL}{100'}\right)] \qquad ....(6)$$

Where:

- F_H = loss coefficient for entry from hood to duct
- N_{el} = number of elbows
- F_{el} = loss coefficient for one 90° elbow
- F_f = loss coefficient due to flow over surface of duct
- L = length of duct
- VP = velocity pressure common to all cross-sections within that section of duct

The estimated sum of coefficients for Z can be defined as:

$$F_{Zest} = [F_H + N_{el}F_{el} + \left(\frac{F_f L}{100'}\right)] \quad ....(7)$$

Where: F_{Zest} = sum of published loss coefficients

Note that the observed value of F_Z can deviate by some error (Ferror) from the value estimated by summing the relevant published coefficients:

$$F_{Zobs} = F_{Zest} + F_{error} \quad ....(8)$$

Where: F_{Zobs} = observed sum of loss coefficients
F_{error} = "other" losses not accounted for by model.

Thus, the estimated sum of coefficients obtained using the published loss coefficients can be calculated if one can select an appropriate published value for each component within a given run of duct.

The pressures measured throughout a system can be employed to determine the "observed" sum of loss coefficients by combining Equations (6) and (7):

$$SP_{Zobserved} = -VP\ [1 + F_{Zobs}] \quad ....(9)$$

Thus solving for $F_{Zobserved}$:

$$F_{Zobserved} = \left(\frac{-\ SP_{Zobs}}{VP_{obs}}\right) - 1 \quad .....\ (10)$$

The error in estimating F_Z is thus:

$$F_{Zerror} = F_{Zobs} - F_{Zest} \quad .....\ (11)$$

Effect of The Error in Estimating F on Airflow Distribution

It has been shown elsewhere that predicting airflow distribution is dependent upon predicting the pressures at a junction fitting.[20] The IVM assumes that the airflow distribution between two ducts arriving at a junction is fixed by the requirement that the static pressure at the junction for each pathway must be the identical pressure:

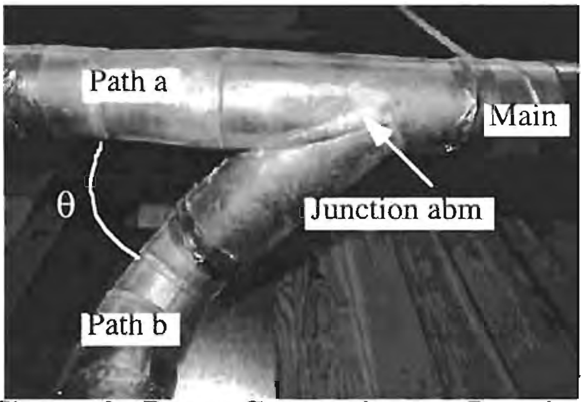

Figure 2: Ducts Converging at Junction

$$SPJ_{patha} = SPJ_{pathb} \qquad \ldots.(12a)$$

Where:

SPJ_{patha} = $-VP_a[1 + F_a + Fen_a]$ (12b)

$SPJpath_b$ = $-VP_b[1 + F_b + Fen_b]$ (12c)

and

VP_a = velocity pressure in path a just upstream of the junction

VP_b = velocity pressure in path b just upstream of the junction

Fen_a = entry coefficient for air mixing at the junction for path a

Fen_b = entry coefficient for air mixing at the junction for path b

Substituting in the definitions of SPJ_{patha}, SPJ_{pathb}, Fen_a and Fen_b, Equation (11) can be restated as:

$$\frac{VP_a}{VP_b} = \frac{[1 + F_a + Fen_a]}{[1 + F_b + Fen_b]} \qquad \text{..... (13)}$$

Since velocity pressure is proportional to velocity squared (V^2) and to density (ρ), and airflow (Q) is equal to the velocity multiplied by the area of the duct (A)

$$Q_a \propto \rho_a * \sqrt{VP_a} * A_a \qquad \text{.... (14a)}$$

$$Q_b \propto \rho_b * \sqrt{VP_b} * A_b \qquad \text{.... (14b)}$$

Where:
ρ_a = density factor for duct a
ρ_b = density factor for duct b
A_a = area of duct a
A_b = area of duct b

Equations (14a) and (14b) can be manipulated to produce:

$$\frac{VP_a}{VP_b} = \left(\frac{Q_a/A_a}{Q_b/A_b}\right)^2 \qquad \text{..... (15)}$$

Substituting Equation (15) into Equation (13) results in the relationship which relates airflow distribution for two ducts arriving at a junction $\left(\frac{Q_a}{Q_b}\right)$ to the loss coefficient values[21]:

$$\frac{Q_a}{Q_b} = \frac{A_a}{A_b}\sqrt{\frac{\rho_b}{\rho_a}}\sqrt{\frac{[1 + F_b + Fen_b]}{[1 + F_a + Fen_a]}} \qquad \text{..... (16)}$$

Using Equations (11) and (16), it is possible to relate the error in estimating F values to error in airflow distribution $\left(\frac{Q_a}{Q_b}\right)$. Rearranging Equation (11):

$$F_{observed} = F_{estimated} + F_{error}$$

In a similar fashion, it can be stated that:

$$Q_{observed} = Q_{estimated} + Q_{error} \qquad \text{..... (17)}$$

Substituting Equations (11) and (17) into Equation (16):

$$\frac{Qest_a + Qerror_a}{Qest_b + Qerror_b} = \frac{A_a}{A_b}\sqrt{\frac{1 + F_{estb} + Ferror_b + Fen_b}{1 + F_{esta} + Ferror_a + Fen_a}}\sqrt{\frac{\rho b}{\rho a}} \quad \ldots\ldots (18)$$

Note that the ratio $\left(\frac{\rho b}{\rho a}\right)$ is largely determined by the temperatures and humidities in duct a and b and can be considered as constants for this analysis.

Using Equation (18), one can relate the errors in F to errors in airflow (Q) and airflow distribution $\left(\frac{Qa}{Qb}\right)$. The IVM considers ± 5% of the target airflow to be an acceptable error.[1] Therefore, the number of interest in this study is the corresponding allowable error in F. Given a 5% increase in the airflow of one converging duct (i.e., duct a) and a 5% decrease in the other (i.e., duct b), Equation (18) yields an "acceptable" error of 16% in Fsum (i.e., produces a shift in Qa and Qb of less than 5%). Figure 3 illustrates the ratio of airflows at a junction changes with differing magnitudes of error in Fsum. It is apparent in Figure 3 that over-estimating and under-estimating pressure loss coefficients have equal effects on the distribution ratio. Therefore, it is a mistake to "conservatively" overestimate loss coefficients. Instead, it is desirable to use the best available estimate for a loss coefficient.

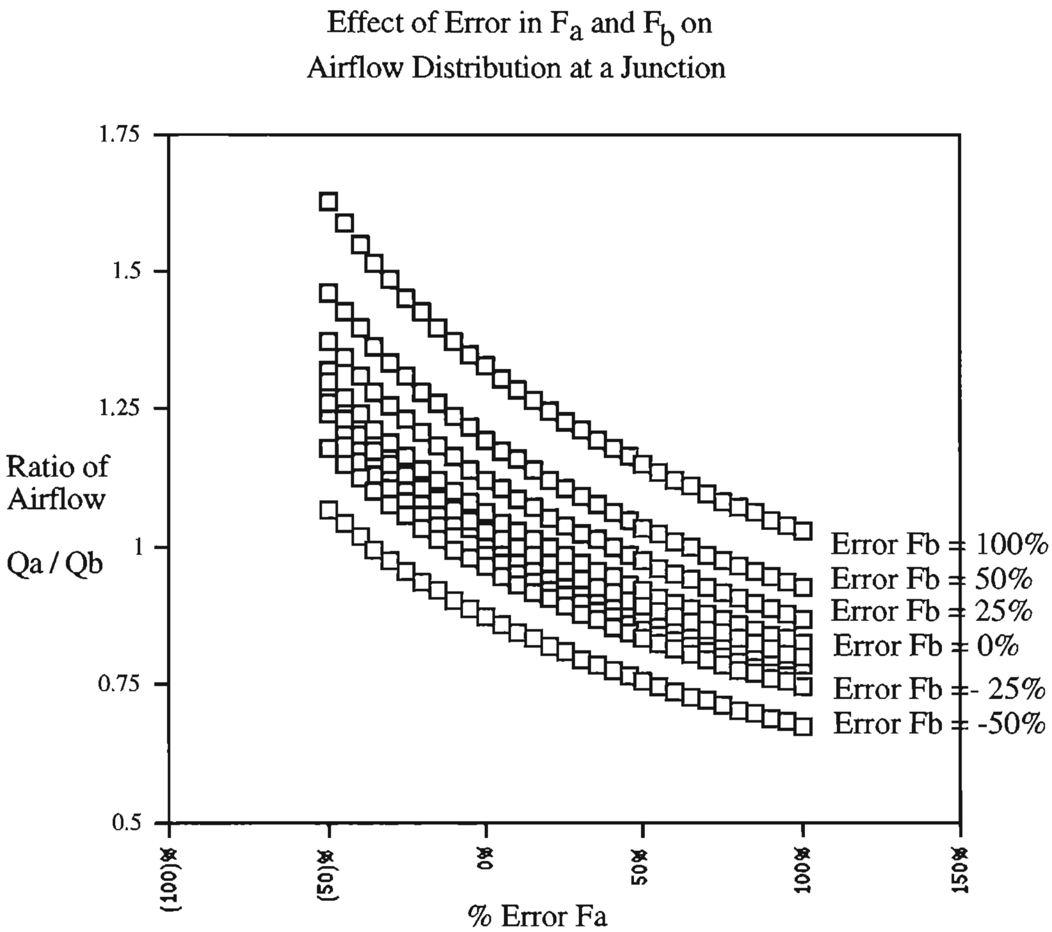

Figure 3: Effect of F_{error} on Airflow Distribution at a Junction

Loss Coefficients: Sources and Derivation

Loss coefficients are determined for new, individual components under laboratory conditions.[1,2,6,7,11,26,28,30,32] The coefficients for hoods, elbows and friction are of the greatest interest to this study. Several organizations, in addition to the ACGIH, publish loss coefficients for various ventilation fittings. These include the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and Sheet Metal and Air Conditioning Contractor's National Association (SMACNA). Because this study focuses on the ACGIH method, the estimated coefficients have been chosen from the IVM.

Sources of Hood Loss Coefficients

IVM loss coefficients for hoods (F_h) originate from studies by Brandt and Dalla Valle in the mid-1940s.[4,11] The hood entry loss is calculated at one location with the contribution due to friction along the length of duct between hood entry and measurement location is subtracted out. Hood entry loss coefficients are listed in Table 1. As can be seen in this table, the IVM is the primary source for many of the pressure loss coefficients used for exhaust design. This is not surprising since ASHRAE focuses on HVAC, and several of the other sources are from hydraulics. It is worth noting, however, that many of the values for the wood-working equipment published in the IVM lack a reference to original published work. Given that the hood entry accounts for a great portion of the losses within a branch, the dearth of published work on the subject is striking. Recent studies by McLoone[28] and Geisberger and Sibbitt[16] attempt to refine and redefine losses for hood entry.

Table 1: Loss Coefficients For Duct Entry From Various Sources

Entry	ACGIH[1]	ASHRAE[3]	Brandt[6]	Dalla Valle[11]	Idelchik[25]	White[32]
Plain	0.93	1.0	0.93	0.719	1.00	0.78
Flanged	0.49	0.50	0.49	0.83	0.50	0.40-0.50
Taper (90°)	0.15	0.16	0.23	-	-	-
Plain/Elbow	1.60	-	+	-	-	-
Floor Sweep	-	-	+	-	-	-
Table Saw	(1)	*	+	#	-	-
Jointer	(2)	*	+	#	-	-
Planer	#	*	+	#	-	-
Belt Sander	$0.40VP_{duct}$	*	+	#	-	-
Disc Sander	(2)	*	+	#	-	-

(1) $Fh = \left(\frac{1.78\ VPslot + 0.25\ VPduct}{VPduct}\right)$ (2) $Fh = \left(\frac{1.0\ VPslot + 0.25\ VPduct}{VPduct}\right)$

gives airflow requirements only

* refers reader to IVM

+ Brandt states that losses for compound hoods should be determined using the sum of the losses of the components of the hood, i.e. flanged entry + tapered take-off, etc.

In searching for coefficients to describe the equipment studied, this author found that even the manufacturers of the wood-working devices could provide no additional information.

Loss Coefficients for Elbows

Loss coefficients for elbows reference a paper by Locklin in 1950, in which the available data was reviewed and consolidated into a single reference describing the losses in a 90° duct elbow.[26] Loss coefficients for elbows of different turning angles were determined mathematically as a proportion of a 90° elbow. Some have found that losses for elbows less than 90° do not necessarily fit a linear relationship, yet it is deemed close enough for design purposes.[9] For example, a 45° elbow is assumed to have half the loss of a 90° elbow. The term "equivalent elbow" refers to what fraction of a 90° elbow loss a given elbow will be assigned. An additional source for elbow losses is Idelchik, in the field of hydraulics.[3] A review of current literature reveals more recent studies that have investigated losses for elbows in the laboratory, in an effort to derive applicable modeling equations or to refine the existing coefficients.[7,12]

Sources of Error in Published Loss Coefficients

Loss coefficients themselves may be inaccurate, thus producing error when applied. Coefficients determined for components may vary with parameters not now considered. For example, Dalla Valle recognized differences in entrance losses with different duct diameters,[11] and ASHRAE research has shown that elbow losses vary with the diameter of the duct as well as geometry.[7] Present IVM elbow coefficients are based solely on the number of sections, radius of curvature and turning angle.

Error in Estimating Friction Losses: As discussed by Guffey, friction losses are determined in the laboratory for length of straight duct some distance up- and downstream of any fitting to assure fully developed flow.[23] Friction loss determined for a given construction and roughness is calculated per unit length, assumed to be uniform along the entire length of the duct. Thus, this friction loss is subtracted from the measured differential across a given fitting when a loss coefficient is determined for that fitting. It is not understood how much error results from applying these friction values in cases near components, such as hoods or elbows.

A recent laboratory investigation by McLoone found that the entry loss determined differed depending on the number of duct diameters distance at which the hood static pressure was measured. He concluded that the variation in the observed hood entry loss was due to the error in accounting for the friction losses to the various measuring points.[28] McLoone suggests that this method of calculating the contribution due to friction may be in error.

Assumption of Additivity of Losses for Components in Series: Of particular importance in modeling an existing system, is the assumption that the coefficients of components in series are additive. However, it may not be accurate to model a series of components as if they are equivalent to a single component having a coefficient equal to the sum of the individual coefficients. Personal communication with D.J. Burton as well as an extensive literature search reveals that the validity of this assumption has not been validated in published literature.

Independence of Losses: Closely mounted fittings may interact with each other, a possibility not generally considered in the IVM. An exception is the ACGIH loss coefficient for a plain duct opening adjacent to an elbow. The plain duct is assigned a loss of 0.93 and an elbow considered separately has a loss coefficient of 0.21 for a total loss coefficient of 1.14. The manual, however, lists a value of 1.6 for the loss of such a fitting.[1]

A study by Sepsy and Knotts (1972) investigated the effects of branch spacing on entry loss coefficients. Using a set-up of two tees, they found that the effect of branch spacing on the upstream tee loss coefficient was negligible. Those for downstream tees, however, decreased with increasing distance.[30]

In addition, in the Handbook of Hydraulic Resistance, Idelchik states that the total resistance coefficient (the equivalent of loss coefficient) for a system can be described as the sum of the separate elements of the system and, as a rule, a correction for the interaction of the adjacent elements of the system.[25]

Robustness of Coefficients: Coefficients assigned to types of fittings may not be accurate across the different configurations within that type, or across slight variations in manufacture and geometry. For example, the coefficient for a table saw may not be robust across all table saws. Geisberger and Sibbitt[16] found this to be the case across 40 different configurations of compound exhaust hoods with slots. They used the slot loss coefficient (1.78VPduct) and the applicable transition loss, finding errors as high as 68%.

It is not known whether published coefficients are robust when applied to aging components. If it is the case that coefficients developed for new components apply poorly to those which are well-used, then if a modification is to be made to an existing system, predictions of the change should be modeled on the system as is.

Common Components Lacking IVM Published Coefficients: Lastly, there remains common fittings for which the IVM does not publish loss coefficients, including dampers, cleanouts and flexible duct. Lack of coefficients in the IVM could be interpreted by naive practitioners to mean that no losses should be computed for these components. However, coefficients for these fittings may be available from other sources. For example, Goodfellow has published values for flexible duct.[17] and ASHRAE assigns a coefficient of 0.19 to a damper.[3]

Coefficients specific to floor sweeps and flexible duct have not yet been published in the IVM. Brandt suggested that losses for compound hoods, such as the woodworking equipment or the floor sweep, could be calculated as the sums of the losses for the various component parts.[6] The published value for a table saw, 1.78VPslot + 0.25VPduct, is a good example. It is comprised of the loss at the slot, which could be seen as an orifice and thus uses the same loss estimate. Next, the loss at the duct entry is calculated, assuming a tapered take-off, with the appropriate loss of 0.25 VPduct assigned to it. Lastly, diligent application of existing coefficients, for example using a value between that for a plain duct opening and that for a flange to describe a floor sweep, may suffice for components which lack published values.

III. HYPOTHESES

The observed sum of loss coefficients (F_{obs}) for each section of each branch is equal to that estimated by the sum of the ACGIH published loss coefficients (F_{est}) for the components in that section:

$$H\o: F_{obs} - F_{est} = 0$$

The accompanying alternative hypothesis is:

$$H\o: F_{obs} - F_{est} \neq 0$$

A second hypothesis is that F_{est} will describe the F_{obs} for a given branch within 16%, the value associated with excessive shifts in airflow (> 5%):

$$H_{\o}: 0.84 (F_{est}) < F_{observed} < 1.16 (F_{est})$$

The alternative hypothesis is:

$$\text{If } F_{obs} > F_{est},\ H_A: F_{obs} - 1.16F_{est} > 0$$

or

$$\text{If } F_{obs} < F_{est},\ H_A: F_{obs} - 0.84F_{est} < 0$$

IV. MATERIALS AND METHODS

Apparatus

Selecting the systems used in the study

The following criteria were used in selecting industrial exhaust systems for modeling in this study:

• Ducts must be accessible in a safe manner.

• At least one of the systems should be newly installed to discount "aging" effects of ducts. Worn ducts and components may be less suitable for modeling with loss coefficients which are determined for pristine components in laboratory conditions.

• Systems should be laid out in a manner conforming as closely as possible to ideal or "preferred" layouts described in the Industrial Ventilation Manual.

• Little or no flexible duct should be present. This proved difficult as flex duct is so convenient in use that it is ubiquitous. Because it is movable, it is difficult to model these ducts over time.

• It must be possible to measure all pressures in one outing to ensure that the system is modeled while operating under consistent conditions (i.e., at consistent fan speed).

• Location of the systems must be convenient to allow for frequent site visits required in conducting a field study.

• The system should be heavily used, a criterion for the troubleshooting method validation study of which this current study is a part.

Systems: Seattle Central Community College Wood Technology Campus

Finding systems that fulfilled all the above criteria proved to be impractical. Due to a lack of choices that met the criteria , all the systems surveyed included dampers, a "necessary evil" for which the IVM has not defined a loss coefficient. In addition, all included flexible duct. Three systems at the Seattle Central Community College Wood Technology Program, however, were found to be the most suitable of those available. Loss coefficients for most of the equipment in the cabinet shop have been published in the IVM. Most junctions in these systems are defined as good in the manual. Because obtaining all the required system pressures is time and labor intensive, this study was limited to the two dust collection systems located in the mezzanine of the facilities, dubbed " Mez East" and "Mez West" according to their location. Both were installed in early 1993. Both contain a small amount of flex duct (most of which is secured into position) and dampers.

At the start of this project, it was not clear whether capped off branches could be modeled with the IVM approach. Mez East contains a number of capped off runs branching off submain 90 (See Figure 4). For that reason, an alternate scheme which truncates this system at submain 80 was used in the later rounds (See Figure 5). This part of the system contains no "dead" runs. It should be noted, however, that there is no documented method of accounting for capped off runs that are installed to allow for future expansion. Due to the lack of available information about them in the IVM, these capped runs were excluded from this project.

This study is limited to the analysis of the sums of coefficients for the branches. Although information necessary to model submains was collected, submains are beyond the scope of this study. The subject of predicting airflow distribution at the junction as well as junction entry losses has been investigated previously.[10,19,21,31]

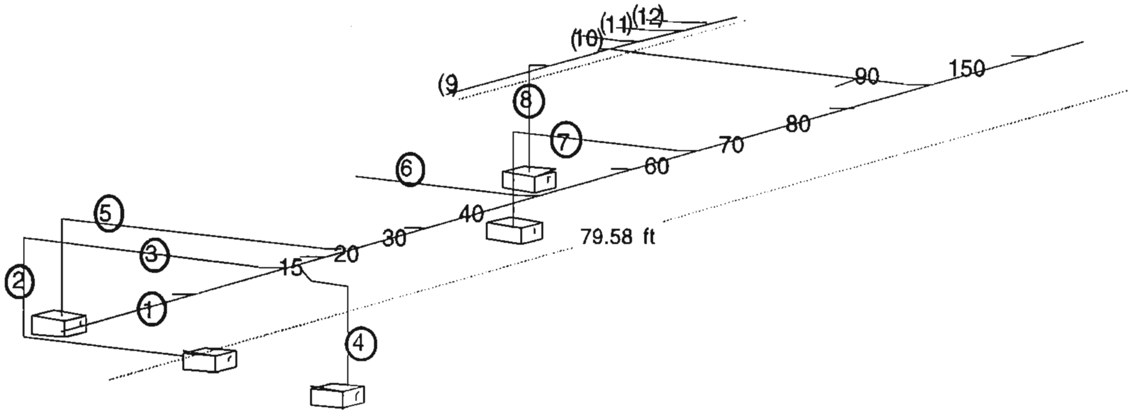

Figure 4: Mezzanine East (MezEast)

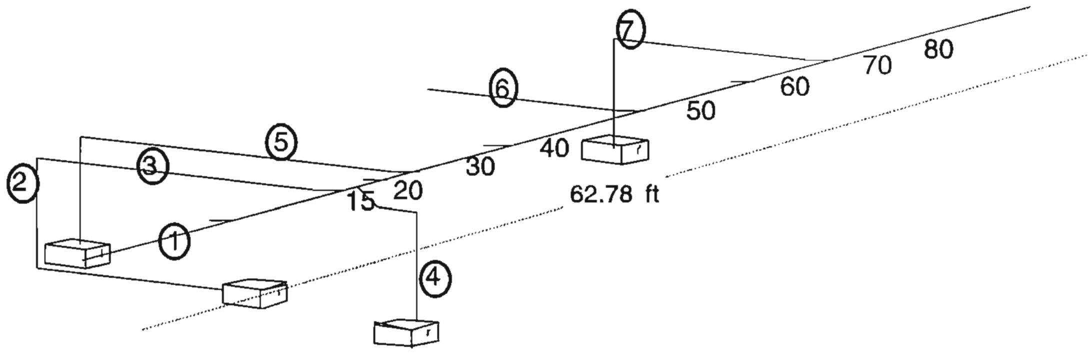

Figure 5: MezEast Truncated at Submain 80

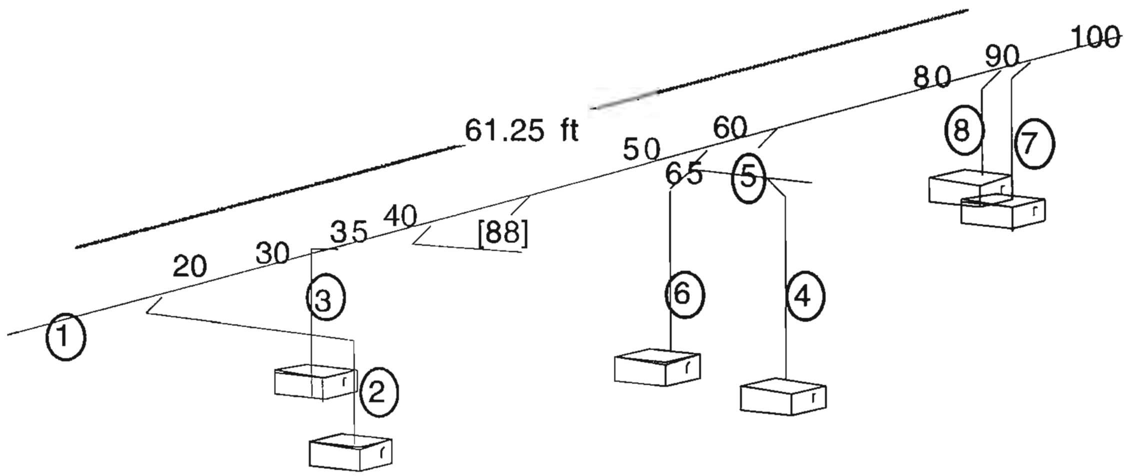

Figure 6: Mezzanine West (MezWest)

Selection of Measurement Locations

Perpendicular ten-point velocity pressure traverses were taken on each branch. Static pressure measurements were taken one to four duct diameters downstream of each hood and at the end of each branch, A midpoint value was also taken on some branches. Static pressure readings were taken at the end of each submain.

The IVM states that velocity pressure measurements should be taken at least seven duct diameters downstream of any obstruction, elbow or other component which may skew the velocity profile and at least two duct diameters upstream of the same.[1] Static pressure measurements can be taken just 1 - 2.5 duct diameters downstream of a hood or obstruction since static pressure resumes an even profile more quickly than velocity pressure.[22]

Such favorable locations were not available in some instances. In those cases, the best available locations were chosen for the necessary measurements.

Characterizing the Systems

Each component of both systems was thoroughly described before selection of loss coefficients from the ACGIH Industrial Ventilation Manual (see Appendix D). Characterization for each branch included:

(a) Identification of each run of duct and assignment of an integer ID number for reference. A new number designated a different branch or submain, or a change in diameter of the same branch or submain. For example, if a branch had a taper within it, the ducts upstream and downstream of the taper were assigned different branch ID numbers.

(b) Measurement of the length of duct for every branch from hood to centerline of the junction and from the hood static pressure measurement location to the "end" pressure measurement location.

(c) Measurement of nominal duct diameters with a steel tape and with a micrometer, where accessible.

(d) Count of elbows per run, and determination of turning angles and radius of curvature for each elbow.

(e) Determination of taper angles, where present.

(f) Measurement and calculation of slot areas for hoods with slot openings.

In addition, all ducts were categorized as to whether or not this author believed that they would be good candidates for modeling. For example, dents, poorly connected junctions, dampers and cleanouts were noted. Most branches (12 of 16) have dampers as well as cleanouts (11 of 16). All leaks that were sealed with duct tape. The quality of the measurement location was also noted. Bad hood static pressure measurement location (5 of 16), and poor velocity pressure traverse locations were noted (4 VP traverses were adjacent to dampers).

The most common theme in this author's *a priori* determinations of the expected predictability of a given branch was the presence of dampers and the inability to account for them. Since the IVM does not account for "fully opened" dampers, no loss was assumed. However, basic fluid mechanics dictates that any impedance to flow, no matter how slight, has the ability to induce separation which is the root of most pressure losses in the system. Even completely opened, the damper still extended slightly into the duct. ASHRAE publishes an expected loss coefficient of 0.19 for open dampers.

Hood slot areas were determined in two ways: from measurements of slot width and height and back calculating the area using the velocity measured in the open areas.

$$Aslot = width_1 height_1 + width_2 height_2 + width_n height_n \quad \text{..... (19)}$$

$$Aslot = \left(\frac{Qobserved_{duct}}{Vmeasured_{slot}} \right) \quad \text{..... (20)}$$

Where: $Aslot$ = area of the slot
$Qobserved_{duct}$ = airflow in duct determined from velocity pressure traverse
$Vmeasured_{slot}$ = velocity measured in open areas with thermoanemometer

The velocity in the open areas was calculated from an average of 10 readings obtained during a casual traverse of the open areas with a thermoanemometer. The direct and indirect measurement of all open areas and the calculated areas were fairly consistent as discussed later for those affected hoods. Because it is possible velocity measurements may over-estimate average velocity, thus underestimating the total area, the area determined from the measured slot velocity was used if it was slightly larger than that indirectly calculated. If they differed to a greater extent, the calculated area was used on the assumption that a sizable error was quite possible in measuring some of the highly irregularly shaped areas. This was the case with the jointer, as is discussed later in this paper.

Selection of Loss Coefficients

Loss coefficients were selected from the values recommended in the Industrial Ventilation Manual (IVM) for each fitting. This was a simple task for the elbows, expansions, and for some hoods. The elbow loss coefficient of 0.21 was assigned, for elbows of 5 sections, with a radius of curvature of 1.75 and a turning angle of 90°. Partially turned elbows were estimated to be proportional to values for 90°, as shown in IVM. Coefficients for expansions are based on the fitting's angle as well as the ratio of the upstream and downstream duct diameters. These can be found in Appendix D. Published values for hoods can be found in Table 1. Loss coefficients were missing for other components.

In these instances, coefficients were contrived based on the information available. A floor sweep is one such example. It is neither a simple transition nor slot plenum hood. A value midway between that for a plain duct opening (0.93) and a flanged opening (0.50) was employed as the best estimate.

The roughness for flexible duct , 0.01, was obtained from Goodfellow.[17] No coefficient for flexible duct was suggested in the IVM.

The IVM friction loss for "average" pipe of all sizes, 0.0005 inches per foot ("/ft),was used for the galvanized spiral wound ductwork. The manufacturer of the ducts (Accuduct) could not provide the actual roughness value.

As mentioned previously, there is no loss coefficient for "open" dampers in the IVM, which assumes no loss if the dampers are fully opened. Likewise, there are no published coefficients for cleanouts. The "expected" coefficients for these components were assigned a value of zero. Their effect on the deviations between estimated and observed sums of loss coefficients is discussed later in this paper.

Instrumentation

A Dwyer Series 475 Mark II Digital Manometer, with accuracy of ± 0.5% and resolution of 0.01 inches water gauge ("w.g.), was used for all measurements. [13]

Dwyer 1/8" and 3/8" pitot tubes with an accuracy of ± 2% (complying with AMCA and ASHRAE specifications) were used.[15] Pitot traverse devices designed by Guffey[18] and described elsewhere were mounted to the ducts and used for velocity pressure traverses. Pitot tubes were connected to the digital manometer using 1/4" Tygon® tubing.

Dry and wet bulb temperatures were measured during each session with a Psychro-Dyne Model 3312-40 psychrometer> These values were used to calculate the density of the air.

A TSI Incorporated "VelociCalc" Model 8325 thermoanemometer was used to measure slot velocities.

Calibration

Initial calibration of the Meriam Wall-Mounted 4" Inclined Manometer (model # 40HE35WM) and the Dwyer Digital Manometer (Series 475 Mark II) was done in October, before field data were collected, using a Dwyer Hook Gage (Series 1425) with 0.001 'w.g. resolution as the primary standard.[14] Subsequent calibrations of the Dwyer digital manometer were done using the wall-mounted inclined manometer. This was done monthly, since readings were taken monthly on each of the two systems.

For calibration, both the Dwyer digital manometer and the Meriam inclined manometer were connected via Tygon® tubing and a manifold to a Meriam hand pump (model # B34348). Pressures ranging from 0.10 - 4.00 inches water gauge ("w.g.) were applied. Readings from both instruments were recorded and compared.

Calibration data is described briefly in the results section of this paper. Complete calibration data can be found in Appendix A.

Data Collection Software

Field data was entered directly into a Toshiba Portege 3400 laptop computer using HV_MEAS spreadsheet software (version 1.0) developed by Guffey for surveying and troubleshooting ventilation systems.

Statistical Software

Statistical analysis for this study was completed using Data Desk®, Version 4.2c software by Data Description, Inc., Ithaca, New York.

Measurement Procedure

Study Design

This study was a natural experiment: that is, a non-intervention, observational project that monitored ventilation systems over time with repeated measurements. Each of the two systems is considered a block, with the identical procedure used on each during each measurement session. Mezzanine East was measured six times over a six month period and Mezzanine West was measured four times over a six month period. The imbalance resulted as one system was measured over consecutive days as a means of assessing daily change over periods of non-use.

System Preparation

The fan was run for at least 30 minutes prior to taking measurements, allowing it to achieve steady operation. While the system warmed up, all dampers were opened fully and secured in that position with a sheet metal screw. Endcaps were removed from some branches to create additional branches that should be clean ducts. Lastly, hoods were checked for obstructions which would interfere with flow and modeling efforts. Contents which may have settled within the ducts themselves were not removed. Upon visual inspection, however, the ducts were clean.

The systems were measured when the shop was not in use to avoid interference with shop activities. This also ensured that the system was not tampered with during the measurement sessions.

Pressure Measurements

All static pressure measurements were taken at the centerline of the duct using a pitot tube. For branches, measurements were taken (1) 1-4 duct diameters downstream of the hood, (2) several duct diameters upstream of the junction ("end"), and where possible, (3) in between ("mid"). For submains, static pressure was measured upstream of the junction ("end"). In addition, ten-point perpendicular velocity pressure traverses were taken for each branch.

Measurements began at the farthest upstream branch and progressed downstream towards the fan. All pressure readings were recorded in HV_MEAS. Immediate comparison to previous measurements revealed some measurement errors, such as inadvertently reading velocity pressure instead of static pressure at a hood. These measurements were immediately redone.

On two occasions, velocity pressure traverses and hood static pressure ratios were taken repeatedly to determine if the systems were fluctuating over the course of a data collection session. In addition, in April repeated "hood" and "end" static pressure measurements were taken every ten minutes in Mez East.

Slot velocities were measured during two sessions using a TSI thermoanemometer to enable a better characterization of the loss coefficients for the woodworking equipment. Velocity pressures across these areas was calculated using Equation (2).

Once the entire system had been measured, three branches and three submains were selected randomly for remeasurement. Thus, measurement error could be quantified.

Modeling the System

Schematics of the dust collection systems were created in HEAVENT, a ventilation design software program created by Guffey.[24] HEAVENT imported the observed values from the appropriate HV_MEAS files. Using the input loss coefficients and the observed pressures, the program computed the sum of coefficients from the published loss coefficients for each duct and computed the difference between the observed and estimated sum of coefficients.

V. RESULTS

Calibration

Regression of the initial calibration of the inclined manometer with the hook gage yielded an R^2 of 100% with a standard error of 0.0137 " w.g. The gain error was less than 0.5% with a zero error of 4.24×10^{-3}. These values are negligible compared to the differences found in the results of this study.

Summary statistics for the calibration of the digital manometer with the inclined manometer are shown in Table 2. The overall R^2 value for calibration of the Dwyer digital manometer versus the inclined manometer over seven months was 100%, as shown in Table 3, with a standard error of 0.0136. Figure 7 presents this graphically. The Dwyer digital manometer typically reported slightly lower values than the Meriam inclined manometer, with the greatest deviation being 1.6%. at 3.0" w.g.(see Figure 8). Complete calibration data can be found in Appendix A.

Table 2: Summary Statistics for (Dwyer Digital Manometer- Meriam Inclined Manometer)

Parameter	Value
Numeric	81
Mean	-0.0088
Standard Deviation	0.0148
Variance	0.0002
Minimum	-0.0500
Maximum	0.0100

Table 3: Regression of Dwyer Digital Manometer versus Meriam Inclined Manometer

Dependent Variable: Dwyer Digital Manometer

Source	Sum of Squares	df	Mean Square	F-Ratio
Regression	114.883	1	114.883	623096
Residual	0.0146	79	0.0002	

Variable	Coefficient	s.e. of Coeff	t-Ratio	Probability
Constant	-1.8635e-3	0.0023	-0.810	0.4204
Meriam Inclined	0.9950	0.0013	789	≤0.0001

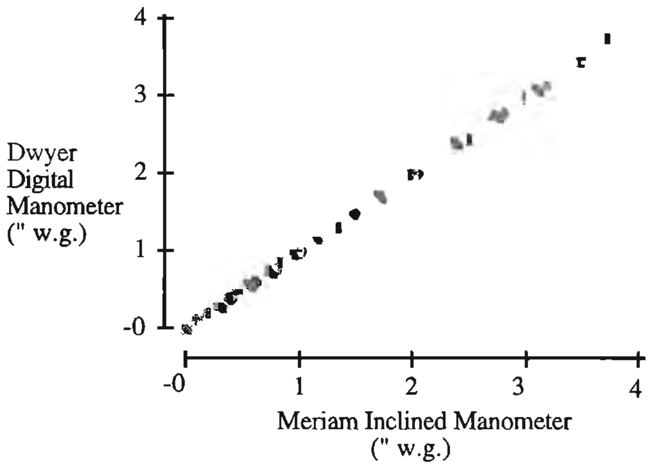

Figure 7: Digital vs. Inclined Manometer Readings

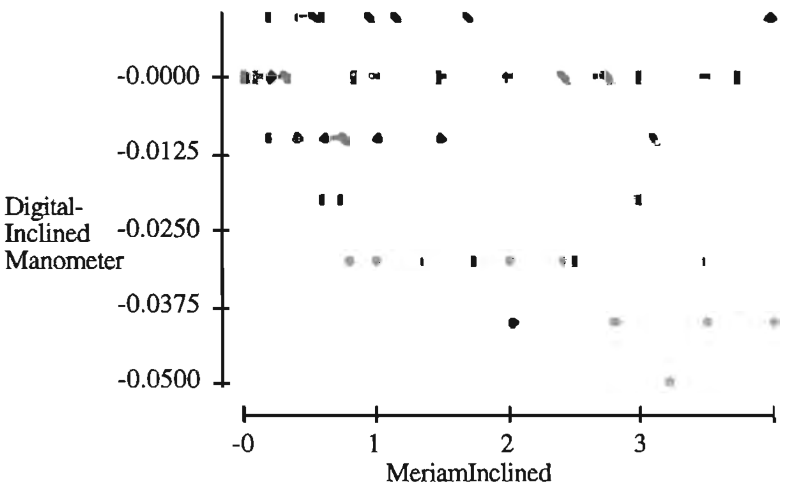

Figure 8: (Digital-Inclined Manometer) vs. Inclined Manometer

Repeatability Measurements

Measurement repeatability was assessed in two ways. To quantify measurement error, three branches and three submains were selected randomly at the end of each data collection session for remeasurement. The values obtained during each repeat round were compared to those initially obtained earlier that day. Figure 9 depicts the plots of the initial and repeated hood and end static pressure measurements. Regression analysis of repeat to initial SPH measurements yielded an R^2 of 99.5% with a standard error of 0.0126. The same analysis for SPend values yielded an R^2 of 99.3% with a standard error of 0.01331.·Data collected during these random repeat measurements can be found in Appendix B.

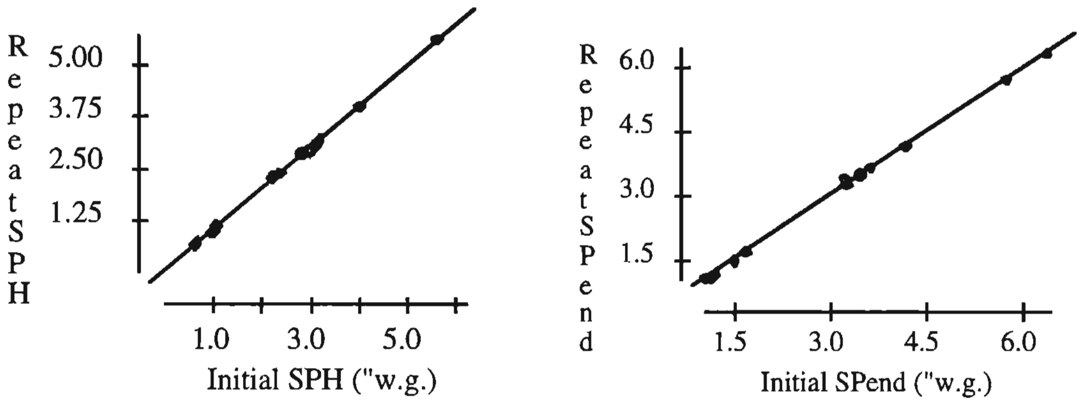

Figure 9: Repeat vs. Initial Static Pressure Measurements

As shown in Figure 9, the initial and final measurements are matched closely. The few substantial deviations from the regression line do not necessarily indicate measurement error. Two of the points which lie off the line represent a table saw, branch 2 in Mezzanine West in November and December. The November repeat hood pressure is lower than initial and the repeat end pressure is higher than the initial. Nothing noted at the time could explain the deviation. The December point is explained in measurement notes made at the time which state that the flexible duct came loose from the galvanized duct between measurements. Thus, when reattached and remeasured, conditions actually had changed as the slight increase in the repeat hood static pressure. It is possible that the earlier differences were due to similar changes that were overlooked.

In estimating measurement error, large deviations that could be explained were removed from analysis. Likewise, the November measurements were taken first and may have included mistakes of inexperience. In fact, all of the unexplained large deviations occurred in November. Regression analysis of repeat to initial measurements with the these points removed yields an R^2 of 99.9% for both hood and end measurements (see Figure 10).

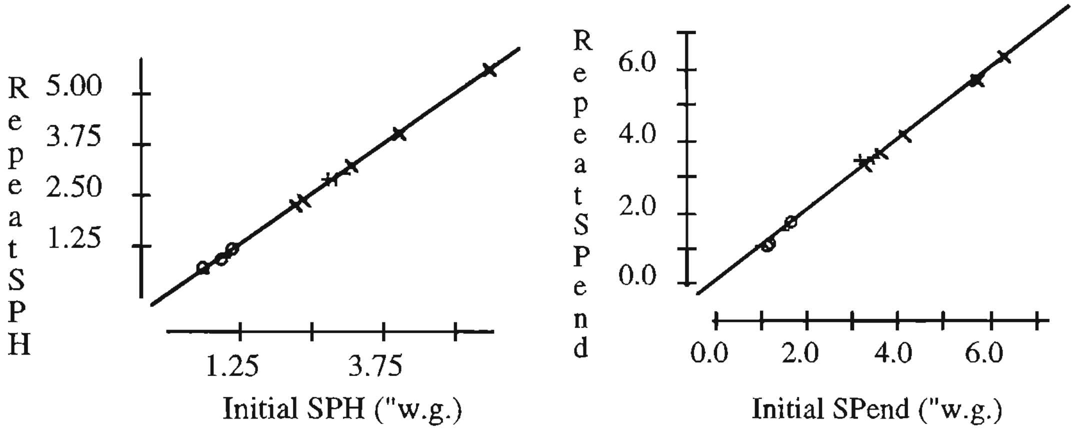

Figure 10: Repeat vs. Initial Static Pressure Measurements

Looking at each static pressure measurement allows calculation of a percent change between the initial and repeat measurements. The change in SPH ranged from 3-5% and that for SPend ranged from 4-7%. The differences between initial and repeated pressure measurements may represent actual changes in the system. For example, if line voltages change during the day the fan output would vary correspondingly.

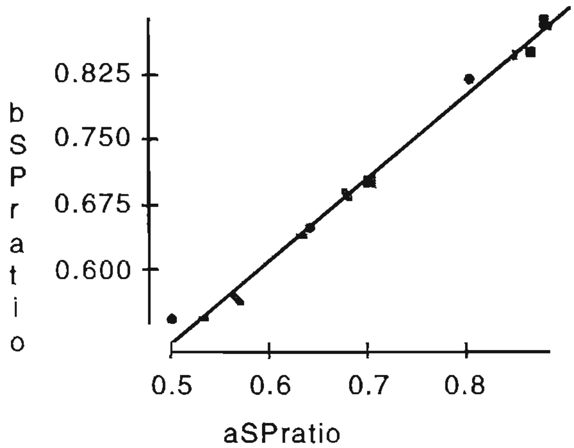

Figure 11: Repeat SPratio vs. Initial SPratio

Table 4: Regression of Repeat to Initial Static Pressure Ratio

Dependent Variable		Repeat Static Pressure Ratio		$R^2 = 99.3$
Source	Sum of Squares	df	Mean Square	F-Ratio
Regression	0.2178	1	0.2178	1489
Residual	0.0016	11	0.0001	
Variable	Coefficient	s.e. of Coeff	t-Ratio	Probability
Constant	0.0473	0.0180	2.62	0.0236
Initial SP Ratio	0.9426	0.0244	38.6	≤0.0001

However, looking at the change in the static pressure *ratio* from the initial to repeat measurements shows a range of 0.5 - 2 % change in these data. Regression analysis of these ratios, as seen in Figure 11 and Table 4 with November points and explained deviations removed, shows a high correlation. Using the static pressure ratio of SPH to SPend removes the effects of systematic variations. They are both taken within minutes during the initial readings and during the repeated readings. Since a change in fan output would change SPH and SPend proportionately, the ratio of SPH to SPend should vary only with short term fluctuations and measurement error. Assuming for simplicity that random error for SPH and SPend are the same, then their ratio should vary more than either SPH of SPend if the variation is due to random errors only. Thus, the change in this ratio from initial to repeat measurements more accurately describes the repeatability of these measurements.

This stability in the static pressure ratios suggest that repeatability error is less than 3% as shown in Figures 12a and 12b. (Repeat measurement data is found in Appendix C.)

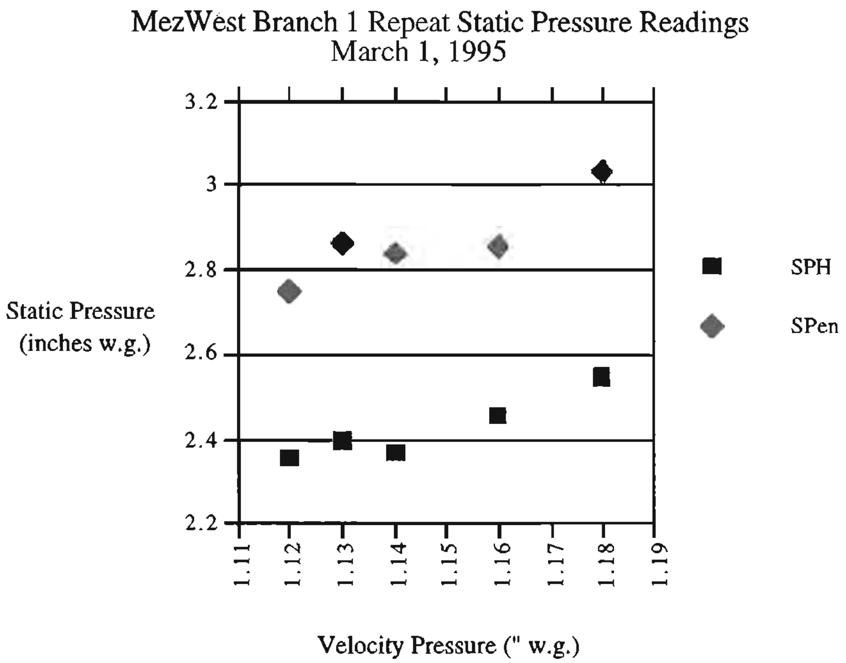

Figure 12a: Repeat Static Pressure : Mez West Branch 1; March 1995

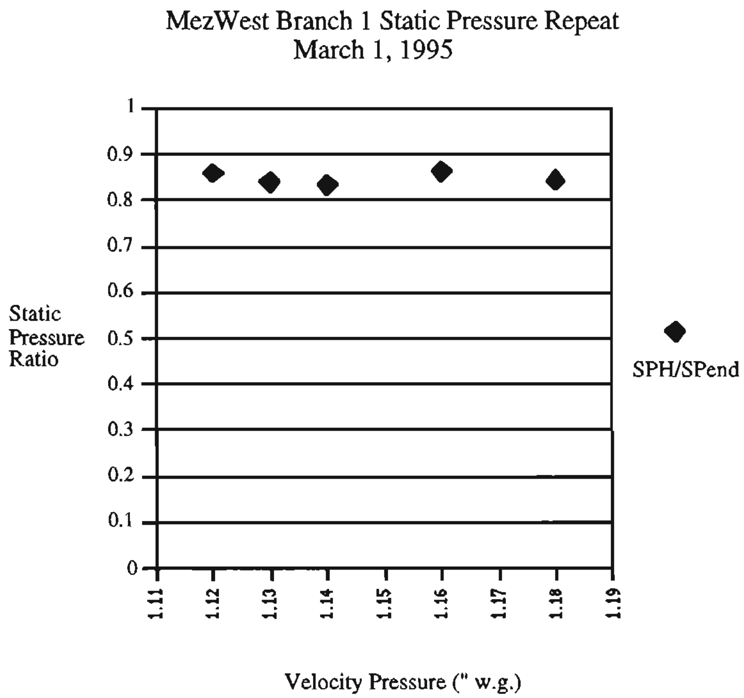

Figure 12b: Repeat Static Pressure Ratios: Mez West Branch 1; March '95

Figure 12a indicates that the pressures throughout the system do change slightly with time. If this change were due to random measurement error, such a steady trend would not be expected. Instead, that rise in pressures over time indicates a systematic change. Both the hood and end pressures change proportionally with the square of airflow. The pressure ratio is normalized by airflow and thus unaffected by system fluctuations, as seen in Figure 12b. Barring changes in conditions between measurements, then, static pressure ratios filter out systematic fluctuations allowing a more accurate description of measurement repeatability.

The velocity pressures are affected the same way as the static pressures. They all rise or fall with fluctuations in the system. Figures 13 and 14 show the simultaneous affect of system changes on static and velocity pressures.

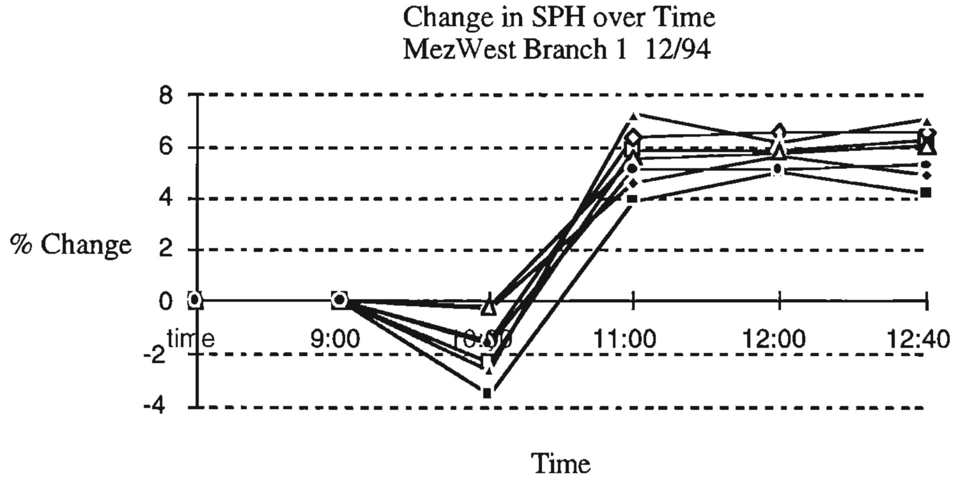

Figure 13: Repeat Hood Static Pressure Readings: Mez West, 12/94
(Note: System shut down for baghouse cleaning about 10:00 a.m.)

Figure 13 employs the initial measurement at 9:00 a.m. as the baseline. Subsequent measurements are graphed relative to it. Note that the system was shut down just before 10:00 a.m. while the baghouse was cleaned. The following hood static pressures were taken just after the system was turned on to determine the time required to ready steady operation. The graph illustrates that once the system stabilized at 11:00, the subsequent readings fluctuated between 4-7%, a 3% range, change from baseline. The same pattern is exhibited in the repeat velocity pressure traverse graph (Figure 14) that follows. Note that the system reached equilibrium after about 30 minutes.

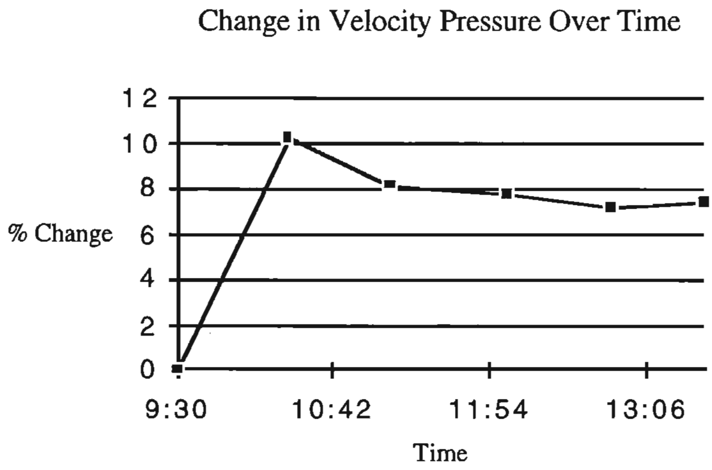

Figure 14: Velocity Pressure Over Time: Mez West Branch 1, 12/94

Also of interest, is the change in pressures seen during time elapsed for complete measurements to be collected from a given branch. This was assessed in March with repeated SPH and SPend readings taken every 10 minutes for each branch in Mez East.

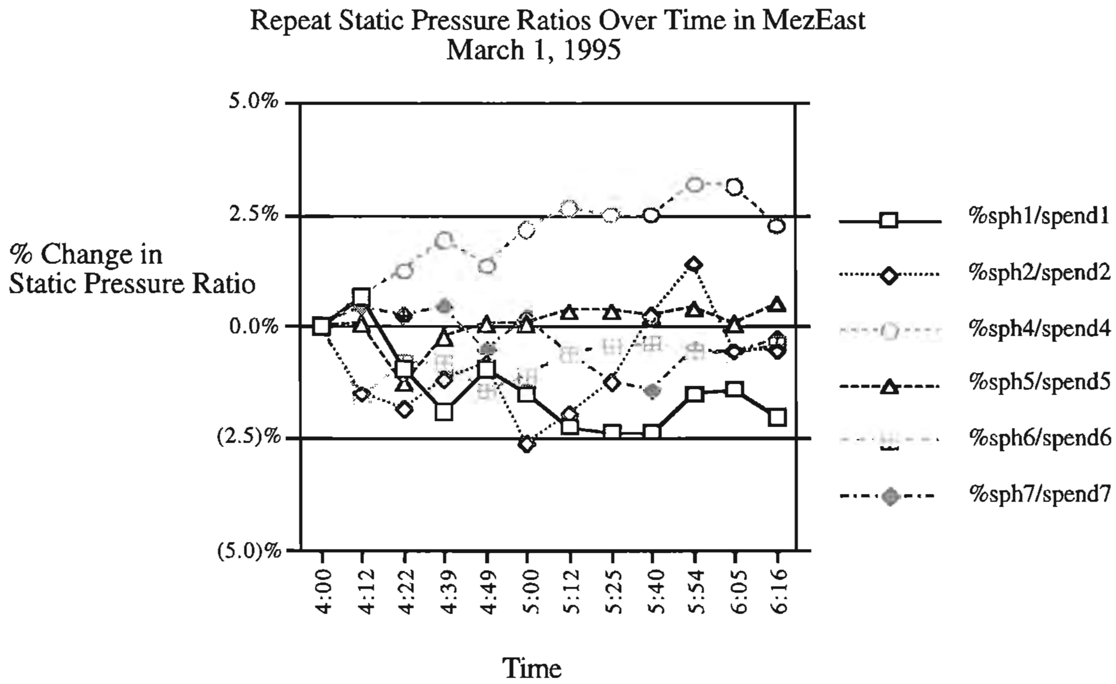

Figure 15: Repeat Static Pressure Ratios: Mez East; March 1995

Based on these data , measurement error in this study is assumed to be less than 3%, as demonstrated in Figure 15. This "error" is the product of both random measurement error and system-wide changes which may occur, such as those due to changes in line voltage. Since the value of F is a ratio of a the total pressure (SP + VP) to velocity pressure, values of F should be as stable as the static pressure ratios, which fluctuated less than 3%.

An additional source of deviation between the initial and repeated measurements is zero drift. To check this, three calibration points were checked over time in the laboratory. This data is included in Appendix A, with the calibration data. A zero drift of 0.03 " w.g occurred over six hours. This is negligible and thus not a contributor to the deviations found.

In summary, the repeatability in this study was determined to be 97%.

Analysis of Observed F_h

The hood entry loss (F_h) accounts for most of pressure loss within each of the branches in this study. For that reason, F_h values were analyzed separately from the losses through the remainder of each branch ($F_{NotHood}$). Note that hood static pressure must be taken several diameters downstream of the hood. Thus, a direct comparison between published and observed values is not possible because the observed hood entry loss includes losses due to the length of duct between the hood entry and the measurement location. For a fair comparison, coefficients for friction loss in that length of duct must also be included in the estimated value of F_h. For example, the published hood entry loss for a plain duct entry is 0.93. Due to the friction loss along the galvanized duct upstream of the hood static pressure measurement location, 0.05 should be added to the published value, producing an estimated loss coefficient of 0.98. Actual published coefficients are listed in Table 1. Estimated coefficients which include the additional losses of friction and elbows are listed in Table 5. Note that two means of estimating a loss coefficient for the floor sweep, which lacks a published value in the IVM, were attempted.

Table 5: FhObserved Summary Data

Hood Type	System	Fh Observed(1) # Obs	Mean	Std Dev	Minimum	Maximum	FhEst(2)
Plain	MezEast	6	1.12	0.09	1.00	1.22	0.98
Plain	MezWest	4	1.23	0.08	1.18	1.35	0.97
Plain/Elbow	MezEast	6	1.13	0.19	0.84	1.30	1.80
Plain/Elbow	MezEast	6	1.27	0.05	1.21	1.32	1.67
Floor Sweep	MezEast	6	0.62	0.06	0.50	0.69	0.67,0.75*
Floor Sweep	MezEast	3	0.72	0.12	0.62	0.89	0.67,0.75
Floor Sweep	MezWest	4	0.63	0.04	0.59	0.69	0.67,0.75
Table Saw	MezEast	6	1.13	0.11	1.00	1.34	0.90
Table Saw	MezWest	4	1.34	0.12	1.16	1.43	0.885
Table Saw	MezWest	4	0.60	0.24	0.42	0.91	0.66
Planer	MezEast	6	2.41	0.23	2.09	2.72	1.31
Jointer	MezWest	4	1.33	0.18	1.12	1.57	0.62
Belt Sander	MezWest	4	12.44	1.49	10.60	14.70	0.46
Disc Sander	MezWest	4	8.30	1.02	7.13	9.61	5.25

(1) $Fh = \left(\frac{SPH + VPduct}{VPduct}\right)$

(2) FhEst = Published value + estimate of contributions from short length of duct,

To compare the corrected estimates of F_h to the observed values, a regression of hood static pressure and velocity pressure in the duct for each hood type was fit to the data. The slope of the regression line is related to the mean $F_h$observed by: mean $F_h$obs = slope -1. The values obtained are shown in Table 6. For hood types for which the regression fit was poor, the regression was forced through the origin to obtain Fh values.

Table 6 : Regression Data for SPH vs. VPduct by Hood Type

Hood Type	R^2	s	slope	s.e. of slope	t-Ratio	p value	Fh Regr
	Regression SPHObs vs.VPductObs						
Plain	99.4	0.08	2.28	0.06	36.30	≤0.0001	1.28
Plain/Elbow	99.8	0.08	2.28	0.03	77.20	≤0.0001	1.27
Table Saw*	-*	0.44	2.08	0.09	23.2	≤0.0001	1.08
Jointer	-*	0.21	2.31	0.08	30.9	≤0.0001	1.31
Disc Sander	-*	0.71	8.82	0.44	20.1	≤0.0001	7.82
Belt Sander	-*	0.81	13.54	0.75	18.1	≤0.0001	15.02
Floorsweep	98.8	0.13	1.65	0.05	30.30	≤0.0001	0.65
Planer	84.6	0.43	4.03	0.77	5.23	0.0034	3.02

* These regressions were forced through the origin. No R^2 value was calculated.

To ease comparison of the values presented thus far, the different values of Fh obtained from the various analysis tools are compared to the mean observed value and the estimated value in Table 7.

Table 7: Comparison of Fh Values Obtained in this Study

Hood Type	Mean Value Fh Obs	Geometric Mean FhObs	Fh- Slope of Regression (1)	FhObs Nearest FhEst (2)	FhEstimated (3)
Plain	1.16	1.15	1.28	1.0	0.97
Plain/Elbow	1.20	1.19	1.27	1.32	1.73
Table Saw	1.09	1.04	1.08	0.94	0.83
Jointer	1.35	1.32	1.31	1.12	0.62
Disc Sander	8.30	8.13	7.82	7.13	5.25
Belt Sander	11.87	12.39	12.54	10.60	0.46
Floor Sweep	0.64	0.64	0.65	0.67	0.67,0.75
Planer	2.41	2.40	3.02	2.09	1.31

(1) from regression of SPH and VPduct
(2) observed value closest to estimated ("expected") value
(3) value determined from IVM loss coefficients

As can be seen in Table 7, there are slight deviations in the estimates of Fh with the various methods of its determination. The mean observed, geometric mean and coefficient of regression are all in fair agreement for all the hoods in this study.

It is important to determine if the observed values for each hood entry loss ($F_h$obs) varied significantly across the rounds of measurements. Note that six rounds of measurements were taken over six months in Mez East and four rounds of data were collected over six months in Mez West.

Table 8: Repeated Measures Analysis of FhObserved by Round

Source	df	Sums of Squares	Mean Square	F-ratio	Probability
Constant	1	152.631	152.631	2.5967	0.1458
System	1	131.139	131.139	2.2311	0.1736
Subject	8	470.226	58.7783	58.275	≤ 0.0001
Repeat	3	5.90649	1.96883	1.9520	0.1482
Sym*Rpt	3	4.19295	1.39765	1.3857	0.2712
Error	24	24.2073	1.00864		
Total	39	635.672			

(Subject is a random term generated by Data Desk®, the software program used. The mean square for subject serves as the denominator for the F-tests.)

The analysis of variance shown in Table 8 indicates that there is no difference in the mean values observed across the rounds by system. That also proved to be true when each system was analyzed separately (not shown). The p-value for repeated measurements of $F_h$obs for Mez East was 0.4887, and for Mez West, 0.1442.

Figure 16 shows the distribution of the error in the Fh values observed, which as shown in Equation (11) is the difference between $F_h$obs and $F_h$est. The observed values are generally higher than the estimated values.

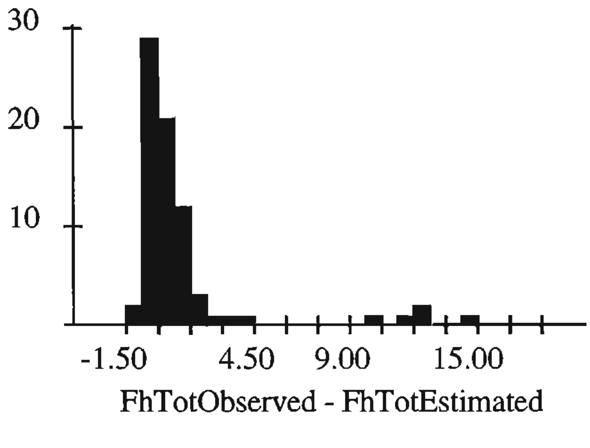

Figure 16: Distribution of Error in Estimating F_h

A t-test of the mean difference between the observed and predicted values of F_h was the initial step in determining the acceptability of the estimated coefficients. If the test failed to reject that the mean difference was zero, one could not conclude that the estimated loss coefficient was erroneous. If the mean was not zero, one could test the hypothesis that the difference was less than an "acceptable" amount (e.g., 16%). For example, if the difference was proven to be less than zero, a test for the difference being greater than 16% lower was calculated. Likewise, if the difference was greater than zero, a test for the difference being more than 16% higher than the estimated value was calculated.

Table 9: t-Test Summary for FhObserved - FhEstimated

	FhTotObs-FhTotEst t-test of μ =0 Ha: μ ≠0		FhTotObs < 0.84 FhTotEst Hø: μ =0, Ha: μ < 0		FhTotObs > 1.16 FhTotEst Hø: μ = 0, Ha: μ > 0	
Hood Type	t statistic	p value	t statistic	p value	t statistic	p value
Plain	6.078	0.0002	-	-	1.071	0.1561
Plain/Elbow	-9.551	≤0.0001	-4.797	0.0003	-	-
Table Saw	1.685	0.1178	-	-	-	-
Jointer	9.297	0.0007	-	-	7.927	0.0007
Disc Sander	5.315	0.0060	-	-	3.663	0.0108
Belt Sander	17.931	0.0001	-	-	17.821	≤0.0001
Floorsweep	-4.197	0.0012	0.638	0.732	-	-
Planer	16.840	≤0.0001	-	-	13.653	≤0.0001

The results from Table 9 can be illustrated graphically as well. Figure 19 shows the mean difference between the observed and estimated values of F_h. The mean difference is 1.17, with the range of (-0.57 to 11.5). It is clear that only the confidence interval for the mean observed value for the table saw spanned zero. The value for the belt sander was off the scale.

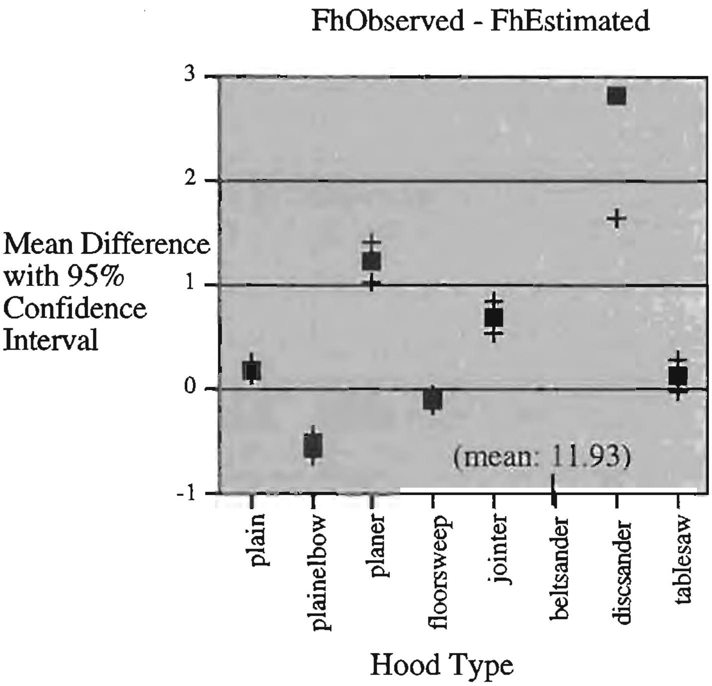

Figure 17: FhObserved-FhEstimated for All Hoods

Figure 18 shows the confidence intervals for hoods in comparison to 16% of their estimated values, the "acceptable" level of error in this study.

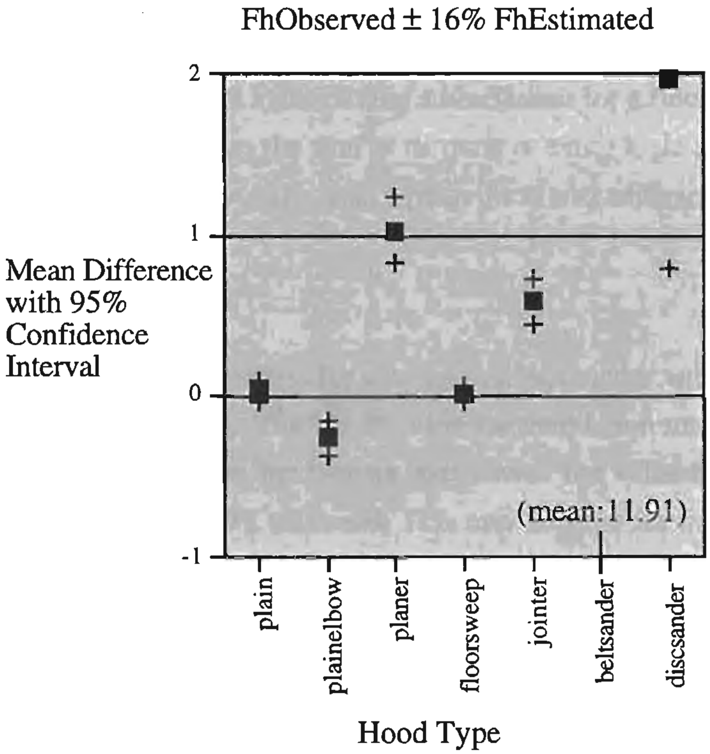

Figure 18: FhObserved ± 16% FhEstimated

This graph (Figure 18) shows that the coefficients for the floor sweep and plain duct were within the allowable margin of ±16% of the estimated value. The values observed for the remaining hoods: plain duct at elbow, jointer, planer, belt and disc sanders were not within 16% of their estimates and thus deemed "unacceptable" in this study.

Table Saw

According to Table 9 and Figure 17, table saws required no testing beyond the initial t-test of the mean difference equal to zero. The published coefficient which was computed from, $\left(\frac{1.78\ \text{VPslot} + 0.25\ \text{VPduct}}{\text{VPduct}}\right)$, adequately characterized these pieces of equipment.

Plain Duct

The results of the t-tests indicated that the observed hood entry loss coefficient for plain duct openings were within 16% of the coefficient of 0.93 listed in the IVM (as shown in Figure 18). This is not surprising as this is a very simple hood.

Floor sweep

Lastly, the t-tests suggested that synthesizing a coefficient for a floor sweep, for which no coefficient is published, as the sum of its parts or using logic and intuition (i.e. loss is greater than a flanged duct but less than a plain duct) was sufficient (see Figure 18).

Horizontal Belt Sander

There is no loss coefficient published for a horizontal belt sander with the single exhaust take-off found in this study. The VS-95-14 in the ventilation manual describes a push-pull system with two exhausts, but lists no coefficient. The value for a horizontal belt sander, 0.40VPduct (VS-95-13), was used. This may account for the large deviation from the estimated value.

Possible Sources of Deviation

Analysis of variance enables identification of possible sources of deviation from the estimated values. As noted earlier, the observed value was generally greater than the estimated value (see Figure 19).

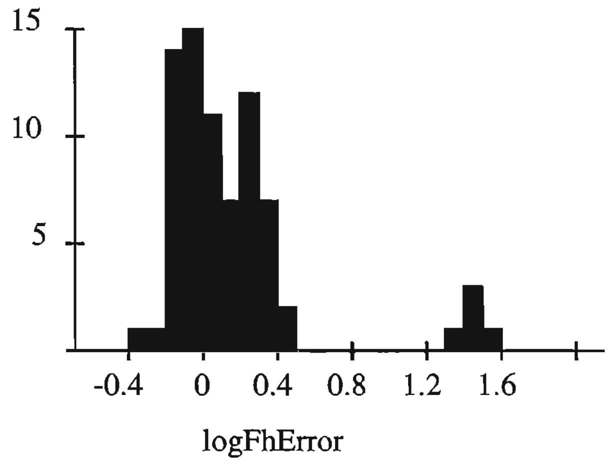

Figure 19: Distribution of log(Error Fh)

Log transformed values were used to eliminate the problems that arise when statistics are calculated for ratios.

Table 10: ANOVA for log $\left(\frac{\Delta TPHobs}{VP} / FhEstimated\right)$

Source	df	Sums of Squares	Mean Square	F-ratio	Probability
Constant	1	1.85744	1.85744	509.84	≤ 0.0001
HoodType	7	7.63896	1.09128	299.54	≤ 0.0001
Lgalv	1	0.022153	0.022153	6.0807	0.0164
Lflex	1	0.098798	0.098798	27.118	≤ 0.0001
Diameter	1	0.001125	0.001125	0.30891	0.5803
Error	64	0.233165	0.003643		
Total	74	10.9919			

The results from the ANOVA in Table 10 suggest that hood type, length of flex duct present as well as length of galvanized duct present were significant contributors to the error observed.

For hood types where more than one of a given hood type existed, an ANOVA was employed to determine if there were differences between these components, whether in the same system or in different systems.

Table 11: ANOVA for Differences Between Hood Types

Hood Type	ANOVA p value
Plain Ducts	0.066
Plain at Elbow	0.008
Table Saws	0.0018
Floor Sweeps	0.2329

As shown in Table 11, no statistically significant difference was found between plain ducts across systems. Likewise, no statistically significant difference between floor sweeps within and across systems was found. However, the plain ducts adjacent to an elbow within Mez East were found to be significantly different. This was expected because branch 2 has a 45° elbow at the entry, whereas branch 6 has a 90° entry. No distinction for elbow angle is discussed in the IVM. Lastly, the table saws were found to differ across systems as well as within. This may be due to branch 2 in Mez West, which has a galvanized elbow at the take-off and an expansion from 4 - 6" downstream of the hood static pressure measurement location. Though an adjustment was made for the velocity pressure at the 4" duct, it may not have accurately characterized the interactions which occurred.

Analysis of $F_{NotHood}$

As mentioned previously, the loss coefficients for branches were broken into two parts: the hood entry (F_h) and the sum of coefficients for the remainder of the branch, $F_{NotHood}$. "Error $F_{NotHood}$" is the difference between $F_{NotHoodObserved}$ and $F_{NotHoodEstimated}$. There are a total of sixteen branches. One branch, Mez East #8, was eliminated in January as the capped branches around it could not be modeled. Six rounds of measurements were taken in Mez East over six months, and four rounds of measurements were taken over six months in Mez West. All branches were analyzed together since the "not hood" portion of each contained similar components (elbows, straight duct, dampers, cleanouts).

Table 12: Summary Statistics of Error $F_{NotHood}$*

Branch ID	System	# Obs	Mean	Std Dev	Minimum	Maximum	Lower C.I.**	Upper C.I**.
1	ME	6	-0.133	0.025	-0.160	-0.100	-0.153	-0.113
2	ME	6	0.293	0.095	0.138	0.375	0.217	0.369
3	ME	6	1.020	0.372	0.751	1.758	0.722	1.318
4	ME	6	0.305	0.110	0.189	0.506	0.217	0.394
5	ME	6	0.490	0.089	0.339	0.577	0.419	0.561
6	ME	6	-0.743	0.030	-0.800	-0.720	-0.767	-0.719
7	ME	6	3.115	0.998	1.984	4.738	2.316	3.914
8	ME	3	-0.253	0.439	-0.760	0.000	-0.750	0.243
1	MW	4	-0.265	0.069	-0.360	-0.210	-0.332	-0.198
2	MW	4	0.881	1.576	-1.310	2.062	-0.664	2.425
3	MW	4	0.177	0.027	0.159	0.216	0.151	0.203
4	MW	4	0.717	0.446	0.364	1.364	0.280	1.154
5	MW	4	2.079	0.757	0.954	2.527	1.338	2.821
6	MW	4	0.946	0.169	0.768	1.172	0.780	1.112
7	MW	4	-1.385	0.796	-2.420	-0.740	-2.165	-0.605
8	MW	4	-0.293	0.233	-0.530	0.018	-0.521	-0.065

* Ideally, values should equal zero.
** 95% confidence interval

The dot plot in Figure 20 show how Error $F_{NotHood}$ varies with duct id. The lighter circles represent MezWest and the darker diamonds represent MezEast.

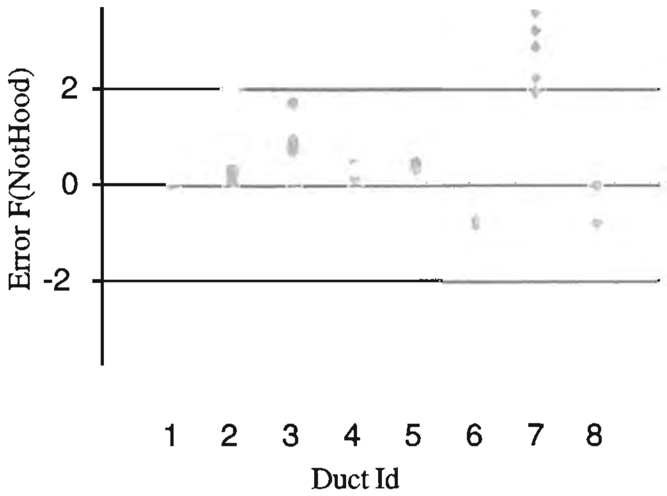

Figure 20: Dot Plot of Error $F_{NotHood}$ by Duct Id

Figure 21 shows that the values of $F_{NotHood}$ observed in this study tend to be greater than the estimated values for the same branch. The mean difference was 0.3331 while the expected difference would be zero.

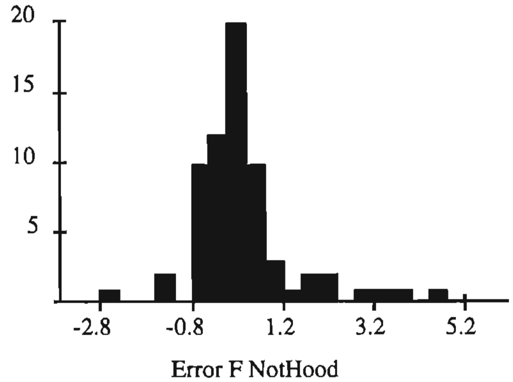

Figure 21: Error $F_{NotHood}$ Distribution

As with the analysis of observed hood entry loss coefficients, it was necessary to determine if the values for $F_{NotHood}$ varied across the rounds.

Table 13: Analysis of Variance for Error $F_{NotHood}$

Source	df	Sums of Squares	Mean Square	F-ratio	Probability
Constant	1	17.5398	17.5398	57.663	≤ 0.0001
System	1	0.664392	0.664392	2.1842	0.1451
Round No	6	1.41365	0.235609	0.77457	0.5933
Duct Id	7	17.3988	2.48554	8.1713	≤ 0.0001
Sym*DcId	7	64.0354	9.14791	30.074	≤ 0.0001
Error	55	16.7299	0.304179		
Total	76	105.661			

The ANOVA results in Table 13 indicate that there is no difference in Error $F_{NotHood}$ across the different rounds or systems. However, both "Duct Id" and the interaction of "Duct Id" and "System" are significant. This was expected since fittings vary by both duct and system, and it is the error in characterizing these fittings that results in Error $F_{NotHood}$.

It is important to confirm that the mean observed values of Ferror can be distinguished from zero. A simple t-test rejected a mean of zero at the 0.0007 significance level.

A reasonable step is to test whether the difference between the observed and estimated values of F for the remainder of the branch–$F_{NotHood}$– is greater than ± 16% different (the level of practical significance). This was done by testing the frequency with which the deviations between Error $F_{NotHood}$ and $F_{NotHood}$ exceeded 16%. The data were log transformed to avoid analyzing ratios. The results of this test are shown in Table 14 which follows.

Table 14: Frequency Breakdown of $F_{NotHood}$ Relative Error

Group	Count	%
< -16%	24	34.3
Within ± 16%	9	12.9
> 16%	37	52.9
Total	70	

Group	Count	%
< -25%	21	30
Within ± 25%	21	30
> 25%	28	40
Total	70	

Group	Count	%
< -50%	15	21.4
Within ± 50%	37	52.9
> 50%	18	25.7
Total	70	

Table 14 indicates that 87% of the observed values for coefficients for the branch excluding the hood were outside the "acceptable" range of 16% error. For 24 of the 70 observations included, the model over-predicted the coefficient for the branch. For 53% of the cases, the model underestimated the observed value by more than 16%. Because a majority of the observed values were outside the acceptable range, the test was repeated to determine the number of values outside the ± 25% and ± 50% as well. It is obvious from Table 14 that an unacceptable amount of error occurred in estimating the losses for the portion of the branch between the hood and end static pressure measurement locations. Only 53% of the values were observed to lie within 50% of their estimated value.

One possible source of error was the effect of measuring SPHobs inaccurately. If an error in the static pressure reading occurs, the power balance downstream at the velocity pressure measurement location will be skewed. This would be caused by reading an extreme, rather than an average, hood static pressure. Thus, error here would translate into error downstream, contributing to modeling error. As mentioned earlier, the quality of the measurement locations was assessed and assigned before analyzing the data because such information could be helpful when explaining deviation from estimated values. Hood static pressure measurement locations which were located in flex duct or too close to the hood entry were deemed likely to be "bad". Table 15 shows the same tests of frequency repeated with branches assigned "SPH bad" removed from analysis.

Table 15: Frequency Breakdown of Relative Error $F_{NotHood}$
(Branches with bad SPH location removed.)

Group	Count	%
< -16%	11	25.6
Within ± 16%	5	11.6
> 16%	27	62.8
total	43	

Group	Count	%
< -25%	8	18.6
Within ± 25%	17	39.5
> 25%	18	41.9
total	43	

Group	Count	%
< -50%	3	6.98
Within ± 50%	32	74.4
> 50%	8	18.6
total	43	

Removing the branches with the bad hood static pressure measurement locations did not improve the percentage of "acceptable" (within 16%) $F_{NotHood}$ values substantially, though it did increase the number of values that were within the ± 25 and ± 50% ranges. Thus, most "unacceptable" deviations cannot be explained by "bad" hood measurement locations.

Analysis of variance was used to test the contributions of the various fittings. It was first helpful to determine which factors contribute to the sum of coefficients observed. Those found to be significant were then tested for significance against Error $F_{NotHood}$.

Table 16: ANOVA for $F_{observed}$ (Log(obsTPnothood/VP))

Source	df	Sums of Squares	Mean Square	F-ratio	Probability
Constant	1	6.60926	6.60926	37.586	≤ 0.0001
FhObs	1	1.07393	1.07393	6.1073	0.0161
Length	1	0.746519	0.746519	4.2453	0.0433
Diameter	1	4.93923	4.93923	28.089	≤ 0.0001
EquivElbows	1	2.13423	2.13423	12.137	0.0009
Damper	1	0.323027	0.323027	1.8370	0.1799
Cleanout	3	1.56217	0.520724	2.9613	0.0385
Error	66	11.6057	0.175844		
Total	74	19.3501			

Table 16 suggests that all of the sources of loss (elbows, friction, cleanouts, diameter) contribute significantly to the observed sum of coefficients as expected. Dampers may not have been significant contributors to $F_{observed}$ because they occurred on 12 of 16 branches.

As with the error in the hood entry coefficients, the observed coefficients for the "branch excluding the hood" tend to be higher than estimated coefficients (see Figure 22). The log of Error $F_{NotHood}$ has a mean value of 0.1782 which is equivalent to an untransformed value of 1.51.

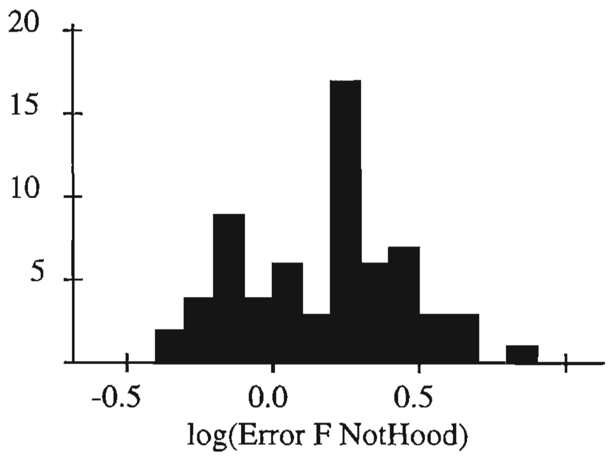

Figure 22: Distribution of log (Error $F_{NotHood}$)

Table 17: ANOVA Results To Determine Sources of log (Error FNotHood)

Source	df	Sums of Squares	Mean Square	F-ratio	Probability
Constant	1	2.06353	2.06353	88.723	≤ 0.0001
FhObs	1	0.489781	0.489781	21.058	≤ 0.0001
Diameter	1	0.115126	0.115126	4.9499	0.0304
Length	1	0.004315	0.004315	0.18554	0.6684
EquivElbows	1	0.014184	0.014184	0.60985	0.4383
MeasQuality	3	0.442685	0.147562	6.3445	0.0009
Damper	1	1.03645	1.03645	44.563	≤ 0.0001
Cleanout	3	0.072189	0.024063	1.0346	0.3848
Error	53	1.23269	0.023258		
Total	64	5.00773			

The ANOVA of the deviation between observed and expected $F_{NotHood}$ values shows that the following components were not significant contributors to Error FNotHood: length, number of equivalent elbows, and cleanouts (see Table 17). It is important to note here that the variable "Measurement Quality" covaries with "FhObserved". As mentioned, this is logical because one of the categories of measurement quality is "bad SPH location" which was associated with the ability to characterize the loss at the hood accurately. An accurate static pressure may not be obtained at these "bad" locations, resulting in modeling error in the remainder of those branches.

Table 18: ANOVA Results To Determine Source of Error $F_{NotHood}$

Source	df	Sums of Squares	Mean Square	F-ratio	Probability
Constant	1	2.06353	2.06353	65.737	≤ 0.0001
FhObs	1	0.223588	0.223588	7.1228	0.0097
Diameter	1	0.261680	0.261680	8.3362	0.0054
Damper	1	3.07008	3.07008	97.802	≤ 0.0001
Error	61	1.91483	0.031391		
Total	64	5.00773			

Once "Measuring Quality" was removed from the analysis, F_hObseved was shown to be a significant contributor to the modeling error between the hood and end of the branch, as seen in Table 18. Duct diameter and the presence of a damper were also significant contributors to the deviation from the model. The importance of a damper was expected because a zero loss is assumed for a fully opened damper. This analysis, however, indicates that dampers should not be overlooked. Figure 23 illustrates the greater magnitude and variance of error in the observed value of $F_{NotHood}$ in branches that contain dampers.

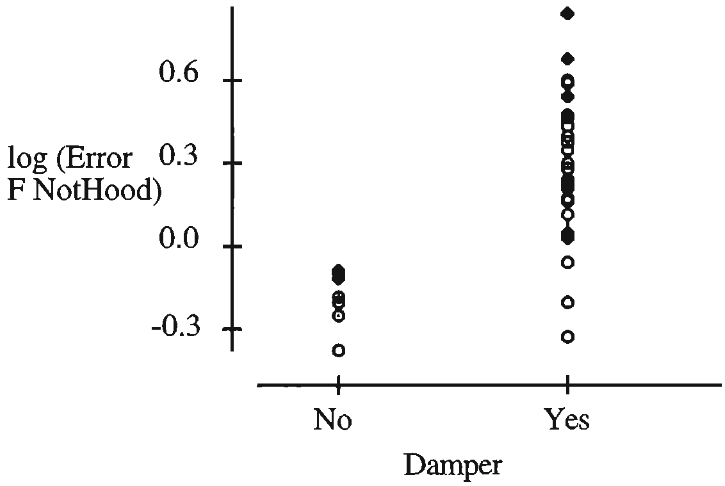

Figure 23: Scatter plot of Error $F_{NotHood}$ by Damper
(Diamonds = MezEast, Dashes = MezWest)

Figure 24 shows Error $F_{NotHood}$ plotted one of these significant variables, diameter. The greatest deviations across diameters was for 5 inch ducts, the duct sizes for two of the table saws, the floor sweeps, planer, disc sander and the jointer. Interestingly, the latter three of these had hood entry losses with great deviations from the predicted as well. Friction loss also varies with duct diameter. Therefore, as mentioned earlier, if the calculation of this loss is incorrect, this error will also vary with duct diameter.

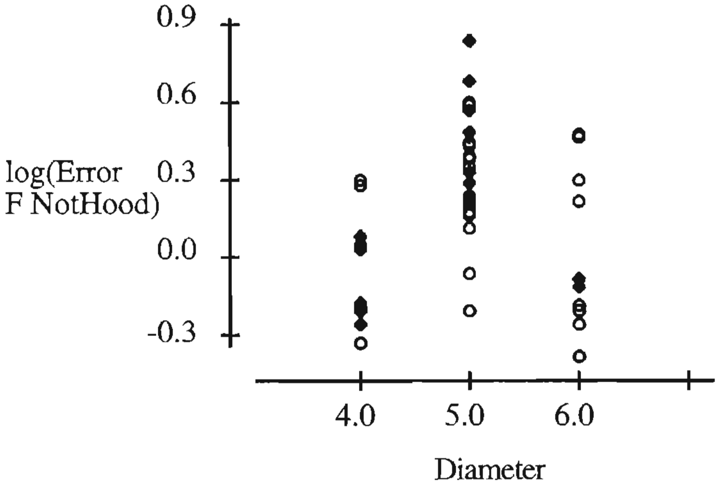

Figure 24: Scatter Plot of Error $F_{NotHood}$ by Diameter

(Diamonds = MezEast, Circles = MezWest)

Total Error

A matter of interest was whether the errors in F_h and $F_{NotHood}$ offset each other. Figures 25 and 26 show the mean errors in F_h and $F_{NotHood}$ plotted next to the total error, which is the sum of the two.

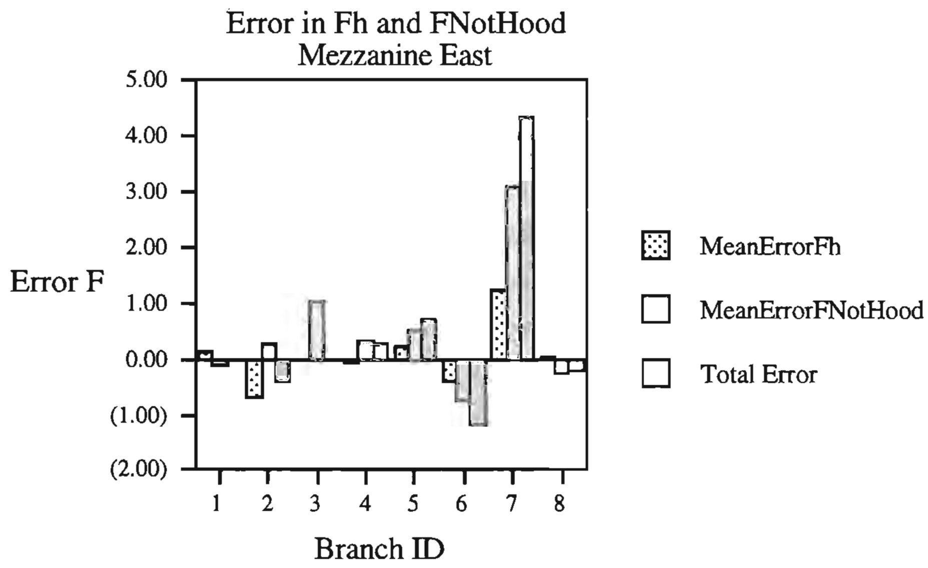

Figure 25: Error in F_h and $F_{NotHood}$ in Mezzanine East

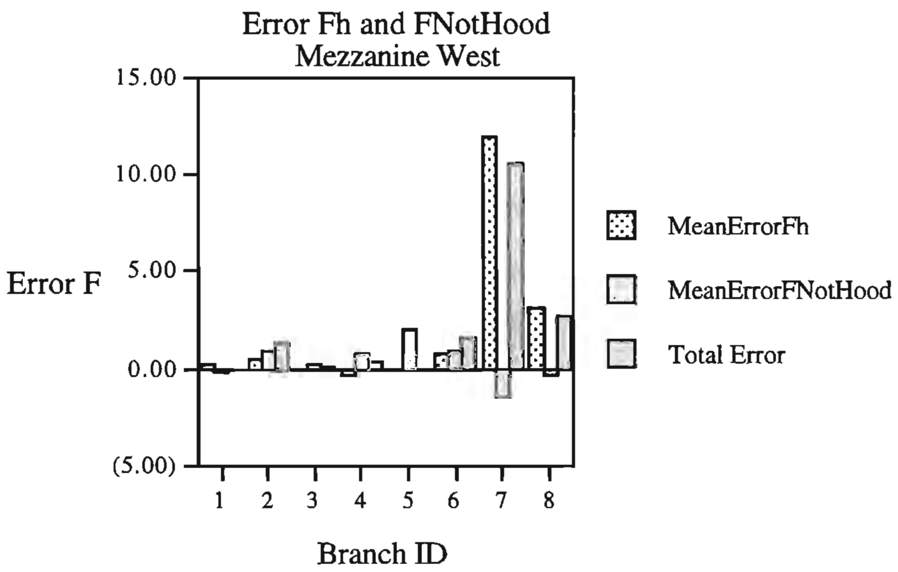

Figure 26: Error in F_h and $F_{NotHood}$ in Mezzanine West

Note that for branch 1 in both systems (plain duct opening), Fh and FNotHood are equal and opposite (Mez East #1: 0.14 and -0.133; Mez West #1: 0.26 and -0.265, respectively). This is the only such case.

VI. DISCUSSION

Calibration

The Dwyer digital manometer proved to be precise during calibration over seven months. As shown in Figure 8, it generally reported a slightly lower pressure than did the Meriam inclined manometer (most of the differences were within 0.025 " w.g., with the extreme difference of 0.05 at 3" w.g.) which showed trivial error when calibrated earlier against a Dwyer Hook Gage. This small error may be the result of observation bias. For example, if the digital manometer was varying between two numbers, the lower number may have been consistently recorded. However, this error is small compared to the magnitudes of pressures measured, which were typically over 1" w.g.

Repeatability

For this study, it was desirable to have no obstructions or other changes to the systems. However, due to the conflicting interest of the parent study, the ducts were not cleaned before each measurement period and some obstructions were noticed during data collection. Removal of the obstruction would occur between the initial and repeat measurements and the change in pressure was noted during the repeat measurement. Thus the highest observed F values were inflated by the presence of obstructions. These points were excluded from the statistics of the repeatability data.

As shown in Figure 9, the initial and repeat hood (SPH) and end (SPend) static pressure measurements are highly correlated, with R^2 of 99.5, and 99.3, respectively. The ratio of static pressures (SPH/SPend) is be less susceptible to fluctuations in the system that may occur during the measuring session because without the presence of an obstruction, both pressures should change proportionally. As such, this ratio can be used to normalize for the effects of fluctuating airflows. The static pressure ratios for initial and repeat measurements were highly correlated, with an R^2 of 99.3 and a p-value of ≤ 0.0001. In this analysis, the initial round of measurements was omitted because the deviations were greater than those in subsequent rounds and they could not be explained, except for initial lack of facility. Subsequent repeat rounds were accompanied by sampling notes to describe possible sources of deviation.

The repeat static pressure readings were used to assess whether the system was fluctuating, which again would inflate estimates of measurement error. As shown in Figure 12a, slight changes in both SPH (-3.5% to 4.5%) and SPend (-5.61% to 4.0%)

were observed over the course of 3.5 hours, the time required for data collection in Mezzanine West. However, the ratio of pressures varied much less (0.22% to 3.07%), as seen in Figure 12b, indicating that the system was not fluctuating substantially between SPH and SPend measurements. Pressures changed over a day's readings, possibly due to changing line voltage and the state of the baghouse filters. The March static pressure ratio data shown in Figure 15 show fluctuations bounded by $\pm 2.5\%$. As a result, repeated measures of static pressures varied by less than 3%. The repeatability of F values should be similar in magnitude. This is not substantial compared to the ± 16% level deemed acceptable for this study.

An additional factor of concern is that of zero drift over a day's data collection period. As discussed earlier and shown in Figure 13, this was minimal, though fairly consistent over time. A drift of +0.03 " w.g. was found over a five hour period. Since observed pressures were generally about 1.0" w.g., the potential error from this was small compared to the 16% shifts in F values considered acceptable

In summary, the calibration proved highly linear and stable. While zero drift occurred, it was within tolerable levels.

Discussion of Fh Observed

Plain Duct

The published coefficient for the plain duct opening is 0.93. The IVM value was adapted from the Brandt laboratory experiments in the 1940's.[5,6] With the losses for friction factored in, the estimated loss coefficient for this hood entry is 0.97. The values obtained in this study are consistently higher than the 0.97 estimate based on IVM published values. In addition, they are consistently higher than the values found recently by McLoone.[28] On the other hand, the mean observed F_h value of 1.16 is within 16% of this value. Even the lowest observed value, 1.0, was greater than the expected value.

The mean of the observed values was used in data analysis. The observed Fh values ranged from 1.0 to 1.35. The lowest and highest values were obtained in the first round, which may have been affected by investigator inexperience. Discarding these, the range was 1.06 to 1.22. It should be understood that the predicted value changed slightly, due to maximum range of friction coefficients of 3% across the 10 observations. Thus, the remaining variation must be due to error or to the occasional presence of obstructions. Measurement error was determined to be low. An obstruction within the duct would contribute to greater pressure loss, however no obstructions were seen in these particular ducts during any of these measurements. This was expected since this duct was normally capped except during measurement sessions. The error in calculating the loss attributable to the 1 foot of galvanized duct upstream of the SPH location cannot be large enough to substantially affect the finding.

As discussed earlier, the higher observed value in the field may be attributable to an interaction between the entry loss and friction loss along the length of duct between the hood entry and the measurement location. In practice, friction loss is calculated per unit length of duct and treated as uniform along the entire run. This is done both during laboratory experimental determination of Fh values and in application in the field. McLoone found that the F_h values he obtained in the lab varied with the distance of the SPH location.[28] This suggests that the error is due to the friction estimates. Fh values determined in the field will include the error due to friction estimation and possibly an interaction between the two.

Plain Duct at Elbow

The IVM lists the coefficient for a plain duct with a close elbow as 1.6. It makes no distinction as to the turning angle of the elbow for which it applies. No reference is given. The mean observed value in this study was 1.20, while the value determined from regression of SPH vs. VPduct was 1.27 (see Table 6). Analysis of variance showed significant differences between the observed values for the two instances for this type of hoods: Mez East Branch 2 (45° elbow)had a mean observed value of 1.13, and Mez East Branch 6 (90° elbow) had a mean observed value of 1.27. The IVM value was consistently higher than the observed value. On the other hand, if one estimated the value as equal to the sum of its components, then assuming an Fel of 0.21 and using the coefficient for a plain duct opening (0.93) gives values of 1.04, and 1.14, respectively. Those values are somewhat lower than the observed values.

Figure 27: Plain Duct at Elbow

Measurement error was too small to explain this deviation. An observed value which is greater than its expected raises the possibility that an obstruction augmented the resistance to flow. However, in this case, the observed value was lower than expected. For this reason, it may be necessary to determine this coefficient empirically for each elbow angle to obtain more accurate values for F_h.

Table Saw

The IVM published loss coefficient for a table saw is estimated from $\left(\frac{1.78VPslot + 0.25VPduct}{VPduct}\right)$. This is the sole hood type for which the mean difference of observed and estimated values may be zero. There are three table saws in this study: one in Mez East and two in Mez West. Analysis of variance found a significant difference among the observed Fh values for the table saws. The observed values ranged from 0.42 to 0.94. The extreme value was obtained in the first round. Discarding this due to measurement experience, closes the observed range to 0.42 to 1.34. The estimated values, however, had a similar range of 0.66 to 0.90. Spreadsheet calculations determined the error between observed and predicted values to be no greater than 6.5%.

Figure 28: Table Saw

It is apparent from the observed and estimated values that there are differences between these table saws, as the ANOVA suggested. Nonetheless, the published equation adequately described each hood's loss.

One difficulty in modeling a component of a complex hood such as this is the measurement of the slot velocity pressure. It may appear plausible that the slot is the tiny area which surrounds the blade. In actuality, the slot area is the sum of all the open areas, a much larger area. Use of the blade passage area would produce enormous errors.

As mentioned briefly, the table saws at the community college did not have the tapered take-off shown in the VS plate of the IVM which describes this component. Naive application of IVM recommendations would lead the reader to use a value of 0.25. Comparison to other flanged take-offs would suggest a value of 0.50. Though this seems logical, spreadsheet calculations did not show a consistent benefit from such a modification, as seen in Table 19.

Table 19: Comparison of Fh Values for Table Saws

Table Saw	Mez East # 5	Mez West #2	Mez West #4
mean observed	1.13	0.60	1.34
mean estimate w/ published coeff	0.90	0.66	0.885
mean estimate w/ modified coeff	1.15	0.91	1.135

Jointer

The coefficient for the jointer, calculated from $\left(\frac{1.0VPslot + 0.25VPduct}{VPduct}\right)$, did not adequately characterize the loss coefficient for this piece of equipment. The mean observed value, 1.33, was double the estimated value, 0.62. The value from regression was the same as the mean observed value. This hood and its branch were looked into in May with a Borescope, and no obstructions were detected. The value obtained in May was 1.44, which was above the mean but in the middle of the range of observed values, 1.12 to 1.57. The extreme value of 1.57 was obtained in the first round and it cannot be said whether or not an obstruction may have been present. Discarding this value, the mean is 1.28, which is well above the estimated value.

Figure 29: Jointer

The slot area was difficult to determine for this piece of machinery. Of the two calculated slot areas generated from the thermoanemometer measurements, 0.3385 ft^2 was used as it was quite a bit larger than that measured with the tape measure and micrometer, 0.23 ft^2. It was this investigator's belief that the larger indirectly determined area should be used after attempting to measure the actual open areas. However, the following values and percent errors between mean observed and predicted values resulted (see Table 20).

Table 20: FhEst Values for Jointer Using Different Slot Areas

Jointer Area Used (ft^2)	FhEstimated	% Difference between Mean Obs and Est Values
0.23	0.96	62%
0.2895	0.73	88%
0.3385	0.62	106%

In this case, a discrepancy in determining the open area could mean the difference between a poorly characterized component and a terribly characterized component. The manufacturer of this jointer was telephoned for assistance with this calculation and for information regarding the pressure loss across it. The technical assistance engineer provided no useful information. In the end, the actual area measured resulted in the least error in $F_h$obs. Table 20 shows that different plausible determinations of slot area can result in varying magnitudes of error.

Because the actual area is difficult to characterize, however, speculation as to where the error lies is difficult.

Belt Sander

As stated earlier, there is no loss coefficient published for a horizontal belt sander with the single exhaust take-off as in this study. The VS-95-14 in the ventilation manual describes a push-pull system with two exhausts, but lists no coefficient. For that reason the value for a horizontal belt sander, 0.40VPduct (VS-95-13), was used. The mean observed value for the belt sander in Mez West was 12.44, and the value obtained from regression was 12.54 when forced through the origin.

Figure 30: Horizontal Belt Sander

In retrospect this may not have been the best choice. However, a practitioner may make the same choice in such a situation. An estimate using 1.78 VPduct, which assumes the entry acts like an orifice, reduces the relative error from 2500% to 550%, but still grossly underestimated the observed value. The loss coefficient for a belt sander of this design should be determined empirically, as no guidance is provided in the IVM.

Disc Sander

The mean observed F_h value was 8.3, with the range being 7.13 to 9.61. This was 53% greater than the estimate of 5.25 obtained using the equation from the IVM, $\left(\frac{1.0 \text{ VPslot} + 0.25 \text{ VPduct}}{\text{VPduct}}\right)$ from VS-95-12. Thus, the t-test for the mean difference equal to zero was rejected at the 16% "acceptable" level. The highest value was obtained during the first round and it cannot be said that there was no obstruction present. The lowest value of 7.13 was obtained the same day that the duct was inspected using the Borescope and found to be clean of debris. This value is 29% greater than the estimate.

Figure 31: Disc Sander

All of the values for the Fh for the disc sander–mean observed, geometric mean observed and the slope from regression–were in agreement. The enormous deviation from the estimated value for the disc sander is difficult to explain. However, if the loss is truly a function of the velocity and static pressures observed, these values may more accurately describe the loss over this piece of equipment.

Such a great deviation suggests an error in characterization or measurement. It was the case with other hoods in this study, that a take-off differed in diameter from the duct at the location of the hood static pressure measurement. Velocity pressure varies with the ratio of diameters to the fourth power so such an error would result in grave a discrepancy. Where this was the case, a correction was made and the fit was greatly improved. However, a special trip to remeasure this diameter did not reveal such an error. Over-prediction cannot be attributable to the presence of an obstruction, as the duct was confirmed clean during the May readings when the value of 7.13 was obtained.

The measured slot area , 0.02 ft^2, differed greatly from the area calculated from the measured slot velocity, 0.057 ft^2. The larger area was used in computing the observed F_h value due to the difficulty in measuring this. The manufacturer's engineering department was contacted for assistance in obtaining either the dimensions of the slot or open areas or a recommended approach to measuring the pressure drop across the disc sander. They provided no useful information.

Spreadsheet calculations were used to test an alternate coefficient, 1.78 VPduct. The error increased. A disc sander of this design and exhaust set-up might require empirical determination to be accurate.

Floor Sweep

The floor sweep was one of the three hood types to be described adequately by the estimated loss coefficient. The mean observed value 0.65 was equal to the value calculated from the regression of SPH and VPduct. The estimated values were derived in two ways: as the sum of its components, (1) using a duct entry coefficient of 0.08 for the 60° taper angle, a flange and an elbow resulting in a coefficient of 0.67, and (2) a logical intermediate between a plain and flanged duct, arriving at 0.72VPduct. The first method was sophisticated in its conception. However, the second intuitive approach proved adequate. This lends credence to the idea that if in the absence of a published value, a knowledgeable practitioner can derive an adequate coefficient. Brandt suggested such a practice for calculating losses for compound hoods from the sum of the losses of its parts.[6]

Figure 32: Floor Sweep

Analysis of variance found no difference in floor sweeps within or across systems. Perhaps this value is a robust coefficient for the three floor sweeps in these systems.

Planer

The IVM does not list a loss coefficient for planers. As in earlier work by Brandt,[6] only the recommended airflow is given. For that reason, the pressure loss was estimated in two ways: as a flanged entry with a value of 0.50VPduct, and as a slot (i.e., 1.78 VPduct) with the estimates of 1.07 and 1.31, respectively. The mean observed value was 2.41, with a range of 2.09 to 2.72, which suggests that neither estimate is adequate. Regression analysis determined an entry loss coefficient of 3.02. The t-test for the mean difference within the "acceptable" 16% range was rejected at the 0.0003 level.

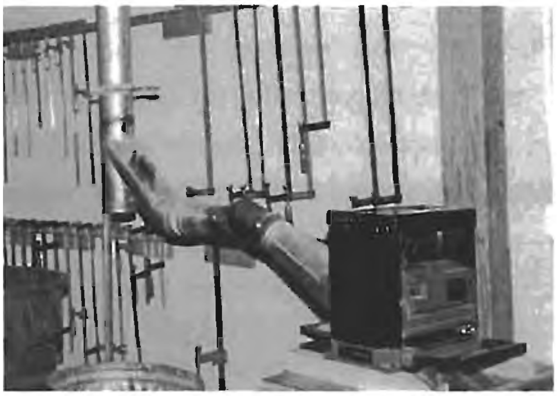

Figure 33: Planer

Unfortunately, this hood and its branch were not checked for obstructions due to inaccessibility. The flex duct connecting the take-off, however, was replaced in early December, so the December reading could be considered a "clean" reading. This was the extreme value of 2.72, refuting the suspicion that the values were high due to an obstruction. All the values obtained were fairly consistent. This hood with its exhaust design may require empirical determination of the loss coefficient.

Summary of F_h Discussion

In summary, three hood types found in this typical wood shop–plain duct opening, table saw and floor sweep–were found to be adequately characterized by their assigned loss coefficients. This leaves five hood types with observed F_h values greater than ± 16% different than the corresponding estimated values. This is unacceptable given the possible consequences of unnecessary worker exposures.

Of interest in the ANOVA (see Table 10) for factors contibuting to the deviation between observed and estimated Fh values is the magnitude of the constant term. It represents the error which is unexplained by the model, after the effects of the listed factors have been taken into account.

Discussion of $F_{NotHood}$

The relative error tables (Tables 14 and 15) summarize the deviations from of $F_{NotHood}$.. Note that 87% of the observed $F_{NotHood}$ values fell outside the ± 16% estimated value range determined to be the limit of acceptable deviation. Analysis of variance identified the diameter of the ducts and the presence of dampers as significant contributors to this error in the predictive method (see Table 18).

Also of interest in the ANOVAs (see Tables 16 ,17, and 18) is the magnitude of the constant term and its large contribution to the total sum of squares. This constant term represents error which is unexplained by the model. This indicates that even when losses over all components within that run are accounted for (see Table 16), a significant error remains. It suggests that something is missing in the model, or that the model is not linear.

The significance of duct diameter could be explained in several ways. First, it could be due to the assignment of an improper roughness factor for the spiral wound galvanized duct. Because no value was available from the manufacturer, the value for "average pipe" was selected from the IVM. Because friction increases inversely with diameter, an error in assumed roughness could be the source of significant error.

However, losses for other components may also be a function of diameter, a possibility not considered by the IVM. Both ASHRAE and Idelchik stated that losses for elbows vary with diameter.[2,25] Interestingly, however, elbows were not a significant contributor to the error in $F_{NotHood}$ according to the ANOVA.

A model of the contributions of friction and elbows to the error in $F_{NotHood}$ was attempted using multiple regression analysis. The aim was to obtain possible correction factors for these factors and thus identify the source of error. With these limited data, a clear linear relationship was not determined, so no further breakdown of the error was possible.

As stated earlier, it was expected in this study that the presence of dampers and the failure of the IVM to account for them could be important.. This proved to be a good intuitive hunch. If no loss coefficient is listed, no loss is assumed. Even if the damper could be completely opened, the mounting brackets usually provide some dimple to the duct. ASHRAE acknowledges this by assigning a loss of 0.19 to dampers.[2]

A second *a priori* observation noted messy elbows or sloppy soldering which could affect results. Elbows which were mounted poorly with the joints soldered excessively, or those which were actually of a larger diameter than the branch duct diameter but crimped to fit were included. Affected branches include Mez West branch #7 (belt sander), Mez West branch #8 (disc sander) and Mez East branch #7 (planer). It is not possible to distinguish if the "sloppiness" had any contribution to the modeling error.

These branches have the dubious distinction of bad hood static pressure measurement locations. As explained earlier, an error in the static pressure reading would skew the observed pressure difference by producing an erroneous Fobs. However, when cases with "bad" hood measurement locations were removed from analysis, 38 of the remaining 43 observations, or 88%, still had observed values greater than ± 16% different from their estimates.

Because this is a field study involving heavily used systems, it could be said that settled materials are the source of deviation between observed and expected values. However, inspection of ducts with a Borescope during the last round of measurements revealed no obstructions. Since the $F_{NotHood}$ values in the last round were generally consistent with earlier rounds, it is likely that no obstructions were present in any round. In addition, in many cases the observed value was less than expected, which cannot be explained by obstructions or leaks, as these were sealed prior to the first round of measurements.

Sources of Error

The most obvious source of error is measurement error. Repeated measurements, however, proved this to be quite small (< 3%) as explained on page 38.

Mischaracterization of the system is possible. Several checks were in place. The system was measured using a standard measuring tape. Blueprints were reviewed to confirm measurements. Duct diameters were verified where possible using a micrometer. Taper angles were calculated based on length of the expansion and the ratio of upstream and downstream diameters. Default values were used for roughness as this information was not available from the manufacturer. Each of these values holds some possibility for error, but only the roughness was assumed without independent verification.

Selection of loss coefficients may be somewhat subjective. Elbow loss coefficients are based on a radius of curvature and angle of curvature. The latter is straightforward, but the radius of curvature is difficult to measure precisely. Differing measurements will result in the selection of different loss coefficients. However, with a single investigator determining the radii, that error would be consistent and thus systematic.

The possibility of reporting bias exists given the fluctuation of the digital manometer during velocity pressure readings. A protocol of taking the reading after covering the display for three seconds was developed. However, knowing the desired velocity contour, one could subconsciously ignore the first value that flashed on the display if it were higher or lower than expected. On the other hand, when two diameters were traversed, the average velocity of each was within 1-3% even for cases with substantially asymmetrical velocity contours.

Density factors for several rounds had to be calculated from observed static pressure measurements due to a software problem which replaced wet and dry bulb temperature readings with default values. However, as the difference in density factors was trivial (<0.5%).

VII. CONCLUSIONS

It was not the purpose of this study to discover more accurate loss coefficients based on the observed values of pressures and flow. Instead, the goal is to determine the error a knowledgeable practitioner using the information from the Industrial Ventilation Manual would experience in modeling two ventilation systems. This is a practical scenario, in the event that an addition is to be made to a system and it's effects predicted before installation. As discussed, such a project may prove to be a challenge.

The observed hood entry loss coefficients for five of the eight hood types in this study deviated from published values by more than 16%, a level of error associated with at least a 5% shift in airflow. Three hood types studied–plain duct entry, table saw and floor sweep–were adequately described by the estimated coefficients determined from the published value and the losses to friction upstream of the SPH measurement location. Therefore, these coefficients might also adequately describe the losses in other geometrically similar hoods.

For the losses in the rest of the branch, 87% or 61 of the 74 observations of the branches in these two systems resulted in observed coefficients for the branch downstream of the hood that differed by more than ± 16% from the estimated values. Deviations of this magnitude would affect the prediction of system performance.

Due to the relatively low number of branches observed, it may be presumptuous to generalize these findings. However, such grave discrepancies in the case of some of the F_h and $F_{NotHood}$ values observed would be difficult to explain away without including the possibility of error in the published coefficients. If it were possible to determine the magnitude of modeling error contributed by each component, these findings could be extrapolated to other existing systems.

These findings call into question the coefficients employed by the IVM. As demonstrated, loss coefficients for hoods may have to be determined empirically for each specific variation in design until a large enough data base is accumulated, from which to draw "generic" coefficients. The data suggest that application of a singular coefficient may not be adequate across a class of hood types.

In addition, it is necessary to validate the assumption of the additivity of the losses for components in series. Idelchik states that in so doing, a correction factor for the interaction of adjacent fittings is a rule.[25] The preponderance of error in modeling the branches between the SPH and SPend measurement locations, may substantiate this.

Analysis of variance for factors contributing to error observed in both Fh and $F_{NotHood}$ generated large constant terms. All components within these branches were assigned appropriate loss coefficients. This constant term suggests that a sizable amount of unexplained error remains. It may be that something is missing from the model. An interaction between the losses for these components should be investigated.

Lastly, the uncertainties in applying the coefficients suggest that the IVM may be written for a knowledgeable audience. As such, it is not simply a cookbook. Earlier discussion revealed uncertainties in determining slot areas and radii of curvature. Since several plausible interpretations are possible, a range of values will result. Luck will have it that some of these values are correct. However, given the consequences of unnecessary worker exposures, it cannot be left to luck. The IVM should provide guidelines for these gray areas. Perhaps it should at least stress the importance of close examination of the system–its hoods and component types–before assigning published values to determine if they apply.

Industrial exhaust systems are designed to minimize worker exposures and it is the obligation of the ventilation designer to achieve this. The manufacturers of this complex equipment share this responsibility. The two could work together to define coefficients empirically for these hoods and this information should ship with the machinery. If a single value is unreasonable than a curve, similar to a fan curve, could be generated to offer guidance to the practitioner in need of this information. Computer modeling of systems was a topic of discussion of the Ventilation '88 monograph. Such techniques should be of great assistance in deriving accurate coefficients for use in design.

Recommendations

It is imperative that good measurement locations are used when modeling an existing ventilation system. This is not always possible. In these cases, effort must be made to ensure that average static and velocity pressures are obtained.

Future studies would be greatly facilitated with a computer interface device where the average of a number of instantaneous pressure readings could be recorded directly into the computer. The accuracy of the recording may improve, bias would be eliminated and time would be conserved.

Future studies should expand on the number of empirical determination of loss coefficients for commonly used shop equipment. To assist in this, a standard laboratory and field protocol should be developed to determine these losses in conditions similar to those experienced in use.

It is not known if capped branches affect the airflow distribution in branches just up- and downstream of them. As they are common in practice, it would be advantageous to determine this, perhaps in a laboratory setting.

Limitations

The systems studied were of modest size, each having eight branches. Pressure measurements are time and labor intensive and therefore the size of the systems involved is dependent on the manpower available. Larger systems with a greater number of similar and diverse hoods would allow greater statistical power to discern differences among and between them.

Mez East contains a large number of capped off branches, installed to allow for future expansion. It was not possible to determine their effect, if any, on the remainder of the system. Such branches appear to be common in practice. Due to the inability to model these, they were eliminated from the study.

Lastly, the deviations observed in this study may be attributed to the fact that these systems are heavily used, and the wear on the ducts may have changed their resistance to flow. It is possible that the IVM coefficients would have fit the observed values better when the systems were initially installed. On the other hand, these systems were both less than 3 years old, and may well be used for 10 to 20 years or more.

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APPENDIX A: CALIBRATION DATA

Location: Northlake Laboratory   Instrument: Dwyer Hook Gauge No. 1425

Date: 941012   Temp: 19 C

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Hook V	0.00	0.10	0.15	0.20	0.25	0.30	0.50	0.75	1.00	2.00
Hook P	0.00	0.10	0.15	0.20	0.25	0.30	0.50	0.75	1.00	2.00
Alnor Digital	0.02	0.20	0.30	0.40	0.49	0.60	1.00	1.50	2.00	3.98
Dwyer Digital	0.00	0.20	0.29	0.39	0.50	0.60	1.00	1.49	1.99	3.99
Meriam Inclined	0.00	0.20	0.29	0.40	0.50	0.61	1.01	1.50	2.03	3.98

Date: 941201   Instrument: Meriam 4" Inclined Manometer
model # 40HE35WM
serial # 149990CI

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Meriam Inclined	0.20	0.40	0.80	1.00	2.00	2.40	2.80	3.20	3.50	4.00
Dwyer Digital	0.19	0.39	0.77	0.97	1.97	2.37	2.76	3.15	3.46	3.96

Date: 950111

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Meriam Inclined	0.00	0.30	0.50	0.75	1.00	1.30	1.75	2.00	3.50	4.00
Dwyer Digital	0.00	0.30	0.50	0.75	1.00	1.29	1.73	1.99	2.99	3.995

Date: 950203

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Meriam Inclined	0.00	0.25	0.50	0.75	0.90	1.20	1.75	2.00	3.00	3.50
Dwyer Digital	0.00	0.24	0.50	0.74	0.90	1.19	1.74	1.95	2.98	3.48

Date:	950307	Instrument:	Meriam 4" Inclined Manometer
		model #	40HE35WM
		serial #	149990CI

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Meriam Inclined	0.00	0.10	0.20	0.40	0.60	0.85	1.50	2.00	3.00	3.75
Dwyer Digital	0.00	0.10	0.21	0.41	0.61	0.85	1.50	2.00	3.00	3.75

Date: 950404

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Meriam Inclined	0	0.30	0.55	0.75	0.95	1.15	1.70	2.40	2.75	3.10
Dwyer Digital	0	0.30	0.56	0.74	0.955	1.16	1.705	2.40	2.75	3.09

Date: 950507

Instrument	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Meriam Inclined	0	0.10	0.30	0.45	0.70	1.00	1.50	2.00	2.70	3.50
Dwyer Digital	0	0.10	0.30	0.455	0.69	1.00	1.50	2.00	2.70	3.50

ZERO DRIFT DATA

Date:	May 17, 1995		
Time	10:20		
	Point 1	Point 2	Point 3
Inclined	0	0.75	3.00
Digital	0	0.75	2.99
Time	11:05		
	Point 1	Point 2	Point 3
Inclined	0	0.75	3.00
Digital	0.01	0.75	3.00
Time	2:00		
	Point 1	Point 2	Point 3
Inclined	0	0.75	3.00
Digital	0.025	0.77	3.01
Time	2:45		
	Point 1	Point 2	Point 3
Inclined	0	0.75	3.00
Digital	0.03	0.77	3.02
Time	4:30		
	Point 1	Point 2	Point 3
Inclined	0	0.75	3.00
Digital	0.03	0.78	3.03
Time	5:00		
	Point 1	Point 2	Point 3
Inclined	0	0.75	3.00
Digital	0.03	0.78	3.02

Thermoanemometer Calibration

(Taken from Olson, M.S. Thesis, 1995)

This data is provided courtesy David M. Olson who completed this calibration.

The TSI VELOCICALC Air Velocity Meter was calibrated against a Beckman and Whitney Model 3-cup anemometer at the National Oceanic and Atmospheric Administration (NOAA) facility, 7600 Sand Point Way, N.E., Building 21. This procedure was taken from a previous Master's Thesis (Gahn 1994).

TABLE XXII. - Calibration Data for the TSI VELOCICALC Thermoanemometer:

Date	Fanvolts	FanRPM	BWHz	TSIfpm
11/15/94	9	100	23.4	231
11/15/94	9	100	23.7	232
11/15/94	18	120	43.8	389
11/15/94	18	120	44.4	390
11/15/94	24	150	56.1	478
11/15/94	24	150	56.3	478
11/15/94	27	160	69.4	585
11/15/94	27	160	67.7	585
11/15/94	32	170	80.1	662
11/15/94	32	170	79.8	662
11/15/94	26	180	92.5	762
11/15/94	26	180	92.3	762
11/15/94	40	185	103.3	843
11/15/94	40	185	103.1	841
11/15/94	45	190	118.7	961
11/15/94	45	190	120.1	963
12/27/94	9	100	17.4	187
12/27/94	9	100	17.3	187
12/27/94	18	120	39.2	362
12/27/94	18	120	39.5	364
12/27/94	24	150	55.4	483
12/27/94	24	150	55.3	481
12/27/94	27	160	63.5	548
12/27/94	27	160	64.1	548
12/27/94	32	170	79.8	679
12/27/94	32	170	79.5	676
12/27/94	36	180	91.5	782
12/27/94	36	180	91.4	781
12/27/94	40	185	104.4	886
12/27/94	40	185	104.8	886
12/27/94	45	190	119.7	1008
12/27/94	45	190	119.9	1008

*BWHz=Beckman and Whitney 3-cup Anemometer rotation frequency, TSIfpm is measured velocity of TSI VELOCICALC Thermoanemometer from Eq. (1) on pg 17. Below is the linear regression operations performed on the date during calibration to determine actual duct velocity that TSI VELOCICALC Thermoanemometer measures.

Data collected 11/15/94

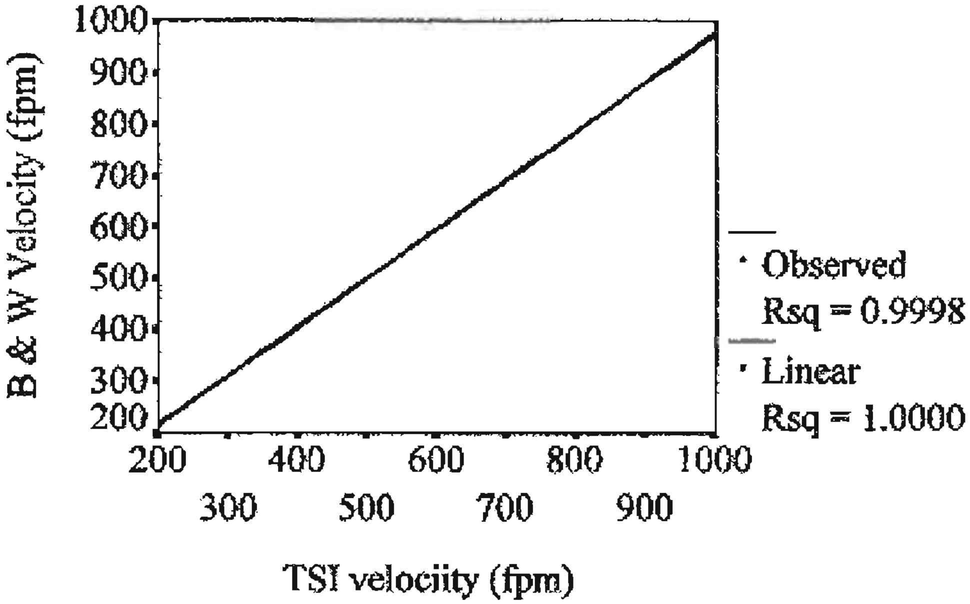

FIGURE 9 - Calibration for TSI VELOCICALC Thermoanemometer 11/15/94-12/27/94

Dependent variable - 3-cup Anemometer velocity

Multiple R .99992 R^2 .99984 Adjusted R^2 .99983 s.e. 2.76165

Analysis of Variance:

Source	DF	Sum of Squares	Mean Square	F	p
Regression	1	6886657.22	6886657.22	90295.28	.0000
Residuals	14	106.77	7.63		

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
TSIFPM	.949495	.003160	.999922	300.492	.0000
(Constant)	2	6.702731	1.988669	13.427	.0000

Actual Velocity (fpm)=TSI(fpm) x 0.949495 + 26.702731 ± 0.33% (1)

Data Collected 12/27/94

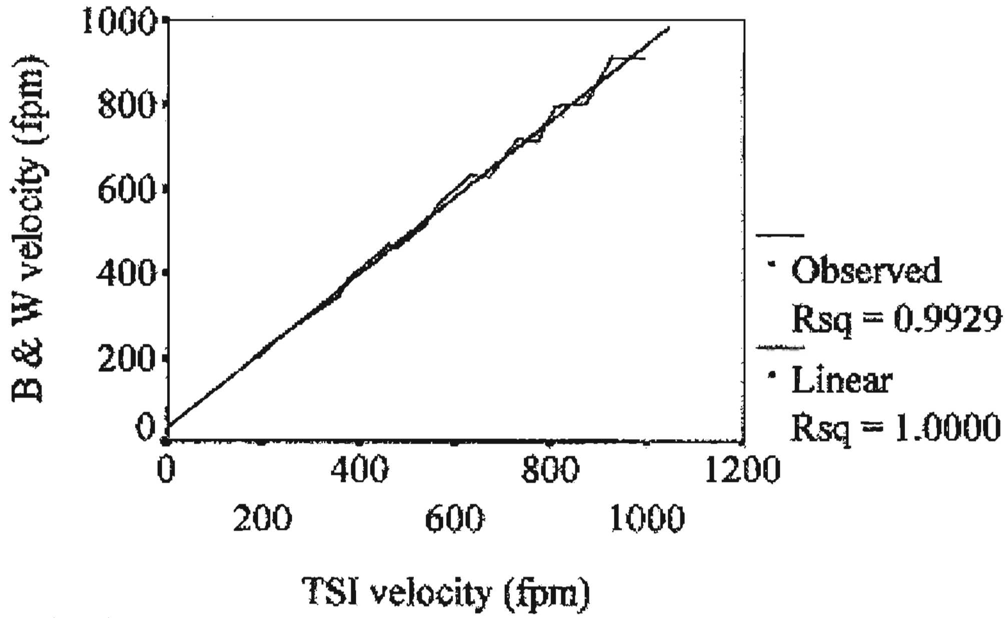

FIGURE 10: Overall Calibration for TSI VELOCICALC Thermoanemometer 11/15/94-1/27/95

Dependent Variable - 3-cup Anemometer velocity

Multiple R	.99642	R^2	.99286

APPENDIX B: FIELD DATA

File:	ME_NOV94	Date measured:	11/4/94
Company:	SCCC MEZ East	Site altitude:	100
Project:	initial measurements	Dry Bulb:	70.0
Instrument:	Dwyer Digital	Wet Bulb:	52.0
Cailbrated:	10/12/94	Measured by:	jh/seg

ID	Type	Dia	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	0.99	0.67	1.24	2825	544
2	Branch	4	0.65	0.91	1.27	2384	208
3	Branch	6	0.00	0.00	1.20	0	208
4	Branch	5	1.04	1.17	1.86	3342	292
5	Branch	5	2.53	2.81	3.72	2812	383
6	Branch	4	3.72	0.00	4.11	5253	430
7	Branch	5	3.09	0.00	4.75	2438	332
8	Branch	5	2.86	2.56	0.00	4970	662
9	Branch	4	0.00	0.00	0.00	0	0
10	Branch	4	0.00	0.00	0.00	0	0
11	Branch	4	0.00	0.00	0.00	0	0
12	Branch	4	0.00	0.00	0.00	0	0
15	Submain	6	0.00	0.00	1.85	0	752
20	Submain	6	0.00	0.00	4.23	0	1043
30	Submain	7	0.00	0.00	5.73	0	1427
40	Submain	9	0.00	0.00	4.70	0	1427
50	Submain	9	0.00	0.00	5.32	0	1857
60	Submain	2	0.00	0.00	4.95	0	1857
70	Submain	10	0.00	0.00	5.63	0	2190
80	Submain	2	0.00	0.00	5.21	0	2190
90	Submain	8	0.00	4.85	5.10	0	0
100	Submain	8	0.00	0.00	4.99	0	0
110	Submain	5	0.00	0.00	5.00	0	0
120	Submain	7	0.00	0.00	0.00	0	0
130	Submain	6	0.00	0.00	0.00	0	0
140	Branch	6	0.00	0.00	0.00	0	0
150	Submain	12	0.00	0.00	5.26	0	2190

File:	ME_NOV94	Date measured:	11/4/94
Company:	SCCC MEZ East	Site altitude:	100
Project:	initial measurements	Dry Bulb:	70.0
Instrument:	Dwyer Digital Manometer	Wet Bulb:	52.0
Cailbrated:	10/12/94	Measured by:	jh/seg

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.35	0.44	0.49	0.51	0.57	0.63	0.64	0.59	0.55	0.39	0.30
2	Branch	0.35	0.39	0.41	0.41	0.37	0.36	0.35	0.34	0.32	0.29	0.23
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.80	0.80	0.88	0.89	0.77	0.78	0.72	0.72	0.70	0.63	0.45
5	Branch	0.47	0.46	0.48	0.49	0.55	0.60	0.67	0.74	0.71	0.58	0.43
6	Branch	1.65	1.84	2.04	2.08	2.05	2.04	2.04	1.88	1.85	1.42	0.95
7	Branch	0.26	0.35	0.36	0.42	0.45	0.45	0.45	0.43	0.37	0.32	0.25
8	Branch	1.50	1.65	1.73	1.71	1.65	1.63	1.69	1.66	1.56	1.30	0.88

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.43	0.50	0.64	0.67	0.71	0.67	0.61	0.52	0.47	0.41	0.32
2	Branch	0.30	0.36	0.37	0.39	0.39	0.38	0.39	0.42	0.40	0.37	0.28
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.55	0.58	0.64	0.67	0.73	0.74	0.76	0.80	0.78	0.68	0.47
5	Branch	0.29	0.31	0.31	0.33	0.44	0.53	0.53	0.58	0.62	0.57	0.42
6	Branch	1.51	1.74	1.91	2.03	2.08	2.07	2.02	1.83	1.65	1.35	0.83
7	Branch	0.31	0.34	0.42	0.40	0.44	0.45	0.46	0.43	0.42	0.34	0.23
8	Branch	1.32	1.47	1.60	1.64	1.67	1.71	1.75	1.78	1.76	1.58	1.15

File:	ME_DEC94	Date Measure	12/2/94
Company:	SCCC MEZ East	Site altitude:	100
Project:	troubleshooting	Dry Bulb:	61.7
Instrument:	Dwyer 475 Digital	Wet Bulb:	50
Cailbrated:	12/1/94	Measured by:	jh/seg

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	0.91	0.92	1.13	2547	500
2	Branch	4	0.60	0.84	1.20	2216	193
3	Branch	6	0.00	0.00	1.09	0	193
4	Branch	5	1.09	1.07	1.70	3196	436
5	Branch	5	2.42	2.68	3.53	2735	373
6	Branch	4	3.51	0.00	3.93	4903	428
7	Branch	5	3.24	4.25	4.52	2368	323
8	Branch	5	2.37	2.42	0.00	4807	656
9	Branch	4	0.00	0.00	0.00	0	0
10	Branch	4	0.00	0.00	0.00	0	0
11	Branch	4	0.00	0.00	0.00	0	0
12	Branch	4	0.00	0.00	0.00	0	0
15	Submain	6	0.00	0.00	1.74	0	693
20	Submain	6	0.00	0.00	4.02	0	1129
30	Submain	7	0.00	0.00	5.48	0	1502
40	Submain	9	0.00	0.00	4.50	0	1502
50	Submain	9	0.00	0.00	5.10	0	1930
60	Submain	10	0.00	0.00	4.73	0	1930
70	Submain	10	0.00	0.00	5.42	0	2253
80	Submain	12	0.00	0.00	5.00	0	2253
90	Submain	8	0.00	4.69	4.69	0	656
100	Submain	8	0.00	0.00	4.85	0	656
110	Submain	5	0.00	0.00	4.80	0	656
120	Submain	6	0.00	0.00	0.00	0	0
130	Submain	7	0.00	0.00	0.00	0	0
140	Branch	4	0.00	0.00	0.00	0	0
150	Submain	12	0.00	0.00	0.00	0	2908

File:	ME_DEC94	Date measured:	12/2/94
Company:	SCCC MEZ East	Site altitude:	100
Project:	troubleshooting	Dry Bulb:	61.7
Instrument:	Dwyer 475 Mark II Digital Manometer	Wet Bulb:	50.0
Cailbrated:	12/1/94	Measured by:	jh/seg

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.33	0.38	0.39	0.43	0.53	0.55	0.53	0.52	0.48	0.40	0.23
2	Branch	0.32	0.36	0.37	0.35	0.35	0.32	0.32	0.34	0.30	0.25	0.20
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.67	0.70	0.77	0.70	0.71	0.72	0.67	0.69	0.68	0.65	0.41
5	Branch	0.43	0.51	0.58	0.62	0.62	0.56	0.54	0.46	0.44	0.34	0.22
6	Branch	1.34	1.52	1.71	1.83	1.91	1.92	1.92	1.70	1.60	1.24	0.75
7	Branch	0.29	0.33	0.35	0.41	0.43	0.42	0.42	0.43	0.39	0.33	0.22
8	Branch	1.57	1.63	1.63	1.66	1.55	1.56	1.52	1.40	1.38	1.17	0.76

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.33	0.40	0.50	0.52	0.54	0.53	0.52	0.42	0.38	0.31	0.21
2	Branch	0.29	0.34	0.34	0.32	0.30	0.32	0.31	0.35	0.34	0.29	0.20
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.54	0.59	0.66	0.64	0.65	0.68	0.69	0.72	0.70	0.67	0.46
5	Branch	0.41	0.52	0.58	0.56	0.56	0.58	0.59	0.52	0.51	0.41	0.23
6	Branch	1.25	1.54	1.67	1.77	1.96	1.92	1.89	1.60	1.49	1.30	0.82
7	Branch	0.30	0.39	0.41	0.38	0.43	0.45	0.43	0.43	0.39	0.28	0.18
8	Branch	1.53	1.59	1.57	1.57	1.55	1.60	1.62	1.61	1.60	1.50	1.10

ID	Type	Comment
1	Branch	no obstruction observed or possible since usually capped
2	Branch	removed cleanout in 3: SPH=.64
3	Branch	removed cleanout and replaced; clean inside: SPend=1.1
4	Branch	small strip of wood removed from hood opening/little change
5	Branch	
6	Branch	
7	Branch	hood had been removed and re-connected
8	Branch	before measuring opened cleanout/heard stuff move through

ID	Type	Description
1	Branch	SPend=1.18; SPH=.96
2	Branch	and SPmid=.865; SPend=1.22
3	Branch	
4	Branch	possible that previous trash made less resistant
5	Branch	table saw has wooden through plate
6	Branch	normally capped
7	Branch	.45 in opening on 10 in. planer
8	Branch	

File:	MEDEC94B	Date measured:	94-12-02
Company:	SCCC MEZ EAST	Site altitude:	100
Project:	repeat measurement	Dry Bulb:	70
Instrument:	Dwyer Digital Manometer	Wet Bulb:	52
Calibrated:	94-12-01	Measured by:	jh/seg

ID	Type	Dia	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	0.91	0.94	1.11	2633	517
2	Branch	4	0.66	0.86	1.21	2201	192
3	Branch	6	0.00	0.00	0.00	0	192
4	Branch	5	1.12	1.10	1.73	3319	453
5	Branch	5	0.00	0.00	0.00	0	0
6	Branch	4	0.00	0.00	0.00	0	0
7	Branch	5	0.00	0.00	0.00	0	0
8	Branch	5	0.00	0.00	0.00	0	0
9	Branch	4	0.00	0.00	0.00	0	0
10	Branch	4	0.00	0.00	0.00	0	0
11	Branch	4	0.00	0.00	0.00	0	0
12	Branch	4	0.00	0.00	0.00	0	0
15	Submain	6	0.00	0.00	0.00	0	713
20	Submain	6	0.00	0.00	0.00	0	1166
30	Submain	7	0.00	0.00	0.00	0	1166
40	Submain	9	0.00	0.00	0.00	0	1166
50	Submain	9	0.00	0.00	0.00	0	1166
60	Submain	10	0.00	0.00	4.72	0	1166
70	Submain	10	0.00	0.00	5.41	0	1166
80	Submain	12	0.00	0.00	0.00	0	1166
90	Submain	8	0.00	0.00	0.00	0	0
100	Submain	8	0.00	0.00	0.00	0	0
110	Submain	5	0.00	0.00	0.00	0	0
120	Submain	7	0.00	0.00	0.00	0	0
130	Submain	6	0.00	0.00	0.00	0	0
140	Branch	6	0.00	0.00	0.00	0	0
150	Submain	12	0.00	0.00	5.63	0	1166

File:	MEDEC94B	Date measured:	94-12-02
Company:	SCCC MEZ EAST	Site altitude:	100
Project:	repeat measurement	Dry Bulb:	70
Instrument:	Dwyer Digital Manometer	Wet Bulb:	52
Calibrated:	94-12-01	Measured by:	jh/seg

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.35	0.42	0.52	0.55	0.57	0.56	0.52	0.47	0.41	0.37	0.25
2	Branch	0.34	0.36	0.36	0.33	0.31	0.31	0.3	0.3	0.27	0.24	0.19
3	Branch	0	0	0	0	0	0	0	0	0	0	0
4	Branch	0.74	0.68	0.74	0.69	0.75	0.7	0.74	0.71	0.74	0.72	0.42
5	Branch	0	0	0	0	0	0	0	0	0	0	0
6	Branch	0	0	0	0	0	0	0	0	0	0	0
7	Branch	0	0	0	0	0	0	0	0	0	0	0
8	Branch	0	0	0	0	0	0	0	0	0	0	0

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.25	0.35	0.41	0.47	0.5	0.56	0.56	0.55	0.52	0.42	0.34
2	Branch	0.28	0.3	0.32	0.32	0.3	0.33	0.33	0.34	0.33	0.3	0.2
3	Branch	0	0	0	0	0	0	0	0	0	0	0
4	Branch	0.61	0.68	0.68	0.7	0.7	0.73	0.74	0.76	0.77	0.68	0.45
5	Branch	0	0	0	0	0	0	0	0	0	0	0
6	Branch	0	0	0	0	0	0	0	0	0	0	0
7	Branch	0	0	0	0	0	0	0	0	0	0	0
8	Branch	0	0	0	0	0	0	0	0	0	0	0

ID	Type	Comment
1	Branch	not selected randomly
2	Branch	SPH=.56 before moving to new location whose value is above
3	Branch	
4	Branch	
5	Branch	
6	Branch	
7	Branch	
8	Branch	

File:	ME950113	Date measured:	1/13/95
Company:	SCCC MEZ EAST	Site altitude:	100
Project:		Dry Bulb:	66.2
Instrument:	Dwyer 475 Digital	Wet Bulb:	56.3
Calibrated:	1/11/95	Measured by:	jh

ID	Type	Dia	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	1.47	1.71	1.82	3380	664
2	Branch	4	1.06	1.40	1.99	2770	242
3	Branch	6	0.00	0.00	1.80	0	242
4	Branch	5	1.81	1.73	2.84	4227	369
5	Branch	5	4.04	4.43	5.76	3407	465
6	Branch	4	5.61	0.00	6.38	6452	563
7	Branch	5	4.66	0.00	7.31	2978	406
8	Branch	5	3.85	3.86	0.00	6157	840
9	Branch	4	0.00	0.00	0.00	0	0
10	Branch	4	0.00	0.00	0.00	0	0
11	Branch	4	0.00	0.00	0.00	0	0
12	Branch	4	0.00	0.00	0.00	0	0
15	Submain	6	0.00	0.00	2.83	0	906
20	Submain	6	0.00	0.00	6.63	0	1275
30	Submain	7	0.00	8.86	8.86	0	1739
40	Submain	9	0.00	7.32	7.32	0	1739
50	Submain	9	0.00	8.21	8.21	0	2302
60	Submain	10	0.00	7.66	7.66	0	2302
70	Submain	10	0.00	8.73	8.73	0	2708
80	Submain	12	0.00	0.00	8.03	0	2708
90	Submain	8	0.00	0.00	7.83	0	835
100	Submain	8	0.00	0.00	7.78	0	835
110	Submain	5	0.00	0.00	7.64	0	840
120	Submain	7	0.00	0.00	0.00	0	0
130	Submain	6	0.00	0.00	0.00	0	0
140	Branch	6	0.00	0.00	0.00	0	0
150	Submain	12	0.00	0.00	8.93	0	3543

File:	ME950113	Date measured:	1/13/95
Company:	SCCC MEZ EAST	Site altitude:	100
Project:		Dry Bulb:	66.2
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	56.3
Calibrated:	1/11/95	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.64	0.78	0.86	0.89	0.91	0.84	0.79	0.68	0.63	0.53	0.34
2	Branch	0.50	0.56	0.56	0.54	0.52	0.51	0.50	0.48	0.46	0.40	0.32
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	1.12	1.22	1.30	1.29	1.17	1.15	1.18	1.18	1.17	1.08	0.70
5	Branch	0.56	0.63	0.77	0.87	0.89	0.90	0.87	0.83	0.77	0.61	0.40
6	Branch	2.31	2.56	2.88	3.11	3.16	3.07	3.04	2.77	2.58	2.20	1.26
7	Branch	0.43	0.48	0.54	0.61	0.62	0.67	0.67	0.65	0.60	0.51	0.33
8	Branch	2.35	2.63	2.67	2.67	2.54	2.47	2.32	2.22	2.16	1.91	1.27

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.59	0.69	0.73	0.77	0.84	0.91	0.92	0.89	0.82	0.65	0.39
2	Branch	0.49	0.53	0.53	0.53	0.51	0.51	0.52	0.48	0.47	0.36	0.32
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.97	1.04	1.03	1.08	1.12	1.24	1.18	1.23	1.26	1.14	0.71
5	Branch	0.65	0.78	0.87	0.92	0.92	0.89	0.84	0.78	0.68	0.56	0.34
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.42	0.52	0.64	0.63	0.65	0.67	0.66	0.64	0.58	0.49	0.30
8	Branch	2.41	2.57	2.49	2.51	2.50	2.62	2.62	2.66	2.51	2.29	1.67

ID	Type	Comment
1	Branch	del SP =0.17
2	Branch	
3	Branch	
4	Branch	
5	Branch	wooden throwplate
6	Branch	
7	Branch	
8	Branch	traverse just below damper

File:	ME950113b	Date measured:	1/13/95
Company:	SCCC MEZ EAST	Dry Bulb:	66.2
Project:	repeat measurements	Wet Bulb:	56.3
Instrument:	Dwyer 475 Digital Manometer	Site altitude:	100
Calibrated:	1/11/95	Measured by:	jh

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	0	0	0	0	0
2	Branch	4	0	0	0	0	0
3	Branch	6	0	0	0	0	0
4	Branch	5	1.74	1.72	0	4252	580
5	Branch	5	4.04	4.45	5.76	3461	472
6	Branch	4	5.63	0	6.36	6400	558
7	Branch	5	0	0	0	0	0
8	Branch	5	0	0	0	0	0
9	Branch	4	0	0	0	0	0
10	Branch	4	0	0	0	0	0
11	Branch	4	0	0	0	0	0
12	Branch	4	0	0	0	0	0
15	Submain	6	0	0	0	0	0
20	Submain	6	0	0	0	0	580
30	Submain	7	0	0	0	0	1052
40	Submain	9	0	0	7.32	0	1052
50	Submain	9	0	0	8.23	0	1610
60	Submain	10	0	0	0	0	1610
70	Submain	10	0	0	0	0	1610
80	Submain	12	0	0	0	0	1610
90	Submain	8	0	0	7.81	0	0
100	Submain	8	0	0	0	0	0
110	Submain	5	0	0	0	0	0
120	Submain	7	0	0	0	0	0
130	Submain	6	0	0	0	0	0
140	Branch	6	0	0	0	0	0
150	Submain	12	0	0	0	0	1610

File:	ME950113b	Date measured:	1/13/95
Company:	SCCC MEZ EAST`	Site altitude:	100
Project:	repeat measurements	Dry Bulb:	66.2
Instrument:	Dwyer 475 Digital	Wet Bulb:	56.3
Calibrated:	1/11/95	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	1.23	1.28	1.32	1.26	1.21	1.18	1.14	1.09	1.07	0.92	0.58
5	Branch	0.65	0.68	0.81	0.89	0.94	0.92	0.89	0.82	0.81	0.60	0.40
6	Branch	2.24	2.60	2.93	2.97	3.13	3.05	3.02	2.73	2.45	2.00	1.36
7	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	1.09	1.19	1.19	1.17	1.15	1.20	1.19	1.24	1.25	1.11	0.85
5	Branch	0.74	0.80	0.90	0.93	0.94	0.86	0.84	0.73	0.69	0.58	0.39
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Type	Comment
1	Branch	
2	Branch	
3	Branch	
4	Branch	doug took initial SPH
5	Branch	
6	Branch	
7	Branch	
8	Branch	

File:	ME9502_B	Date measured:	95-02-16
Company:	SCCC Woodshop: MezEast	Site altitude:	100
Project:	Truncated at 80:no capped	Dry Bulb:	65.3
Instrument:	Dwyer 475 Digital	Wet Bulb:	53.6
Calibrated:	95-02-03	Measured by:	jh/dh

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	1.16	1.30	1.42	2977	584
2	Branch	4	0.84	1.10	1.54	2473	216
3	Branch	6	0.00	0.00	1.41	0	216
4	Branch	5	1.41	1.40	2.18	3792	517
5	Branch	5	3.13	0.00	4.54	3217	439
6	Branch	4	4.48	0.00	5.04	5644	493
7	Branch	5	3.70	0.00	5.80	2819	384
15	Submain	6	0.00	0.00	2.23	0	801
20	Submain	6	0.00	0.00	5.16	0	1318
30	Submain	7	0.00	0.00	7.02	6804	1757
40	Submain	9	0.00	0.00	5.78	0	1757
50	Submain	9	0.00	0.00	6.52	0	2250
60	Submain	10	0.00	0.00	6.05	0	2250
70	Submain	10	0.00	0.00	6.90	4799	2634
80	Submain	12	0.00	0.00	6.35	0	2634

ID	Type	Comment
1	Branch	del SP1-2:.12; del SP2-3:.095;thermo: 3372 fpm
2	Branch	thermo: 2627;SPH 14.5in below,SPmid 17 in above damper
3	Branch	
4	Branch	thermo: 2526 at center
5	Branch	thermo:slot-481;frt-918;duct4460;back631;undertopfr555s928
6	Branch	thermo: 5813; SPH SPmid jumpy!
7	Branch	thermo:against slot 2466;area=12.5x2x8in,SPH&end jumpy
15	Submain	
20	Submain	
30	Submain	del SP1-2:.67;del SP2-3:0.04;del L1-2:3 ft;del L2-3:1 ft
40	Submain	
50	Submain	
60	Submain	
70	Submain	del SP1-2:.16; del SP2-3:.09;del L1-2:4 ft; del L2-3:6 ft
80	Submain	

File:	ME9502_B	Date measured:	95-02-16
Company:	SCCC Woodshop: MezEast	Site altitude:	100
Project:	Truncated at 80:no capped	Dry Bulb:	65.3
Instrument:	Dwyer 475 Digital	Wet Bulb:	53.6
Calibrated:	95-02-03	Measured by:	jh/dh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.47	0.57	0.67	0.72	0.74	0.71	0.64	0.55	0.52	0.46	0.26
2	Branch	0.36	0.42	0.45	0.44	0.42	0.41	0.39	0.38	0.37	0.33	0.26
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.95	1.04	1.06	1.05	1.01	0.93	0.97	0.96	0.96	0.83	0.57
5	Branch	0.56	0.70	0.82	0.84	0.81	0.78	0.69	0.63	0.57	0.49	0.33
6	Branch	1.62	1.92	2.23	2.34	2.51	2.48	2.37	2.17	2.05	1.62	1.13
7	Branch	0.45	0.52	0.58	0.61	0.62	0.64	0.64	0.62	0.57	0.46	0.35
15	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Submain	2.73	3.03	3.51	3.72	3.72	3.65	3.47	3.14	2.83	2.06	1.02
40	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	Submain	1.03	1.25	1.39	1.44	1.69	1.83	1.86	1.69	1.57	1.39	1.01
80	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.38	0.47	0.57	0.58	0.64	0.70	0.70	0.69	0.65	0.55	0.35
2	Branch	0.35	0.40	0.42	0.41	0.42	0.41	0.41	0.44	0.43	0.35	0.25
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.73	0.82	0.85	0.89	0.90	0.97	0.96	1.02	1.00	0.86	0.58
5	Branch	0.55	0.67	0.74	0.77	0.77	0.78	0.78	0.75	0.68	0.53	0.34
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.36	0.41	0.47	0.49	0.53	0.56	0.56	0.53	0.48	0.39	0.27
15	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

File:	ME950309	Date measured:	95-03-09
Company:	SCCC MEZ EAST	Site altitude:	100
Project:	consecutive measurements	Dry Bulb:	77.9
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	52
Calibrated:	95-03-07	Measured by:	jh

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	0.83	0.96	1.01	2465	484
2	Branch	4	0.59	0.78	1.11	2060	180
3	Branch	6	0.00	0.00	1.01	0	180
4	Branch	5	0.99	0.97	1.59	3114	425
5	Branch	5	2.23	0.00	3.28	2688	367
6	Branch	4	3.21	0.00	3.64	4782	417
7	Branch	5	2.37	0.00	4.19	2257	308
15	Submain	6	0.00	0.00	1.64	0	671
20	Submain	6	0.00	0.00	3.72	0	1101
30	Submain	7	0.00	5.07	5.04	5502	1473
40	Submain	9	0.00	4.17	4.17	0	1473
50	Submain	9	0.00	0.00	4.68	0	1897
60	Submain	10	0.00	0.00	4.35	0	1897
70	Submain	10	0.00	0.00	4.96	4004	2201
80	Submain	12	0.00	0.00	4.59	0	2201

ID	Type	Comment
1	Branch	del SP1-2:.095;del SP2-3 .06
2	Branch	
3	Branch	
4	Branch	
5	Branch	SPH 2= 2.12; .75' downstream SPH1 which is off taper
6	Branch	SPH jumpy:3.18-3.24
7	Branch	SPH 2 at end of flex 3.14;realized dmpr slightly closed!
15	Submain	
20	Submain	
30	Submain	del SP1-2 .375; de; SP2-3 .045
40	Submain	
50	Submain	
60	Submain	
70	Submain	del SP1-2:.02;del SP 2-3 .15
80	Submain	

File:	ME950309	Date measured:	95-03-09
Company:	SCCC MEZ EAST	Site altitude:	100
Project:	consecutive measurements	Dry Bulb:	77.9
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	52
Calibrated:	95-03-07	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.27	0.34	0.36	0.39	0.47	0.50	0.52	0.48	0.44	0.34	0.21
2	Branch	0.26	0.31	0.31	0.31	0.28	0.27	0.27	0.26	0.25	0.22	0.16
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.61	0.65	0.69	0.67	0.65	0.65	0.65	0.63	0.63	0.61	0.37
5	Branch	0.34	0.42	0.52	0.57	0.59	0.55	0.51	0.45	0.43	0.37	0.23
6	Branch	1.25	1.49	1.67	1.77	1.81	1.79	1.72	1.55	1.38	1.10	0.73
7	Branch	0.28	0.30	0.33	0.34	0.35	0.36	0.36	0.34	0.32	0.26	0.22
15	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Submain	1.76	2.26	2.54	2.66	2.63	2.50	2.47	2.21	1.83	1.14	0.12
40	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	Submain	0.74	0.92	0.95	1.03	1.20	1.29	1.28	1.16	1.08	0.91	0.52
80	Submain		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.37	0.44	0.48	0.50	0.51	0.48	0.44	0.38	0.34	0.28	0.16
2	Branch	0.24	0.28	0.28	0.29	0.28	0.28	0.29	0.31	0.30	0.26	0.17
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.52	0.58	0.61	0.62	0.64	0.65	0.67	0.69	0.69	0.60	0.38
5	Branch	0.44	0.50	0.51	0.55	0.55	0.55	0.56	0.52	0.46	0.38	0.24
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.29	0.32	0.34	0.36	0.36	0.35	0.37	0.32	0.31	0.26	0.18
15	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	Submain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

File:	ME950309b	Date measured:	95-03-(
Company:	SCCC MEZ EAST	Site altitude:	100
Project:	repeat measurements	Dry Bulb:	78
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	52
Calibrated:	95-03-07	Measured by:	jh

ID	Type	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	0.00	0.00	0.00	0	0
2	Branch	0.00	0.00	0.00	0	0
3	Branch	0.00	0.00	0.00	0	0
4	Branch	0.00	0.00	0.00	0	0
5	Branch	2.26	0.00	3.29	2780	379
6	Branch	3.23	0.00	3.67	4890	427
7	Branch	2.38	0.00	4.19	2231	304
15	Submain	0.00	0.00	0.00	0	0
20	Submain	0.00	0.00	0.00	0	0
30	Submain	0.00	0.00	0.00	0	0
40	Submain	0.00	0.00	4.18	0	0
50	Submain	0.00	4.70	4.70	0	427
60	Submain	0.00	0.00	0.00	0	427
70	Submain	0.00	0.00	0.00	0	731
80	Submain	0.00	0.00	4.60	0	731

File:	ME950309b	Date measured:	95-03-0
Company:	SCCC MEZ EAST	Site altitude:	100
Project:	repeat measurements	Dry Bulb:	77.9
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	52
Calibrated:	95-03-07	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0	0	0	0	0	0	0	0	0	0	0
2	Branch	0	0	0	0	0	0	0	0	0	0	0
3	Branch	0	0	0	0	0	0	0	0	0	0	0
4	Branch	0	0	0	0	0	0	0	0	0	0	0
5	Branch	0.45	0.48	0.56	0.58	0.57	0.58	0.56	0.53	0.48	0.4	0.26
6	Branch	1.28	1.45	1.65	1.73	1.82	1.79	1.76	1.62	1.41	1.18	0.75
7	Branch	0.23	0.29	0.32	0.35	0.36	0.36	0.36	0.35	0.32	0.29	0.18

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0	0	0	0	0	0	0	0	0	0	0
2	Branch	0	0	0	0	0	0	0	0	0	0	0
3	Branch	0	0	0	0	0	0	0	0	0	0	0
4	Branch	0	0	0	0	0	0	0	0	0	0	0
5	Branch	0.38	0.48	0.56	0.6	0.61	0.57	0.53	0.46	0.43	0.36	0.24
6	Branch	0	0	0	0	0	0	0	0	0	0	0
7	Branch	0.24	0.32	0.32	0.34	0.35	0.36	0.35	0.33	0.31	0.27	0.18

ME950309C

Repeat branch 7 opened damper fully

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
7	Branch	0.3	0.4	0.44	0.46	0.48	0.48	0.48	0.44	0.39	0.33	0.22

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
7	Branch	0.35	0.39	0.42	0.46	0.46	0.47	0.48	0.45	0.4	0.32	0.24

File:	MW941118	Date measured:	11/18/94
Company:	SCCC MEZ WEST	Site altitude:	100
Project:	initial measurements	Dry Bulb:	
Instrument:	Dwyer 475 Digital. Manometer	Wet Bulb:	
Calibrated:	10/12/94	Measured by:	jh/seg

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	2.89	3.12	3.20	4438	871
2	Branch	6	2.64	0.00	2.62	2092	411
3	Branch	5	3.56	3.56	5.33	5860	799
4	Branch	5	3.36	4.08	4.08	3035	414
5	Branch	6	0.00	0.00	4.51	0	413
6	Branch	5	3.05	4.60	5.08	4398	600
7	Branch	4	5.80	0.00	5.72	2723	238
8	Branch	5	6.18	0.00	6.26	1977	270
20	Submain	6	0.00	0.00	6.62	0	1288
30	Submain	7	0.00	0.00	9.23	0	1288
35	Submain	7	0.00	0.00	9.23	0	2090
40	Submain	9	0.00	0.00	6.87	0	2090
50	Submain	9	0.00	0.00	7.10	0	2090
60	Submain	12	0.00	0.00	6.37	0	2090
65	Submain	6	0.00	0.00	6.34	0	1013
70	Submain	12	0.00	0.00	6.80	0	3103
80	Submain	14	0.00	0.00	6.34	0	3103
88	Branch	6	0.10	0.10	6.87	0	0
90	Submain	14	0.00	0.00	6.40	0	3341
100	Submain	14	0.00	0.00	6.80	3630	3611

File: MW941118
Company: SCCC MEZ WEST
Project: initial measurements
Instrument: Dwyer 475 Digital. Manometer
Calibrated: 10/12/94

Date measured: 11/18/94
Site altitude: 100
Dry Bulb:
Wet Bulb:
Measured by: jh/seg

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPacl	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.93	1.20	1.51	1.61	1.66	1.55	1.52	1.28	1.15	1.03	0.68
2	Branch	0.23	0.31	0.31	0.29	0.28	0.25	0.31	0.34	0.36	0.31	0.20
3	Branch	2.03	2.33	2.41	2.42	2.40	2.25	2.30	2.35	2.31	2.10	1.40
4	Branch	0.52	0.56	0.61	0.65	0.69	0.63	0.64	0.63	0.61	0.54	0.38
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	1.07	1.23	1.32	1.46	1.42	1.41	1.33	1.24	1.23	1.11	0.78
7	Branch	0.44	0.53	0.63	0.58	0.60	0.54	0.47	0.45	0.41	0.35	0.29
8	Branch	0.23	0.29	0.31	0.36	0.32	0.28	0.23	0.18	0.20	0.20	0.14
100	Submain	0.65	0.72	0.70	0.68	0.77	0.75	0.75	0.80	0.90	0.99	0.80

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.97	1.13	1.21	1.24	1.51	1.62	1.64	1.48	1.41	1.17	0.66
2	Branch	0.09	0.16	0.20	0.22	0.25	0.28	0.30	0.34	0.40	0.33	0.26
3	Branch	1.74	1.94	2.07	2.13	2.25	2.34	2.45	2.46	2.44	2.00	1.35
4	Branch	0.53	0.64	0.64	0.67	0.68	0.66	0.62	0.59	0.51	0.46	0.29
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	0.93	1.17	1.20	1.27	1.28	1.41	1.10	1.38	1.29	1.03	0.98
7	Branch	0.38	0.48	0.53	0.46	0.55	0.55	0.49	0.45	0.43	0.37	0.31
8	Branch	0.15	0.20	0.24	0.27	0.28	0.24	0.28	0.30	0.26	0.25	0.21
100	Submain	1.01	0.91	0.89	0.87	0.77	0.67	0.67	0.76	0.91	0.99	0.78

File:	MW941118	Date measured:	94-11-18
Company:	SCCC MEZ WEST	Site altitude:	100
Project:	repeat measurements	Dry Bulb:	70
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	52
Calibrated:	94-10-12	Measured by:	jh/seg

ID	Type	Dia	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	2.74	3.15	3.21	4560	895
2	Branch	6	2.38	2.72	3.08	2273	446
3	Branch	5	0	0	0	0	0
4	Branch	5	0	4.08	4.08	3002	409
5	Branch	6	0	0	0	0	0
6	Branch	5	0	0	0	0	0
7	Branch	4	0	0	0	0	0
8	Branch	5	0	0	0	0	0
20	Submain	6	0	0	6.63	0	896
30	Submain	7	0	0	0	0	1342
35	Branch	7	0	0	0	0	0
40	Submain	9	0	0	0	0	1342
50	Submain	9	0	0	7.09	0	1342
60	Submain	12	0	0	6.36	0	1342
65	Submain	6	0	0	0	0	409
70	Submain	12	0	0	0	0	1752
80	Submain	14	0	0	0	0	1752
88	Branch	6	0	0	0	0	0
90	Submain	14	0	0	0	0	1752
100	Submain	14	0	0	0	0	1752

File:	MW941118	Date measured:	94-11-18
Company:	SCCC MEZ WEST	Site altitude:	100
Project:	initial measurements	Dry Bulb:	70
Instrument:	Dwyer 475 Dig. Manometer	Wet Bulb:	52
Calibrated:	94-10-12	Measured by:	jh/seg

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	1.02	1.11	1.21	1.33	1.54	1.60	1.68	1.57	1.46	1.27	0.73
2	Branch	0.30	0.35	0.35	0.35	0.33	0.33	0.33	0.41	0.41	0.37	0.21
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.50	0.56	0.58	0.65	0.64	0.65	0.60	0.62	0.62	0.59	0.37
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	1.02	1.30	1.54	1.62	1.67	1.66	1.54	1.32	1.25	1.16	0.70
2	Branch	0.20	0.22	0.26	0.28	0.27	0.31	0.35	0.40	0.40	0.36	0.26
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.49	0.57	0.63	0.70	0.71	0.67	0.59	0.56	0.49	0.45	0.31
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Type	Comment
2	Branch	duct had come loose about mid point

File:	MWDEC94	Date measure	94-12-09
Company:	SCCC MEZ WEST	Site altitude:	100
Project:		Dry Bulb:	61.7
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	41.4
Calibrated:	94-12-01	Measured by:	jh

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	2.79	0.00	3.22	4487	881
2	Branch	6	2.15	2.45	3.10	2181	428
3	Branch	5	3.67	3.73	5.60	6093	831
4	Branch	5	3.44	4.27	0.00	3117	425
5	Branch	6	0.00	0.00	4.69	0	423
6	Branch	5	2.96	4.78	5.27	4598	627
7	Branch	4	6.03	5.96	5.96	2914	254
8	Branch	5	6.39	6.52	6.52	2166	295
20	Submain	6	0.00	0.00	6.95	0	1308
30	Submain	7	0.00	0.00	9.67	0	2134
35	Branch	7	0.00	0.00	9.67	0	0
40	Submain	9	0.00	0.00	7.18	0	2134
50	Submain	9	0.00	0.00	7.38	0	2134
60	Submain	12	0.00	0.00	6.65	0	2134
65	Submain	6	0.00	0.00	6.62	0	1046
70	Submain	12	0.00	0.00	7.04	0	3180
80	Submain	14	0.00	0.00	6.62	0	3180
88	Branch	6	0.10	0.10	7.18	0	0
90	Submain	14	0.00	0.00	5.72	0	3432
100	Submain	14	0.00	0.00	7.10	3774	3725

File:	MWDEC94	Date measured:	94-12-09
Company:	SCCC MEZ WEST	Site altitude:	100
Project:		Dry Bulb:	61.7
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	52
Calibrated:	94-12-01	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPacl	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.72	0.93	1.13	1.25	1.42	1.63	1.64	1.55	1.48	1.25	0.95
2	Branch	0.22	0.23	0.24	0.25	0.27	0.30	0.32	0.36	0.38	0.37	0.28
3	Branch	2.15	2.40	2.47	2.60	2.44	2.45	2.48	2.51	2.50	2.24	1.51
4	Branch	0.47	0.58	0.63	0.71	0.73	0.72	0.71	0.66	0.63	0.56	0.40
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	1.04	1.18	1.27	1.37	1.47	1.51	1.52	1.48	1.45	1.33	0.90
7	Branch	0.66	0.73	0.73	0.68	0.60	0.52	0.50	0.46	0.42	0.35	0.31
8	Branch	0.32	0.36	0.37	0.37	0.35	0.31	0.25	0.24	0.24	0.25	0.20
100	Submain	1.01	1.11	0.99	0.87	0.80	0.81	0.76	0.89	0.92	1.00	0.76

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	1.30	1.47	1.56	1.65	1.63	1.54	1.52	1.37	1.22	1.05	0.67
2	Branch	0.28	0.30	0.31	0.30	0.27	0.26	0.32	0.35	0.36	0.32	0.21
3	Branch	2.08	2.26	2.32	2.32	2.36	2.47	2.56	2.59	2.49	2.23	1.46
4	Branch	0.56	0.65	0.68	0.73	0.73	0.72	0.69	0.61	0.55	0.47	0.35
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	1.20	1.36	1.47	1.51	1.54	1.48	1.46	1.35	1.34	1.21	0.81
7	Branch	0.41	0.47	0.52	0.55	0.53	0.55	0.58	0.58	0.56	0.52	0.38
8	Branch	0.21	0.23	0.23	0.24	0.28	0.33	0.34	0.36	0.36	0.33	0.24
100	Submain	0.74	0.75	0.76	0.80	0.78	0.82	0.80	0.87	0.97	1.06	0.83

File:	950119	Date measured:	95-01-19
Company:	SCCC MEZ WEST	Site altitude:	100
Project:		Dry Bulb:	71.6
Instrument:	Dwyer 475Digital Manometer	Wet Bulb:	58.1
Calibrated:	95-01-11	Measured by:	jh

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	2.95	3.36	3.47	4673	918
2	Branch	6	2.37	2.66	3.33	2180	428
3	Branch	5	3.55	3.64	5.48	5957	812
4	Branch	5	3.47	4.26	4.71	3081	420
5	Branch	6	0	0	4.71	0	420
6	Branch	5	2.74	4.77	5.26	4553	621
7	Branch	4	6.89	5.99	5.99	2860	250
8	Branch	5	6.34	6.54	6.54	2119	289
20	Submain	6	0	0	6.90	0	1350
30	Submain	7	0	0	5.79	0	1350
35	Submain	7	0	0	9.55	0	2163
40	Submain	9	0	0	7.18	0	2163
50	Submain	9	0	0	7.35	0	2163
60	Submain	12	0	0	6.62	0	2163
65	Submain	6	0	0	6.61	0	1041
70	Submain	12	0	0	7.06	0	3204
80	Submain	14	0	0	6.65	0	3204
88	Branch	6	0.10	0.10	7.18	0	0
90	Submain	14	0	0	6.70	0	3453
100	Submain	14	0	0	7.16	3801	3741

File:	95-01-19	Date measured:	95-01-19
Company:	SCCC MEZ WEST	Site altitude:	100
Project:		Dry Bulb:	71.6
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	58.1
Calibrated:	95-01-11	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPaclA	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	1.10	1.44	1.66	1.71	1.79	1.77	1.57	1.35	1.35	1.17	0.79
2	Branch	0.20	0.23	0.25	0.27	0.28	0.29	0.32	0.37	0.38	0.34	0.20
3	Branch	2.05	2.44	2.44	2.38	2.42	2.45	2.40	2.44	2.40	2.06	1.39
4	Branch	0.48	0.55	0.65	0.71	0.72	0.73	0.70	0.63	0.61	0.57	0.43
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	1.29	1.38	1.42	1.54	1.49	1.43	1.40	1.33	1.27	1.10	0.83
7	Branch	0.64	0.70	0.72	0.70	0.62	0.53	0.52	0.46	0.46	0.38	0.31
8	Branch	0.27	0.30	0.35	0.33	0.35	0.32	0.29	0.26	0.25	0.27	0.22
100	Submain	0.74	0.78	0.76	0.78	0.84	0.82	0.83	0.88	0.97	1.09	0.85

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	0.95	1.17	1.27	1.40	1.57	1.74	1.78	1.64	1.50	1.32	0.76
2	Branch	0.29	0.31	0.31	0.31	0.27	0.29	0.31	0.36	0.38	0.36	0.22
3	Branch	2.00	2.22	2.24	2.32	2.41	2.54	2.60	2.57	2.43	1.86	1.36
4	Branch	0.56	0.66	0.69	0.72	0.76	0.68	0.67	0.59	0.54	0.45	0.33
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	1.15	1.22	1.35	1.39	1.42	1.45	1.49	1.48	1.42	1.24	0.79
7	Branch	0.42	0.48	0.49	0.54	0.57	0.56	0.57	0.52	0.47	0.44	0.33
8	Branch	0.16	0.17	0.18	0.20	0.28	0.34	0.36	0.36	0.37	0.37	0.25
100	Submain	1.06	0.96	0.98	0.89	0.87	0.83	0.85	0.86	0.91	1.00	0.76

File:	950119	Date measured:	95-01-19
Company:	SCCC MEZ WEST	Site altitude:	100
Project:	repeat for meas error	Dry Bulb:	71.6
Instrument:	Dwyer 475 Dig Manometer	Wet Bulb:	58.1
Calibrated:	95-01-11	Measured by:	jh

ID	Type	Diameter	SPH	SPmid	SPend	Vmeas	Qact
1	Branch	6	2.96	3.39	3.50	4782	939
2	Branch	6	0	0	0	0	0
3	Branch	5	0	0	0	0	0
4	Branch	5	0	0	0	0	0
5	Branch	6	0	0	0	0	0
6	Branch	5	0	0	0	0	0
7	Branch	4	0	0	0	0	0
8	Branch	5	0	0	0	0	0
20	Submain	6	0	0	6.93	0	939
30	Submain	7	0	0	5.86	0	931
35	Submain	7	0	0	0	0	0
40	Submain	9	0	0	0	0	0
50	Submain	9	0	0	7.39	0	0
60	Submain	12	0	0	0	0	0
65	Submain	6	0	0	0	0	0
70	Submain	12	0	0	0	0	0
80	Submain	14	0	0	0	0	0
88	Branch	6	0	0	0	0	0
90	Submain	14	0	0	0	0	0
100	Submain	14	0	0	7.16	3815	4079

File:	950119	Date measured:	95-01-19
Company:	SCCC MEZ WEST	Site altitude:	100
Project:	repeat for meas error	Dry Bulb:	71.6
Instrument:	Dwyer 475 Digital Manometer	Wet Bulb:	58.1
Calibrated:	95-01-11	Measured by:	jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPacl	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	1.23	1.48	1.69	1.81	1.79	1.73	1.60	1.49	1.41	1.12	0.69
2	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	Submain	1.07	0.95	0.96	0.85	0.83	0.84	0.76	0.87	0.96	1.03	0.78

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	1.12	1.26	1.33	1.41	1.58	1.81	1.80	1.71	1.58	1.30	0.83
2	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	Submain	0.70	0.72	0.79	0.85	0.82	0.86	0.90	0.92	1.01	1.10	0.86

File:	MW950508	Date measured:	5/8/95
Company:		Site altitude:	100
Project:	system checked with borescope	Measured by:	jh
Instrument:	Dwyer Digital		
Calibrated:	950507		

ID	Type	Diameter	SPH	SPmd	SPen	Vmeas	Qact
1	Branch	6	2.35	2.69	2.78	4218	828
2	Branch	6	2.07	2.34	2.65	2181	428
3	Branch	5	2.84	2.94	4.34	5448	743
4	Branch	5	2.77	3.37	3.37	2949	402
5	Branch	6	0.00	0.00	3.72	0	402
6	Branch	5	2.52	3.78	4.16	4133	564
7	Branch	4	5.14	4.76	4.76	2520	220
8	Branch	5	5.12	5.17	5.17	2073	283
20	Submain	6	0.00	0.00	5.47	0	1256
30	Submain	7	0.00	0.00	4.60	0	1256
35	Submain	7	0.00	0.00	7.58	0	1999
40	Submain	9	0.00	0.00	5.69	0	1999
50	Submain	9	0.00	0.00	5.81	0	1999
60	Submain	12	0.00	0.00	5.25	0	1999
65	Submain	6	0.00	0.00	5.17	0	966
70	Submain	12	0.00	0.00	5.56	0	2965
80	Submain	14	0.00	0.00	5.24	0	2965
88	Branch	6	0.00	0.00	0.00	0	0
90	Submain	14	0.00	0.00	5.29	0	3185
100	Submain	14	0.00	0.00	5.66	3557	3468

File: MW950508
Company:
Project: system checked with borescope
Instrument: Dwyer Digital
Calibrated: 950507

Date measured: 5/8/95
Site altitude: 100
Measured by: jh

ID	Type	VPa1	VPa2	VPa3	VPa4	VPa5	VPacl	VPa6	VPa7	VPa8	VPa9	VPa10
1	Branch	0.80	0.94	1.04	1.12	1.26	1.42	1.45	1.35	1.24	1.06	0.62
2	Branch	0.26	0.28	0.30	0.28	0.26	0.28	0.30	0.34	0.36	0.32	0.24
3	Branch	1.81	1.86	1.90	1.92	1.98	2.07	2.11	2.03	1.99	1.73	1.06
4	Branch	0.43	0.50	0.59	0.63	0.62	0.60	0.58	0.55	0.53	0.49	0.40
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	1.06	1.12	1.15	1.19	1.15	1.14	1.09	1.05	1.02	0.92	0.66
7	Branch	0.49	0.50	0.48	0.47	0.39	0.38	0.35	0.33	0.32	0.30	0.22
8	Branch	0.26	0.27	0.29	0.31	0.30	0.28	0.25	0.22	0.24	0.28	0.19
100	Submain	0.76	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.76

ID	Type	VPb1	VPb2	VPb3	VPb4	VPb5	VPbcl	VPb6	VPb7	VPb8	VPb9	VPb10
1	Branch	1.04	1.23	1.37	1.42	1.45	1.33	1.28	1.14	1.06	0.89	0.72
2	Branch	0.21	0.23	0.26	0.28	0.29	0.29	0.31	0.36	0.37	0.34	0.21
3	Branch	1.46	1.62	1.77	1.85	1.95	2.02	2.04	2.04	2.00	1.82	1.14
4	Branch	0.48	0.55	0.60	0.64	0.65	0.61	0.59	0.51	0.48	0.42	0.37
5	Branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Branch	0.92	0.98	1.08	1.08	1.12	1.17	1.16	1.15	1.10	1.01	0.67
7	Branch	0.34	0.36	0.39	0.41	0.40	0.39	0.40	0.41	0.40	0.42	0.34
8	Branch	0.18	0.18	0.21	0.23	0.28	0.32	0.31	0.32	0.31	0.29	0.25

APPENDIX C: REPEAT MEASUREMENT DATA

**Repeated Static Pressure Hood Pressure Data:
Mez West; December 1994**

Time	SPH 1	SPH 2	SPH 3	SPH 4	SPH 6	SPH 7	SPH 8
9:00	2.81	2.22	3.49	3.22	2.75	5.72	6.08
10:00	2.71	2.17	3.48	3.17	2.68	5.71	5.98
11:00	2.92	2.35	3.65	3.43	2.95	6.04	6.39
12:00	2.95	2.35	3.69	3.43	2.92	6.05	6.39
12:40	2.93	2.36	3.66	3.43	2.95	6.07	6.41

**Repeated Velocity Pressure Traverse Data:
Mez West Branch 1; December 1994**

Time	VP1	VP2	VP3	VP4	VP5	VPcl	VP6	VP7	VP8	VP9	VP10
9:30	0.72	0.93	1.10	1.25	1.42	1.63	1.64	1.55	1.48	1.25	0.95
10:21	0.89	1.01	1.21	1.34	1.56	1.66	1.89	1.70	1.64	1.42	1.03
11:09	0.87	0.96	1.16	1.34	1.55	1.75	1.79	1.75	1.59	1.39	1.15
12:02	0.84	1.00	1.18	1.28	1.55	1.72	1.82	1.74	1.59	1.3	0.98
12:50	0.89	1.02	1.16	1.28	1.49	1.78	1.8	1.64	1.53	1.37	0.97
1:33	0.91	0.96	1.18	1.29	1.54	1.76	1.86	1.67	1.57	1.36	0.95

Time	VP11	VP12	VP13	VP14	VP15	VPcl2	VP16	VP17	VP18	VP19	VP20
9:30	1.30	1.47	1.56	1.65	1.63	1.54	1.52	1.37	1.22	1.05	0.67
10:21	1.30	1.55	1.71	1.74	1.78	1.74	1.61	1.52	1.48	1.30	0.78
11:09	1.33	1.52	1.65	1.77	1.76	1.67	1.64	1.42	1.32	1.19	0.70
12:02	1.21	1.53	1.71	1.80	1.74	1.78	1.62	1.50	1.42	1.13	0.70
12:50	1.28	1.47	1.69	1.75	1.79	1.78	1.6	1.47	1.39	1.16	0.68
1:33	1.28	1.51	1.70	1.72	1.76	1.77	1.59	1.40	1.35	1.17	0.73

Repeated Static Pressure Data: Mez West; March 1995

Date	Branch	Time	Vmeas	VP	Qact	SPH	SPen	SPH/J
950301	1	4:25	4319	1.16	848	2.46	2.86	0.8601
950301	1	5:16	4263	1.13	837	2.4	2.865	0.8377
950301	1	6:21	4284	1.14	841	2.37	2.84	0.8345
950301	1	7:30	4236	1.12	832	2.36	2.75	0.8582
950301	1	7:45	4357	1.18	856	2.55	3.03	0.8416

Repeat Hood Static Pressure Data: Mez East; March 1995

Round	Time	SPH1	SPH2	SPH4	SPH5	SPH6	SPH7
1	4:00	.950	.680	1.105	2.330	3.530	4.33
2	4:12	.940	.670	1.100	2.300	3.460	4.34
3	4:22	.945	.665	1.100	2.300	3.500	4.34
4	4:39	.940	.675	1.120	2.300	3.500	4.34
5	4:49	.945	.680	1.120	2.300	3.480	4.31
6	5:00	.940	.670	1.110	2.300	3.500	4.32
7	5:12	.945	.675	1.115	2.300	3.500	4.275
8	5:25	.940	.680	1.110	2.300	3.480	4.24
9	5:40	.940	.690	1.120	2.310	3.500	4.23
10	5:54	.980	.715	1.140	2.310	3.475	4.28
11	6:05	.945	.690	1.130	2.300	3.485	4.27
12	6:16	.955	.690	1.130	2.310	3.490	4.29

Repeat End Static Pressure Data: Mez East; March 1995

Round	Time	SPend1	SPend2	SPend4	SPend5	SPend6	SPend7
1	4:00	1.160	1.235	1.770	3.620	4.000	4.57
2	4:12	1.140	1.235	1.750	3.570	3.985	4.56
3	4:22	1.165	1.230	1.740	3.620	4.000	4.57
4	4:39	1.170	1.240	1.760	3.580	4.000	4.56
5	4:49	1.165	1.245	1.770	3.570	4.000	4.57
6	5:00	1.165	1.250	1.740	3.570	4.010	4.55
7	5:12	1.180	1.250	1.740	3.560	3.990	4.54
8	5:25	1.175	1.250	1.735	3.560	3.960	4.53
9	5:40	1.175	1.250	1.750	3.580	3.980	4.53
10	5:54	1.215	1.280	1.770	3.575	3.960	4.54
11	6:05	1.170	1.260	1.755	3.570	3.975	4.535
12	6:16	1.190	1.260	1.770	3.570	3.970	4.54

APPENDIX D: CHARACTERIZATION DATA

Mez East Characterization Data

duct id	type	diam. (")	length (ft) total	length (ft) delta	# elbows 90	45	30	damper	taper angle	Fexp p. 5-35	flex duct length (ft)
1	usu. capped	6	16.75	14.75	-	-	-	no			
2	naked duct	4	18	16.56	1	2	-	yes			
3	ext of 2	6	10.83	9.83	-	1	-	no	9.46	0.24	
4	floor sweep	5	9.71	8.75	1	-	-	yes			
5	table saw	5	27.92	27	1	2	-	yes			3.0
6	usu. capped	4	12.33	10.37	1	1	-	no			
7	planer	5	19.5	17.25	1	2	-	yes			*1.67
8	floor sweep	5	7.66	6.67	1	-	-	yes			
9	dead	4	8.66	8.66	1	-	-	-			
10	dead	4	3	3	1	1	-	-			
11	dead	4	3	3	1	1	-	-			
12	dead	4	3	3	1	1	-	-			
15	submain	6	2	0.83	-	-	-	-			
20	submain	6	5.75	4.79	-	-	-	-			
30	submain	7	13.25	12.79	-	-	-	-			
40	submain	9	1.92	1.67	-	-	-	-	9.46	0.12	
50	submain	9	9.25	8.92	-	-	-	-			
60	submain	10	1.71	1.71	-	-	-	-	4.76	0.22	
70	submain	10	16.5	16	-	-	-	-			
80	submain	12	1.625	1.33	-	-	-	-	9.46	0.18	
90	submain	8	21.33	20.04	-	3	-	-			
100	submain	8	1.33	1.33	-	-	-	-			
110	submain	5	4	4	-	1	-	-			
120	submain	7	2.08	2.08	-	-	-	-			
130	submain	6	3.83	3.83	-	-	-	-			
140	submain	6	4	4	-	-	-	-			
150	main	12	10.83	10.83	-	-	-	-			

*contains SPH location

Mez West Characterization Data

duct id	type	diam	length (ft) total	length (ft) delta	# elbows 90°	45 °	30 °	damper	taper angle	Fexp p. 5-35	flex duct length (ft)
1	usu. capped	6	18.58	14.58	-	-	-	no			
2	table saw	6	21.08	18.59	1	2	-	yes			3
3	floor sweep	5	9.75	7.67	1	-	1	yes			
4	table saw	5	12	6.62	1	2	-	yes			3
5	ext. of 4	6	3.5	3.08	-	-	-	no	26.57	0.26	
6	jointer	5	10.625	9.62	1	1	-	yes			*1.25
7	belt. sndr	4	5.69	4.02	1	1	-	yes			*1.33
8	disc sander	5	7.33	5.08	1	1	-	yes			1.17
20	submain	6	6.5	5.96	-	-	-				
30	submain	7	1.75	1.75	-	-	-		4.76	0.18	
35	submain	7	1.42	1.42	-	-	-				
40	submain	9	1.92	1.17	-	-	-		9.46	0.12	
50	submain	9	15	14.67	-	-	-				
60	submain	12	2.875	1.35	-	-	-		7.13	0.13	
65	submain	6	1	0.96	-	-	-				
70	submain	12	10.9	10.5	-	-	-				
80	submain	14	8.83	1.5	-	-	-		9.46	0.2	
88	dead branch	6	0	8	2	1	-				
90	submain	14	0.92	0.33	-	-	-				
100	main	14	8.03	8.03	-	2	-				

* contains SPH location

APPENDIX E: EQUIPMENT LIST

Dwyer Series 475 Mark II Digital Manometer	SN
N23F118	
TSI Incorporated "VelociCalc" Model 8325 Thermoanemometer	SN 2035
Cole-Palmer Psychro-Dyne Psyhchrometer	
Toshiba Portege Model T3400 Laptop Computer	SN 0243171
HEAVENT Ventilation Design Software	
HV_MEAS Pressure Measurement Spreadsheet Software (version 1.0)	
3 Traverse Device with Dwyer 1/8" Pitot Tube, 12" long	
1 Traverse Device with Dwyer 3/8" Pitot Tube, 18" long	
Traverse Device Slide Inserts - 4" - 14"	
Dwyer 1/8" Pitot Tube, 12" long for hand-held static pressure measurements	
Tygon® Tubing	
Plastic Interlocking Couplers for Tygon® Tubing	
Flashlight	
DeWalt Cordless 3/8" VSR Drill	SN 200925
Fowler Instruments 12" Micrometer	SN 6904096
Safety Glasses	
Colored Plastic Tape for Marking Measurement Points	
Duct Tape	