American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

Ventilation design by microcomputer

DAVID E. CLAPP , D.J. GROH & C.M. Nenadic

To cite this article: DAVID E. CLAPP , D.J. GROH & C.M. Nenadic (1982) Ventilation design by microcomputer, American Industrial Hygiene Association Journal, 43:3, 212-217, DOI: 10.1080/15298668291409622

To link to this article: https://doi.org/10.1080/15298668291409622

Published online: 04 Jun 2010.

The design of ventilations systems is an arduous task if done by hand. This paper describes an interactive computer program for the Apple II Microcomputer which virtually eliminates the manual calculations while providing the additional power and flexibility of computer processing. Ventilation designs can be reworked numerous times with final designs stored on diskette for later recall, review, and possible redesign. The computer program prompts the user through the design process in a logical step by step manner. Most design data is contained in the program and the user only needs a schematic drawing of the layout and a selection of hoods including exhaust volume, duct velocity, and entry losses. The program requires an Apple II Microcomputer with 48 K of RAM and at least one disk drive. A version of the program for the TRS-80 Model I or III is also available.

Ventilation design by microcomputer

DAVID E. CLAPP, Ph.D., P.E.,[A] D.J. GROH, D.S.[B] and C.M. Nenadic, J.D., C.I.H., P.E.[B]
[A]Chief, Industrial Hygiene Section, Industry Wide Studies, NIOSH (DSHEFS), 4676 Columbia Parkway, Cincinnati, OH 45226; [B]CES Inc., P.O. Box 75120, Cincinnati, OH 45275

introduction

The microcomputer is becoming more widely evident in industrial hygiene practice. The first article regarding such applications appeared in a recent issue of the *AIHA Journal* entitled "Management of Exposure Records at Small Businesses with a Personal Computer — A Simple Approach".(1) This first article presages the development of a continuing series of contributions describing where the microcomputer can reduce computational effort while increasing the power and flexibility in industrial hygiene practice.

This article describes a major application area where the microcomputer can provide significant power and flexibility — ventilation design. Ventilation design has long been one of the more computationally complex activities in industrial hygiene practice. This complexity has generally restricted design to a limited number of specialists who could acquire the knowledge and maintain the necessary skills to perform this analysis competently. The microcomputer program described here can potentially permit a far wider selection of individuals to competently perform ventilation design.

The microcomputer chosen for this application is the APPLE Microcomputer System. The minimum configuration necessary to operate the program is the Apple II Plus Keyboard equipped with 48000 8-bit bytes of random acess memory (48K RAM) and a suitable television monitor. One disk drive is necessary to store the program as well as to store data resulting from specific designs. The use of a disk to store the program and data offers considerable input and output capability. Finally, a line printer (e.g. the Integral Data Systems "Paper Tiger") is desirable to produce hard copy of final design data. The cost of the entire system, including the printer, is less than $3000. A printer is not absolutely necessary since design data may be hand copied from the television screen. The printer however, provides rapid copy which is especially useful in analyses where the solution is attempted several times with only slight changes in the design parameters.

The Apple II is well suited to perform the ventilation design program. The microcomputer is compact and lightweight (about the size and weight of a portable typewriter) and can be easily transported to any location where there is 110 volt power and a TV monitor available. Using the Apple, the ventilation designer can take the computer to any convenient location, such as a conference room, where other individuals interested in the design may participate and view the development of results.

The ventilation program can be modified to operate on other computer systems. Such systems should have similar configuration including a disk drive and at least 48 K of RAM. An effort is currently underway to modify the program for another popular microcomputer — the Radio Shack TRS-80. The ventilation program is written in the

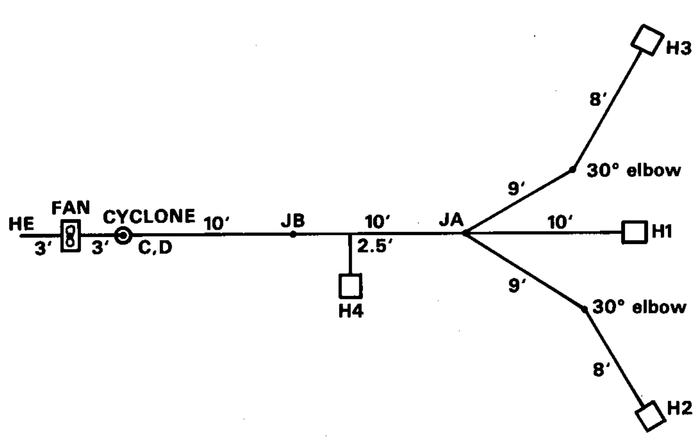

Figure 1 — Top view of ventilation design.

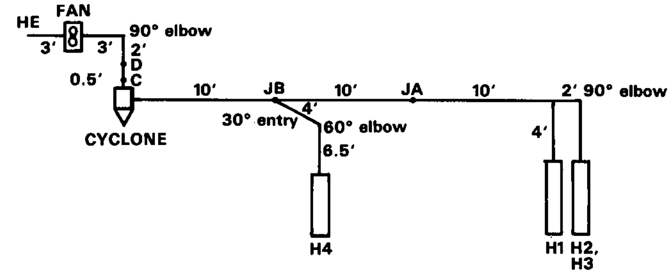

Figure 2 — Side view of ventilation design.

TABLE I
Hood Design Data

Hood	Description	VS Print	Min Exhaust
1	3 x 2 ft Welding Bench	416	1050
2	Metal cutting Bandsaw	418	800
3	Metal cutting Bandsaw	418	800
4	Grinder Wheel Hood	411	500

TABLE II
System Details

Branch	Minimum CFM Required	Length (ft)	Elbows	Entries
H1-JA	1050	14	1-90°	
H2-JA	800	21	1-90°, 1-30°	30°
H3-JA	800	21	1-90°, 1-30°	30°
A-JB	2650	10		
H4-JB	500	13	1-90°, 1-60°	30°
B-C	3150	10.5		
C-D	3150	Expansion	30° taper	
D-Fan	3150	2	1-90°	
Fan HE	3150	3		
Cyclone	--	1" W.G. pressure drop		

BASIC computer language which is common to most microcomputer systems, and is available on some larger mini-computers and full size computer systems.

The ventilation program described here is not based on any prior computer programs. Some years ago, a FORTRAN program was available from the American Conference of Governmental Industrial Hygienists (ACGIH). While this program was effective and useful, its scope and philosophy is not suitable for the modern microcomputer. The current program is entirely new and is written to take advantage of the unique operating characteristics of the microcomputer. The program follows the "Equivalent Length Method" described in *Industrial Ventilation*, 16th Edition, published by ACGIH.[2]

A major feature of the design of the ventilation program is interactive operation. This mode of operation is user oriented and provides an instant response to each input. In this sense, the program is tutorial since the user designs the system interactively and it is not necessary to have the design completely defined before beginning to use the program. The user is prompted to follow a logical sequence of decisions through the system design. The beginner may use the program as a training tool to identify decisions which must be made and to determine the impact of these decisions in the final design.

The program is complete and self sufficient and the design rationale follows the recommended procedure in *Industrial Ventilation*. The program does not require user to look up tabulated data. All of the relevant tables, curves, and other data are included in the program either in tabular form or as an interpolation of a curve. Hence, the user is largely free to design a ventilation system without frequently referring to specific Chapters in *Industrial Ventilation*. Some data from the handbook must be manually selected; (as shown in Figure 1) however, this is usually done one time at the outset of the design process. Most data for this purpose is taken from the typical hood designs in Chapter 5. This requirement is further described below in the description of the program operation.

program operation

The design process begins with the manual development of a schematic as shown in Figure 1 and Figure 2. Two views are necessary to reflect both vertical and horizontal turns in the duct system. The layout shown is fairly typical for a metal working shop and includes a welding bench (H1), two band saws (H2, H3), and a grinder (H4). The details of these hoods, from Chapter 5 of *Industrial Ventilation* are summarized in Table I.

While most of the system details (lengths, elbows, etc.) are shown in Figures 1, and 2, it is convenient to place this data in a table for ready review during the computer design process. These details are shown in Table II.

In Table II, for simplicity, all elbows are considered to have a centerline radius of two (2) duct diameters. Other radius values may be inserted in actual designs with the program. In Table II, as well as Figures 1 and 2, the branches are identified in a specific way to insure correct input of the system layout. All atmospheric openings must have the prefix "H" and all junction points the prefix "J" (Example H1-JA) and the prefix "F" is reserved for fan locations. Any additional desired labelling letters or numbers, may be added as long as the "H", "J", and "F" convention is not violated. As a checking mechanism, the program automatically drops the "J" prefix after a junction is balanced. With this procedure, the designer can readily verify that the bal-

TABLE III
Preliminary Data Display

ST	ED	VEL	LOSSES	Q	DIAM
H1	JA	1925.1	.56	1050	10
H2	JA	4074.3	4.43	800	6
H3	JA	4074.3	4.43	800	6

TABLE IV
Balanced Data at Junction JA

ST	ED	VEL	LOSSES	Q	DIAM
H2	JA	4074.3	4.43	800	6
H3	JA	4074.3	4.43	800	6
H1	JA	5686.3	4.43	1116.5	6
HJ	A	4611.7	4.43	2716.5	10.3923

TABLE V
Balanced Data at Junction JB

ST	ED	VEL	LOSSES	Q	DIAM
H2	JA	4074.3	4.43	800	6
H3	JA	4074.3	4.43	800	6
H1	JA	5686.3	4.33	1050	6
HJ	A	4611.7	4.33	1116.5	10.39
A	JB	4116.2	.22	2716.5	11
H4	JB	4857.3	4.65	536.48	4.5
HJ	B	4222.4	4.65	3252.9	11.88

TABLE VI
Final Design Data

ST	ED	Q	VE	VP	DD	DL	SLOT	HOOD	DUCT	ELBW	ENTR	TOTAL
H2	JA	800	4074	1.03	6	21	0	2.84	.93	.42	.22	4.43
H3	JA	800	4074	1.03	6	21	0	2.84	.93	.42	.22	4.43
H1	JA	1117	5686	2.02	6	14	.13	2.52	1.18	.61	0	4.43
HJ	A	2717	4611	1.33	10.4	56	0	0	4.43	0	0	4.43
A	JB	2717	4116	1.06	11	10	0	0	.21	0	0	.22
H4	JB	536	4857	1.46	4.5	13	0	2.42	1.15	.75	.31	4.63
HJ	B	3253	4222	1.11	11.9	23	0	0	4.64	0	0	4.63
B	C	3253	4142	1.07	12	10.5	0	0	1.19	0	0	1.19
D	FAN	3253	1491	.14	20	5	0	0	7E-3	.04	0	.05
C	D	3253	1491	.14	20	0.6	0	0	-.36	0	0	-.36
FAN	HE	3253	1491	.14	20	3	0	0	4E-3	0	0	4E-3

FAN STATIC PRESSURE DIFFERENCE (W.G.) = 5.42
FAN DESIGN Q (CFM) = 3253
INTAKE DUCT DIAMETER (INCHES) = 20
OUTPUT DUCT DIAMETER (INCHES) = 20

ance has been completed at a given point by simply glancing at the design data display or printout.

To begin the design process, the user typically starts at the end point in the system of greatest resistance or loss. This is an arbitrary rule and if desired, design can be begun at any terminal point in the layout (here at H1, H2, H3, or H4). For the branch H1, JA the user simple responds to the following questions from the program (user responses shown in parenthesis)

Computer Question	User Response
STARTING POINT?	(H1)
END POINT?	(JA)
DESIGN Q (CFM)?	(1050)
TRANSPORT VELOCITY (FPM)?	(2000)
ARE THERE ENTRY LOSSES?	(YES)
ARE THERE ANY SLOTS?	(YES)
SLOT AREA VELOCITY (FPM)?	(1000)
SLOT ENTRY LOSS FACTOR (UP)?	(1.78)
HOOD ENTRY LOSS FACTOR (VP)?	(.25)
ARE THERE ANY DUCT LOSSES?	(YES)
LENGTH (FT)?	(14)
ARE THERE ANY FITTINGS?	(YES)
ARE THERE ANY ELBOWS?	(YES)
CENTERLINE RADIUS (DUCT DIAMETERS)?	(2)
NO. OF 90 DEGREE ELBOWS?	(1)
NO. OF 60 DEGREE ELBOWS?	(0)
NO. OF 45 DEGREE ELBOWS?	(0)
NO. OF 30 DEGREE ELBOWS?	(0)
ARE THERE ANY ENTRIES?	(NO)
ARE THERE ANY OTHER PRESSURE LOSSES (IF THERE ARE NO OTHER LOSSES THEN TYPE 0)	(0)
IS THIS SATISFACTORY?	(YES)

The questions above are basically all the input required to describe a typical branch of a ventilation system. Some details of input have been omitted from this description, and users of the program should obtain a user's manual (instructions at end of this article) for a step-by-step description of each feature of the program. The reader will note that most of the responses given above are taken from the system schematic (Figures 1 and 2) as well as the system details in Table II. Some data (e.g. hood entry loss factor) is taken from VS 416 in Chapter 5 of *Industrial Ventilation*. Most of the entries are straightforward and the computer responds by developing interim results (e.g. after entering slot entry loss factor of 1.78), the slot entry loss of 0.11$ water gauge (W.G.) is displayed. After completing the input of this first branch data, the user may wish to print a summary of the results.

The program includes two options for display. The first option displays losses (in inches W.G.) as follows (Definitions of the heading for all printed computer outputs are given at the end of this paper):

ST	ED	SLOT	HOOD	DUCT	ELBW	ENTRY
H1	JA	.1109	.2888	.0802	.0769	0

The second option lists the following values for the entire branch including the sized diameter of this length of duct as:

ST	ED	VEL.	LOSSES	Q	DIAM
H1	JA	1925.1	.55698	1050	10

The user requests these displays by typing an index code (a number from 1 to 15). A menu of these codes is displayed for the user at each point where a selection can be made; hence the user need not memorize which code activates which function. Only a few of these functions are illustrated in this article. The remainder are best reviewed by actually running the program since several are "utilities" which serve to clean up the display or simplify data entry such as permitting entry of a duplicate branch with a single command. The next activity in the computer design process is to enter branch H2-JA. This procedure is identical to the steps followed for branch H1-JA above. The specific data is different (e.g. design Q of 800 cfm, length of 21 ft, etc.) but the procedure is the same. This branch has a 30° entry as shown in Figure 1 and Table II.

TABLE VII
Manual Solution of Example System

CALCULATION SHEET							STATIC PRESSURE BALANCE																					EQUIVALENT LENGTH METHOD			
							ENTRY LOSSES									DUCT LOSSES			FITTING LOSSES												
							SLOTS						HOODS						ELBOWS					ENTRIES							
Duct Number or name	Design Q. CFM	Min. tran. velocity, FPM	Duct diam. inches	Duct area, ft.^{2}	Actual duct velocity, FPM	Actual duct velocity press. in.W.G.	Slot area ft.^{2}	Slot velocity, FPM	Slot velocity press. in.W.G.	Slot entry loss factor VP	Accel. factor* (1.0 + col. 11)	Slot entry loss in.W.G.* (col. 10 x col. 11) or (col. 10 x col. 12)	Hood entry loss factor VP	Accel. factor* (1.0 + col. 14)	Hood entry loss in.W.G.* (col. 7 x col. 15) or (col. 7 x col. 14)	Length, ft.	Friction loss per 100 ft. in.W.G.	Duct loss in.W.G. $\left(\frac{\text{col. 17 x col. 18}}{100}\right)$	Centerline rad. duct diam.	Equiv. length per 90° elbow	Number of 90° ells	Equiv. lengths, ft.	Elbows loss in.W.G. $\left(\frac{\text{col. 18 x col. 23}}{100}\right)$	Angle of entry, deg.	Equiv. length per entry, ft.	Entry loss in.W.G. $\left(\frac{\text{col. 18 x col. 26}}{100}\right)$	Miscellaneous Calculations	Total losses (SP) in.W.G. (col. 13 + 16 + 19 + 24 + 27)	Cumulative losses (SP) in.W.G.	Governing SP in W.G.	Balanced Q. CFM
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
H1-JA	1050	2000	.10	.545	1925	.231	1.05	1000	.062	1.78	--	.11	.25	1.25	.29	14	.57	.08	2	14	1	14	.08					.56		4.41	
H2-JA	800	4000	6	.196	4074	1.03							1.75	2.75	2.85	21	4.44	.93	2	7	1.33	9.31	.41	30	5.	.22		4.41			
H3-JA			SAME AS H2-JA																												
BALANCE JA: SP_H/SP_L = 4.41/.56 = 7.88 → Redesign H1-JA																															
H1-JA	1050		6	.196	5348	1.78	1.05	1000	.062	1.78	--	.11	.25	1.25	2.23	14.	7.45	1.04	2	7	1	7	.52					3.90		4.41	1117
BALANCE JA: SP_H/SP_L = 4.41/3.90 = 1.13 → Increases flow through H1-JA New Q = 1050 $\sqrt{1.13}$ = 1117																															
JA-JB	2717	4000	11	.660	4116	-1.06										10	2.06	.22										.22	4.63	4.63	536
H4-JB	500	4500	4.5	.110	4527	1.28							.65	1.65	2.11	13	7.71	1.00	2	5	1.66	8.3	.64	30	3.5	.27		4.02			
BALANCE JB: SP_H/SP_L = $\frac{4.63}{4.02}$ = 1.15 Increase flow through H4-JB New Q = 500 $\sqrt{1.15}$ = 536																															
JB-C	3253	4000	12	.785	4142	1.07										10.5	1.97	.20									Add 1.0" Cyclone Loss	.20	-5.82		
C-D			EXPANSION																												
30° TAPER, D_1 = 12", D_2 = 20", D_2/D_1 = 1.67, R = 0.70 x 0.57 (within 5' of disturbance)																															
SP = SP_1 + R (VP_1 - VP_2) = -5.82 + .39 (1.07 - .14) = -5.47																															
D-FAN	3253		20	2.18	1491	.14										5	.15	.01	2	32	1	32	.05					-.05	-5.52		
Fan-HE	3253	1460	20	2.18	1491	.14										3	.15	0										0			
FAN SP = SP_{out} - SP_{in} - VP_{in} = 5.52 - .13 = 5.39 in. H_2O																															

*This represents the amount of energy needed to get air to flow into the hood. NOTE: When dealing with hoods that also contain slots, add the acceleration factor to either the hood VP or slot VP, whichever has the higher value (usually the hood VP). This is only added *one* time, that is, only where air initially enters the duct (e.g., through a hood).

Designed by: Robert B. Weidner, J.D., P.E.
Feb., 1975, NIOSH, Division of Training

PLANT NAME ____________________
LOCATION ____________________
DEPARTMENT ____________________

CALCULATIONS BY ____________________
CHECKED BY ____________________
APPROVED BY ____________________

EVALUATION ____________________
TEMPERATURE ____________________
DATE ____________________

Branch H3-JA is identical to branch H2-JA, hence data entry is very simple. In this case, the user specifies a "duplicate branch" function and simply responds to questions regarding beginning and ending points of the new and old branches respectively. After completing this function, the user should request a display of data to insure that the duplication was performed correctly. For this example, the data shown in Table III would be displayed.

Now all branch designs are complete to Junction A (or JA), and a junction balance may be attempted. Due to the large difference in pressure loss (over 20%) between branch H1-JA (0.91) and branches H2-JA, H3-JA (both 4.43), the diameter of H1-JA must be redesigned. An option in the program permits entering a new diameter; in this case a smaller diameter is needed to increase the resistance in H1-JA. By a trial and error method, a suitable new dimension may be found. In this problem, a diameter of 6" yields a branch loss of 3.92" W.G. which can balance with the other incoming branches. The computer will automatically increase the airflow in this branch to balance it with the other branches. The results are displayed in Table IV. The last branch listed is the equivalent of three incoming branches. The reader should notice that the prefix "J" for function JA has been dropped in the equivalent branch indicating the balance is complete. The loss (4.43" W.G.) is the loss of the branch with greatest losses. The airflow (2650 cfm) is the sum of the airflows of the incoming branches. The equivalent duct area is the sum of the duct areas of the incoming branches. The velocity (4499 fpm) is computed from the equation Q = VA.

After balancing at A, the design is carried on to point JB (See Figures 1, and 2). This is a straightforward application of the technique described earlier. In this case, the computer suggests an input transport velocity to A of 4611 fpm (from the balance at A) but only 4000 fpm is desired. The 4000 fpm desired value is input, overriding the 4611 fpm from the preceding branch. Similarly, the design for branch H4-JB is completed as previously shown. The design Q and velocity for this branch (500 cfm and 4500 fpm) are taken from Table II and other data from VS Print 411 in *Industrial Ventilation.*

The losses of the branches leading to junction JB are within 20% (4.04 vs 4.64): hence the computer will automatically readjust the balance by increasing airflow in the branch with the least losses. This readjustment is performed when a balance is requested at Junction JB and the results are shown in Table V.

After the balance at Junction B (renamed after balance) the design continues to point C; or branch B-C. This again is a straightforward application of the prior design technique except the cyclone must now be considered. The cyclone is accounted for by simply assigning an extraneous loss of 1$ W.G. as specified in Table II. This loss is entered by answering the question "ANY OTHER PRESSURE LOSSES" with the value of 1" W.G. when prompted by the program.

After continuing through the cyclone the next design point is "D". The branch C-D is an expansion and design convention requires designing the branch after the expansion *first* then returning to the sizing of the expansion; hence, the branch D-Fan must be completed. This process is straightforward and once the D-Fan is sized, the expansion C-D may be designed. In this case, a static pressure regain must be computed. The calculation of regain is automatic using an equation derived from empirical data.

The final branch, Fan-HE is the last calculation in the design. This branch is similar to previous calculations and once the data is entered, the fan static pressure may be automatically computed by selecting an option in the program. The final, completed, design is shown in Table VI. This design may be directly compared to a manual solution as shown in Table VII.

conclusion

The description of the ventilation design computer program in this article was not intended to be complete. The detail given here should be sufficient for the reader who has previously designed a ventilation system, since the computer program closely follows the design procedure specified in *Industrial Ventilation.* For the novice designer, however, this description cannot totally describe the techniques of ventilation design. It would be impractical to provide sufficient detail here to describe ventilation design from an account of a computer program. This description, however, should reveal the power and application of the microcomputer in this area. Since the program is "tutorial" it brings the beginner along step by step, prompting him/her to the next step in the procedure. If an error is made, it may be easily corrected or if necessary, the design may be started over from the first step.

The program is also a valuable aid to the experienced designer. While other computational assistance is available (e.g. programmable calculator programs), this program offers certain unique features. For example, All table look-up is eliminated; but perhaps more importantly the program stores results of the design on a diskette for further analysis or for a future redesign starting point. System designs for existing systems can be recalled for redesign when and if they no longer meet specification. Further design considerations, such as recirculation of exhaust air or economic analysis routines could be considered as additional analyses to be added to refine the present design.

Perhaps the greatest advantages of the microcomputer version of ventilation design are flexibility and portability. Flexibility is provided by the interactive operation of the program. With interactive operation, the user can design over and over again while making only slight changes to the input data. Microcomputer systems are small and portable and can be taken to the site of the work and/or business meetings where results will be reviewed. The modern microcomputer system is an ideal companion for the industrial hygienist. The notion of the decade of the 80's being an "electronic revolution" is not too far fetched. Rather than causing alarm, this revolution should dramatically increase the capability and competency of professionals in all fields, including industrial hygiene.

references

1. **Wu, D.L.**: Management of Exposure Records at a small business with a Personal Computer — A Simple Approach. *Am. Ind. Hyg. Assoc. J. 42*:38-41 (1981).
2. *Industrial Ventilation,* 16th Edition Committee on Industrial Ventilation, P.O. Box 16153, Lansing, MI 48901 (1980).
3. **Alden, J.L. and J.M. Kane:** *Design of Industrial Exhaust Systems,* 4th Edition, Industrial Press, Inc., New York (1970).
4. **McDermott, H.J.:** *Handbook of Ventilation for Contaminant Control,* Ann Arbor Science Publishers, Inc., Ann Arbor, MI (1976).

APPENDIX

Definitions of Abbreviated Column Headings use in Computer printouts:

List of Abbreviations

ST	Starting point of duct on branch.
ED	Ending point of duct on branch.
SLOT	Entry loss through slot, in inches H_20.
HOOD	Entry loss through hood, in inches H_20.
DUCT	The sum of the friction loss (inches H_20) through a specific section of duct and any other loss not attributable to an elbow entry, slot, or hood.
ELBW	Static pressure loss through an elbow, in inches H_20.
ENTR, ENTRY	Static pressure loss attributable to an entry, in inches H_20.
VEL, VE	Velocity of air in fpm.
TOTAL, LOSSES	Total static pressure loss for a specific section of a duct including all fitting and hood losses.
Q	Airflow through hood or duct in cfm.
DD, DIAM	Duct diameter in inches.
VP	Velocity pressure of moving air in inches H_20.
DL	The length, in feet, if duct in a specific branch.

Obtaining Program Currently a version of the program and user's manual is available for the Apple II Computer and the Model I or Model III TRS-80. Send a stamped, self addressed envelope to Dr. David Clapp, NIOSH (DSHEFS), 4676 Columbia Parkway, Cincinnati, OH 45226 for further details.