AIR FLOW PRESSURE DROP IN TYPICAL RADON PIPING

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ABSTRACT

The radon industry typically uses plastic piping from 2" to 6" in diameter in the installation of active soil depressurization systems (ASD). It is also typical to use 2" by 3" or 3" by 4" aluminum downspout for exterior piping. In a previous paper, (ref 1), the exhaust airflow in 87 NJ ASD mitigation systems was measured from a low of 11 cfm to a high of 167 cfm with a median level of 70 cfm. Fifty-six percent of these systems had air flows between 40 and 90 cfm. These typical airflows can have a large pipe pressure drop because of the system design that will reduce the systems final effectiveness. Most radon mitigators have little idea how much impact changing the pipe size has on their final system performance or how to calculate the pipe pressure drop. This paper discusses the development of a pipe pressure drop calculation for standard mitigation piping and fittings. The formulas for calculating the pressure drop were obtained from the ASHRAE Handbook of Fundamentals (ref 2). Correction factors for these formulas and testing of fittings and piping not included in the Fundamentals were obtained by carefully testing the pressure drops in the range of air flow and pipe sizes previously mentioned. The pressure drop in PVC piping was found to be from 9% to 23% less than the ASHRAE calculations. The pressure drop in PVC fittings was found to be from 53% less to 109% greater than the ASHRAE calculations. Using the corrected values attained from the study, a spreadsheet program was developed to allow easy calculations of pressure drop in a radon system. AARST will be offering copies of this spreadsheet program to its members. Two typical radon mitigation system layouts are used to demonstrate the expected pressure loss that would occur with typical airflows and different piping sizes. Some general system installation recommendations are made in the final analysis.

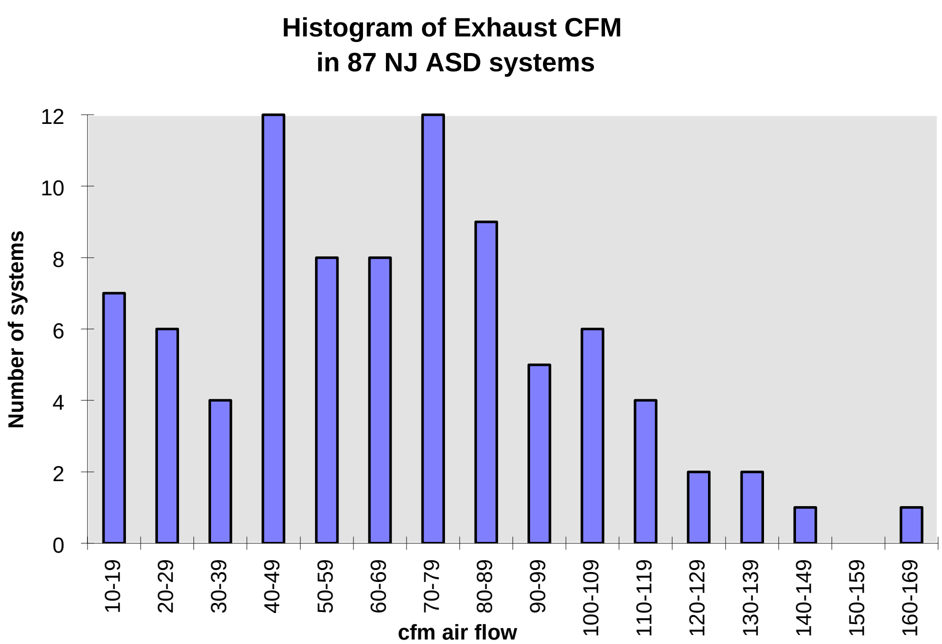

Figure 1 - ASD system Airflow from NJ study of mitigated houses

INTRODUCTION

The primary method used to reduce radon levels in residential structures is to install an ASD system. This system typically uses PVC piping to exhaust air from the soil under or around a house and/or by exhausting air from a block wall or crawl space. The effectiveness of these systems is due to the creation of depressurization in these areas in comparison to the basement. Most residential mitigation companies use either 3" or 4" diameter PVC pipe to accomplish this. Occasionally 2" and sometimes even 1 ½" or smaller piping is used. For large commercial installations 6" and even 8" PVC is often used, especially for the main trunk of the system. The 3", 4" and 6" piping used by the industry for residential installations is typically schedule 20 which is manufactured primarily for underground drainage. Schedule 20 is a lighter gauge than schedule 40, which is manufactured primarily for house plumbing. The pipe sizes that are 2" and smaller are only available in schedule 40. In this study only light gauge schedule 20 PVC was used for the 3", 4" and 6" pressure drop testing.

MEASUREMENT INSTRUMENTS

This study was designed to make measurements that had a n measurement error less than 5%. In order to accomplish this the instrument used to make the pressure readings was a digital micro-manometer capable of reading tenths of a Pascal (0.00025") and a instrument error of less than 1%. This monitor included an automatic zeroing, two channels to allow easy measurement of pressure drop and airflow, as well as having a setting that averaged 10 seconds of measurements. This instrument was calibrated the week before the study began. In order to confirm that it had been calibrated properly an EDM digital micro-manometer was sent to a different manufacture to be calibrated. Both instruments were then compared by having them measure the same pressure difference as the pressure was varied in test piping. The instruments had identical readings throughout the range of pressures used in this study.

All airflow speeds in this study are either feet per minute air speed inside the pipe or the actual cubic feet per minute (cfm). There are a number of methods used to determine the airflow speed inside a pipe. The measurement method that is most widely recognized is the use of a Pitot tube. This instrument is a tube within a tube that simultaneously measures the total airflow pressure and the sidewall static pressure. This allows the sidewall static pressure to be used as the reference pressure thus automatically subtracting it from the total pressure. The remaining pressure is referred to as the velocity pressure. ASHRAE fundamentals define the precision of Pitot tube measurements as between 1 and 5%. The airflow within a pipe however is not uniform. In order to minimize the effect of different airflow's within a pipe a Pitot tube flow grid was placed inside a section of 4" PVC piping. This allowed for a simpler and more consistent measurement throughout the study. All airflow measurements were made with this 4" flow grid that always had greater than ten pipe diameters of straight piping (40”) both in front and behind the flow grid.

FAN AIR FLOW

The piping with the flow grid inside was then connected to a HP220 Fantech fan that was mounted on a stand. This fan can move 200 cfm of air at a static pressure of 1" and is capable of moving 50 cfm at greater than 2" of static pressure. The fan was set up to always be pulling the air though the pipe. The fan exhaust was discharged out a two-foot section of 4" PVC piping. Initially a speed control was used top vary the airflow within the pipe but it was discovered that a more consistent flow was achieved by installing a series of increasingly restrictive caps on the end of the discharge side of the PVC piping. The use of restrictive discharge capping also allowed a fairly consistent pattern of six airflow's for most of the tested fittings and piping. The airflow's averaged approximately 13 cfm, 32 cfm, 65 cfm, 100 cfm, 140 cfm and 170 cfm. These are the typical range of airflow's of most radon systems. See Figure 1.

CALIBRATING THE FLOW GRID

The pressure drop taking place across a fitting or piping varies with the airspeed within the piping. It is of course critical to know the airflow as accurately as possible in order to define the correct calibration constant for each fitting or length of piping. A number of quality assurance checks were made to ensure this by careful placement of the airflow-measuring device, calibration of the measuring equipment and exacting measurements. All pressure measurements made in this study were in units of Pascals and then converted to inches of water. One inch of water column is the equivalent pressure of 248.9 Pascals.

After the flow grid was installed inside the pipe it was re-calibrated in order to provide accurate airflow measurements. This calibration factor was obtained by carefully making a series of transverse Pitot tube measurements in a 10 foot long straight section of 4" piping. The exact procedure recommended by ASHRAE fundamentals was used to make this re-calibration. This procedure defines sixteen transverse locations in the pipe where the Pitot measurements are made. A small jig was set up to make sure the Pitot tube was inserted properly into the pipe and each velocity pressure measurement was averaged over ten second readings. The corresponding flow grid velocity pressure was checked several times during these measurements to ensure that it had not changed because of a variation in the fan speed. The Pitot tube velocity pressure measurements are then averaged to determine the actual cfm airflow using the following formula.

$$cfm = \left[1097 * \sqrt{ptvp / ad}\right] * sa$$

$ptvp =$ average velocity pressure in inches of water from Pitot tube transverse

$ad =$ air density lbs / cf (use 0.075 if unknown)

$sa =$ area of duct in square feet

Formula 1 - CFM determination from transverse Pitot tube reading

AIR FLOW MEASUREMENTS

The calibration factor for the flow grid is then determined from the velocity measurements of the flow grid and the cfm results using Formula 1. The velocity pressure readings from this flow grid were used exclusively to determine the actual airflow during the measurement of pressure drop across the pipe, fitting or fittings. The formula for determining the cfm from the flow grid is given below in Formula 2.

$$cfm = fgcf * \sqrt{fgvp / ad}$$

$fgvp =$ Flowgrid velocity pressure in inches of water

$ad =$ air density in lbs / cf (use 0.075 if unknown)

$fgcf =$ Flowgrid calibration factor

Formula 2 - CFM determination from flow grid

STATIC PRESSURE READINGS

The pressure drop measurement across each pipe fitting or length of pipe was made using the static pressure port of two Pitot tubes. Each Pitot tube was inserted into the center of the pipe on opposite sides of the fitting or a known distance between straight ducting. The static pressure port of the Pitot tube was always facing the fitting or length of pipe being tested so that the Pitot tube itself caused no additional resistance. The digital micro-manometer had the reference port always connected to the Pitot tube farthest from the fan and the signal port connected to the Pitot tube closest to the fan so that the pressure difference caused by the airflow resistance in the pipe was measured directly as a positive pressure. It was determined initially that four feet from each side of the fitting was a enough distance to allow measurement of the full pressure drop from the fitting. The true pressure drop of the fitting or fittings was calculated by taking the total pressure drop and subtracting the calculated pressure drop for that particular airflow from the straight run of ducting on each side of the fitting and any additional straight ducting that was placed between two fittings.

The pressure drop of straight sections of ducting was measured by laying out about 30 feet of the pipe with a minimal amount of joints. The Pitot tubes were then placed at the farthest distance apart while still maintaining at least 10 pipe diameters away from any disturbance on either end of the ducting. This allowed the measurement of the pressure drop across approximately 23 feet with typically two pipe joints in between. Any seams in the piping that were not totally airtight were sealed with duct tape. All test holes used for the measurements in the piping were sealed when not in use. The Pitot tube hole was also the exact size of the Pitot tube to minimize any additional loss. Each Pitot tube was clamped in its position and checked with a square to ensure it was orient in the correct position. All angled fittings were also checked to ensure that their angle was appropriate to the fitting.

Each pressure drop measurement of pipe length or fitting was tested at five or six different airflow's. The measurement sequence was to measure the airflow first by measuring the flow grid velocity pressure with a series of 10-second average readings. The digital micro-manometer was then switched to read the pressure drop across the pipe or fitting(s) for 10-second averages. The digital micro-manometer was then switch back to the airflow grid velocity pressure and 10 second averages were again obtained to confirm that the airflow had not changed. If duplicate airflow or pressure readings varied greater than one or two Pascals, the measurements were repeated. This procedure was repeated for each airflow and for each fitting or pipe. In all over 1500 10-second pressure readings were made in order to accurately determine the pressure drop of the components tested.

Each set of 10-second average pressure drop or flow grid velocity pressure readings for each flow was then averaged. These average readings were then entered into a spreadsheet program. The air density used in the airflow calculation at each reading was determined by measuring the temperature and humidity at the testing location and then calling the nearest local airport to obtain the current barometric pressure. These factors were then entered into a slide rule used for obtaining the air density that is supplied by Dwyer Instruments. Each of the changes in weather can influence the reading by a few percent. Below is a chart of the differences that can be expected in the readings as the weather varies from the standard. As can be seen from the Table 1 below, the changes in weather factors cause only a slight difference

The standard air density of 0.075" is based on 30.0" of barometric pressure
at 70 degrees and 20% relative humidity.

If humidity is actually 50% versus 20% the measurement will be biased low 0.2%
If humidity is actually 80% versus 20% the measurement will be biased low 0.45%

If Barometric pressure is 31.0" instead of 30.0" the measurement will be biased high 1.6%
If Barometric pressure is 29.0" instead of 30.0" the measurement will be biased low 1.7%

If temperature is actually 80 degrees versus 70 degrees the measurement will be biased low 1.0%
If temperature is actually 60 degrees versus 70 degrees the measurement will be biased high 0.9%

Table 1 - Small airflow measurement variation due to weather or altitude

COMPARISON OF MEASURED VERSUS CALCULATED VALUES

The straight pipe pressure drops at different air flows were then compared to the results of the Darcy formula given in the ASHRAE Fundamentals Handbook (ref 2) to determine how well they compared. Correction factors were then determined for each size of straight ducting and new coefficient factors were derived for each fitting. In general the Darcy equation given in ASHRAE Fundamentals over predicted the pressure drop of straight piping by 9% to 23%. The variation in measured values versus calculated values for fittings varied more significant and in different directions. The following chart is a summary of the difference.

Size	straight pipe	90° sweep	90° sharp	45° sweep	45° mitered	22.5° sweep	90° sweep w/burrs
2"	- 23%	9%		- 9%			
3"	- 18%	38%			13%	- 19%	110%
4"	- 9%	60%	61%		11%	- 22%	
6"	- 10%		72%		- 8%	- 53%	

Table 2 - Average variation (at different airflows) of the measured pressure drops
from the calculated pressure drop using the formulas given in ASHRAE Fundamentals
(- 10% means actual pressure drop was 10% less than calculated amount)

After the above correction values were included in the formulas, the measured values versus the calculated values typically had excellent consistence (precision) between the different flow rates although the higher flow rates (65, 100, 135, 170cfm) were almost always more consistent. Typically these higher flow measurements were within 1% to 5% of the corrected calculated values. The lower flow readings tended to vary more from the corrected calculated values although they were often within 15% of the calculated values. Overall this degree of precision gave good confidence to the validity of the corrected formulas for the fittings tested.

$$pd = ff\left(\frac{12dl}{hd}\right) * vp * cf$$

pd = Pressure loss (in of H_2O) for Duct Length (dl)

$$ff = \text{Friction factor} = 0.11\left(\frac{rf}{\left(\frac{hd}{12}\right)} + \frac{68}{rn}\right) \wedge 0.25$$

rf = Roughness factor (0.0001 for pvc piping)

$$hd = \text{Hydraulic Diameter} = 4 * \left(\frac{Sq.In\ of\ Duct\ area}{Inches\ of\ Perimeter}\right)$$

$$rn = \text{Reynolds Number} = \frac{hd * fpm}{0.01224}$$

$$fpm = \text{Duct air velocity in Feet per Minute} = 1097 * \sqrt{\frac{vp}{ad}}$$

vp = Duct velocity pressure (inches of water)

ad = Air Density, (Standard ad = 0.075 lbs / cf)

cf = Correction Factor given in Table 3

Formula 3 - Darcy formula for determining pressure drop in straight pipe

The formula used in ASHRAE (Formula 4) for determining the pressure drop across a fitting is simpler than the above Darcy formula.

$$fpd = vp * fcf$$

fpd = Fitting pressure drop

vp = Piping velocity pressure

fcf = Fitting coefficient factor (values in Table 3)

Formula 4 - Formula to determine pressure drop in fittings

Table 3 below lists the correction factors in column 2 that are multiplied times the results of the Darcy formula to determine the correct pressure drop in straight pipe. The remaining columns are the average coefficient factors that were averaged from different airflow measurements for different fittings. These coefficient factors are multiplied times the velocity pressure in the pipe to determine the pressure drop of the fitting. The R/D at the top of the table is the sharpness of a 90-degree fitting as defined by the radius of the turn divided by the diameter of the fitting.

pipe size	Darcy Multiplier w/straight Pipe	straight opening	R/D = straight w/coupling	0.875 | 90° sweep	1.0 | 90° sweep	1.0 90° sweep w/burrs	0.5 | 90° sharp	45° sweep
2"	0.77				0.24			0.12
3"	0.82	1.37	1.06		0.31	0.46		
4"	0.91	1.42	1.08	0.49			1.14	
6"	0.90						1.22	
3X4	1.29							1.05
2X3	0.82							0.42
Pipe Size	45° mitered	22.5° sweep	2 - 90° elbows offset	2 - 45° elbows offset	2 - 90° elbows offset 12"	2 - 45° elbows offset 12"	straight Tee	4" round to rectangular Transition
3"	0.48	0.099	0.76	1.12	0.91	1.12	1.41	
4"	0.38	0.089	0.86	0.89	0.80	0.83	1.53	
6"	0.39	0.115						
3X4						2.30		0.26
2X3						1.28		0.48

Table 3 - Correction factors and Coefficients for determining pressure drop in piping and fittings

PRESSURE DROP IN EQUIVALENT FEET OF PIPING

Another way to understand the pressure drop in a fitting is to compare it to the number of feet of straight piping that would produce the equivalent pressure drop. The equivalent fitting pressure drop in straight lengths of piping varies with piping airflow. Table 4 presents the Pressure drop for each fitting in equivalent feet of straight piping for 70 cfm velocity.

Pipe Size	Sweep 90°	Sweep 90° w/burrs	Sharp 90°	Sweep 45°	Mitered 45°	Sweep 22.5°	Straight Tee	Round to 2x3 or 3x4	Open Pipe	Open with tapered coupling
2	1.9			0.4						
3	3.8	5.8			6.1	1.2	17.9		17.4	13.4
4	7.0		16.4		5.5	1.3	22.0		20.4	15.5
6			24.1		7.7	2.3				
2X3				8.8				5.5		
3X4				2.6				2.2		

Table 4 - Equivalent pressure drop in feet of straight piping versus pressure drop of fitting

EXAMPLES OF PRESSURE DROP IN TYPICAL RADON INSTALLATIONS

In the example of a typical ASD system below (Figure 2), the radon fan exhaust location is 15' away from the main house in the rear garage roof in order to avoid the window looking on the garage roof. The piping below and above the fan equals four feet. The piping from the garage attic is down through the garage and then extends along the short wall for five feet and then turns and extends another 15' down the long basement wall. At the bottom of the pipe there are two 45-degree elbows above the suction hole to allow the piping to hug the foundation wall, but clear the footer.

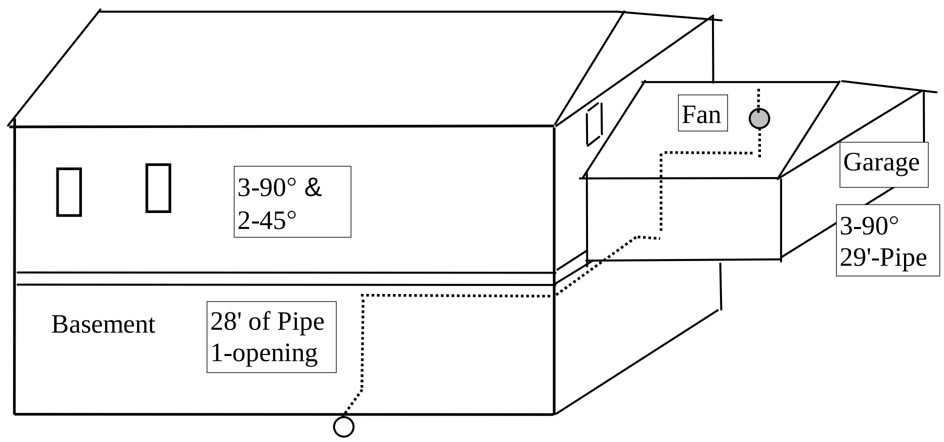

Figure 2 Example of a common ASD system with pipe routing through the garage

Tables 4 and 5 give the pressure drop for Figure 2 assuming three different air flows and for four inch versus three inch pipe. Independent testing of an HP190 Fantech fan showed that the fan produces about 435 Pascals of pressure at 20 cfm, 345 Pascals at 60 cfm and 230 Pascals at 100 cfm. The two tables indicate that if the system airflow is 20 cfm or less then the use of three inch piping should only reduce the sub-floor vacuum in the suction hole by 5% or less (less than 0.1"). In the NJ study, 15% of the systems had air flows less than 20 cfm (Figure 1). If the system airflow is 60 cfm or greater however, which more than half of the NJ ASD systems had, than the pressure drop is three times greater using three inch PVC rather than four inch and the vacuum in the suction hole using the same fan is reduced in half. It is not possible to get 100 cfm of airflow through this layout of three inch PVC piping. The use of four inch will produce 0.17" of vacuum in the suction hole at 100 cfm.

cfm	PD of 1 4" opening	PD of 57' 4" piping	PD of 6 4" 90° elbows	PD of 3 45° elbows	Total PD	vac in pit w/HP190 fan
20	1.2 Pa	4.3 Pa	2.4 Pa	1.0 Pa	9 Pa	426 Pa / 1.71"
60	10.4 Pa	29.7 Pa	21.5 Pa	9.3 Pa	71 Pa	274 Pa / 1.10"
100	28.9 Pa	73.8 Pa	59.7 Pa	25.8 Pa	188 Pa	42 Pa / 0.17"

Table 5 - Pressure Drop (PD) of Figure 2 with all 4" PVC

cfm	PD of 1 3" opening	PD of 57' 3" piping	PD of 6 3" 90° elbows	PD of 3 45° elbows	Total PD	vac in pit w/HP190 fan
20	3.5 Pa	15.4 Pa	4.8 Pa	4.1 Pa	28 Pa	407 Pa / 1.63"
60	31.7 Pa	108.0 Pa	43.0 Pa	37.0 Pa	220 Pa	125 Pa / 0.50"
100	88.0 Pa	270.0 Pa	119.4 Pa	102.7 Pa	581 Pa	N/A

Table 6 - Pressure Drop of Figure 2 with all 3" PVC

In the second example of a typical ASD system (Figure 3), the radon fan is located outside with two 45° elbows above the fan. The exhaust piping up the two story sidewall of the house is either PVC piping or a transition adapter and rectangular aluminum downspout. There are two 45° elbows at the top of the exhaust piping to allow clearance of the one foot overhang of the roof. Under the fan is a 90° elbow as the piping enters the house and a 45° elbow to get below the floor joist. The piping then turns to the rear wall and then turns to run 15 feet down the long wall of the basement before turning down into a suction hole. There are two offset 45° elbows above the suction hole to allow the PVC pipe to hug the foundation wall but miss the footer under the slab.

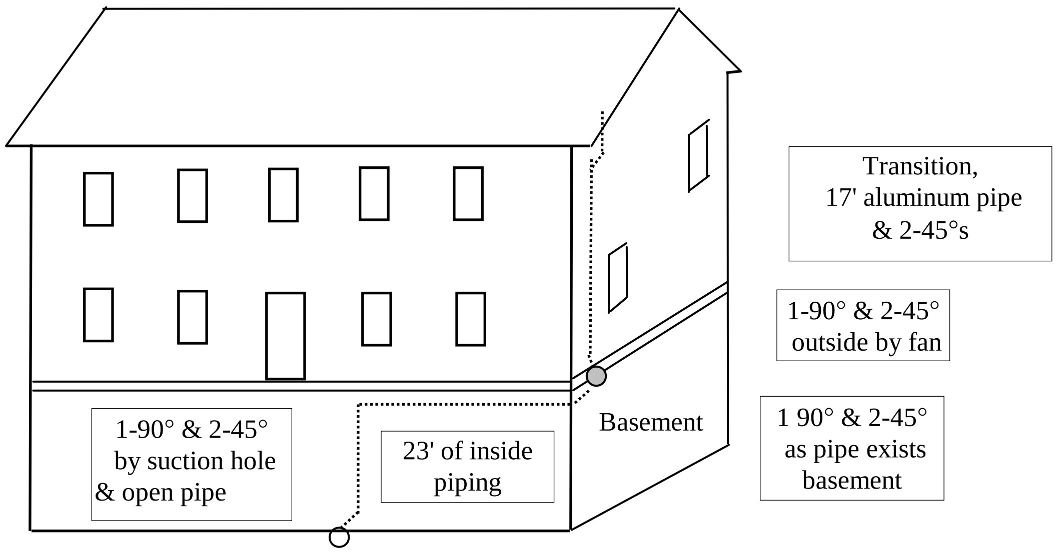

Figure 3 Example of a common ASD system with pipe routing up the exterior

Tables 7 through 12 list the pressure drop at 20, 60 and 100 cfm airflow speeds using different configurations of piping but the same amount of elbows. Table 13 summarizes the final vacuum in the suction hole from these tables. The bottom percentage in each square is the difference in the final vacuum as compared to using 4" PVC for the whole system.

If the system is only moving 20 cfm the most restricting piping of 3" PVC and 2X3" downspout only reduces the vacuum by 6%. If the system is moving 60 cfm however this type of piping would reduce the suction hole vacuum by 74%, almost a four fold difference. Note that 3" PVC exhaust piping at 60 cfm produces half of the vacuum that 3X4" downspout allows. Even if all the interior piping is all 3" PVC it is beneficial to use 3X4" downspout exhaust piping versus three inch PVC. If 3" PVC at 60 cfm airflow is used instead of 4" PVC throughout the whole system, the final vacuum is, as in the garage-routed system, one half the strength.

Cfm	PD of 4" pit opening	PD of 23' 4" piping	PD of 4 4" 90° elbows & 3-45° elbows	PD of 17' PVC pipe	PD of 2 45° Elbows	Total PD	Vac in pit w/HP190 Fan
20	1.2 Pa	1.7 Pa	3.3 Pa	1.3 Pa	0.7 Pa	8 Pa	427 Pa/1.71"
60	10.4 Pa	12 Pa	33.4 Pa	8.9 Pa	6.5 Pa	68 Pa	277 Pa/1.11"
100	28.9 Pa	29.8 Pa	117.1 Pa	22.0 Pa	18.1 Pa	182 Pa	48 Pa/0.19"

Table 7 - Pressure Drop of Figure 3 with all 4" PVC piping

cfm	PD of 4" pit opening	PD of 23' 4" piping	PD of 4 4" 90° elbows & 3-45° elbows	PD of 17' Downspout & Transition	PD of 2 Alum Elbows	Total PD	Vac in pit w/HP190 Fan
20	1.2 Pa	1.7 Pa	3.3 Pa	4.5 Pa	2.1 Pa	11 Pa	424 Pa/1.70"
60	10.4 Pa	12 Pa	33.4 Pa	35.2 Pa	18.5 Pa	90 Pa	255 Pa/1.02"
100	28.9 Pa	29.8 Pa	117.1 Pa	47.3 Pa	51.2 Pa	241 Pa	N/A

Table 8 - Pressure Drop of Figure 3 with all 3" PVC piping

cfm	PD of 4" pit opening	PD of 23' 4" piping	PD of 4 4" 90° elbows & 3-45° elbows	PD of 17' Downspout & Transition	PD of 2 Alum Elbows	Total PD	Vac in pit w/HP190 Fan
20	1.2 Pa	1.7 Pa	3.3 Pa	9.7 Pa	4.6 Pa	21 Pa	414 Pa/1.66"
60	10.4 Pa	12 Pa	33.4 Pa	71.9 Pa	41.1 Pa	166 Pa	179 Pa/0.72"
100	28.9 Pa	29.8 Pa	117.1 Pa	184.5 Pa	114.1 Pa	441 Pa	N/A

Table 9 - 4" PVC in the basement and 2"x3" aluminum downspout up the outside

cfm	PD of 3" pit opening	PD of 23' 4" piping	PD of 4 3" 90° elbows & 3-45° elbows	PD of 17' PVC pipe	PD of 2 45° Elbows	Total PD	Vac in pit w/HP190 Fan
20	3.5 Pa	6.2 Pa	10.2 Pa	4.6 Pa	2.9 Pa	27 Pa	408 Pa/1.63"
60	31.7 Pa	43.6 Pa	91.5 Pa	32.2 Pa	25.9 Pa	225 Pa	120 Pa/0.48"
100	88.2 Pa	109.2 Pa	345.8 Pa	80.7 Pa	71.9 Pa	604 Pa	N/A

Table 10 - 3" PVC in the basement and 3" PVC up the outside

cfm	PD of 3" pit opening	PD of 23' 4" piping	PD of 4 3" 90° elbows & 3-45° elbows	PD of 17' PVC pipe	PD of 2 45° Elbows	Total PD	Vac in pit w/HP190 Fan
20	3.5 Pa	6.2 Pa	10.2 Pa	2.4 Pa	2.1 Pa	24 Pa	411 Pa/1.65"
60	31.7 Pa	43.6 Pa	91.5 Pa	16.7 Pa	18.5 Pa	202 Pa	143 Pa/0.57"
100	88.2 Pa	109.2 Pa	345.8 Pa	41.5 Pa	51.2 Pa	544 Pa	N/A

Table 11 -3" PVC in the basement and 3"x4" aluminum downspout up the outside

cfm	PD of 3" pit opening	PD of 23' 4" piping	PD of 4 3" 90° elbows & 3-45° elbows	PD of 17' PVC pipe	PD of 2 45° Elbows	Total PD	Vac in pit w/HP190 Fan
20	3.5 Pa	6.2 Pa	10.2 Pa	9.0 Pa	4.6 Pa	34 Pa	401 Pa/1.61"
60	31.7 Pa	43.6 Pa	91.5 Pa	65.4 Pa	41.1 Pa	273 Pa	72 Pa/0.29"
100	88.2 Pa	109.2 Pa	345.8 Pa	166.7 Pa	114.1 Pa	732 Pa	N/A

Table 12 - 3" PVC in the basement and 2x3" aluminum downspout up the outside

cfm	4" PVC Inside and Outside	4" PVC Inside and 3x4 alum Outside	4" PVC Inside and 2x3 alum Outside	3" PVC Inside and Outside	3" PVC Inside & 3x4 alum Outside	3" PVC Inside and 2x3 alum Outside
20	427 Pa 1.71" Change ->	424 Pa 1.70" (99%)	414 Pa 1.66" (97%)	408 Pa 1.63" (96%)	411 Pa 1.65" (96%)	401 Pa 1.61" (94%)
60	277 Pa 1.11" Change ->	255 Pa 1.02" (92%)	179 Pa 0.72" (65%)	120 Pa 0.48" (43%)	143 Pa 0.57" (52%)	72 Pa 0.29" (26%)
100	48 Pa 0.19"	N/P	N/P	N/P	N/P	N/P

Table 13 - Comparison of Final vacuum in the suction pit with different piping for system routed up the outside of a house and a HP 190 fan (Figure 4)

DESIGNING RADON PIPING

The data in Table 3 and 4 presents some revealing factors that should be taken into consideration when designing a radon system. The first interesting fact is the pressure drop of mitered 45° 4" fittings is equal to a sweep 90° 4" fitting. A mitered fitting has a sharp inside edge instead of an inside sweep in its radius. In the case of 3" schedule 20 fittings, the mitered 45° fitting actually has a 57% greater pressure drop than a sweep 90° degree 3" fitting. In the case of 2" fittings that are full sweeps with an R/D ratio of 1.0, the 45° elbows is half the pressure drop of a 90° fitting as one might expect. All of the sharp bend fittings produced significantly more pressure drop than the sweeps. The sharp 4" 90° elbow was 2.3 times more restricting than a sweep 90° 4" fitting. All the six-inch fittings were sharp mitered fittings and subsequently had large pressure drops.

Another interesting discovery was the impact of low quality PVC extrusion. A 3" smooth sweep and a 3" smooth sweep with two burred edges were tested. Although the radius was the same for both fittings, the burred edge increased the pressure drop by 51%. These burred edges were only 1/16" to 1/8" high! In a similar test a 90° 4" elbow was tested for pressure drop with PVC pipe on each side of the elbow that did not have the burred edges removed caused by cutting the pipe. In the second test of this same fitting the burred edges were removed and the pressure drop was reduced by 18%. Even small imperfections can make a difference in the total pressure drop.

When two offset elbows were tested either with a 12" offset or connected directly together the pressure drop of this combination versus that of two individual fittings separated by 10 pipe diameters was sometimes less by 1% to 19% and sometimes more pressure drop by 9% to 18%.

A straight tee fitting has a pressure drop that is significant and may be overlooked. Straight Tee's have no sweep on both the outer edge and the inside edge. The arrangement of the airflow through the tee can also affect the pressure drop. The tees were only measured as if a main trunk from the attic was routed directly down into a tee in the ceiling of a basement so the airflow could be split in two directions with equal flow and resistance. One straight four-inch tee in this configuration has the pressure drop in both directions of three 4" sweep elbows. A three-inch tee has an even greater pressure drop equaling 4.5 times that of a single three inch 90 degree sweep elbow.

If aluminum downspout is used on the outside of a building to exhaust an ASD system above the roof, a round to rectangular fitting is typically used. Although most people consider this transition to cause the greatest pressure drop it did not appear to do so. In Table 4, column 9, this transition was only equivalent to 2 to 6 feet of piping or the equivalent of only about one 90-degree sweep elbow. The use of 2x3" aluminum downspout and fittings caused a 35% reduction in the final suction hole vacuum at 60 cfm with 4" PVC piping for the remaining system.

The open end of the PVC pipe that is placed in the suction hole has the equivalent pressure drop of a straight tee. This sharp edge orifice can have its impact reduced by about 23% if a transition coupling to the next larger size is placed on the end of the pipe in the suction hole. This should always be done when using 3" PVC since a 3" to 4" adapter will fit into the concrete floor opening.

In general it is recommended that all elbows be sweeps whenever possible. If only mitered 45-degree fittings are available then 90-degree elbows should be used preferentially. Poor quality fittings and sharp bends should be avoided.

SUMMARY

This paper demonstrates the use of formulas from the ASHRAE Handbook of fundamentals and compares them to actual measured values to confirm their validity and to obtain correction factors. Addition calibration factors for fittings and piping not included in the ASHRAE Handbook are included. The ASHRAE calculations have been incorporated into a spreadsheet program that allows input of the correction factors determined from the actual measurements made in this study. Note that the shape of the fittings used in this study will vary from one manufacture to another and can impact the results significantly. These correction factors should be used only after checking the radius angle and interior smoothness of the fittings as described in this paper.

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