LBL-33818

March 11, 1993

#7472

Field Comparison of Alternative Techniques for Measuring Air Distribution System Leakage

Mark P. Modera

Submitted for ASTM Symposium on *Airflow Performance of Building Envelopes, Components, and Systems*, October 10-11, 1993, Ft. Worth TX.

KEY WORDS

Ducts, Leakage, Air-tightness, Fan pressurization, Measurement, Infiltration

ABSTRACT

ASTM has recently standardized a methodology for measuring the leakage of residential air distribution systems to unconditioned zones. The standard includes two alternative leakage measurement techniques, one of which requires only a blower door, whereas the second technique requires a flow-capture hood as well as a blower door. This paper reports on the results of field measurements in 30 houses using both measurement techniques, and analyzes the relative strengths and weaknesses of the two techniques. The repeatability of each of the techniques, as well as the comparability of the results from the two techniques, are examined. A key issue that is addressed in this paper is the importance of duct pressure measurements in each of the two techniques. Analyses show that the leakage measured with the blower-door-only technique would be negatively biased by 30-50% if the duct pressure was not incorporated into the measurements and analyses as is specified in the standard. Similarly, it is shown that supply leakage measurements with the flow-capture-hood technique would be negatively biased by 33% if the envelope pressure differential was used instead of the duct pressure differential.

INTRODUCTION

Over the past several years there has been a tremendous increase in the number of air leakage measurements on residential air distribution systems (Robison and Lambert 1989, Cummings et. al. 1990, Modera 1991, Kinert et. al. 1992, Palmiter and Bond 1992). These measurements have focused mainly on determining the leakage between the duct system and outdoors (including unconditioned spaces such as attics or crawlspaces). As the groups performing these measurements were accustomed to using fan pressurization (i.e., blower doors) to measure envelope leakage, the first technique to be commonly used involved blower doors. This technique is based upon subtracting the results from two blower-door tests of building envelope leakage, one with the duct system registers open to the house, the second with those registers sealed. The second technique to come into common use involved the use of a direct measurement of duct leakage flow in combination with the blower door (Robison and Lambert 1989). The main impetus for developing the second technique was that the changes in blower-door flows between the sealed and unsealed configurations is generally small compared to the total blower flow, and therefore can be dramatically affected by the uncertainties in blower-door measurements. Measuring the duct-leakage flow directly with a flow-capture hood can significantly reduce this flow measurement uncertainty.

Approximately two years ago, ASTM began the standardization process for the blower-door-only and the combination blower-door/capture-hood measurement techniques. This paper reports on the results of field measurements in 30 houses using both measurement techniques, and analyzes the relative strengths and weaknesses of the two techniques, and well as the importance of direct duct-pressure measurements for each technique.

FIELD PROCEDURE AND APPARATUS

The results reported in this paper are based upon a field study of 30 houses in California, each of which was submitted to a two-day set of diagnostic measurements designed to characterize the performance of the duct system (Modera 1991).The diagnostic measurements performed included leakage measurements following both ASTM measurement methods, measurements of duct pressures and register flows during normal system operation (auxiliary measurements in ASTM standard), measurements of pressure differentials across internal doorways with the fan on and the doors closed, and measurements of building air exchange rates with and without the distribution-system fan in operation.

The leakage measurements were performed using a blower door that required angular velocity (rpm) and pressure differential measurements to calculate the flow through the fan, a commercially-available flow capture hood, electronic pressure transducers, and a computerized data acquisition system. All measurements were automatically time-block averaged within the computer, including the angular velocity of the fan. The program employed would digitally filter and display on the screen the pressure differential across the building envelope (which utilized a four-wall pressure averaging probe), the pressure difference across the fan, and the angular velocity of the fan. When the operator was satisfied with the pressure differential across the envelope, hitting any key would initiate a time-block average of those three values, as well as time block averages of various other pressure differentials of interest, including the pressure differentials across the supply and return plenums, the return duct near the register, the longest and shortest supply ducts near their registers, the attic, and the crawl-space. The additional pressure measurements were made with two transducers. One end of each of the transducers was connected to a rotary-valve pressure-port multiplexer, and their other ends were connected to the main living-zone or the four-wall pressure averaging probe. All time-block averages were for approximately 10 seconds.

Although a standard-size flow-capture hood was used to measure register flows and duct leakage flows, particular attention was paid to data precision and accuracy so as to extend its measurement range down to low flows (i.e., 10 m^3/h). All flows were determined from the measured pressure differential across the pressure sensing probes provided by the manufacturer, which was read and time-block averaged by the computer. All flow-capture pressure differentials were measured simultaneously with two different pressure transducers built by different manufacturers. To minimize the impact of zero drift in the pressure transducers, the zeros of the transducers were automatically measured prior to each set of flow measurements (register flows or duct leakage flows).

Blower-Door-Only Protocol (Method A)

The basic protocol in the ASTM standard for blower-door-only measurements consists of three distinct fan pressurization tests whose results are compared to obtain the leakage of the supply and return ducts separately. The first test is a standard fan pressurization test with all of the duct registers open to the house. For the second fan pressurization test, all return registers are sealed, the return side is sealed from the supply side at the fan, and the supply registers are kept open to the house. For the third test, both the supply and return registers are sealed, and the seal between the supply and return sides at the fan is removed. The standard specifies that the pressures in the duct system be monitored during the second and third pressurization tests to account for any leakage from the house to the ducts during those sealed-duct tests.

The blower-door-only measurement protocol utilized in the field study differed somewhat from the protocol specified in the ASTM standard. The major differences were that in the field study the fan seal was kept in place during the third pressurization test (i.e., when both the supply and return registers are sealed), and the return air filter was not removed in the field study, contrary to the ASTM protocol. Because the fan seal was not removed in the third fan pressurization test, the supply-plenum pressure was substituted for the return-plenum pressure in the correction factor for the total duct leakage calculations.

Blower-Door/Capture-Hood Protocol (Method B)

The blower-door/capture-hood measurement protocol in the ASTM standard basically consists of two fan-pressurization tests that use a flow capture hood to directly measure the leakage flow through the ducts. One test measures the leakage of the supply ducts, while the second test measures the leakage of the return ducts. The standard allows these tests to be performed simultaneously if two flow-capture hoods are utilized.The standard specifies that the pressure differential across the duct system be separately monitored for use as the pressure reference in the leakage calculations.This pressure is measured at two locations on the return side, and two locations on the supply side.

The protocol used in the field study was essentially identical to that specified in the standard, the only differences being: 1) that the return filter was not removed in field tests (contrary to the standard requirement, and 2) that in a few houses, the return registers were kept sealed during the supply-leakage measurements.

DATA ANALYSIS

The data analysis protocol for the flow-capture method (Method B) is relatively straight-forward, however for the blower-door-only technique (Method A), the data analysis protocol specified in the ASTM standard, and that used to analyze the field data collected, require some explanation.

The aspect of the ASTM data analysis for Method A that stands out is the correction factor applied to the results of subtractions of subsequent blower-door tests. This correction factor accounts for the bias in subtractions of sealed-duct test results from unsealed-test results, which stems from leakage between the house and the theoretically sealed duct. The correction is based on treating the house/duct system as a series combination of leaks. More specifically, the measured flow through blower door fan while the duct system remains unsealed (first fan pressurization test) can be expressed as:

(EQ 1)

$$Q_{FAN_{unseal}}(\Delta P) = Q_{ENV}(\Delta P) + Q_{duct}\left(\Delta P_{duct_{unseal}}\right)$$

while the fan flow when the ducts are sealed (second or third test) can be expressed as

(EQ 2)

$$Q_{FAN_{seal}}(\Delta P) = Q_{ENV}(\Delta P) + Q_{duct}\left(\Delta P_{duct_{seal}}\right)$$

Subtracting Equation 2 from Equation 1 yields:

(EQ 3)

$$\Delta Q_{FAN}(\Delta P) = Q_{duct}\left(\Delta P_{duct_{unseal}}\right) + Q_{duct}\left(\Delta P_{duct_{seal}}\right)$$

which, assuming that $\Delta P_{ductunseal}$ is equal to ΔP (an experimentally confirmed assumption), and that the flow through the duct leaks is described by a power law, can be reexpressed as:

(EQ 4)

$$\Delta Q_{FAN}(\Delta P) = Q_{duct}(\Delta P)\left(1 - \left(\frac{\Delta P_{duct_{seal}}}{\Delta P}\right)^{n_{duct}}\right)$$

Solving Equation 4 for $Q_{duct}\,(\Delta P)$ yields:

(EQ 5)

$$Q_{duct}(\Delta P) = \Delta Q_{FAN}(\Delta P)\left(\frac{1}{1 - \left(\frac{\Delta P_{duct_{seal}}}{\Delta P}\right)^{n_{duct}}}\right)$$

The term in parentheses in Equation 5 is the correction term incorporated into the ASTM standard. It is used to correct the return duct leakage obtained by subtracting results of the second fan pressurization test (i.e. sealed return grilles) from the first fan pressurization test results (i.e., all grilles open). It is also used to correct the total duct leakage obtained by subtracting the results of the third fan pressurization test (i.e., sealed return and supply grilles) from the first fan pressurization test results (i.e., all grilles open).

MEASUREMENT RESULTS

The measurements performed in this study were designed to examine the consistency of the results obtained with Method A and Method B, to examine the comparability of the results obtained with the two techniques, and to examine the sources of bias or uncertainties in the two techniques that affect both consistency and comparability. In addition, as mentioned above, the ASTM standard requires the measurement of several pressures that have not typically been measured as part of duct leakage testing. In particular, the pressures at the supply plenum, the furthest supply register, a return grille, and the return plenum are required to be measured for both the blower-door subtraction method (Method A) and the flow-capture/blower-door method (Method B). To provide some evidence of the importance of making these additional pressure measurements, the ratios of these pressures to the indoor-outdoor pressure difference, and their ultimate impact on the leakage results, are also examined. Finally, the results of some of the auxiliary measurements required by the standard are presented in order to provide an expected range of results and point out the potential utility of these measurements.

Method A Results

The supply and return side duct leakage measured by the blower-door subtraction method are summarized in Figures 1 through 3, in which the leakage areas at 4 Pa and the leakage flows at 25 Pa are compared between pressurization and depressurization for supply and return leakage, and the total leakage flow at 25 Pa is compared between pressurization and depressurization. Examination of these figures brings out two points: 1) there is reasonably good agreement between pressurization and depressurization results, with no apparent bias, and 2) the scatter between pressurization and depressurization results is significantly smaller for the flows at 25 Pa compared to the leakage areas at 4 Pa.

The houses for which subtraction results yielded negative leakage areas are not included in Figures 1 through 3. For the effective leakage area at 4 Pa, 15 out of 56 measurements yielded negative return leakage estimates based upon subtraction results, and 10 out of 56 subtractions yielded negative supply leakage areas. For the 25 Pa leakage flows, the comparable results were 9 negative return results and 5 negative supply results. It should be noted that the supply leakage results were based upon subtracting zero from the total leakage results whenever the return leakage was calculated to be negative.

This treatment of the data assures that there will not be any cases in which the supply leakage could be computed to be larger than the total leakage of the duct system.

The better performance of the measurement technique at 25 Pa is not surprising, as those results are less sensitive to the uncertainty in the measured flow exponent because they do not depend upon extrapolation outside of the measurement range. In general, these negative results are somewhat discouraging, as they imply null measurement results 22% of the time for leakage areas, and 13% of the time for the leakage flow at 25 Pa. Based upon the premise that Method A performs better for leakier duct systems in tight houses due to the larger percentage uncertainties associated with taking small differences of large numbers, the distribution of negative results was checked relative to the ratios of duct leakage to envelope leakage. The results were that two thirds of the negative results were in the lowest 50% of duct to envelope leakage ratios, both for the effective leakage area and 25-Pa flow results. As would be expected based on their larger magnitude, the total duct leakage results (based upon subtractions of the results of the third pressurization test (all registers sealed) from the first test (all registers open)) only turn out to be negative in 4 instances out 56 leakage area calculations (7%) and in 2 out of

56 calculations of 25-Pa leakage flow (4%). A comparison of pressurization and depressurization results for total duct leakage in shown in Figure 3.

To examine the importance of measuring duct pressures during sealed-duct conditions, the magnitude of the pressures observed in the ducts and the corrections based on Equation 5 are summarized in Table 1.

TABLE 1. Ratios of duct pressure differentials to envelope pressure differentials during sealed-duct conditions, and associated correction factors for pressurization tests (Method A) (28 houses)

Pressure Ratio (Test)	Mean Ratio	Maximum Ratio	Minimum Ratio	Mean Correction Factor (median)
Return Grille/Outdoor to Indoor/Outdoor (Sealed Return)	0.27	0.66	0.01	1.89 (1.85)
Return Grille/Outdoor to Indoor/Outdoor (Sealed Supply and Return)	0.17	0.57	-0.01	
Supply Plenum/Outdoor to Indoor/Outdoor (Sealed Supply and Return)	0.14	0.52	-0.02	1.41 (1.30)

The results in Table 1 are quite dramatic, basically indicating that return duct leakage would be underestimated by almost 50% on average if the correction factor is not applied to the data, and that the equivalent underprediction for the total leakage would be almost 30% on average.The maximum underpredictions are as much as 76% for the return leakage, and 64% for the supply leakage. These results indicate that the measurement of duct pressures during sealed-duct conditions is a critical component of the standard. It is worth noting that the field measurements performed differ from those specified in the ASTM standard in that the fan seal was not removed for the third pressurization test (i.e., when both supply and return grilles are sealed) in the field test. It is for this reason that the return pressures are not equal to the supply pressures in the third fan pressurization test, during which both the supply and return grilles were sealed (the supply-plenum pressures were used for the corrections). From the results in Table 1, one can also infer that the fan seal was not perfect, as indicated by the change in return-side duct pressures between the second and third tests. Any leakage at the fan seal is exacerbated by the fact that the pressure difference across that seal can change sign between the two tests.

Method B Results

The supply-side and return-side duct leakage measured by the flow-capture-hood method are summarized in Figures 4 and 5, in which the leakage areas at 4 Pa and the leakage flows at 25 Pa are compared between pressurization and depressurization. Examination of these figures brings out two points: 1) the agreement between pressurization and depressurization results is even better than that observed with the blower-door subtraction method, and 2) once again, the scatter between pressurization and depressurization results is significantly smaller for the flows at 25 Pa compared to the leakage areas at 4 Pa.

For the flow-capture-hood measurements (Method B), the measured pressure difference across the ducts is used directly in the flow/pressure regressions used to characterize the duct leakage. In Table 2, the return-duct pressure differentials in the return leakage tests, and the supply duct pressure differentials in the supply leakage tests, are compared with the envelope pressure differentials measured simultaneously during those tests.

TABLE 2. Ratios of Duct Pressure Differentials to Envelope Pressure Differentials for Capture-Hood Tests of Duct Leakage (Method B)

Pressure Differential Ratio	Mean	Minimum	Maximum
Return Grille/Outdoor to Indoor/Outdoor (28 houses)	0.94	0.63	1.0
Return Plenum/Outdoor to Indoor/Outdoor(25 houses)	0.91	0.65	1.0
Near Supply Grille/ Outdoor to Indoor/ Outdoor(30 houses)	0.65	0.32	1.0
Supply Plenum/Outdoor to Indoor/Outdoor(30 houses)	0.54	0.11	1.0
Far Supply Grille/ Outdoor to Indoor/ Outdoor(30 houses)	0.53	0.11	0.99

The results in Table 2 clearly demonstrate the importance of direct measurements of duct pressures for determining duct leakage characteristics with Method B. The pressure differential is generally not dramatic for the return ducts, however in at least one case the pressure differential across the ducts is only two thirds of that across the envelope. The effect is clearly more pronounced for supply duct measurements, which is due to the larger resistance of supply registers and ducts to air flow. More specifically, there appears to be a large pressure drop across the supply grille to which the capture hood is connected, after which there is a non-negligible pressure drop through that supply duct, and a negligible pressure drop after the supply plenum. This is not surprising, as the resistance of the supply grille is large compared to the duct resistance, which in turn is large compared to the resistance of all the remaining ducts in parallel. To understand the impact of not measuring duct pressure, the results in Table 2 indicate that the calculated supply duct leakage would be 33% low on average if the house pressure were substituted for the measured duct pressure, and that the underprediction could be as much as 76%.

Comparison of Method A and Method B

The duct leakage flows at 25 Pa determined with Method A and Method B are compared in Figures 6 and 7, as well as in Table 3. Figure 6 is a scatter-plot of Method A results against Method B results for supply and return leakage flows at 25 Pa, and Figure 7 is a similar scatter-plot for total duct leakage flows at 25 Pa. What is clear in both those figures is that the agreement between the two techniques is much worse than the agreement of pressurization and depressurization results for either of the two techniques. The negative results obtained with Method A are included in these figures, as they make it clear that the frequency of null results (i.e. negative duct leakage values) is much smaller for the total duct leakage, compared to that for supply or return leakage only. These results are disappointing, however not that surprising when you consider that the best precision to be expected for fan pressurization tests would be 3% (Modera and Wilson 1990). For Method A, this uncertainty translates to an average uncertainty of 27% for total duct leakage, and 53% for either supply or return leakage, based upon the observed average fraction of envelope leakage in the ducts of 16% (split about evenly between supply and return). Table 3 presents a simple statistical summary of the data in Figure 7.

TABLE 3. Summary of total duct leakage flows at 25 Pa obtained with Method A and Method B (28 houses)

Data Set	Mean Duct Leakage [m3/h]	Median Duct Leakage [m3/h]	Minimum Duct Leakage [m3/h]	Maximum Duct Leakage [m3/h]
Total Leakage with Method A (pressurization)	400	345	-66	1025
Total Leakage with Method B (pressurization)	421	351	155	820
Total Leakage with Method A (depressurization)	376	382	-21	761
Total Leakage with Method B (depressurization)	425	337	193	1025

The results in Figure 3 suggest that despite the large scatter in the comparative results in Figures 6 and 7, there isn't any significant bias between the two measurement techniques

Auxiliary Measurement Results

The ASTM standard also specifies that duct-system pressures be measured under normal distribution-fan operation. The results of these measurements in the field study are summarized in Table 4.

TABLE 4. Pressure Differences Between Ducts and Their Surroundings During Normal System Operation

Location	Mean Value [Pa]	Standard Deviation [Pa]	Minimum [Pa]	Maximum [Pa]
Supply Plenum	46	28	9	138
Supply Duct Average	29	17	7	83
Return Plenum	-88	43	-14	-181
Return Duct Average	-57	31	-5	-126
Supply Duct Average =(2*Plenum+(Near Register) + (Far Register))/4 Return Duct Average=(Plenum + Grille)/2				

The results in Table 4 bring to light several points. These include: 1) that the pressures across duct system leaks during normal fan operation are significantly higher than those across leaks in building shells, 2) that the pressure differentials across return leaks are typically higher than those across supply leaks, and 3) that there is a large variability in operating pressures across duct leaks. The third observation is most pertinent to the ASTM standard, as it points out the importance of performing the auxiliary duct pressure measurements if one would like to be able to estimate the leakage rate of a given duct system during normal operation.

DISCUSSION

Several of the measurement and analysis results merit some further discussion. More specifically, it is clear from the data presented that Method B should generally produce more precise measurements of duct-system leakage, however it also became clear while performing these analyses that there is source of bias associated with Method B. Namely, the results in Table 1 made it clear that even with the care taken in the field test to seal the fan as well as possible, that the fan seal can be expected to leak.The ramification of this observation is that duct leakage results will tend to be underestimated with Method B. This underprediction results from the fact that it is implicitly assumed that all of the flow through the duct leaks is passing through the flow-capture hood. However, if the fan seal is leaking, it is leaking in parallel with the flow-capture hood, thereby causing an underestimation of the flow through the duct leaks. It should be noted that any leakage between the house and the duct system has the same effect as fan-seal leakage on Method B results. Finally, the size of this effect is dependent on the pressure difference across the fan seal and the duct house leaks. Thus for the sample reported on in this paper, this underprediction could matter for the supply-side leakage, but is unlikely to have had a significant impact on the return-side measurements.

The results in Table 2 brought up another discussion item relative to Method B. Namely, as the pressure drop through the return grille was less than 10% of the total pressure drop, whereas the pressure drop through the supply grille and the short adjoining duct were almost 50% of the pressure drop across the envelope, it seems that the standard could be modified to reduce the need for duct pressure measurements with Method B. The modification would be to measure return leakage with the fan sealed and then to measure total duct leakage with the fan unsealed and the flow-capture hood installed on the return grille. Under these circumstances, the pressure is likely to be far more uniform throughout the duct system, and should be fairly close to the pressure in the house (as observed for the return side). With such a protocol, the supply leakage would be obtained by subtracting the measured return leakage from the measured total leakage. It should be noted however that the results in Table 2 stem from the type of duct-system construction observed in California. Namely, large central return grilles and ducts are typically used in sunbelt houses instead of multiple smaller return grilles, which are more prevalent in some regions of the country. Finally, another potential modification to Method B would be to use a fan in conjunction with the flow capture hood to assure that the average pressure inside the duct system was equal to the pressure inside the house. This modification would essentially eliminate the parallel leakage problems discussed above. The best situation would be to combine the fan-assist with the switch to measuring flows only on the return side, in which case it seems that a uniform pressure equal to that in the house could be achieved for the entire duct system.

CONCLUSIONS

Several conclusions can be drawn based upon the results presented in this paper. The first and foremost conclusion is that internal duct-pressure measurements, and appropriate analysis procedures based upon those measurements, are necessary to provide reliable unbiased estimates of duct leakage to unconditioned spaces This was demonstrated to be the case both for Method A and Method B. Another important conclusion is that although no significant bias was observed between the two methods, Method B seemed to be superior, both in its better internal consistency between pressurization and depressurization results, and in that it does not provide negative duct leakage results. In addition, although Method A has more scatter, neither technique showed any significant bias between pressurization and depressurization results. Finally, the data presented also made it clear that the reproducibility, and the degree of physical confidence in the results was significantly better for the leakage flow at 25 Pa versus the effective leakage area at 4 Pa.

ACKNOWLEDGEMENTS

The research reported here was funded in part by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor. This work was also supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES

Cummings, J.B., Tooley, J.J. Jr. and Dunsmore, R., 1990. "Impacts of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Homes", Proceedings of ACEEE Summer Study, Pacific Grove, CA, August 1990, American Council for an Energy Efficient Economy, 1001 Connecticut Ave. N.W., Suite 535, Washington D.C. 20036.

Modera, M.P. and Wilson D.J., 1990. "The Effects of WInd on Residential Building Leakage Measurements", *Air Change Rate and Air Tightness in Buildings,* ASTM STP 1067, M.H. Sherman, Ed. American Society for Testing and Materials, Philadelphia, 1990, pp. 132-145, Lawrence Berkeley Laboratory Report LBL-24195.

Modera, M.P. 1991, "Characterizing the Performance of Residential Air DIstribution Systems", Lawrence Berkeley Laboratory Report LBL-32532.

Palmiter, L., and Bond, T., 1992. "Impact of Mechanical Systems on Ventilation and Infiltration in Homes", Proceedings of ACEEE Summer Study, Pacific Grove, CA, August 1992, American Council for an Energy Efficient Economy, 1001 Connecticut Ave. N.W., Suite 535, Washington D.C. 20036.

Kinert, R.C., Engel, D.C., Proctor, J.P., and Pernick, R.K., 1992. "The PG&E Model Energy Communities Program: Offsetting Localized T&D Expenditures with Targeted DSM", Proceedings of ACEEE Summer Study, Pacific Grove, CA, August 1992 American Council for an Energy Efficient Economy, 1001 Connecticut Ave. N.W., Suite 535, Washington D.C. 20036.

Robison, D.H.; Lambert, L.A. 1989. "Field investigation of residential infiltration and heating duct leakage", *ASHRAE Trans.* Vol. 96, Part 2.

LIST OF FIGURES

Depressurization vs. Pressurization (Method A)

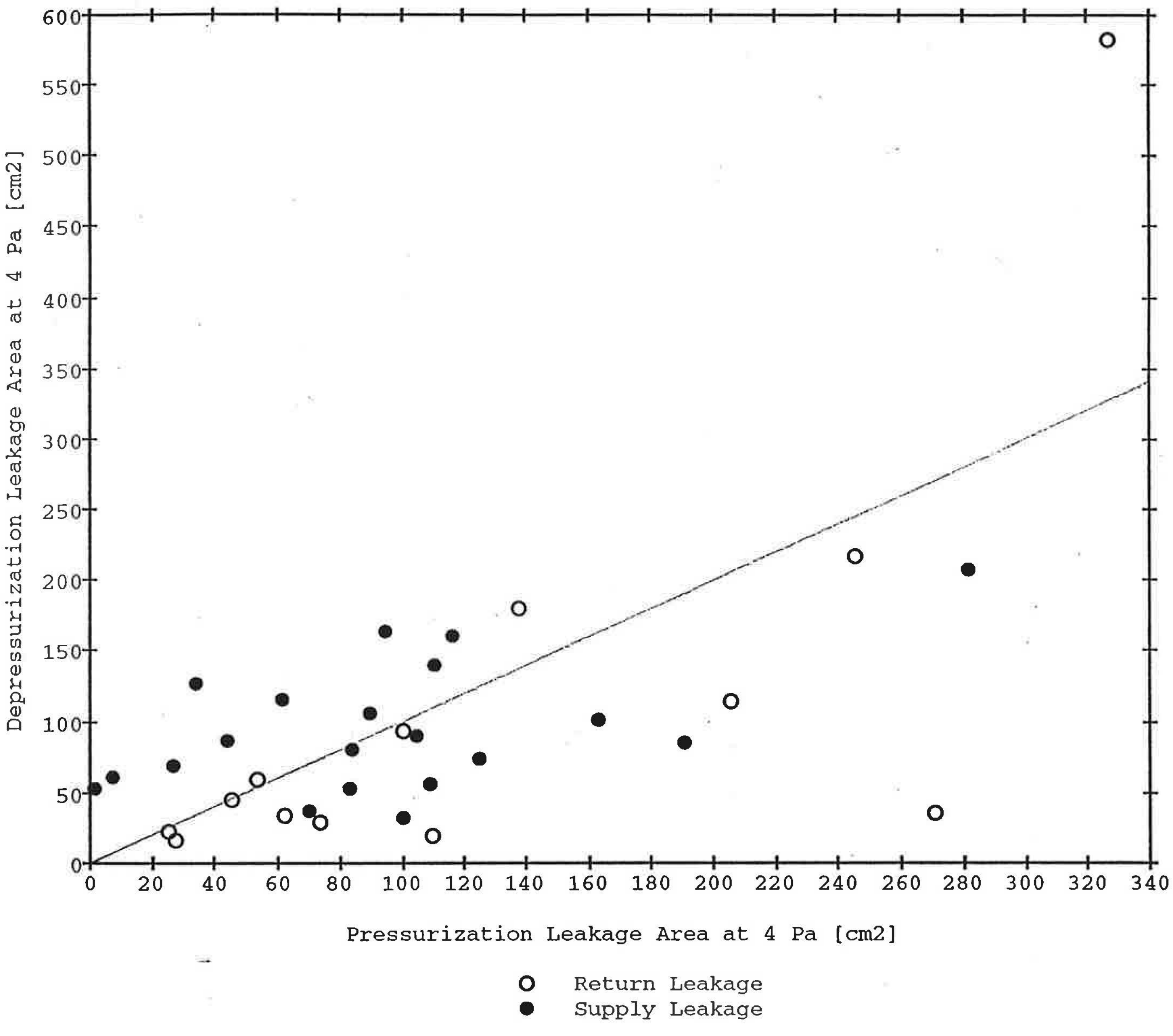


FIGURE 1. Comparison of Pressurization and Depressurization Results for the Return Duct and Supply Duct Leakage Areas at 4 Pa obtained with Method A (blower-door subtraction)

Depressurization vs. Pressurization (Method A)

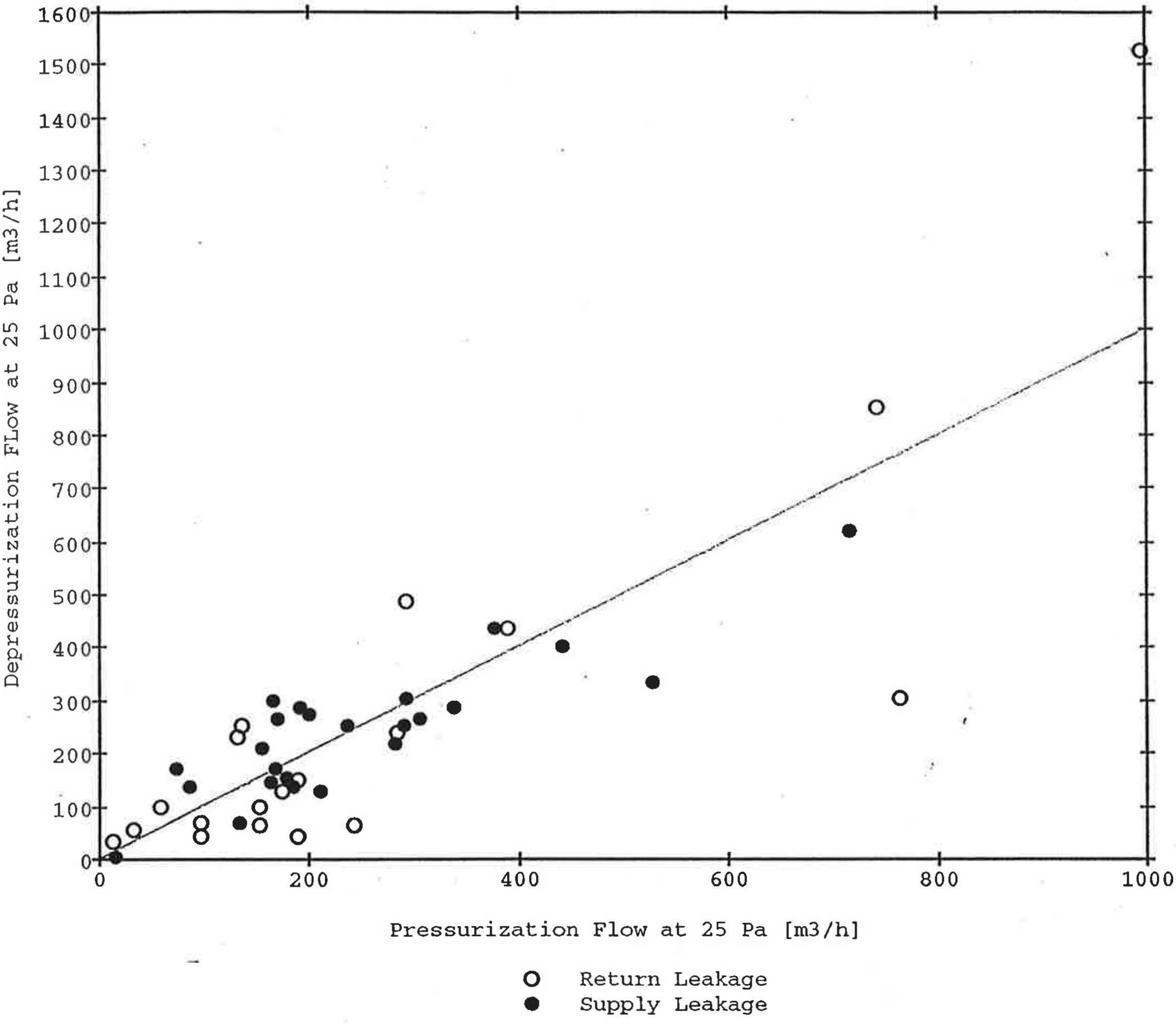


FIGURE 2. Comparison of Pressurization and Depressurization Results for the Return Duct and Supply Duct Leakage Flows at 25 Pa Obtained with Method A (blower-door subtraction)

Depressurization vs. Pressurization (Method A)

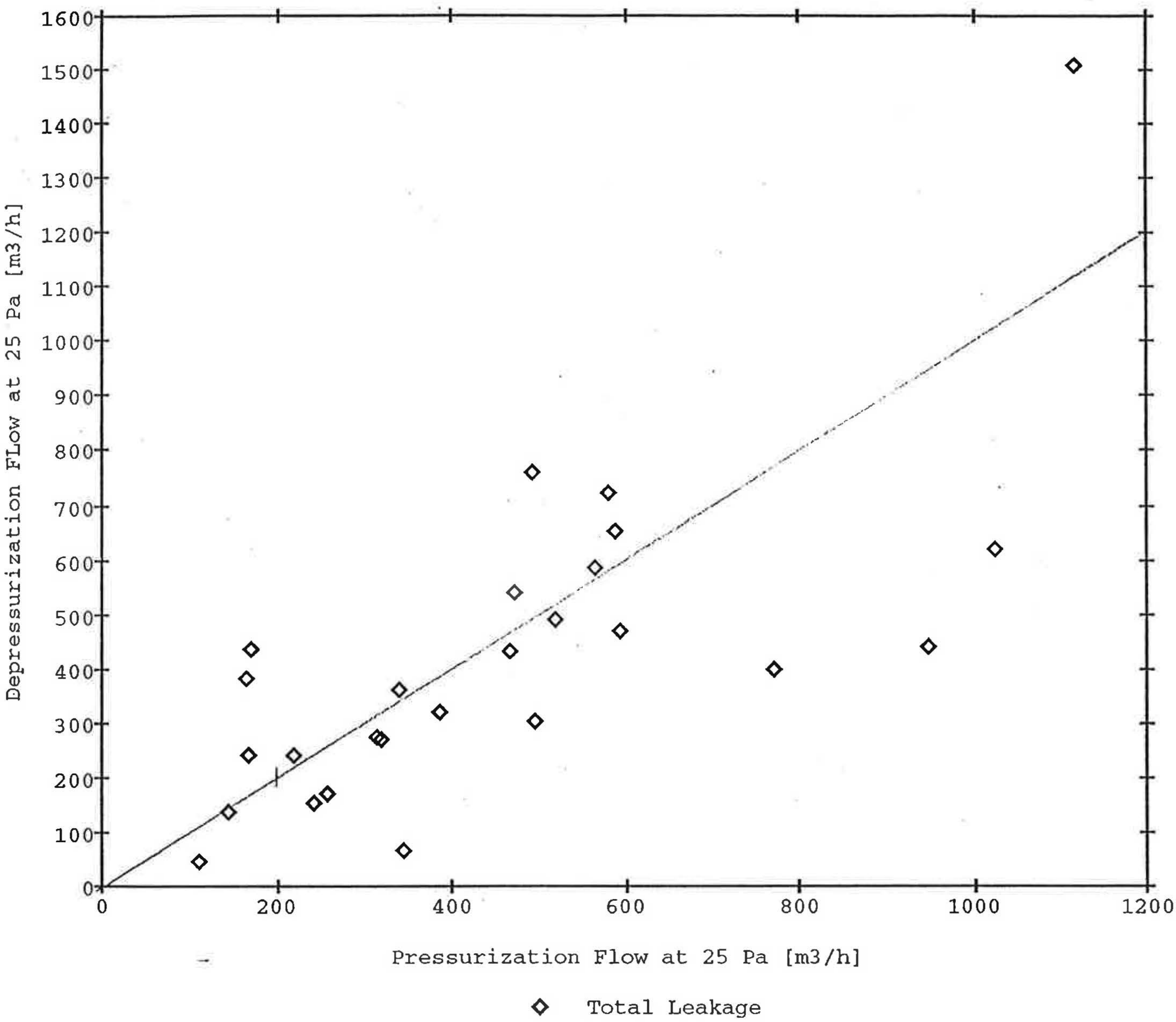
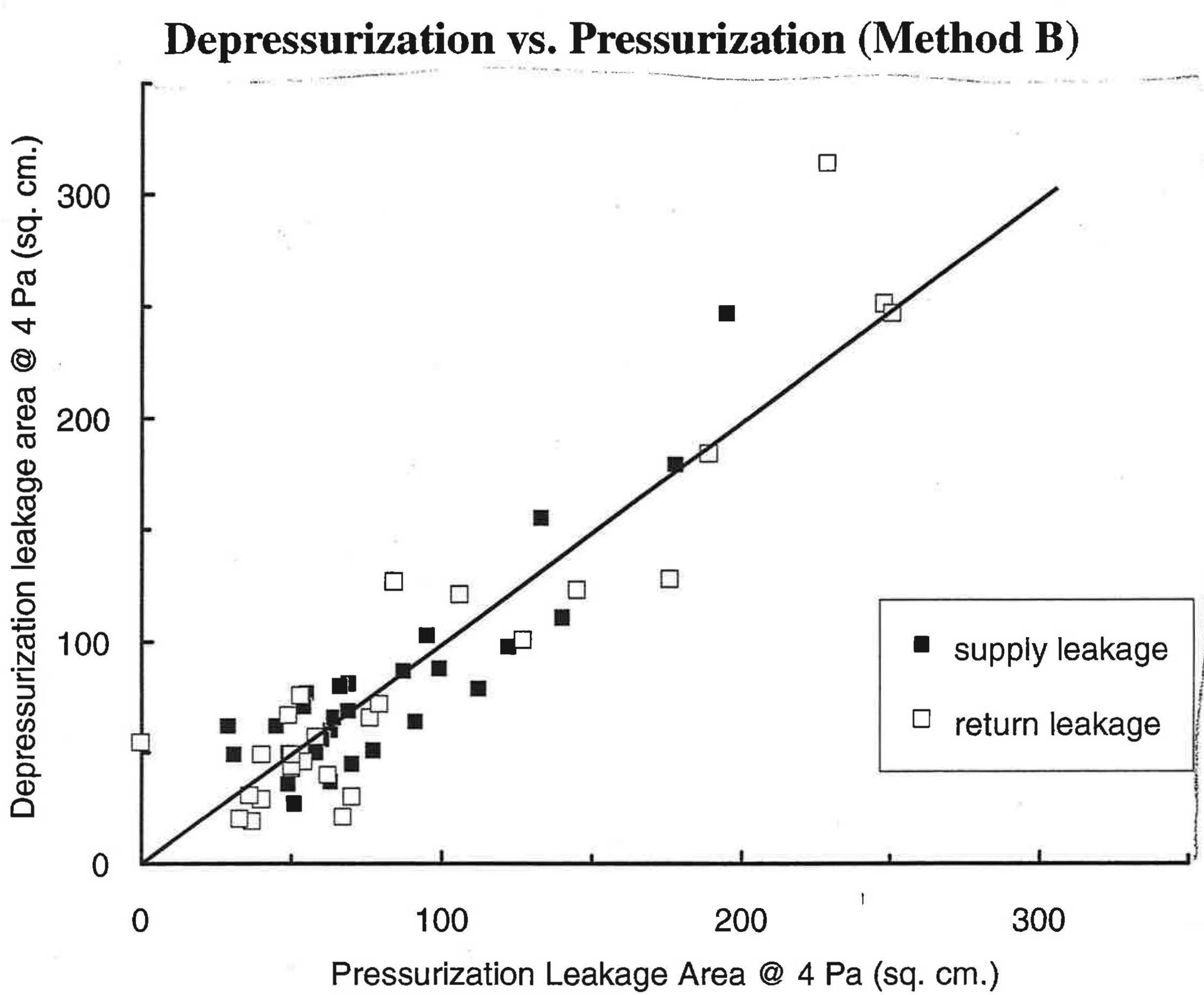


FIGURE 3. Comparison of Pressurization and Depressurization Results for Total Duct Leakage Flows at 25 Pa Obtained with Method A (blower-door subtraction)


Depressurization vs. Pressurization (Method B)
Depressurization leakage area @ 4 Pa (sq. cm.)
0
100
200
300
0
100
200
300
Pressurization Leakage Area @ 4 Pa (sq. cm.)
supply leakage
return leakage

ELA4FH
Fig. 1

Depressurization vs. Pressurization (Method B)

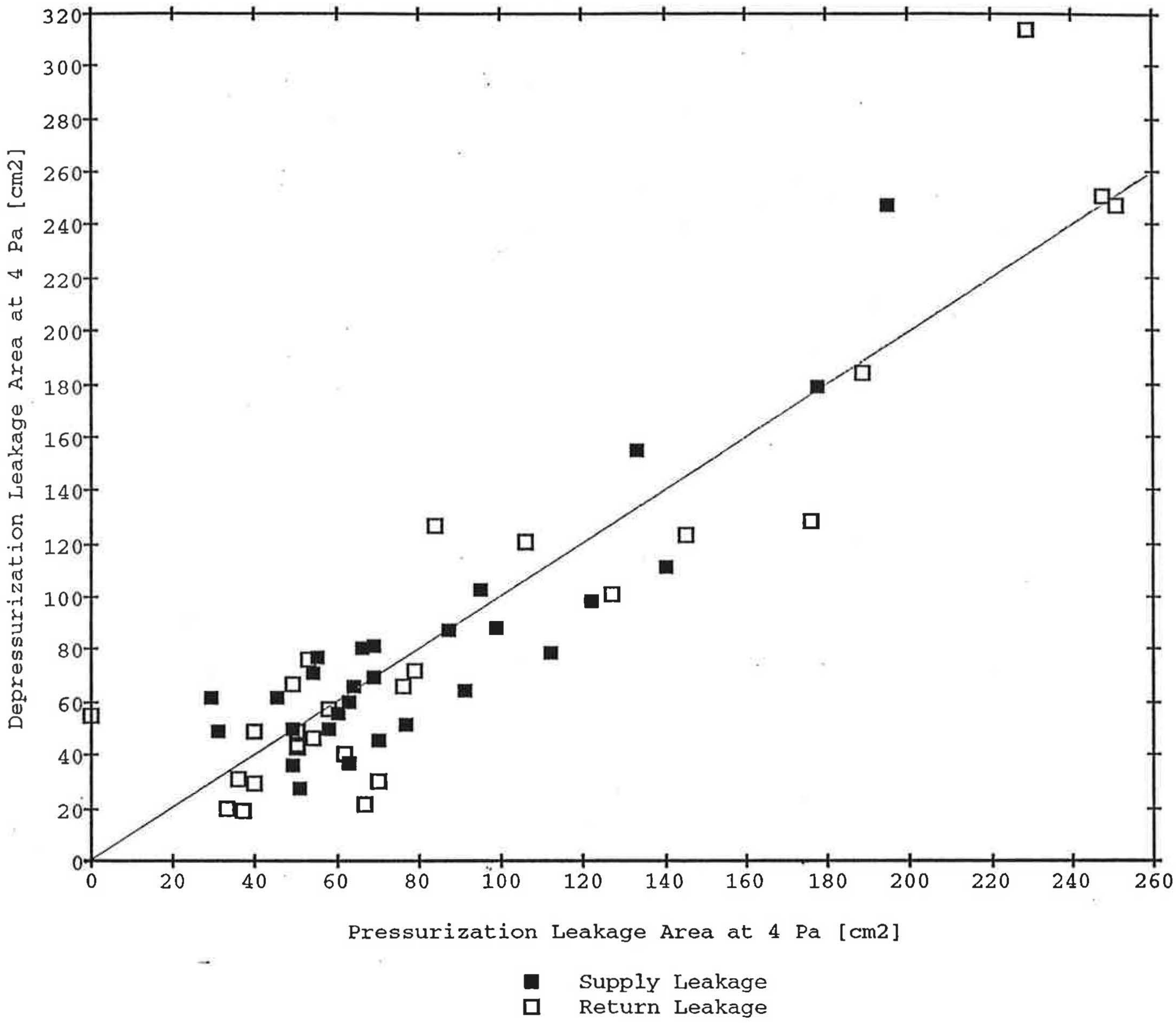


FIGURE 4. Comparison of Pressurization and Depressurization Results for the Return Duct and Supply Duct Leakage Areas at 4 Pa obtained with Method B (flow-capture hood)

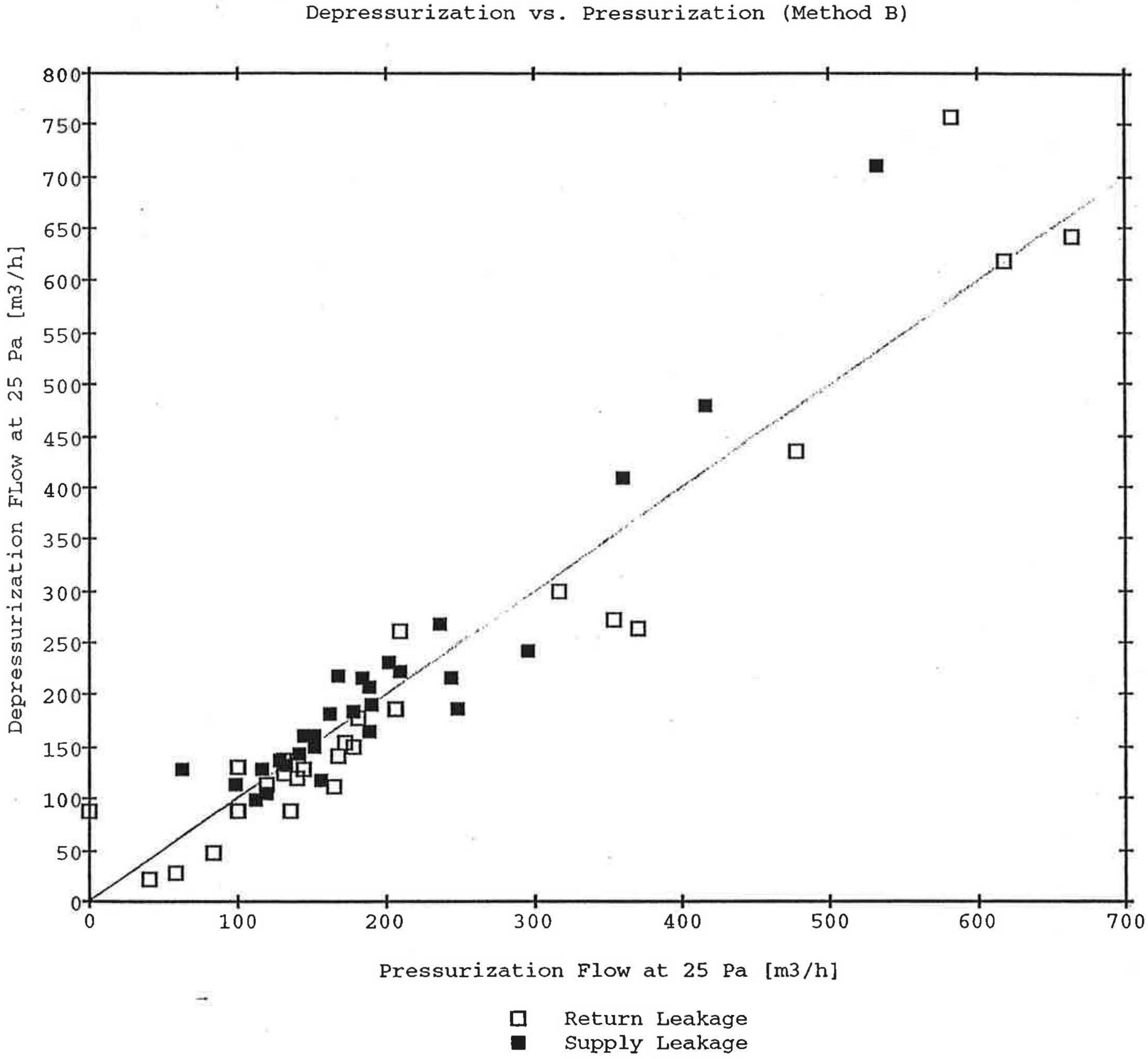


FIGURE 5. Comparison of Pressurization and Depressurization Results for the Return Duct and Supply Duct Leakage Flows at 25 Pa Obtained with Method B (flow-capture hood)

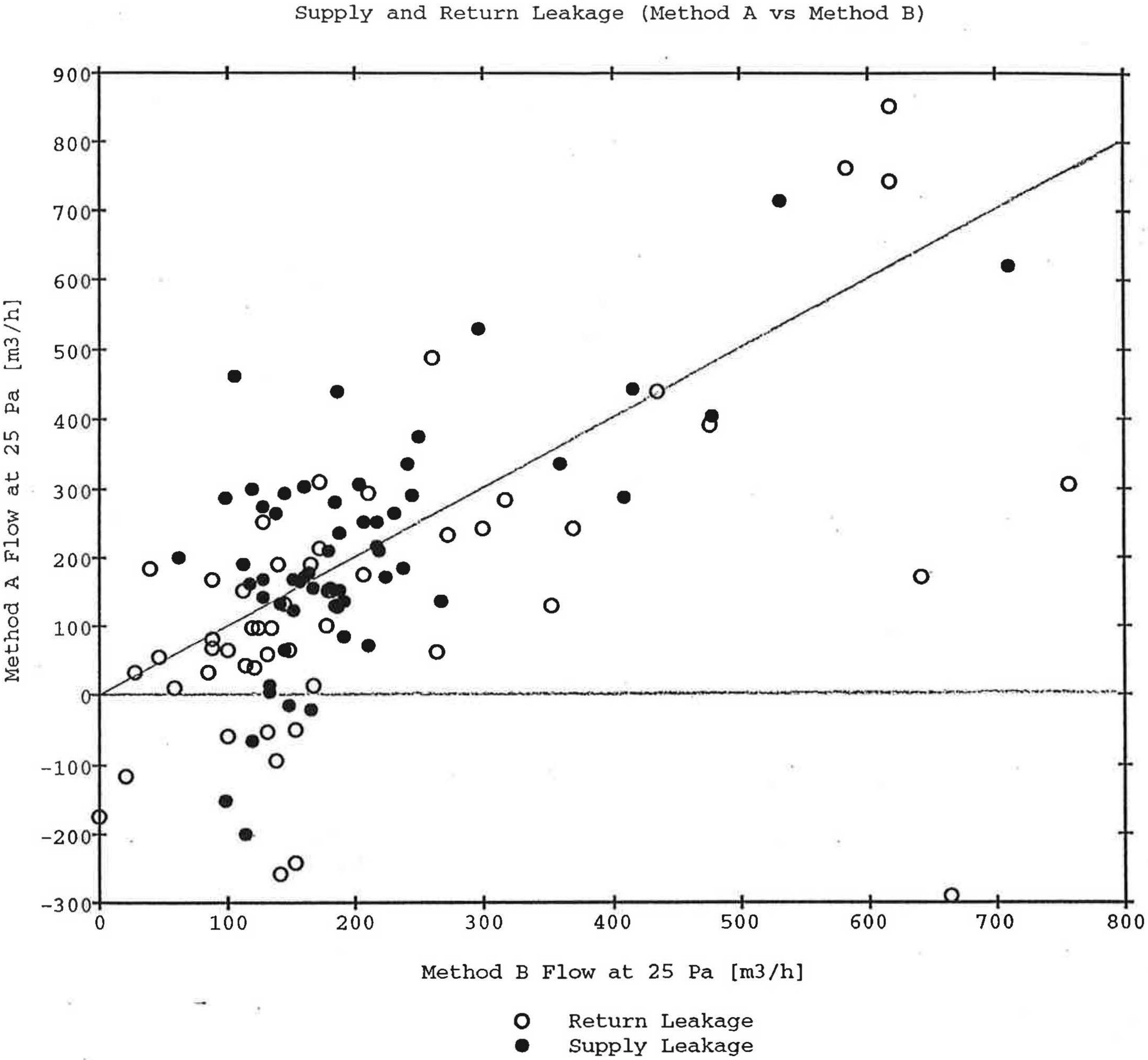


FIGURE 6. Comparison of Return Duct and Supply Duct Leakage Flows at 25 Pa Obtained with Method A (blower-door subtraction) and Method B (flow-capture hood)

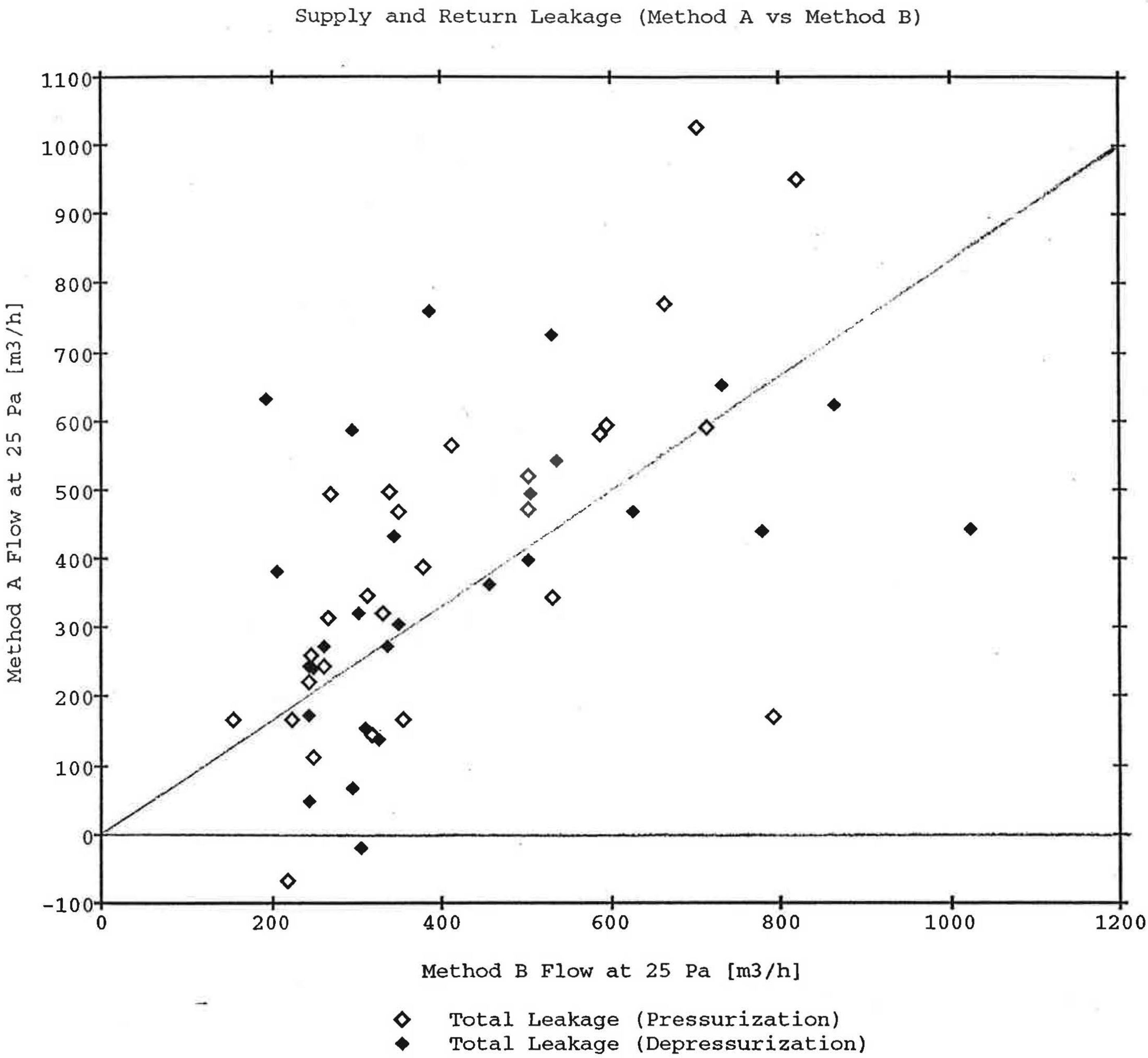


FIGURE 7. Comparison of Total Duct Leakage Flows at 25 Pa Obtained with Method A (blower-door subtraction) and Method B (flow-capture hood)