A New Device for Field Measurement of Air Handler Flows

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ABSTRACT

Accurate measurement of air handler flows is important for estimating duct efficiency and for verification of adequate flow for air conditioners and heat pumps. This paper describes the development and test results for a new device that offers improved accuracy over traditional methods. The device has been under development for about two years.

The initial proof-of-concept laboratory tests demonstrated that accuracy of a few percent was obtainable. This paper describes the laboratory test results for the final design as well as the results of field evaluation of the device on several dozen homes. Results from the flow device are compared with those from use of a duct tester as well as the traditional temperature rise method. Both accuracy and precision are evaluated for all three methods.

Introduction

The flow rate of air through residential air handlers is an important quantity; both for assuring adequate flow across a heat pump or air-conditioning coil and for the accurate estimation of the thermal efficiency of duct systems. However, the primary method of estimating the air handler flow rate, which is the temperature rise across the air handler fan, has been found to be highly problematic. Another method of measuring the air handler flow, which uses a calibrated fan installed at the air handler cabinet with the return isolated from the rest of the system, is time-consuming and somewhat difficult to do. It is desirable, then, to have a method of estimating the airflow that is both more accurate than the temperature rise method and faster and simpler than the calibrated fan method.

In 1997 the Department of Energy sponsored a project under the Small Business Technology Transfer Program (STTR) to develop a device that would meet the need for a more accurate and simpler method. The project team was a collaboration involving three entities: Ecotope Inc. located in Seattle, WA; Washington State University Energy Extension Program located in Olympia, WA; and The Energy Conservatory located in Minneapolis, MN. Phase I of this project was a proof-of-concept phase. The results were very favorable which led to Phase II, in which the device was redesigned and extensively field-tested.

In this paper we give a very brief overview of the Phase I results, followed by a summary of the Phase II results. More details for Phase I can be found in Palmiter and Francisco (1998) and for Phase II in Palmiter and Francisco (2000).

Phase I

In Phase I we tested a 20-inch x 20-inch perforated metal plate that was instrumented with small metal tubes up- and downstream of the plate. The center of the plate was taped off to counter jet effects. The upstream pressures were measured with a small diameter tube that was centered in the square annular opening where the perforated plate was not masked.

There were twelve pressure measurement points that were averaged by the tube. Each measurement point consisted of a small hole facing upstream. This was located in the center of a small "wing" in the form of an upstream facing V-shape which created an upstream total or stagnation pressure measurement averaged roughly over the projected area of the "wing". This type of sensor arrangement is employed in a number of commercially available flow measurement devices. The downstream static pressure measurements employed an identical pressure-averaging tube with twelve simple holes facing downstream, but without the "wings".

The actual measured pressure difference in both the Phase I and Phase II devices is an averaged upstream total pressure minus an averaged downstream static pressure. Using the upstream total pressure rather than static pressure is a simple way to increase the magnitude of the measured pressure difference, which improves the measurement accuracy at low flow rates.

An electric furnace air handler with a nominal rating of 855 cubic feet per minute (cfm) at an external static pressure of 75 Pascals (Pa) was used for all of the subsequent Phase I lab tests. A return plenum 20x20 in. and 24 inches tall was fabricated for the air handler. Two 14-inch diameter round collars were attached to the plenum, one centered in the top of the plenum and the other one centered in one side of the plenum. In use, one of the collars was sealed; the other was used for the return flow.

Tests were done at several flow rates from 550-850 cfm and for several upstream duct configurations. The true flow was measured through the use of a calibrated Duct Blaster that was attached to the inlet of the upstream duct configuration. A second Duct Blaster was installed downstream of the air handler fan, and was used to modulate the flow.

Four standard duct configurations were used to evaluate the effects of inlet geometry and expansion ratio. These four configurations were side entrance with and without a 10-foot duct and top entrance with and without the duct. None of these four configurations used an elbow. Three additional configurations involved the use of a round elbow that was fastened to one of the collars without the 10-foot duct. The configurations were side with elbow in an "S" configuration, side with the elbow parallel to the top of the plenum, and top with the elbow parallel to the top of the plenum. A schematic of the side entrance without the duct, as used for the final calibration testing, is shown in Fig. 1 along with schematics of the duct and elbow.

The primary focus of this phase was to determine if it was possible to apply a single calibration equation to the pressure drop across the flow plate across a range of flows and provide good agreement with the flow as measured with the upstream Duct Blaster. This was done by dividing the measured flow from the Duct Blaster by the square root of the pressure drop across the flow plate over the above set of flow rates and upstream duct configurations. The results are detailed in Table 1 and depicted in Fig. 2.

These results show that the standard deviation of the calibration coefficient over all flow rates and configurations is only 1.8% of the mean value. Further, the average over all flow rates for each upstream configuration was within 1.5% of the mean value. This was considered extremely good agreement, and proof that a calibrated flow plate could meet the objectives of the project.

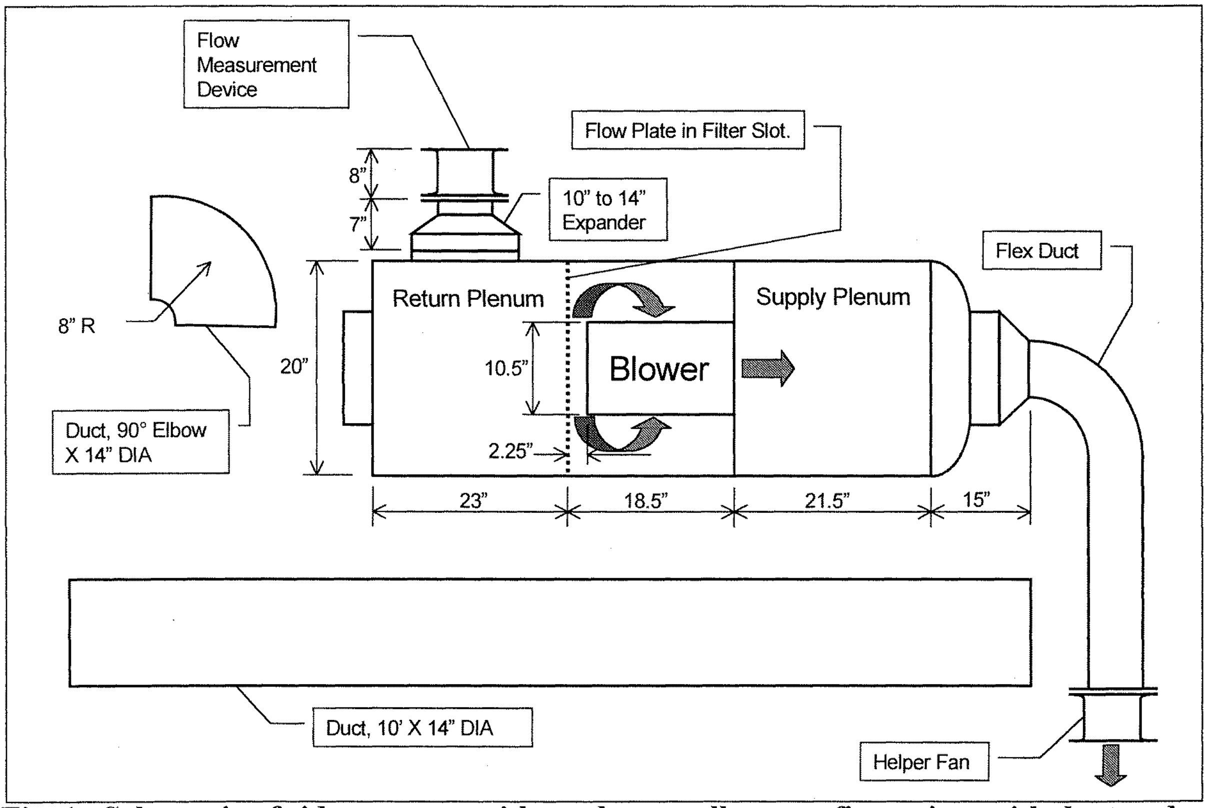

Fig. 1. Schematic of side entrance without duct or elbow configuration, with duct and elbow shown for scaling.

Table 1. Seven-point calibration results for seven duct configurations

Duct Configuration	C_d (cfm/Pa$^{0.5}$)	Std. Deviation (cfm/Pa$^{0.5}$)	Difference from Overall, %	Number of points
Side with no duct or elbow	138.3	2.4	1.1	49
Top with no duct or elbow	138.8	1.5	1.5	49
Side with 10' duct, no elbow	136.0	1.8	-0.7	49
Top with 10' duct, no elbow	135.5	1.5	-1.0	49
Side with no duct, elbow in "S"	136.7	2.3	-0.1	35
Side with no duct, elbow up	135.4	2.1	-1.0	35
Top with no duct, elbow up	136.1	1.7	-0.5	35
Overall	136.8	2.3		301

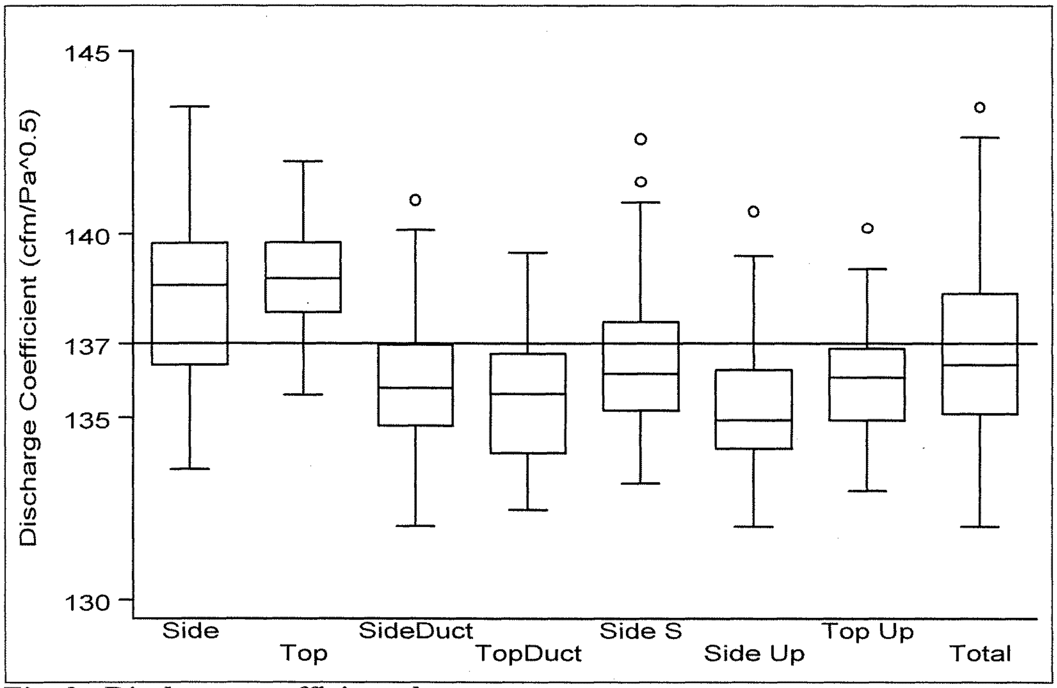

Fig. 2. Discharge coefficients by return type.

Phase II

There were two primary objectives for Phase II. The first was to build on the work from Phase I and refine the device to be more durable for widespread use in the field and more reproducible in manufacture so as to avoid the need for individual calibration of each device. In addition, the issues of multiple filter sizes and air handler configurations were addressed. Multiple filter sizes were addressed by making three different sizes of plates, each to be used with spacers (if necessary) to provide an assembly the same size as the filter slot.

The Phase II prototype used a thin plastic plate with several precision-machined holes, rather than perforated metal plates. Copper tubing was used for pressure measurement, with holes in the upstream tubing in the center of each hole in the plate (for upstream pressures) and holes in the downstream copper tubes behind the solid portion of the plate. Small plastic tubing exited the copper tubes and need to be pulled through an access in the air handler or plenum and attached to a pressure reading device.

The new prototype was then tested in the same laboratory setting as was done in Phase I. The Phase II prototype had the same small sensitivity to different return configurations as that shown in Phase I, although there were differences in which configurations had the highest or lowest calibration coefficients.

It was realized that the flow plates might change the flow rate in the air handler by being either more or less restrictive than the filter. To address this problem, a pressure correction method was devised whereby the pressure between a location in the duct system and the house would be measured both with the filter and with the flow plate. The nominal flow rate measured by the flow plate would then be multiplied by the square root of the ratio of the pressure difference with the filter to that with the flow plate.

The second objective was to test the new prototype in the field. Despite the extremely promising results from the lab testing in both Phase I and Phase II, it was deemed necessary to perform field-testing on a substantial number of homes. This was for several reasons. Though the air handler in the lab testing did have a working fan, it did not have any heating elements and was not connected to an actual supply-side duct system. This meant that it was not possible to compare the prototype to other methods of measuring air handler flow. Also, the lab testing was only able to look at one size of return plenum and a few upstream duct configurations. Field-testing provides a suitably large sample of air handler sizes and configurations, equipment types, and duct sizes, and allows for comparisons with other measurement techniques. It also provides real world situations in which to confirm that the device is practical and easy to use. Further, the suitability of the pressure-ratio method of correcting the flow could be assessed.

Field Measurement Methods

The flow plate testing methodology is as follows:

- Insert a pressure measurement device at an acceptable location in the distribution system, such as a static pressure probe in the supply plenum or a total pressure tap in the downstream corner of the supply plenum.
- Turn air handler on and measure the pressure between the supply system and the house.
- Replace the filter with the flow plate assembly, bringing the small plastic hoses that measure the pressures up and downstream of the flow plate through the air handler/duct system, making sure to seal around the flow plate in the filter slot and around the access point for the plastic hoses.
- Turn on air handler and measure the pressure at the same location as when the filter was in place relative to the house.
- Measure the flow through the assembly using the pressure drop measured across the flow plate.
- Calculate correction factor and multiply by the measured flow to get the flow that was moving through the system with the filter in place.

In addition to using the flow plate, two additional distinct methods of estimating airflow were performed in the field tests. The first of these is a traditional temperature rise method, in which temperatures are measured in the supply and return plenums, and combined with the equipment output capacity to estimate airflow. The primary purpose for using the temperature rise method was to provide a comparison of the flow plate method with the standard procedure currently in use by field technicians.

This method is known to be problematic due to the non-uniformity of supply plenum temperatures and the possibility that the capacity changes between times when the temperatures are measured and when the capacity is measured. This change in capacity is usually due to resistance elements cycling on and off. In heat pumps and air conditioners, the difficulty in knowing the compressor efficiency also makes it difficult to determine an output capacity to be combined with the temperatures.

In an attempt to reduce the variability of the temperature rise method, the field tests also included a multi-point supply temperature test. In this test, supply plenum temperatures were measured at nine points corresponding roughly to the centers of rectangular areas resulting from division of the supply plenum cross-section into nine equal rectangles. Return temperature measurements were made at a single point before and after the supply temperatures were measured, and the average of these two measurements was used as the return temperature corresponding to the average of the supply temperatures. This should largely address the issue of the air heating up during the supply temperature measurements. A simple average of the nine supply temperatures was used in combination with the return plenum temperature in calculating the airflow. The single-point supply test results used only the central temperature.

When performing the temperature rise test, the furnace was allowed to run for several minutes to assure that all of the operational elements would have sequenced on. Heat pumps were set to run in emergency (resistance-only) mode so as to remove the need for estimation of compressor efficiency.

The other method of estimating air handler flow used a Duct Blaster attached to the front of the air handler cabinet. This method is in the current version of ASHRAE Standard 152P (ASHRAE 1999). Prior to running this test, the pressure between the supply system (usually measured at or near the plenum) and the house is measured under normal operation. The return ducts are then isolated through the use of a barrier placed in the filter slot. After the Duct Blaster is installed, the air handler fan is turned on and the calibrated fan is adjusted to provide the same supply system-to-house pressure as measured previously. If the pressure is not matched, a correction is applied. This correction is the square root of the ratio of the normal operation pressure to the pressure measured during the test. This test is usually fairly accurate, but can take a significant amount of time to set up.

When performing the flow plate and Duct Blaster pressure matching tests, pressure measurements were made in the return and supply plenums as well as in several other locations in the duct system. These pressures were used to apply any correction to normal operating conditions that was necessary, and to determine the best location for measuring the pressure. The locations in addition to the plenums varied from house to house due to the wide variation of duct configurations, so the results presented are restricted to the supply plenum location. The return plenum pressure location was not used for comparison to other tests because the Duct Blaster pressure-matching test requires that the return be isolated.

The flow plate was typically used as the barrier for the Duct Blaster pressure-matching test, with the holes covered over with masking paper. This allowed for a simple installation of the barrier.

Typical installations of the field test equipment are illustrated in Figs. 3 and 4. Figure 3 shows the flow plate installed in the filter slot of a typical down-flow electric furnace. Figure 4 shows the setup for a down-flow heat pump. This picture was selected to show the placement of the holes in the supply plenum for measuring the supply plenum temperatures. The three holes are visible at the bottom of the unit. In this photo, the central hole has a static pressure tap installed. Some return plenum pressure taps are visible on the left. The flow plate was mounted in the electronic air-cleaner just out of sight at the top of the photo.

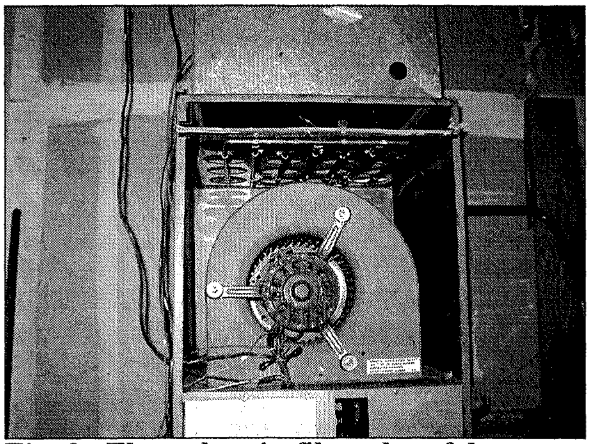

Fig. 3. Flow plate in filter slot of down-flow furnace

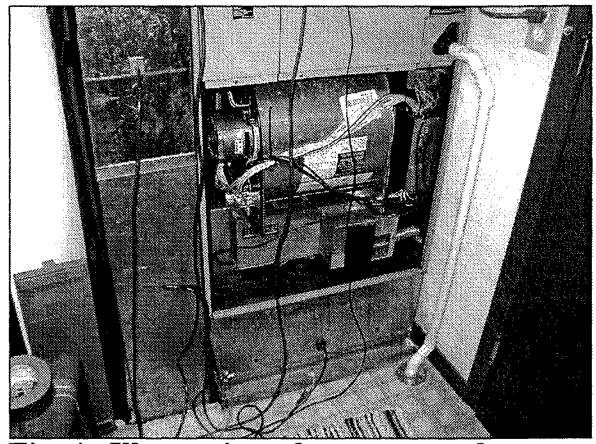

Fig. 4. Illustration of pressure and temperature measurement locations

Flow Results from Field Tests

The main results from the field tests are shown in Fig. 5 and Table 2. The Duct Blaster test method was used as the reference or "truth" value. Fig. 5 shows box-plots of the results for each of the other three airflow measurement methods expressed as ratios to the Duct Blaster result.

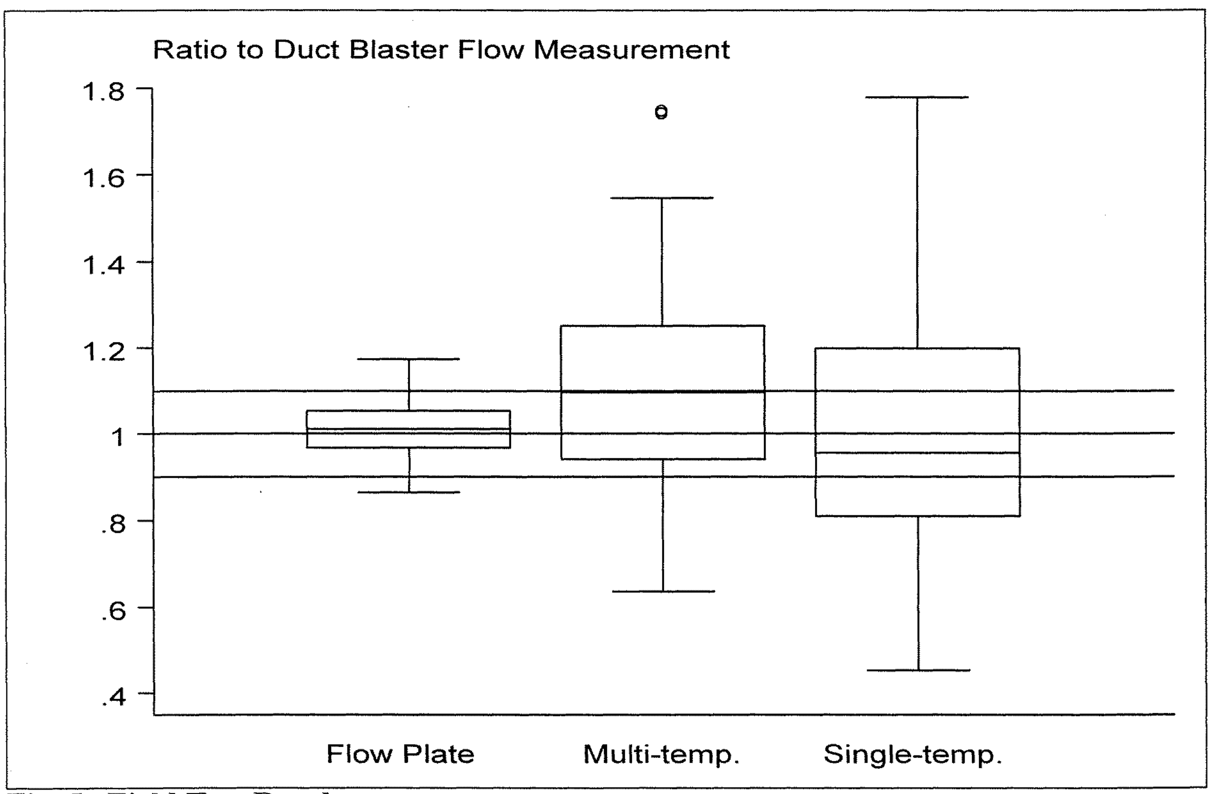

Fig. 5. Field Test Results

Table 2. Field Test Results

	Ratio to Duct Blaster Flow Measurement							
	n	Mean	Std. Dev.	Min.	Q1	Median	Q3	Max.
Flow Plate	65	1.01	0.068	0.86	0.97	1.01	1.05	1.17
Multi-temp	56	1.10	0.222	0.64	0.94	1.10	1.25	1.74
Single-temp	62	1.01	0.297	0.45	0.81	0.96	1.20	1.78

In the box-plots the box extends from the 1st quartile to the 3rd quartile; the central line indicates the median; and the whiskers extend to roughly 3 standard deviations from the median. The circles are outliers. There are reference lines at 1.0, which indicates exact agreement with the Duct Blaster result, and at 1.1 and 0.9, or plus-or-minus 10 percent.

The figure illustrates the improvement in bias and scatter of the flow plate when compared with the standard temperature rise method. The inter-quartile distance for the flow plate is about 4.5 times smaller than that for the single-point temperature method. It is interesting to note that the multi-point temperature method, although reducing the scatter by about 25%, is biased 10% high relative to the single-point method, based on means. This is because the cooler temperatures measured at the peripheral sampling points tend to be associated with lower velocity air. Thus simple averaging of the temperatures produces a temperature that is lower than a velocity-weighted temperature, leading to a calculated flow that is higher than the true value.

Table 2 gives a statistical summary of the same data. The number of homes for each test is the maximum number of homes for which valid data were obtained for that test. Reducing the summary to the subset of 56 homes for which all three tests were available had almost no impact on the summary values.

Note that the standard deviation of the flow plate measurements, 6.8%, is about 4.4 times less than that of 29.7% for the single-point temperature method. The quartiles show the single-point temperature method has errors greater than 20% in about half of the homes tested. In the worst cases it was wrong by about a factor of two. In contrast, the flow plate does not have any cases where the error is as much as 20%, and more than half of the tests have errors of 5% or less.

In summary, relative to the standard temperature method, the flow plate provides a large improvement in the accuracy of airflow measurement for about the same time and effort invested.

Practical Issues

The field tests provided a means of not only assessing the accuracy of the flow plate, but also of determining how easy the device is to use. In order to gain acceptance by contractors, utilities, etc., the device has to be simple and fast to use as well as accurate.

The flow plate was found to be about as fast as performing the single-point temperature rise method, including the measurement of the output capacity. Output capacity needs to be measured, as taking the nominal rated value may be incorrect. For example, electric resistance elements may be burnt out, or a gas furnace may be dirty, compromising the combustion efficiency. The flow plate was significantly faster than the Duct Blaster method.

In addition, there were several houses at which the temperature rise method could not be implemented, whereas the flow plate could be used. There were two main reasons that temperature rise measurements were unavailable. The most common was equipment whose output capacity could not be measured. In some cases heat pumps were not wired for resistance-only operation, and without the compressor efficiency it was not possible to use power measurements to obtain the output capacity. Prior experience suggests that using the manufacturer's rated compressor efficiency can lead to poor results, and that for an accurate estimate of flow the actual efficiency would need to be measured. Oil furnaces created a different problem. Even if combustion efficiency could be measured, there was no way to measure the input rate of consumption.

The only cases in which the flow plate could not be used were those where the filter slot did not have at least one dimension of a minimum of 20 inches and down-flow gas furnaces with the flue pipe in the way of the filter location.

The field tests also confirmed that in most cases the flow through the air handler with the flow plate in place was essentially the same as that with the filter in place, so that the correction factors derived from the auxiliary plenum pressure measurements were quite small. However, in a few cases these corrections were fairly large. More than half of the houses required less than a 10% pressure correction, which corresponds to about a 5% or less correction to the flow. There were a few cases where a large correction was necessary, however, though rarely was a pressure correction of greater than 25% required (corresponding to about a 12% flow change). One common cause of a large correction was a very dirty filter. In these cases, the flow plate was significantly less restrictive than the filter.

Findings and Conclusions

The Phase II results show that the primary goals of the project have been met. The new flow plate device:

- Is easy and fast to use in the field, requiring about the same time as the single-point temperature rise method when including the time required in the temperature method to measure the output capacity.

- Is fairly robust in accuracy over a wide range of return plenum and fan location configurations as experienced in the field.

- Is about 4.5 times more precise than the single-point temperature method (standard deviation of 6.8% compared to 29.7% for the single-point temperature rise method), and of comparable accuracy to the Duct Blaster or calibrated fan method.

- Is applicable to many systems for which the temperature method cannot be used due to inadequate or absent supply plenum temperature measurement points.

- Requires a relatively small amount of equipment.

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References

ASHRAE. 1999. *ASHRAE Standard 152P: Method of Test for Determining the Steady-State and Seasonal Efficiencies of Residential Thermal Distribution Systems.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Palmiter, L. and P. W. Francisco. 1998. *Development of a Simple Device for Field Air Flow Measurement of Residential Air Handling Equipment.* Seattle, WA, Ecotope, Inc.

Palmiter, L. and P. W. Francisco. 2000. *Development of a Simple Device for Field Air Flow Measurement of Residential Air Handling Equipment: Phase II.* Seattle, WA, Ecotope, Inc.