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DUCT TEST RIG

(THE DEVELOPMENT AND EVALUATION
OF DEVICE FOR TESTING RESIDENTIAL DUCTS, VENTS,
AND CHIMNEYS)

FINAL REPORT

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A DEVICE FOR TESTING RESIDENTIAL DUCTS, VENTS, AND CHIMNEYS

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EXECUTIVE SUMMARY

This report describes research and design work carried out for the purpose of developing a DUCT TEST RIG. The research was conceived and funded by the Canada Mortgage and Housing Corporation (CMHC).

The Duct Test Rig (or DTR) is a new device capable of determining air flow and air pressure characteristics of residential ventilation and venting systems. It can also be used to measure heat losses from ducts and flues.

The DTR is designed for testing most types of ventilation systems. Air flow is measured by means of a variable area orifice mounted inside a portable flow chamber. A variable speed fan, also mounted inside the flow chamber, is used in combination with the orifice to create varying amounts of over and under pressure at the inlet or outlet of the ventilation device under test. The fan can also be used to compensate for backpressure created by the DTR and its measuring orifice, thereby permitting accurate flow measurements under "zero" pressure conditions.

Either end of the portable flow chamber can be placed over an inlet or outlet grille, for measuring supply or exhaust systems. The flow chamber is equipped with specialized hoods and gaskets to permit easy, airtight connections with most types of ventilation systems, including open fireplaces, clothes dryer outlets, wall/floor/ceiling grilles, and furnace vent connectors. One hood incorporates an electric duct heater for contributing a known quantity of heat to air passing through the flow chamber. A steel fish-tape and thermometer can be used to monitor air temperatures at a remote location.

The DTR includes a separate control module for controlling fan speed and monitoring air pressures and temperatures. A collapsible tripod and cradle permits one-person operation of the DTR, if necessary.

The DTR was developed to provide a means for investigating a number of problems, that have recently come to light, with the performance of installed ventilation systems. It was also recognized that an increasing reliance on mechanical ventilation, and the adoption of many new and innovative approaches to ventilation of houses, has produced many new opportunities and demands for performance testing of installed systems. Prior to the development of the DTR, no existing device appeared suitable for these purposes.

The research project was completed in three phases: Design, Building and Evaluation, and Documentation. The design process included field evaluations of existing technology and the development of a series of prototypes. The building and evaluation phase included lab tests of various design configurations using a Flow Calibration Chamber (ANCI/AMSA 210-85), as well as field tests on ten houses in order to evaluate the DTR performance on a complete range of ventilation systems. Documentation included a detailed account of the decisions which lead to the final DTR design, as well as a Users' Manual for the DTR.

The lab tests and calibration data indicated that the DTR can provide stable, repeatable air flow measurements over a range of 5 to 360 Litres per second. Field testing of the DTR helped to modify the DTR design in important ways, and emphasized the value of a device using a variable area orifice and fan to measure air flows.

Ten household residential ventilation systems tested with the DTR covered a wide range of air flows, and were sometimes sensitive to small variations in static pressure. Exhaust fan air flows averaged 14 Litres per second (L/s), clothes dryers averaged 29 L/s, range hoods averaged 43 L/s, one fireplace measured 67 L/s, a furnace flue measured 8 L/s, warm air registers averaged 16 L/s, return air registers averaged 31 L/s, and vacuum cleaner inlets averaged 18 L/s.

The field evaluations of the DTR indicated that, with few exceptions, the device is easy to attach to all standard residential venting systems, and is capable of satisfying most intended applications. The modularized design creates a considerable degree of flexibility, and it is expected that further applications of the device will lead to additional test procedures and applications.

It may be possible to further enhance applications of the DTR through a number of design modifications, including a custom carrying box, a microprocessor read-out, a higher pressure range, and a new plug for connecting the device to rectangular openings.

1. A DESCRIPTION OF THE DUCT TEST RIG

The Duct Test Rig (or DTR) is a device for making air flow, air pressure, and heat loss measurements in residential ventilation and venting systems.

It can be used by one or two persons, and is intended to provide rapid, accurate feedback on how the system is performing.

Essentially, the DTR is designed for three tasks:

1. air flow, air pressure, and air temperature measurements at inlet or outlet grilles, and at the entrance or exit opening of ducts and chimneys;
2. air temperature measurements at remote locations like chimney tops or exhaust hoods; and
3. heat generation and delivery to ducts, vents, and chimneys.

It can do all these tasks at the same time if desired. It can also be used to control the conditions under which the measurements occur. For example, flow into an exhaust fan can be measured at selected amounts of backpressure, or forward pressure; or chimney top temperatures can be measured at selected amounts of heat input and air flow.

The DTR can be adapted to many possible applications. So far, it has been successfully used to measure the performance of the following systems:

- bathroom exhaust fans,
- kitchen range hoods,
- clothes dryers (from outside the house),
- central vacuum systems,
- fireplaces (operating and not operating),
- masonry chimneys,

- B vents,
- furnace/chimney systems (operating and not operating),
- circulating blowers on warm air furnaces,
- warm supply registers,
- return air inlets,
- through-the-floor diffusers,
- make-up air ducts, and
- inlet and exhaust openings for air-to-air heat exchangers.

Flow measurement by the DTR is achieved by means of a variable area orifice mounted inside a portable flow chamber. By adjusting the size of the orifice, accurate flow measurements can be achieved from 5 L/s to 360 L/s. The orifice can also be used to impose any desired amount of flow restriction (or backpressure).

The portable flow chamber also contains a 250 mm diameter tube-axial fan which can be adjusted from zero to full speed. This fan is used to compensate for backpressures created by the DTR, or to vary pressures at the inlet or outlet of the ventilation device under test.

Either end of the portable flow chamber can be placed over an inlet or outlet grille. The flow chamber is equipped with specialized hoods and gaskets to suit varying depths and sizes of grilles, and to permit a direct connection with ducts and flue pipes. Pressure differences across the hood are monitored to provide an indication of how much the DTR is affecting the flow through the ventilation device.

When pressure differences across a connecting hood of the DTR are zero, then the DTR has <u>no</u> affect on the ventilation device, and flow measured in the DTR is assumed to equal flow through the ventilation device (under those conditions prevailing at the time of the test). The open ends of the DTR measure 350 mm X 350 mm and can be fitted over most residential ventilation grilles.

An optional hood that clips onto the DTR measures 900 mm X 1000 mm at its open end, and is suitable for mating the DTR with fireplaces, or large return air registers. Another optional hood attachment is a thick foam gasket that permits an airtight connection even where grilles protrude from a wall, or where surrounding surfaces are irregular.

Another specialized hood for the DTR incorporates an electric 1 kw duct heater which can be used to generate heat while measuring air flows. The duct heater is intended to be used in combination with a chimney insertion device connected to a thermometer inside an open metal cage. The thermometer and cage can be fed into flues or ducts and used to monitor temperatures at a remote location.

A separate control module is attached by a cable to the flow chamber and is used to control the fan speed and monitor temperature and pressure data. The control module incorporates two panel meters, and zero adjustment knobs for two pressure transducers.

The control module is designed to be hung from a shoulder during the test. It can be used by the same person who holds the flow chamber to the ventilation device, or by another person.

To facilitate a one-person operation, the DTR accessories include a collapsible camera tripod and a cradle for holding the flow chamber during a test. The flow chamber can be mounted horizontally or vertically on the cradle, and the tripod can be used to adjust the height of the cradle from knee level to the ceiling.

2. BACKGROUND

2.1 A Rationale for the Duct Test Rig

Three justifications have been presented for the development of a Duct Test Rig:

1. increased evidence of venting systems problems that can not be well characterized or remedied without a better knowledge of the actual installed performance of the ventilation system;

2. an increased reliance on mechanical ventilation systems in housing, many of which are innovative or otherwise difficult to characterize without performance tests; and

3. the absence of any portable, accurate device for use by researchers and tradespersons on residential applications.

Appendix I of this report provides additional background on the need for a Duct Test device, and elaborates on each of the justifications presented above. A brief summary of this material is provided below:

1. <u>Highlights of Recent Research</u>

   Because ventilation systems in houses can interact in unintended ways, it is expected that the residential construction industry will increasingly rely on designed systems, and improved installation guidelines.

   Recent research has revealed a number of areas where unknown variables have prevented an accurate modeling of venting systems performance. In such cases, the development of a DTR would provide a means to characterize system performance for many houses, helping to avoid false assumptions, to improve installation and maintenance practices, and, generally, to refine our understanding of the existing situation.

Some of the more critical issues that need to be addressed by means of a DTR include:

- Determining the installed capacity of supply and exhaust fans. Special attention should be given to determining the impact of backpressures, the effect of ducting components, and the air flow losses attributable to duct leakage and dirty screens and filters.

- Measuring fireplace flow quantity and flow direction while varying pressures and rates of burn. This type of testing will help to assess the health hazard posed by pressure-induced spillage of combustion gasses.

- Characterizing the thermal effectiveness of different chimney designs. In particular, tests are required to assess the susceptibility of chimneys to condensation and pressure-induced spillage problems, with special attention given to the effect of downsized burners/flues, and deteriorated masonry.

- Exploring different approaches to make-up air supply. More testing is needed to assess the impact of P ducts, dampers, return air connections, and tempering systems, and to better understand duct surface condensation and frosting problems.

- Measuring the efficiency of forced-air distribution systems in houses. Special attention needs to be given to the problems created by furnace room depressurization, by heat losses through small diameter ducts, and by short-cycling of furnaces connected to massive duct systems.

- Optimizing designs for fuel conversions. More research is required in order to avoid chimney failures resulting from excessively leaky or large flues, and excessively long or convoluted runs.

- Commissioning up-graded chimneys. Methods of testing are required to ensure that caps, liners, dampers, connectors, and other components, work together in ways that avoid spillage and maintain the integrity of the venting system.

2. New Technologies and Standards/Codes

A number of new and proposed standards and codes are placing greater emphasis on the performance of residential ventilation systems, despite the lack of information in this area. Of particular importance are:

- CSA C260.1 - Installation Requirements for Residential Ventilation Devices.
- CSA F326 - Residential Ventilation Requirements.
- NBC 1985, Section 9.33.3 - Mechanical Ventilation.

The promulgation of these new standards across Canada will greatly increase the quality and sophistication of residential ventilation systems, and will generate a great deal of innovation.

The introduction of new equipment and the evolution of building standards is creating a situation where generalized reference tables. rules of thumb, site inspections, and other prescriptive approaches are becoming less effective and less acceptable. The DTR will permit a more flexible and, sometimes, a more practical approach to evaluating innovative systems, including:

- low pressure duct designs;
- higher quality filtration systems;
- smaller diameter ductwork;
- flexi-duct installations; and
- sealed, lined, and insulated chimney retrofits.

3. The Lack of an Existing Test Device Suitable for Residential Applications

To measure flow in ducting, venting, and chimneys requires a test rig that can determine the pressure versus flow characteristics, as well as the heat loss characteristics. No device currently exists which can successfully meet these objectives, although some existing tools can provide a head start.

Appendix I includes a summary of the operating principles and deficiencies for the most common air flow measurement devices, including:

- pitot tubes and arrays,
- flow hoods,
- orifice meters,
- venturi cones and nozzles,
- thermal sensors,
- house depressurization fans,
- vane anemometers,
- smoke guns,
- air bags, and
- zero-pressure devices.

None of these devices have the capability for creating a range of back and forward pressures while measuring flow. And none are designed to easily mate with a range of installed systems including chimneys, return air openings, fireplace openings, and clothes dryers.

2.2 Design Criteria

The objective of this project was primarily to design, build, evaluate, and demonstrate the utility of a device for testing residential ducts, vents, and chimneys. It was intended that the final device should satisfy the following design criteria:

1. easy to attach to all standard types of residential venting systems, without any need for disassembly or other time-consuming activity;

2. easy to interpret and accurate enough to satisfy most potential applications, using a computer where necessary to improve accuracy or avoid difficult calculation;

3. light enough for one person to operate without strain (eg. less than 20 kg);

4. capable of establishing a relationship between flow and pressure (0 to 50 Pascals) for the following systems:

   - heating duct work,
   - supply ducting,
   - exhaust ducting,
   - furnace or DHW chimneys,
   - fireplace chimneys, and
   - other miscellaneous ducting;

5. capable of measuring the leakage area (unintended ELA) and leakage flow in cases where ducts, vents, and chimneys can be accessed from both ends;

6. capable of determining the approximate friction losses of duct systems where the ELA value is known or approximated;

7. capable of rating the percent thermal effectiveness of air ducts and chimney systems (but, not necessarily differentiating between effects of air leakage, thermal mass, and thermal resistance); and

8. capable of measuring air flow at either intakes or outlets.

3. PRODUCT DEVELOPMENT

3.1 Methodology

The project was divided into three roughly equal sections covering:

- Design,
- Building and Evaluation of the Device, and
- Documentation and Reporting.

Each of these stages of the project is briefly outlined below to provide an overview of the approach.

1. Design Stage

- Two-day strategy meeting with CMHC;
- Collection and construction of various prototype test devices (a Version 1 Test Kit):
- Group walk-through of test procedures;
- Selected interviews with potential user groups;
- Round-table discussion and brainstorm with experts;
- Resolution of outstanding issues;
- Finalized prototype design: attachment devices, plugs, heaters, thermometer, flow measuring devices, and pressure measuring devices.

2. Building and Evaluation

- Mock-up of working test device (Version 2);
- Sequential lab and field tests of each component;
- Redesign of components;
- Data analysis, computer calculations, and programming;
- Construction of an improved prototype test devices (Version 3);
- Field evaluations on at least five houses;
- Presentation and analysis of test results;

- Final modifications to prototype device (Version 4); and
- Final calibration tests.

3. Documentation and Reporting

- Preparation of instruction manual;
- Outline of alternative designs, potential simplifications, and procedures for design modification; and
- Final Report.

A number of important guiding principles directed the approach to research throughout the course of the project. These principles were important to the success of the project, and have been briefly summarized below:

- A creative design process was developed, intended to stimulate technical innovations. This process entailed a circular, or spiralling, design process with a constant feed-back system looping back to check on original assumptions and objectives. The project allowed for four separate versions of the prototype to be constructed prior to final delivery of the device.

- A balance was achieved between design, testing, and reporting. Extensive discussions and research took place at the front end of the project, to make optimum use of existing knowledge and experience in the field.

- Soliciting input from key user groups and manufacturers insured that the design process took into account important issues such as cost, size, weight, shipping dimensions and containers, equipment accuracy, and so on.

- Designing primarily for the expert user group was another guiding principle. The expert group is most in need of and most likely to use a Duct Test Rig. It was also felt to be preferable to over-design the equipment, in terms of utility and accuracy. The device could then be scaled down to a simpler and less costly tool if required.

- Developing a hands-on familiarity with similar technologies was felt to be critical. The design phase included a simultaneous comparison of all possible existing devices for achieving the objectives of this project.

- Potential applications were ranked in order of priority, to ensure that the device would be successful in those areas where it is most needed. Where compromises were required, preference was given to the priority applications. House venting systems that can benefit from performance testing were ranked in the following order:

    1. Exhaust fans and ducts;
    2. Supply fans and ducts;
    3. Supply ducts without fans;
    4. Masonry chimneys (lined and unlined);
    5. General ventilation ductwork;
    6. Forced-air distribution ductwork;
    7. Metal chimneys; and
    8. Miscellaneous systems.

- Learning from the application of airtightness testing equipment in houses was important, as depressurization fans are similar equipment to the Duct Test Rig and are used by the same type of tradesperson. The experience from airtightness testing equipment suggested that time-saving attachment designs are crucial, accuracy can be extremely important and that the measurement range should be carefully tailored to the application. Blower doors also show that simple computer programs can be incorporated into the equipment without any difficulty, and that the availability of design schematics and key components will influence the acceptance and evolution of the Duct Test Rig.

- Networking with other consultants, and particularly with Standards Working Committees, was felt to be important because of the rapid change in the ventilation industry at present, and the potential for incorporation of a test device or our field research results into the upcoming Standards on fan installation (CSA 260.1) and residential ventilation requirements (CSA F326).

- Documenting failures and alternatives encountered during this research project was felt to be an important task. Good documentation should help to improve efficiency of follow-up work on this device or other devices for use on testing residential ventilation systems. (The Appendices in this report have been included with this in mind.)

- A special emphasis was applied during the design process to the concept of a two-way flow hood utilizing a zero-pressure principle. This approach involves the use of a hood to channel flow moving into or out of a grille, while at the same time using a variable-speed fan mounted inside the hood to compensate for any resistance inside the flow metering components of the device. Fan compensation is provided by means of a pressure measurement across the hood to ensure a null or neutral pressure exists at the point where the hood mates with the grille. By using fan compensation in this way, it is possible to achieve extremely accurate flow measurements over a wide range of flows without impacting on the operation of the system being tested. For example, a small orifice can be used to meter and the additional pressure drop can be made up through fan operation. The combination of fan and orifice can also be used to create a given amount of forward or backward pressure during testing; to establish the performance of the venting system under varying pressure differentials. This entire approach was conceived by Sheltair during the process of preparing the proposal for CMHC, for this project. Initial experiments were also conducted with great success and, consequently, the research method for the project involved considerable investigation into improving and perfecting this technique.

3.2 Design and Preliminary Prototypes

As expected, the design phase for this project involved an extensive amount of discussions and field experiments on the appropriateness of different design features, as well as a considerable amount of careful laboratory testing to refine the flow metering techniques. Detailed descriptions of all tasks undertaken as part of the design phase are provide in Appendix II to this report. Because of the complexity of these design issues, and the many small projects that were undertaken as part of the design phase, it is recommended that readers with a special interest in the design issues refer to Appendix II. Some of the highlights of this phase of the research are presented below:

- Comparative testing was conducted on two test houses using a variety of different measuring devices. Special effort was made to obtain a full assortment of flow measuring tools, including arrangements to have a flow tester specially designed by a French company air-freighted to Sheltair for a one-week period. The French device was particularly interesting because it was designed to measure residential systems quickly and accurately. A comparison of all the flow measuring devices produced some interesting results. The most challenging task was not measuring the air flows and pressures, but determining how best to attach the measurement device to the various ducts and vents. Range hood fans and furnace blowers were particularly problematic. Most air flow measuring devices have been designed for use in a commercial building environment, and are not appropriate for residential work. The residential equipment covers an extremely wide range of air flows. As well, the back pressures created by the flow measurement device can significantly influence the flow quantities through many residential systems.

- During the design process it was recognized that the accuracy of any flow measuring device was primarily a function of how controllable the device was, and how stable and easily-read the readings could be for the device. A large number of variables affected the stability and controllability of the flow measurement device, and, consequently, it was decided that the only option was to build a flow calibration chamber for repeated use in evaluating design changes. Consequently, a ANCI/AMSA Standard 210-85 Flow Calibration Chamber was built to specifications, using ASME long-radius flow calibration nozzles. Although the construction of this calibration chamber incurred delays in the project schedule, development of this chamber was the only cost-effective means of resolving many of the issues identified during the design phase. Much of the data and conclusions presented in Appendix II regarding the optimum design features are based on the results of testing with the flow calibration chamber.

- After the comparative testing of the device, a decision was made to pursue the improvements to the original idea of using a customized flow hood with an adjustable orifice upstream of an adjustable in-line fan.

- A key component to the test device became the light-weight, powerful, fully-controllable fan needed to compensate for pressure balances and to vary pressures during the tests. Eventually, a 10 inch diameter axial fan manufactured by EBM, Germany was selected as the most suitable product.

- After establishing that the best option for measuring flow was the use of an adjustable orifice plate, a considerable amount of time was lost in the process of trying to source an adjustable manufactured orifice that would suit the purposes of this device. An adjustable orifice manufactured by Sheltair was found to provide an inadequate opening size to achieve the minimum required air flows at full volume. A world-wide search revealed several iris diaphragm orifices that could be used to meter flow, but the high cost of these devices prevented their use in this application. Eventually, a low-cost duct balancing system based on a conical iris diaphragm was obtained from Finland and incorporated into the Duct Test Rig. Unfortunately, the Finnish device was too imprecise and flimsy to be used in the Duct Test Rig, and further effort was required to adapt Sheltair's own orifice design.

- It was discovered through careful dimensioning and the use of flow straightening materials that it was possible to construct a miniature flow chamber using an orifice and fan that could produce sufficient resolution and stability for accurate flow measurements.

- A variety of hoods were constructed for field measurement purposes. As well, surveys were conducted to determine the optimum sizes for various types of ventilation systems. Eventually, it was recognized that a single, light-weight, collapsible, very large flow hood would be suitable for measuring most systems. A custom designed hood was developed for this purpose by Shortridge Instruments Inc.

- Laboratory testing was conducted to determine if the high velocity air stream in the centre of the flow hood needed some kind of settling means or baffling to prevent interference of air flow patterns on inlet grilles. The effect of these high velocities was found to be insignificant and baffling was not included in the hood design.

- Air pressure measurements on either side of the hood and either side of the orifice required selection of two pressure gauges. The decision was made to use electronic differential pressure transmitters because they are accurate, sensitive, compact, light-weight, long-lasting, fast to respond, and, because of their voltage outputs, can be automatically zeroed and connected to an electronic display meter or a circuit board for conversion into direct flow units.

- A variety of approaches were considered for calculating and displaying flow and pressure information. Initially, it was hoped that some method of automating the entire test procedure might be feasible, that would allow the fan to be cycled from stop to maximum flow and back again while pressure is sampled and converted to flow. A flow versus pressure curve could then be established for any ventilation system. For reasons of complexity, inflexibility, and high cost, this approach was rejected in favour of direct read-out of flow and pressure data.

- A variety of approaches to thermal testing of ducts and chimneys was explored by the research team. Testing chimney structures with large mass required considerable heat input to achieve any resolution in the chimney top temperatures. For this reason, it was thought that the appliance itself should be used to generate heat in the case of testing masonry chimneys. Further testing using portable electric resistent duct heaters connected to a Duct Test Rig revealed that, despite the small amounts of heat, this approach was much more convenient and still provided sufficient resolution to evaluate thermal effectiveness.

- A high-quality electrician's fishing line was found to be the easiest way to obtain chimney top temperatures. An integrated circuit thermometer can be connected to this fishing line and simply fished up to the top of the chimney. No other approaches were found suitable for obtaining safe and convenient measurements of chimney top temperatures.

3.3 Prototype Development

The second phase of the project involved building a Version 3 prototype suitable for extensive field applications. In the process of constructing and using the device, numerous and important changes were made to the design features and proposed method of operation. Both the design changes and the results of field tests on the ventilation systems are presented in a detailed manner in Appendix III of this report.

Some of the most important modifications that occurred during the building and evaluation phase are summarized below:

- Orifice Design: A fully adjustable iris diaphragm was manufactured and incorporated into the device to permit accurate flow measurements over a range from 5 L/s to 150 L/s. In addition, the adjustable orifice is removable and leaves in its place a single orifice comprised of a 210 mm diameter fan inlet ring made from stamped steel. This large orifice can be used for testing systems with very high air flows.

- Carrying Tripod: Despite the light-weight design of the Duct Test Rig, field evaluations revealed major problems for one-man operation. The solution was found to be an adjustable camera tripod, fitted with a customized cradle of aluminum extrusion. The Duct Test Rig can be held vertically or horizontally on this cradle and used to evaluate a ventilation system hands-free.

- Reversible Foam Gasket: Construction of a very thick foam gasket, that can be alternately fitted over either end of the flow measurement chamber, greatly extended the versatility of the device. The foam allows the device to be easily fitted over protruding hoods, and to mate with overlapping siding and other irregular wall finishes while still providing a tight air seal. The foam gasket is designed to be removable and is used only when required.

- Downstream Duct Requirements: A straight section of duct downstream of the fan was found to greatly improve the performance of the device, by:

  i) eliminating the swirling action against zero-pressure taps around the perimeter of the hood, and

  ii) preventing backpressures from the ventilation system being transferred around the perimeter of the fan blades and into the orifice chamber.

- Separate Control Modules: The gauges and most of the electronics and controls for the Duct Test Rig were de-coupled from the flow chamber, so that the chamber could be used at any angle or configuration without complicating the use of controls or the reading of gauges. This design change was compatible with the use of a tripod and cradle and also greatly facilitated longer-term tests, such as can occur when monitoring chimney flows or creating flow/pressure curves. A separate control module, hung over the shoulder, also makes the device more suitable for one- or two-person operation.

- Computerized Readout Not Included: Although the initial plan was to design and build a Rig with a control display panel designed for converting pressure and temperature outputs into flow outputs with a computer chip, this approach was eventually rejected due to the high cost for a once-only production unit. Instead, the approach adopted was to provide direct digital readout of pressure and temperature, and allow the operator to have the option of using a hand-held computer or a paper graph, to correlate orifice pressure and size with actual flows. Temperature and atmospheric pressure corrections are provided as a single-correction factor.

- Chimney Thermal Tester: It was discovered that the best and most convenient approach to conducting thermal testing was to construct an optional hood for the Duct Test Rig, incorporating a CSA approved 150 mm in-line duct heater with 1 kW heat output. A series of spun-aluminum expanders or reducers are slipped on to this hood to provide a direct, smooth, and airtight fitting to a varying range of ducts or flues. A switch on the control panel allows the operator to directly monitor real time and temperature at the chimney top, using the electrician's fishing tape connected to an AD590 integrated circuit thermometer.

- For the current design, the minimum air flows that can accurately be measured are a function of the minimum size of the flow metering orifice. Since this orifice can be levered down to very small openings, there should be no problem in measuring flows as low as 1 to 2 L/s. The maximum flow range is a function of the EBM fan flow capacity and the maximum orifice size and should be approximately 310 L/s. Increasing this maximum flow capacity is not possible without completely redesigning the test device with larger components.

While the maximum flow for the DTR determines what systems can be measured at free-flow (or null pressure), it should be recognized that this limit may not apply to the most powerful fan in a house is the furnace blower. If the Duct Test Rig is connected to the blower compartment door and the return air plenum is blocked, the flow capability of the Duct Test Rig will be enhanced by a static-pressure drop in the range of 50 to 75 Pascals.

3.4 Possible Further Developments

The final delivered prototype of the DTR could benefit from a number of design improvements, depending upon the intended applications. A list of possible further developments is presented below:

1. A durable, custom designed carrying box is needed for the DTR and its accessories.

2. A microprocessor read-out (complete with EPROM and A-D converter) could be used to permit automatic density corrections and a direct read-out of air flow in Litres per second.

3. A higher range for the pressure transducers is warranted to increase the measurement range for the DTR, and to avoid possible over pressure errors.

4. A two-way expandable plug is still required for quickly connecting the DTR directly to any rectangular opening. This would permit easy connection to a variety of openings including range hoods, open windows, furnace blower compartments, attic hatches, stove top fan openings, etc. This is possible at present only by cutting a piece of cardboard.

5. A refined and simplified method for installing pressure tubing inside the large capture hood so that the hood is easier to set-up and collapse.

6. Lighter gauge aluminum for the flow chamber to further reduce weight.

These proposed developments have not been incorporated in the current version of the DTR due to time and budget restraints, or because the design changes were not possible for a one-off unit.

4. FIELD TESTS

4.1 Field Trials On 10 House Ventilation Systems

Six houses were identified through newspaper advertisements for inclusion in a field evaluation phase of the Duct Test Rig project. It was necessary to visit an additional four houses, however, in order to include in the test data results of air flow and pressure testing on a complete range of ventilation systems.

While it was hoped to complete measurements at varying pressures for all systems, it was found to be too tedious a procedure to use when having to replace fixed-size orifices to create pressure differentials. (Thus, the field evaluations emphasized the value of a single adjustable orifice as provided with Version 4.) Creating backward and forward pressures during flow measurements was also complicated because of the pressure sensitivity of forced-air distribution systems and the instability of some household fans when operated close to the stall pressure.

The field evaluations were useful in identifying important design features that could be incorporated into the final version of the Duct Test Rig. They also confirmed the overall effectiveness of the Duct Test Rig design. In almost all situations it was possible to obtain accurate and repeatable flow measurements, as long as a hood or other "mating" system could be used in combination with the portable flow measurement chamber. An exception to this was fireplaces with very rough surface materials which, inevitably, caused some leakage to occur around the edge of hood. Fortunately, the zero-pressure approach around the edge of the hood meant that there was little incentive for air loss to occur at this location and that a perfect seal may not be required when measuring existing flows. The issue of sealing hoods around fireplaces became much more important when attempting to create a flow versus pressure profile for the fireplace and chimney system, or any other "hard-to-seal" inlets. Custom range hoods above stoves were another hard-to-seal area. The only suitable approach appeared to be to cover the entire bottom of the range hood with a sheet of plastic or cardboard, and cut a suitably sized hole in this sheet to permit direct insertion of the flow measurement chamber.

4.2 Test Results on Installed Systems

Detailed test data for the ventilation devices on a house-by-house basis is presented in Appendix III. Highlights are summarized below.

Ten bathroom exhaust fans were tested. The flows at zero hood pressure ranged from 5.5 to 22.6 L/s. The average bathroom exhaust flow was 13.9 L/s. Figure 1 shows a flow versus pressure graph for one of the exhaust fans.

Two clothes dryers were tested, with air flows recorded to be 25.5 and 33 L/s at zero hood pressure.

Four range hoods were tested, with air flows recorded at 67, 50, 40, and 14 L/s.

One fireplace was tested after 5 minutes of firing, and was measured to draw 64 L/s. Other fireplaces were tested without a fire and with the chimney damper closed to measure the leakage rates for these fireplaces when not operating. Figure 2 shows the flow versus pressure for one of these fireplaces.

A gas-fired furnace was tested by covering both the combustion and dilution air openings with the DTR capture hood. The combined appliance flow was measured at 8.1 L/s at zero hood pressure, and 13.2 L/s at 60 Pascals of positive hood pressure.

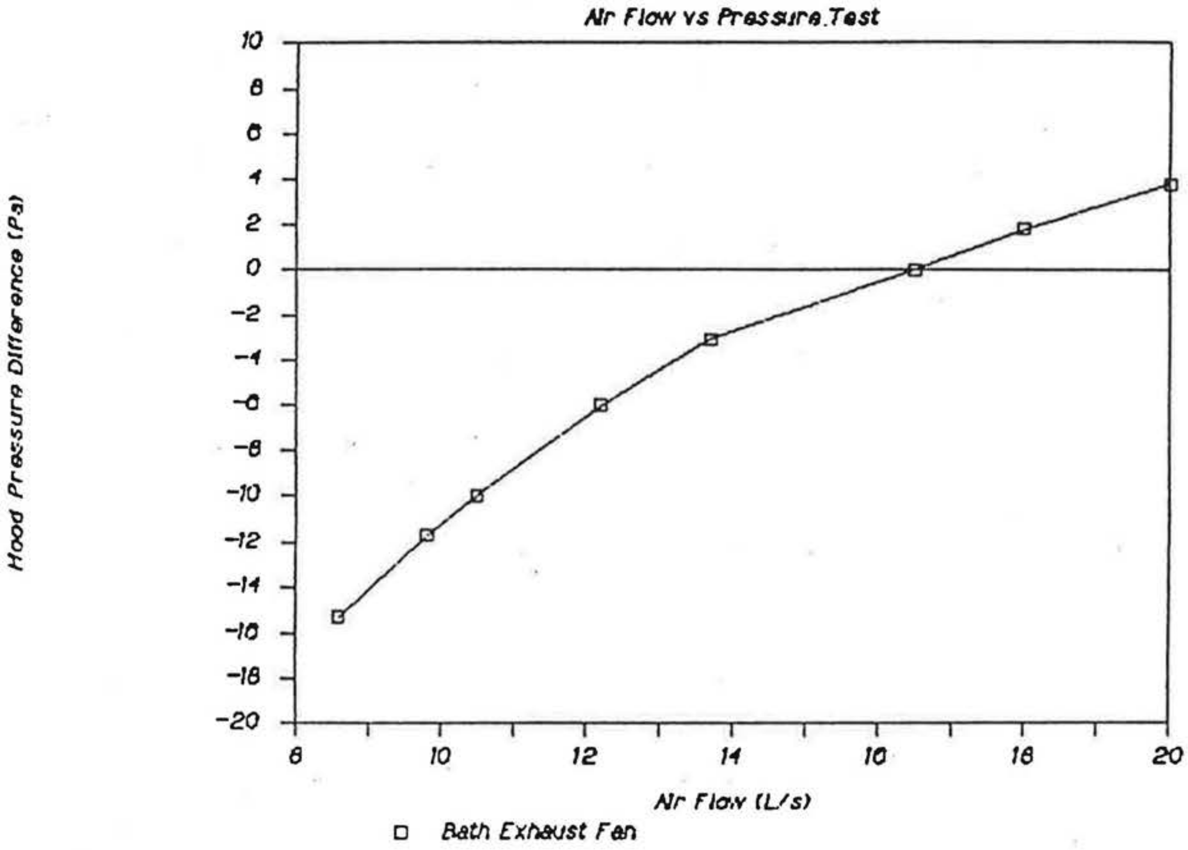
Eighteen warm air supply registers were measured. Flows ranged from 4.2 L/s to 27 L/s and averaged 16 L/s. Nine return air registers were measured. Two of the return air registers had been shut off and measured less than 3 L/s. The remainder ranged from 9.4 L/s to 96 L/s, and averaged 31 L/s.

Three central vacuum cleaner inlets were measured (all in one house) and flows were recorded at 18, 17, and 20 L/s.

Figure 1

DUCT TEST RIG FIELD TEST RESULTS*

AIR FLOW VERSUS PRESSURE TEST ON A BATHROOM EXHAUST FAN

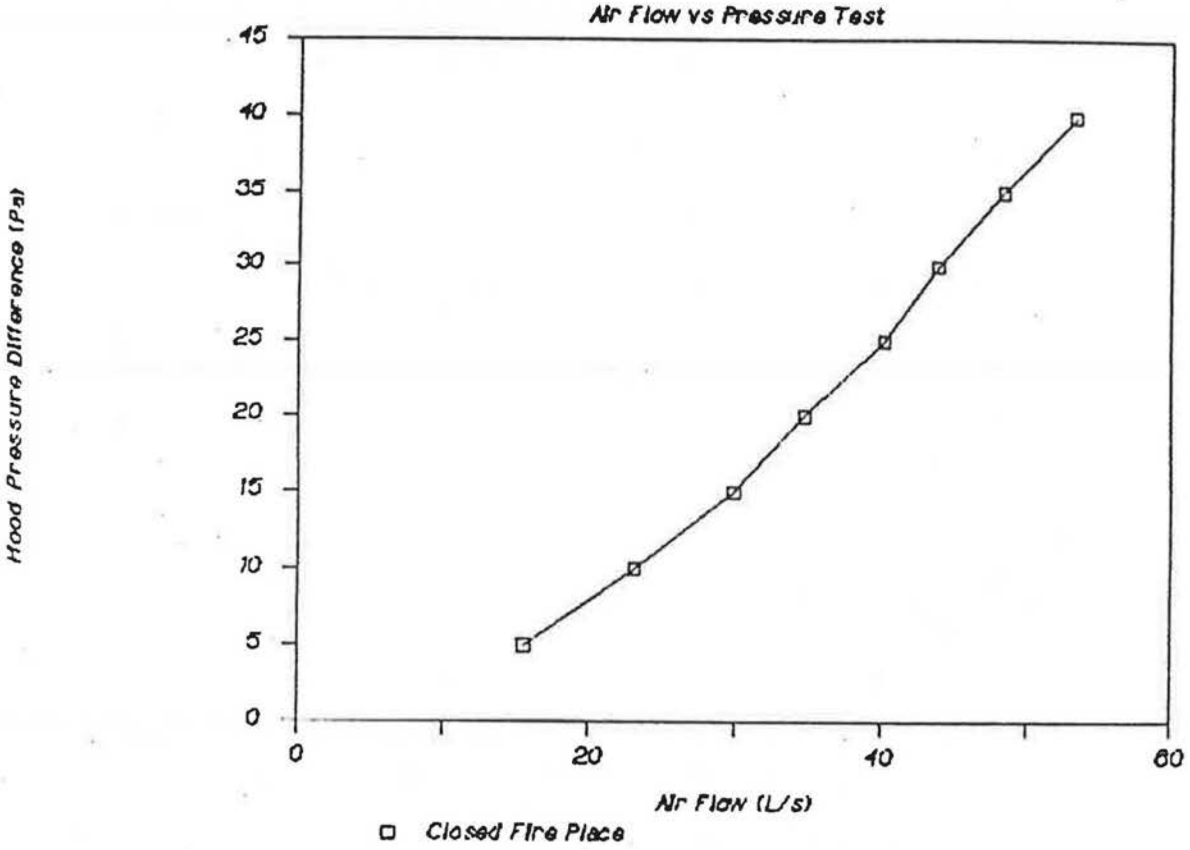


* 2127 West 6th Avenue, Vancouver, B.C.

Figure 2

DUCT TEST RIG FIELD TEST RESULTS*

AIR FLOW VERSUS PRESSURE TEST ON A CLOSED FIREPLACE



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* 2127 West 6th Avenue, Vancouver, B.C.; site-built masonry fireplace with a 24" X 32" firebox.

5. CONCLUSIONS

A device for testing residential ducts, vents, and chimneys has been designed, constructed, and field tested, and appears to successfully have achieved the objectives outlined for this project. With a few exceptions, the device is easy to attach to all standard types of residential venting systems, without need for any disassembly of those systems or extensive modification of the device. Generally, all that is required is the slip-on or clamp-on attachment device for those systems that cannot be directly mated to a 350 mm square box. The device appears to provide good resolution and repeatability over a wide range of flows, and, if properly calibrated, should satisfy most applications of a research tool.

Interpretation of the data from the device requires some manipulation on the part of the operator, and, without further field applications of the device, it is difficult to know to what extent this is a problem with the final design.

Since the flow chamber weighs only 11 kg, it may be used by one person in many circumstances. However, two persons are preferable.

The device is designed so that a flow versus pressure relationship can be established for heating ductwork, supply ducting, exhaust ducting, furnace or DHW chimneys, fireplace chimneys, and other miscellaneous systems.

No attempt as yet has been made to use the device for measuring the leakage area and/or friction losses of duct systems, although the field evaluations indicate that this kind of data interpretation should not pose problems.

The device is a multi-purpose testing tool that can be used to both measure flow and pressure of a system, as well as the thermal characteristics of the system. It can be used, for example, to compare the thermal characteristics of different chimney styles, their equivalent leakage area and equivalent flow area, and to monitor the flow through appliance and chimney under normal operating conditions.

The modularized design of the Duct Test Rig creates a considerable degree of flexibility in how it is applied to evaluating ventilation systems, and it is expected that further applications of the device in the field will lead to additional test procedures and applications.

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THE DEVELOPMENT AND EVALUATION OF A DEVICE FOR TESTING RESIDENTIAL DUCTS, VENTS, AND CHIMNEYS

APPENDIX I

BACKGROUND ON THE NEED FOR A DUCT TEST RIG

June 5, 1987

APPENDIX I: BACKGROUND ON THE NEED FOR A DUCT TEST DEVICE

INDEX

APPENDIX I: BACKGROUND ON THE NEED FOR A DUCT TEST DEVICE

1. UNDERSTANDING OF THE PROBLEM

CMHC has presented several reasons for the development of a duct test device. For simplicity, we have summarized CMHC's position into three arguments:

1. Recent research has identified venting system problems that cannot be well characterized or remedied without a better knowledge of the actual installed performance of ventilation systems;
2. An increased reliance on mechanical ventilation systems in housing is likely to spur the development of new and modified technologies which are best regulated through performance testing (as opposed to prescriptive measures); and
3. no suitable duct test device now exists for residential applications.

In this Appendix we further develop each of these arguments.

1.1 Highlights of Recent Research

It is now well understood that venting systems in houses can interact in unintended ways and that related problems, such as pressure-induced spillage, are likely to be increasing in a significant portion of Canadian houses.

Until this time, much of the focus for research by CMHC into these issues has involved describing the nature and extent of problems and prescribing simple remedial measures. As the residential HVAC industry matures, however, we can expect to see an increased reliance on "designed" systems and improved installation guidelines.

More information is required before designs and guidelines can be trusted to reflect the reality of system performance. Recent research by Sheltair and other consultants has revealed a number of areas where unknown variables have prevented an accurate modeling of venting systems performance. Some of these areas are briefly described below.

In each case, the development of a duct test device would provide a means to characterize system performance for many houses, helping to avoid false assumptions, to improve installation and maintenance practices, and, generally, to refine our understanding of the existing situation.

The Capacity of Installed Supply and Exhaust Fan Systems

Determining the installed capacity of supply and exhaust fans has proven difficult because fan manufacturers in Canada currently do not subscribe to standardized tests. In some cases, manufacturers cannot provide test data to justify flow specifications. The effect of increased static pressure drops in depressurized houses is a further complication. Some residential fans are weak - experiencing significant cavitation and loss in flow at house depressurization in the 10 to 15 Pascals range. More often, fans are relatively stiff, experiencing little loss in pressure or flow over the 0 to 50 Pascals range. Even more significant is the impact of ducting components on flow through fans. Inlet grills, elbows, insect screens and rain louvers all entail further losses, and typically reduce the ELA of the duct by 50% or more. These friction losses are hard to estimate for installed systems because components are often difficult to inspect and dirt and grime tend to occlude grills and screens. Most ducts are also very leaky. It is speculated that residential duct systems are equivalent to the leakier commercial layouts, where leakage can typically account for 15 to 30 percent of total flow.

In the context of the above, it is easy to see why an inspection of a system is no substitute for empirically measuring flows at varying pressures.

Fireplace Performance

The operation of fireplaces in houses has been identified as a source of potential problems both because of their significant exhaust capacities and sensitivity to back pressure. Estimating flows from fireplaces is difficult, due to the variations in pressures with rates of burn and the influence of unique firebox, damper, and chimney geometrics.

Chimney Effectiveness

The deterioration of mortar, tile, and bricks in masonry chimneys has been recognized as a source of potential venting failures. Leakage through the masonry materials can reduce the effective height of a chimney by increasing the dilution air ratios. The result can be chimneys that are susceptible to increased condensation problems, and that may also experience pressure-induced spillage when exposed to marginal house depressurization.

The design and installation of masonry chimneys have not been well researched or regulated in the past, and many systems are inherently inadequate. Tall, massive chimneys with three or more sides exposed to outdoor temperatures are particularly susceptible to backdrafting and condensation problems. The downsizing of heating appliances in many Canadian houses has exaggerated the impact of poor thermal performance and leakage, since the chimneys are not usually re-sized to match the reduced firing rates.

Make-Up Air Requirements

A tremendous amount of effort and money has already been spent providing make-up air to houses in Canada - often in response to utility or provincial regulations. An argument can now be made that this has been, largely, an exercise in futility. Fan depressurization testing by various consultants, in different regions of the country, has indicated that many typical make-up air ducts have virtually no effect on house pressures and provide very little "make-up air." As mentioned previously, poor design and installation, and lack of maintenance have all contributed to ineffective ducts. There has also been a general state of confusion about the difference between make-up air, combustion air, and fresh air requirements in houses.

Connecting make-up air ducts to return air circulation systems has sometimes created comfort problems due to pooling of air or excess flows. Various approaches to controlling air flow (J ducts, dampers) have been proposed and promoted without much justification. Different approaches are now being taken to temper incoming air - also with little effort to monitor effectiveness.

Condensation on exposed ducting has long been a problem for make-up air ducts since insulation has seldom been installed. It is not even clear if insulation is the best way to avoid condensation. Since the air needs tempering, a better solution may be to install radiating foil fins, thereby avoiding excess condensation and improving tempering. Alternative approaches such as this have not been explored, and cannot be easily accepted until testing procedures for flow and heat loss in ducts are more developed and widespread.

Forced Air Distribution Systems

The results of Venting System Tests, conducted in houses by CMHC research consultants, have revealed cases where forced air distribution systems have depressurized houses - or portions of houses - and have contributed to pressure-induced spillage from fireplaces and/or furnace/chimney systems. Poor duct layout is sometimes the problem, but more commonly the source of problems is leaky ductwork. Leaky return air ducts can suck air away from the furnace room, and leaky supply ducts can lose air to far away rooms or to outside the house via crawl spaces, attics, and wall and floor cavities. Unlike commercial ventilation systems, there has been virtually no commissioning of residential HVAC ductwork, and there are no ratings for acceptable leakage flows.

Leaky and poorly designed or installed duct systems can also fail to deliver heat properly. Research by the Ontario Ministry of Energy has revealed houses where delivered heat from supply registers represented as low as 16% of the total appliance output, due to air leakage and conductive losses.

The effect of thermal mass is likely to become more important as houses become more energy efficient. Shorter furnace cycle times mean that much of the heat generated by the appliance is lost to the duct work, especially the more massive ductwork close to the appliance. Air flow to far away rooms is cooled during these duct 'warm-up' periods, and the system becomes imbalanced. Smaller appliances in energy efficient houses need much less massive duct systems. At present, however, it is difficult to locate and purchase 75 mm or smaller diameter ducts, and little attention is given to the inappropriate use of traditional duct system layouts. Increased performance testing of these systems would be a move in the right direction.

Fuel Conversions

Converting from oil to gas heating has created numerous potential problems with chimney performance. The phenomenon has been revealed through field tests by Sheltair on houses with venting problems, and is well documented in CMHC's reports on Residential Combustion Venting Failures. Some types of chimneys have excess volume, leakage, mass, or transmission losses to be safely connected to gas-fired appliances. Additional vent connections, Tees, longer and lower runs, etc. make guidelines very difficult to prepare and emphasize the need for increased performance testing of these systems prior to conversion. Tests are especially appropriate given the high cost of liners and other chimney reparations.

Chimney Upgrading

Field research surveys have revealed houses where improperly sized liners, restrictive chimney caps, uninsulated metal liners inside masonry chimneys, and a general lack of attention to vent connector upgrading have all contributed to a loss in chimney effectiveness. Currently, the recommended performance test for a converted (or retrofitted) chimney is to use the flame from a match to determine whether any spillage is occurring at the chimney base or dilution air inlet. When consideration is given to the amount of money spent on upgrading and maintaining chimneys, and the concerns for safety and durability of chimney systems, an argument can be made for more thorough and substantive performance testing. At a minimum, tests should be performed to determine that chimney capacity is adequate, (pressure versus flow), and that the chimney thermal performance is sufficient to achieve a net buoyancy under typical operating conditions.

1.2 New Technologies and Standards Requirements

CSA 260 Committee

The CSA standards C260.1 and C260.2, covering residential air exhaust equipment and the installation code for residential mechanical exhaust systems, respectively, have not yet been adopted by Canadian industry. This is likely to change in the near future. The CSA Standards Writing Committee for the C260 standards has been reconvened and a new edition of both these standards is currently under preparation. It is expected that the new C260 standards will be referenced in other standards that are currently enforced, including the installation code for heat recovery ventilators (444 M) and the CSA standard on Requirements for Residential Ventilation (CSA F326). If so, we can expect to see more attention given to the operation of exhaust equipment, both manufactured and installed. In addition, it is expected that the new C260 standards will incorporate supply air systems and make-up air systems. Whereas previously the installation code (C260.1) addressed installation procedures using complex reference tables similar to what currently exists in the Residential System Design Manual of HRAI, the committee is now exploring alternative approaches that would permit greater flexibility in application of the standard. An obvious alternative would be installed performance testing, assuming the availability of an appropriate testing device. is a voting member of the CSA 260 Committee and a member of the working group on installation practices.

1985/1990 Building Code Requirements

The National Building Code of Canada 1985, which is currently being adopted across Canada by the provinces, requires, in sub-section 9.3.3, that dwelling units be provided with mechanical ventilation systems capable of providing at least one-half air change per hour. This required system is to be independent of natural sources, including windows and air infiltration. As a result of these requirements, it can be expected that many more mechanical ventilation systems will be designed and installed in houses in Canada. With increased installations of residential HVAC systems, we can expect to see an increased frustration level with the existing fan sizing tables. Moreover, the reference tables require too much time and effort for many tradespeople, and are not well used outside of Ontario. Designers, installers, and inspectors require a better grounding in the relation between various duct designs and fan systems. A most effective means of improving an understanding it the widespread use of instrumentation to measure pressure and flow characteristics. The subject of this study is just such a device.

Innovative Duct Designs

It is certain that the increase in HVAC system installations will also produce many innovations in ventilation technology. Some innovations are already apparent. Examples include:

- the development of low-pressure duct designs to facilitate the use of quiet computer-type fans;

- more extensive and complex filtration systems to prolong the life of the ventilation system and to improve air quality indoors;

- small diameter ducting to reduce the heat loss, increase discharge velocities, lower costs and installation work, and facilitate more extensive distribution systems indoors;

- use of flexible ducts and flexible liners to facilitate installation of retrofit venting systems, or installation in smaller, more restricted spaces;

- tempering systems;

- supply systems, which in many cases will use similar ducting components, but which require a different set of fan sizing tables, since the restrictions caused by particular components will vary depending upon the direction of air flow.

Chimney Component Alterations

A wide variety of upgrading measures and (sometimes gimmicky) devices are being promoted for existing chimneys. These can be expected to alter chimney performance in ways difficult to predict without performance testing. Some examples of the new technologies expected to be promoted for existing chimneys include:

- flow restrictors for improved heat recovery;
- caps for masonry chimneys;
- double-walled and/or air-sealed vent connectors;
- exterior insulation systems for masonry chimneys;
- thermal and mechanical dampers for chimneys;
- retrofit-induced fans for vent connectors; and
- sealed venting systems.

The impact of such a range of measures on an existing venting system is difficult to predict through laboratory tests and reference tables.

Once again, a need is developing for simple and accurate field testing of venting systems.

To summarize, it is fair to say that the introduction of new equipment and the evolution of building standards is creating a situation where generalized reference tables, rules of thumb, site inspections and other prescriptive approaches are becoming less effective and less acceptable.

1.3 The Lack of an Existing Appropriate Test Device

To measure flow in ducting, venting and chimneys requires a test rig that can determine the pressure versus flow characteristics as well as the heat loss characteristics. No device currently exists which can successfully meet these objectives, although some existing tools can provide a head start.

The requirement for heat loss characteristics is obviously a new challenge for field equipment, and can be justified primarily on the basis of research recently conducted by CMHC. We have been unable to identify any existing device suitable for characterizing the thermal characteristics of chimneys, vent connectors, heat distribution systems and make-up air ducts.

Air flow measurements (and related leakage test equipment) on the other hand, are a regular part of HVAC installation and commissioning in commercial and industrial buildings. Consequently, a large number of devices exist for making air flow measurements, including pressure devices, thermal sensors, vane anemometers and a variety of more exotic technologies. Table 1 includes a brief description of the most common flow measuring devices currently in use and describes their recommended uses, calibration and accuracy. Table 1 has been extracted from "HVAC Systems, Testing, Adjusting, and Balancing" by SMACNA,

Table 1

A SUMMARY OF THE MOST COMMON AIR FLOW MEASURING DEVICES

	RECOMMENDED USES	CALIBRATION REQUIRED	ACCURACY OF FIELD MEASUREMENT
U-TUBE MANOMETER	Air and gas (with water or oil instrument): Measuring pressure drops above 1" w.g. across filters, coils, eliminators, fans, grilles and duct sections. Measuring low manifold gas pressures.	None (Zero adjustment required for each set-up).	
MANOMETER VERTICAL/ INCLINED	Use with Pitot tube or static probe to determine static pressure, total pressure and velocity pressure in ductwork.	Same as U-Tube Manometer.	
MICRO-MANOMETER (HOOK GAUGE)	For air velocities below 600 ft/min. or low air pressure or vacuum readings. Used to calibrate other instruments. Difficult to use in the field.	Same as above. (All units must be accurately leveled before and after each reading.)	
PITOT TUBE	Measurement of airstream "total pressure". Measurement of airstream "static pressure", and Measurement of airstream "velocity pressure".	None required. However, the Instrument must be maintained in clean condition.	Accuracy for field use is ±5% for the combination of the Pitot tube and the indicating instruments
PRESSURE GAUGE (MAGNEHELIC)	Use with Pitot tube or static probe to determine static pressure, total pressure and velocity in ductwork.	None. Check against inclined draft gauge frequently.	Readable to 0.05 inches
ROTATING VANE ANEMOMETER	Measurement of supply, return and exhaust air quantities at registers and grilles. Measurement of air quantities at the faces of maximum return air dampers or openings, total air across the filter or coil face areas, etc.	By an approved test agency every 6 months depending on usage. Check against recently calibrated instrument on each TAB project.	Average ±10%.
FLORITE ANEMOMETER	For measuring relatively uniform airflow at grilles and other air terminals	By an approved test agency every 6 months depending on use. Frequent comparison with an instrument of known accuracy is recommended.	Within 10% of the range of the instrument
PITOT TYPE ANEMOMETER	This instrument may be used for measurements of air velocity through both supply and return air terminals using the proper jet and the proper air terminal k factor (effective area) for the air flow calibration The instruments may also be used for measuring some lower velocities where the instrument case itself is placed in the airstream	The instrument should be checked by an approved (test) agency every 6 months or less depending on usage. Check against recently calibrated instrument on each project.	Accuracy is within ±10% when the instrument is in calibration and is used in accordance with the manufacturer's recommendations
HOT WIRE ANEMOMETER	Used to measure very low air velocities such as room air currents and airflow in hoods and troffers. It is used for measurements at grilles and diffusers, although much less frequently than other velocity measuring instruments.	By the manufacturer or factory approved agency every 6 months. Check against recently calibrated instrument on each project. When in use frequently check zero or the calibration point setting.	Accuracy is ±10%
FLOW MEASURING HOOD	To measure air distribution devices directly in cfm. When balancing a large number of ceiling diffusers or balancing troffer diffusers.	The flow measuring instrument used with the hood should be calibrated by the manufacturer or factory approved agency every 6 months	If the hood is properly shaped and positioned at the air terminal, accuracy of field measurements will be within the limitations of the flow reading instrument.

January, 1983. Chapter 5 of the SMACNA manual also contains an extensive discussion on each of these technologies, with illustrations and sample calculations.

It is not our intention here to summarize trade knowledge on air flow measuring technologies. However, only through familiarity with the current state-of-the-art in flow measurement systems, is it possible to appreciate the value of a new approach. In this context, we feel it is important at this time to review all currently available devices that can be used to measure air flow and flow versus pressure through ducts, fans, chimneys, and other types of ventilation systems in houses.

First, it should be pointed out that none of the current devices on the market have the capacity for creating a range of backpressures and forward pressures on a venting system and measuring the flow under these conditions. In this sense all the existing equipment is deficient for this project's requirements. Another aspect of the current testing devices that is inappropriate to meet CMHC objectives is the attachment mechanisms for venting systems. Test devices for use in commercial buildings are typically designed with capture hoods ranging from 900 x 900 mm, down to 600 x 600 mm. There is certainly nothing available with the versatility required to test chimneys, central vacuum cleaners and fireplace openings. Hence, although the flow systems themselves are very refined and in a variety of approaches could be used for our purposes, an appropriate range of attachment devices is definitely lacking.

Pressure-Sensing Flow Testing Devices

- Pitot Tubes and Arrays: The most common device used to measure air flow is the pitot tube. The pitot tube measures total pressure and the static pressure in the duct and then subtracts to determine the velocity pressure. The velocity pressure is used to calculate the average flow velocity across the area. A single pitot tube is an impractical approach to measuring air flow for household ventilation systems. Inside a duct it is difficult to locate, centre, and direct the tube perfectly upstream. At an inlet or outlet grille, it is difficult to measure the average pressures due to the extreme variations that can take place in the flow profile across the opening due to vena contracta phenomena. Also, at the low flows experienced by many household venting systems, the velocity pressures are extremely difficult to measure accurately.

For all these reasons, the pitot tube is usually combined with a number of similar pitot tubes to create a pitot array. The pitot array is intended to account for the velocity profile in the duct by generating an average differential pressure over the cross section. The pitot array is widely used because it is simple, has no moving parts, and produces extremely repeatable results. Its disadvantages are that the non-linear relationship between pressure and velocity are introduced as an averaging error; that the tiny holes used are subject to fouling by particles in the air stream; and its sensitivity is greatly reduced in low-velocity air streams.

- Flow Hoods: The most commonly used device which incorporates a pitot array system for field measurements is the Shortridge Flowhood, manufactured by Ernie Shortridge of Shortridge Instruments Inc. in Arizona. There are over 6,000 flowhoods now in use for testing and balancing of commercial duct systems. A copy of the Shortridge Flowhood is produced by Alnor Instruments and marketed as an Alnor Balometer.

The Shortridge flow instrument is probably the most suitable commercial device currently available to achieve at least some of the objectives outlined for the CMHC duct testing device. Its lightweight, compact size, ease of assembly and disassembly, and universal attachment mechanisms are very useful as a model for the duct test device. The device emerged five years ago through evaluation of the Murphy Box (a simple cardboard box with a round orifice hole cut in it). Recent developments in the Shortridge Flowhood are especially encouraging. The latest, most deluxe version of the Flowhood incorporates a specially adapted strain gauge which provides an electronic measurement of pressure over an incredible range from 0.01 Pascals to 13 kPa. A micro-computer chip takes multiple readings into memory, sampling from a 16-point criss-cross velocity pressure manifold in the flowhood base. With this electronic averaging it is possible to measure velocities as low as 0.10 meters per second, with some loss in accuracy (± 0.025 m/s).

The new flowhoods also incorporate partial dampers in the flowhood base to allow the operator to intentionally create a 20 to 25 percent restriction in the flowhood. By creating this known restriction to flow, and measuring the impact on flow for a given system, it is possible to extrapolate and predict the impact of the flow measuring device itself. In this way, the flow hood will automatically correct for the backpressure it exerts on the system and make appropriate corrections to the flow calculations.

- Orifice Meters: Another pressure device that is sometimes used to measure flow in ventilation systems is the orifice meter. This is a simple square-edged orifice with pressure taps located upstream and downstream. The orifice meter is a restrictive device which introduces an appreciable loss in total pressure, and thus it requires a flow coefficient (or some other means of correcting flow) to calculate the actual flow rate. One approach to backpressure compensation is to take two flow measurements, one with an additional known source of resistance in the flow path, and then correct the flow in the opposite direction to eliminate the effect of backpressure from the unrestricted device. (This approach is incorporated into one version of the Shortridge flow hood.)

Orifice meters are particularly appropriate for measuring low flows, and if the dimensions are correct, can achieve accuracies as high as ± 1 percent. Experimentation by Sheltair with house depressurization fans has shown the orifice approach to be suitable for accurate and repeatable measurements in houses. It is notably insensitive to movement around the flow testing device or slight changes in upstream pressure due to wind or other factors.

A box-type orifice meter has been developed by Sheltair to test different approaches to flow measurement as part of support for the CGSB Standard 51.70 "Determining Ventilation Requirements for Dwelling Units After Retrofit Air Sealing." A box-type device was created with multiple orifices (similar to the Retrotec Door Fan) which could be placed over an inlet or outlet. The orifices could then be opened up until a given pressure was achieved, at which time a count of the orifices and a multiplication would produce a reasonable estimate of air flow.

Recently, a more sophisticated orifice meter was witnessed by Sheltair during testing and evaluation of the Aereco Ventilation System developed in France. The Aereco Ventilation System is a central exhaust ventilation system which relies on humidity controlled extractors and supply diffusers. The research and development arm of Aereco (in France) has developed a hand-held device for measuring the flow into the humidity controlled extractors and out of the supply diffusers. Their test device is called a SAM. It incorporates an adjustable orifice meter and is shaped similar to a tuba. The large opening is placed over the inlet or outlet grille and a trigger on the handle is used to open and close an adjustable orifice. The opening and closing of the orifice is powered by a 22 volt, reversible DC motor (battery powered) mounted on the unit. The device is constructed of a clear plexiglass-type plastic which permits viewing of the inlet or outlet and the geared operation inside the hood. A pressure gauge on the side of the unit allows self-calibration, and another gauge reads out flow directly. The size of the orifice automatically adjusts to create a static pressure drop of 7 Pascals. This type of device is most suitable for use with systems where the fan curves are known, or where the total pressure in the duct system remains constant due to multiple inlets or outlets.

- Venturi and Nozzles: An alternative to the orifice meter, which also relies on pressure drops, is the venturi cone. Once again, pressure is monitored across a given size of opening and standard calculations or calibrations provide a relationship between pressure and flow. The purpose of the venturi cone is to minimize pressure loss in the system - an important factor when testing household ventilation systems.

Thermal Sensing Flow Devices

Thermal flow sensors, often called hot-wire anemometers, measure the heat transfer from a heated element to a flowing fluid. This heat transfer is then related to the mass flow rate of the fluid. All fans have a non-uniform outlet velocity, that is, velocity varies over the cross section of the fan outlet. Consequently, either a traverse must be taken manually or a grid must be set up to determine the velocity profile required to obtain the volumetric flow (similar to a pitot traverse). In most designs, the sensor temperature is maintained at a constant level above the ambient temperature of the flow.

Thermal flow measurement systems using an array have the advantage that temperature of the flow can be outputted simultaneously with the flow rate. Other advantages include high sensitivities at low flows and the ability to measure convective currents in a room. The device is also insensitive to airborne particles and has a wide range capability. The drawbacks of thermal sensors are the non-linear output that requires a linearization circuit and the high cost of these units. Most thermal sensors are also restricted in their temperature range, and thus could not be used inside chimneys.[1]

Both Sheltair Scientific Ltd. and Scott Technical Service have used hot-wire anemometers extensively in testing low flows in ventilation systems. The instruments we have used have been developed by Kurz Instruments Inc., a California company that is an international innovator in the use of thermal flow sensors. Dr. Jerry Kurz, the principle of Kurz Instruments Inc., has prepared numerous technical papers proposing the more extensive use of thermal anemometers for flow measurement systems (see References). A Canadian

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[1] Expensive platinum thermistors can sometimes be operated in temperatures as high as 500°C.

division of Kurz Instruments Inc. has recently been established in Edmonton, Alberta. Following discussions with representatives of Kurz Canada, a Kurz Eva 4100 electronic velocity array system was made available for our inspection and evaluation. Combining the Kurz velocity array with a velocity profiler produces an extremely sophisticated, durable, and accurate device for measuring air flows and temperatures. The outputs of the velocity sensor are inherently correct at the standard conditions of 25°C and 101 KPa.

House Depressurization Fans

Another approach used extensively by Sheltair to determine ventilation flow and pressure characteristics has been a depressurization fan. Although these fans are normally used to determine house envelope tightness, they can also produce accurate and repeatable measurements of household fan flow capacities at varying pressures. The use of depressurization fans for characterizing ventilation system flows has been well described in CMHC reports.[2] More recently, Sheltair has extensively used door fans for rapidly measuring flows of ventilation fans. (This approach has also been used for measuring flows from the Aereco system described earlier.) Our usual approach is to establish a constant indoor/outdoor pressure difference (eg. 10 Pascals) before and after operating a ventilation fan. The difference in flow through the door fan is accurately measured and is assumed to be equivalent to the flow that has been created by the operation of the ventilation system. The advantage of this system is that it requires only one attachment mechanism and one set-up, and is suitable for both mechanical and passive venting systems. Its disadvantages are the high cost of equipment, the requirement for setting-up stable and repeatable conditions throughout the entire house, and a difficulty in achieving sufficient resolution to accurately measure low flows, especially in leakier housing.

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[2] See the description of Vent/Pressure Profiles in "Design and Evaluation of Chimney Backdraft Checklist," Sheltair Scientific Ltd., for CMHC, December, 1984.

Rotating Vane Anemometer

Another approach to air flow measurements that has recently been applied to testing residential systems is the rotating vane anemometer. The rotating vane anemometer consists of a smooth, light-weight, wind-driven wheel (or propeller) connected through a gear train to a set of recording dials that read the air flow directly. Instruments come in different sizes suitable for a wide range of flows. When fitted into the top of a boot or flow capture hood, they are easily placed over return air grilles or warm air registers in residential forced-air distribution systems. Most instruments are not sensitive below 1 meter per second. Their advantages include low cost, ruggedness, and ease of operation. The rotating vane also has the advantage of averaging pressures and thereby compensating for non-uniform outlet velocity profiles. The disadvantages of the rotating vane anemometer are the somewhat non-linear response over a wide range of velocities and the requirement for time averaging before calculating flow. These disadvantages have been partly overcome through technical innovations by Scott Technical Service Ltd. They have recently developed two prototype units incorporating a micro-chip which permits automatic time averaging for much greater flow measurement accuracy. No attempt has yet been made to connect a rotating vane anemometer, incorporating a micro-chip, to a flow capture device for use in residences.

Smoke Guns and Bombs

A simplistic approach to flow measurement is to use contaminants, i.e. smoke, for flow measurement. The smoke is introduced to the flow and timed until it reaches the end of the duct. Dividing the length of the duct by this time will yield an average velocity for the flow. The advantages of this method are its simplicity and low cost. The disadvantages are that two persons are required, linked by some form of communication, and that the length of the duct must be known.

Bagging Air

A low-tech method to measure air flow is to use a capture device at a duct outlet, essentially to "bag" the air. The tester would monitor the time required to fill a known volume and divide the volume by the time to calculate the volume flow rate. We have not heard of this technique being used (although a self-timing bag has been manufactured in Scandinavia for this purpose), but it seems to be a simple and fast way of determining volume flow. A connecting box could be used to create varying amounts of back pressure for exhaust fan systems, while deflating the bag to measure flow. A 0.5 cubic meter bag would be sufficient for most residential systems. The accuracy of this approach is offset by the inability to obtain real time measurements, the inability to measure accurately high-flow systems, and the inability to measure flow at exhaust air or return air inlets.

Zero Pressure Flow Measurement Devices

In the process of developing the Duct Test Rig, information was provided to CMHC by the National Research Council on a device recently developed in Holland that is based on a similar principle to the DTR. The Dutch device is called a Flow Finder. It was developed in part by the TNO, and is marketed by Acin bv, in Den Haag. The flow finder is a smaller device than the DTR, with a built-in hood. It is battery operated and operates in a lower range of flows. (See references.) Although attempts were made during this project to obtain a Flow Finder for evaluation, this was not possible.

THE DEVELOPMENT AND EVALUATION OF A DEVICE FOR TESTING RESIDENTIAL DUCTS, VENTS, AND CHIMNEYS

APPENDIX II

THE DESIGN PHASE

September 23, 1987

INDEX

1. INTRODUCTION

This Appendix describes work undertaken during the design phase of a CMHC project on the Development and Evaluation of a Device for Testing Residential Ducts, Vents, and Chimneys. The organization of this Appendix parallels the approach outlined in our work plan and provides a description of each completed task.

2. STRATEGY MEETING

The Design Phase of this project began with a strategy meeting. A number of new issues were raised during this meeting:

- It was recognized that one single device to achieve the objectives outlined in our terms of reference is likely to be impractical. A kit of devices may be the best approach.

- A measurement accuracy of ± 20 percent has been defined as appropriate by NRC advisory personnel, but improved accuracy is hoped for.

- The ventilation compliance of some systems may cause problems when trying to determine flow versus pressure relationships, especially axial-propeller fans which are particularly soft, responding quickly to variations in pressure.

- Conducting a flow versus pressure test on fans may result in considerable noise in the data at those flow/pressure points where the fan becomes unstable.

3. COMPARATIVE TESTING DURING A WALK-THROUGH OF TWO TEST HOUSES

A variety of flow and pressure measurement equipment was assembled for comparative testing purposes, and a team of skilled individuals walked through two test houses. The purpose of this walk-through was to explore various approaches and combinations of equipment, and familiarize key participants in this project with the constraints imposed upon anyone attempting to test a variety of residential ventilation systems.

Two field test houses were identified for the walk-through testing. These two houses included the full range of devices identified in the work plan. A selection of test equipment used during the walk-through included:

- a velometer.
- a flow hood.
- a hot wire anemometer,
- a Version 1 Prototype (Sheltair's Zero-Pressure Test Apparatus),
- a digital rotating vane anemometer,
- a calibrated automatic adjusting orifice (the SAM)[1]

The team of individuals assembled to use the test devices and comment on their appropriateness included:

- Michael Scott of Scott Technical Services and
- David Hill of Eneready Products.

Photograph 1 illustrates the Sheltair Version 1 Prototype being used to measure return air flow through a floor register in the test house. Photograph 2 shows

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[1] The SAM flow tester was shipped by Aereco from France to Sheltair explicitly for comparative testing. Although this incurred considerable expenses to Sheltair, the SAM was of special interest because of its adjustable orifice mechanism.

the flow hood measuring flow through the same return air register. Photograph 3 shows a vane anemometer also used to test the same register. A comparison of flows through this inlet produced the following data:

- rotating vane anemometer	36.3 L/s
- flow hood	42.5 L/s
- Version 1 Prototype	46 L/s (using both a flow-cal pitot grid and nominal k values for a sharp-edged orifice)

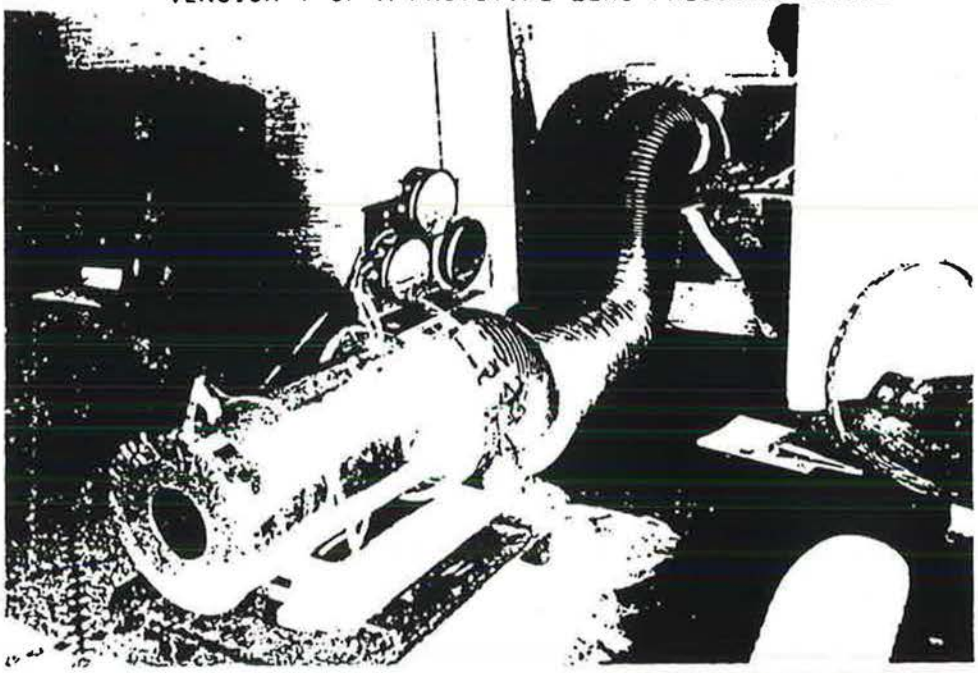
As expected, the flow hood appeared to underestimate flows and was found to be difficult to read at the lower flow ranges typical of residential systems. The capture hood was also excessively long for many applications.

Establishing a zero pressure at the hood using the Version 1 Prototype was found to be trickier than expected, due to a lag time between speed adjustments and a response by the pressure gauge, and due to very sensitive pressure readings at the hood which were difficult to steady. The centrifugal blower also developed considerable inertia due to the ball bearing-mounted rotating motor, and this further extended the lag times.

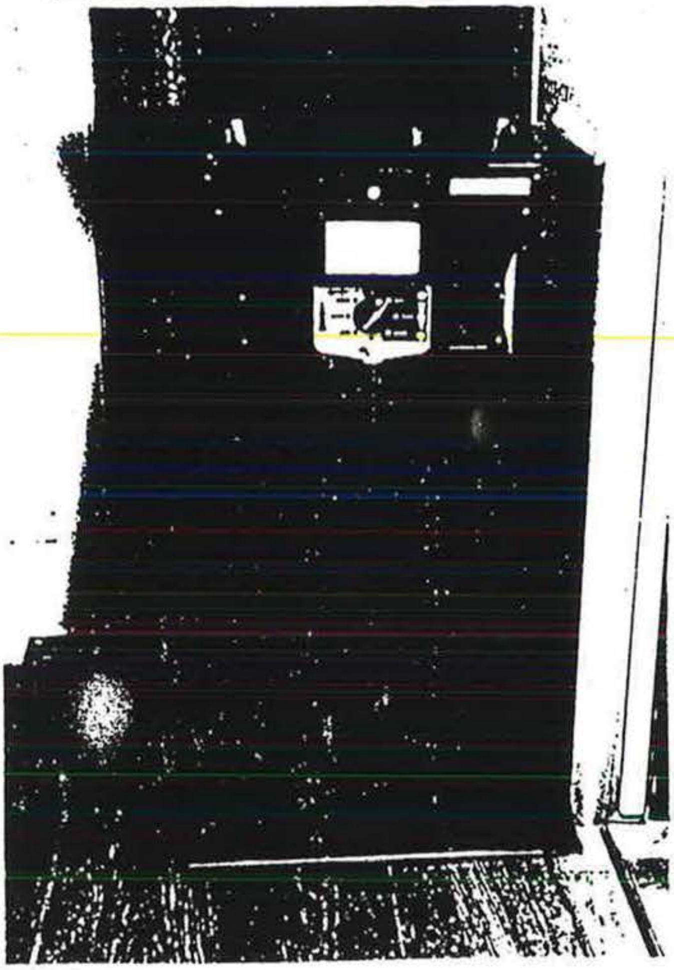
The SAM Aereco flow measuring system was found to be extremely easy to use in houses. Photograph 4 illustrates the components of the SAM. Photograph 5 shows the SAM being used to measure flows into a kitchen range hood fan. Photograph 6 shows the Version 1 Prototype also measuring flows into the kitchen range hood fan. As expected, the 7 Pascals of back pressure automatically created by the use of the SAM resulted in a lower flow measurement (45 L/s) in comparison to the Version 1 Prototype (55 L/s).

Many ideas were generated for various attachment mechanisms suitable for matching a flow measuring device to residential vents, ducts, and chimneys. The most challenging task was not measuring flows and pressures, but attaching the measuring device to various ducts and vents. The greatest difficulty was

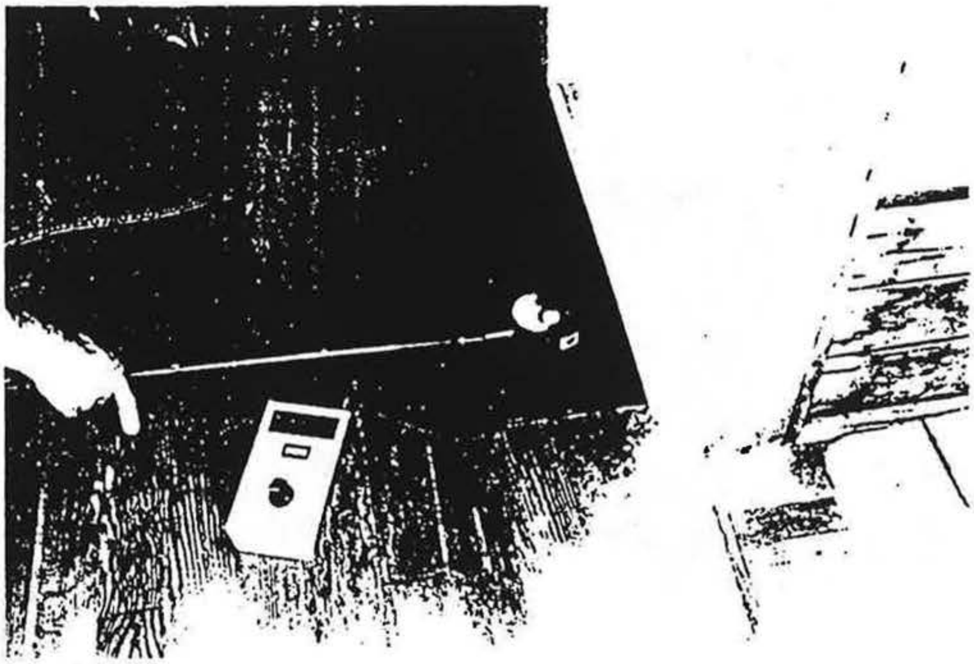
Photograph 1: MEASURING FLOW AND PRESSURE AT RETURN AIR INLET USING VERSION 1 OF A PROTOTYPE ZERO-PRESSURE DEVICE



Photograph 2: SHORTRIDGE FLOW HOOD USED OVER THE SAME RETURN AIR INLET

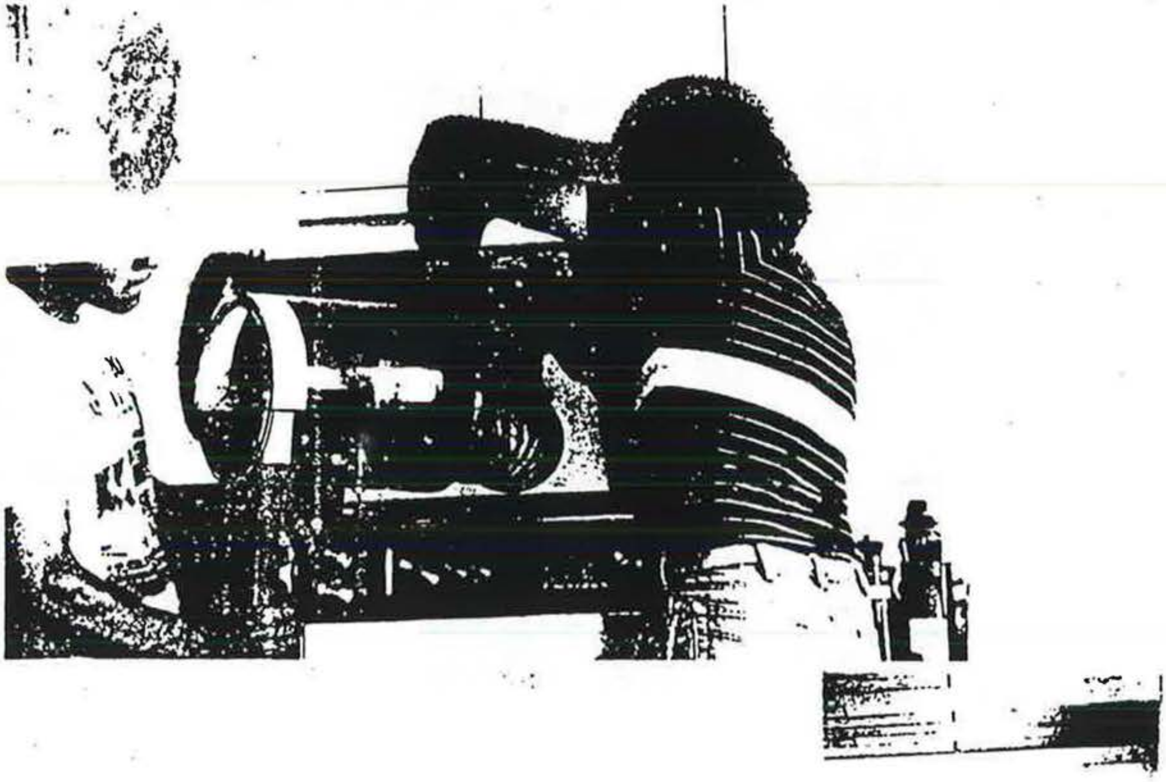


Photograph 3: VANE ANEMOMETER USED OVER RETURN AIR INLET

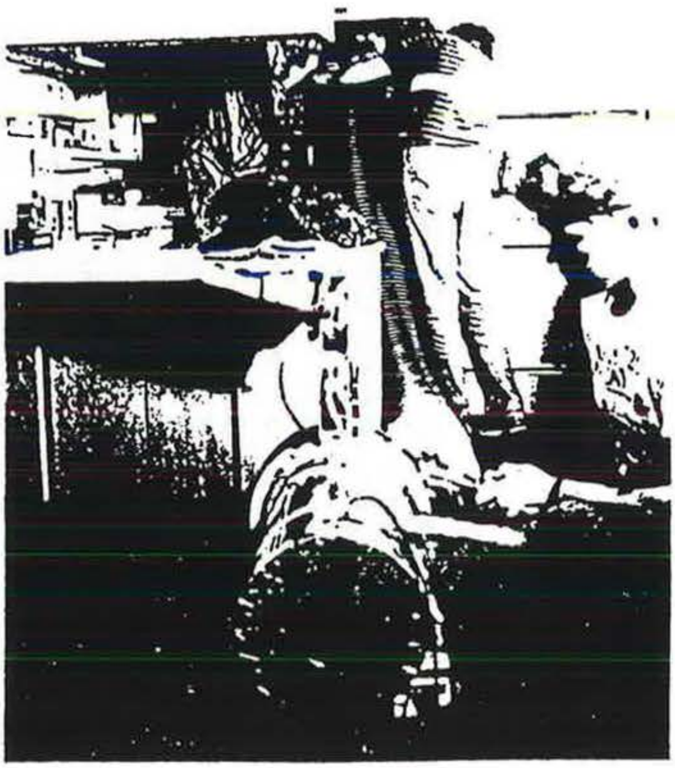


Photograph 4: SAM AERECO FLOW MEASURING DEVICE

Photograph 5: SAM USED TO MEASURE FLOW INTO KITCHEN RANGE HOOD FAN

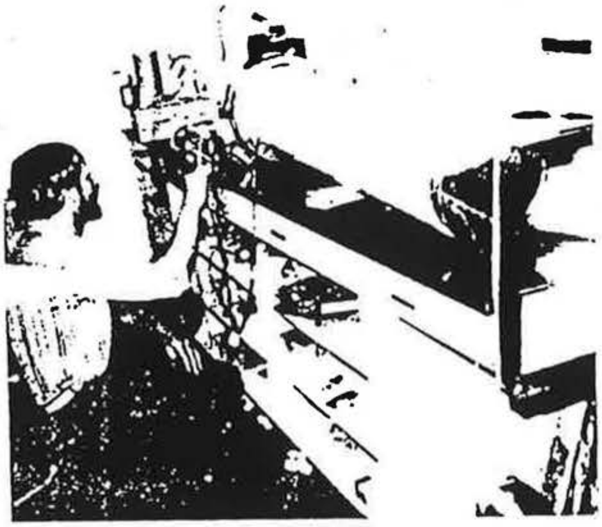


Photograph 6: VERSION 1 PROTOTYPE USED TO MEASURE FLOWS INTO KITCHEN RANGE HOOD FAN



Photograph 7: SHELTAIR'S FLOW CALIBRATION AND COMPARATIVE TEST CHAMBER

Photograph 8: EVALUATING THE IMPACT OF ORIFICE LOCATION RELATIVE TO FAN



encountered with the range hood fan and the furnace. In the field, both these situations proved more difficult than expected. We had made a specially designed range hood attachment for Version 1, using an inflatable inner tube from a mountain bike as a gasketing material, and a design that matched all dimensions supplied by range hood manufacturers. However, the protrusions from walls, mitred corners and varying locations of fans within the hoods prevented application of this hood. The only suitable approach was found to be to cover the entire range hood with a rigid board cover or a flexible sheeting material, and then mate a flow-measuring device to a hole in this cover.

4. DISCUSSIONS WITH EXPERTS

A round-table discussion on critical issues relating to the design of the device, was organized for August 13, 1987. The meeting was held at Sheltair's offices, and, in addition to Sheltair personnel, included Colin Genge of Retrotec Energy Innovations, Michael Scott of Scott Technical Services, Michael Lucking of Star Heating Exchanger Corporation, Murray Ward of Enviroscience Ltd., and Tom Tutt Western Canada representative for Zielbeg and EBM Fans. The meeting lasted a full day and included a conference call with Ernie Shortridge of Shortridge Instruments, who found he was unable to attend in person on the day selected for the meeting.[2]

All components of the testing device were discussed during this round-table meeting and a wide range of issues were identified for later investigation. Issues which received the greatest attention included:

- Choice of the most suitable flow-measurement technology.
- Quantifying the performance requirements for the device.

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[2] Mr. Shortridge was provided with a kit of materials and selected list of questions for this conference call, including detailed questions on the electronics of the Shortridge Air Data Multimeter, and the logistics involved in designing and constructing a custom hood for our device.

- The need for baffling and flow-settling devices to avoid interference with air flow patterns around inlets and outlets under test.
- Optimum dimensions and locations for each component.
- Suitable construction material for the prototype.
- Weight limitations and the possibility of developing a one-piece device as opposed to a fan connected to flexible duct.
- The necessity for a fan to match the flow of the fan being tested.
- Selecting a fan type most suitable for meeting our requirements.

The following two sections of this report will cover some of the highlights of these discussions, as well as most of the ensuing research undertaken to resolve these issues. In these sections of this report, the device used to determine the flow and pressure characteristics of ducts and vents is referred to as a FLOW TESTER. Equipment used to determine the thermal characteristics of ducts and vents is referred to as a THERMAL TESTER.

5. CONSTRUCTION OF A CALIBRATION CHAMBER

Because the field measurement device is to be thoroughly calibrated, and will be assisted by computer computations, the question of accuracy of measurement is a non-issue. What is more important to the functional utility and accuracy of the device is its ability to provide consistent, repeatable, and stable readings that are easily controlled and interpreted by the operator.

In order to establish the impact of various design modifications on these factors, it was found necessary to obtain a calibration chamber for use at this stage in our research. Only by means of a calibration chamber could we establish a basis of comparison between the different configurations and evaluate the usefulness of the design modifications. The calibration chamber provides a means of recreating, at any time, a specific range of flows and pressures, which can then be matched by the device under test. Although at this stage the calibration chamber would not be used to calibrate these devices for flow, the same chamber will later be used for flow calibrations on the final version.

An extensive review was undertaken of the ANCI/AMCA Standard 210-85 and the ASHRAE Standard 51-1985, in order to identify the most appropriate chamber for these purposes. A chamber was then constructed precisely according to specifications in these standards, including choice of settling means materials. pressure taps, instrumentation, and nozzles. (A series of burnished aluminum ASME long-radius, flow calibration nozzles were obtained from Helander Manufacturing in Chicago.) The ducts on both ends of the calibration chamber were fitted with back-boards and grilles so that the duct test device could be mated to either the inlet or the outlet of the calibration chamber. Photograph 7 presents Sheltair's flow calibration and comparative test chamber as built. Figure 2 is a schematic of the chamber, extracted from the ANCI/AMCA Standard 210-85.

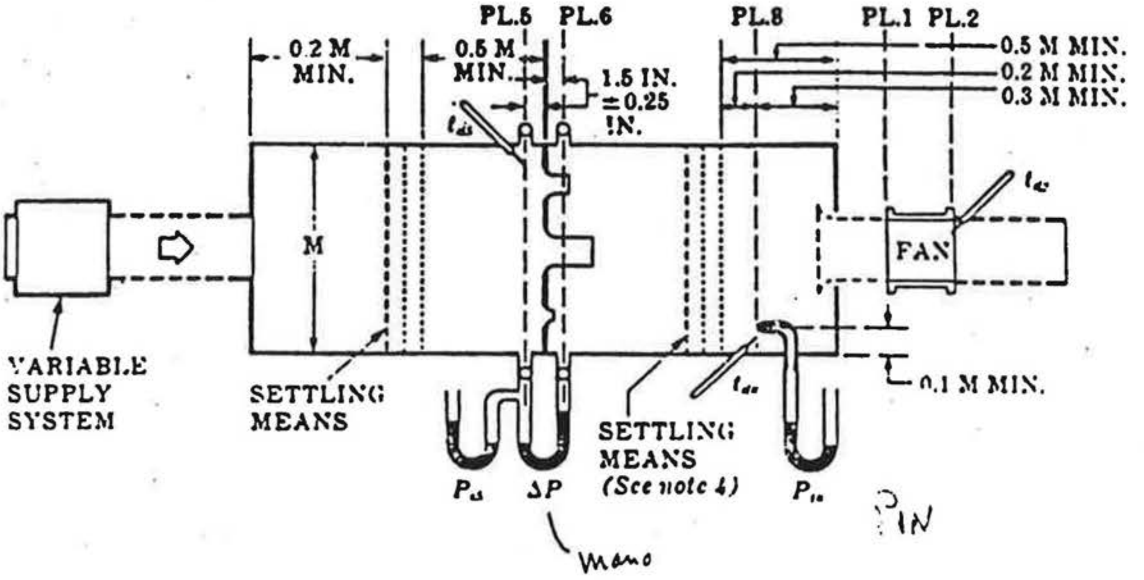
Although the construction of this calibration chamber incurred delays in the project schedule. the development of a chamber provided the only cost-effective means of resolving many of the issues identified during this design phase.

6. REFINING THE DESIGN FEATURES FOR VERSION 2

6.1 Fan and Controls

The selection of a suitable fan has proved to be the most challenging aspect of designing a Version 2 Flow Tester. Ideally, the fan in the Flow Tester should be capable of matching the flow rates in the most powerful residential systems (e.g. range top barbecues and fireplaces), which typically blow in the 140 L/s range. Even better, although less critical, is to include a fan that is capable of matching the capacity of typical furnace blowers, which are thought to blow approximately 350 to 400 L/s. In addition, the fan must be capable of smooth speed control from zero to full range. Ideally, the flow versus pressure profile

Figure 2: DESIGN SPECIFICATIONS FOR SHELTAIR'S FLOW CALIBRATION AND COMPARATIVE TEST CHAMBER



FLOW AND PRESSURE FORMULAE

$$Q_5 = 1096\, Y \sqrt{\Delta P / \rho_5}\, \Sigma(CA_6) \qquad P_v = P_{v2}$$

$$Q = Q_5 \left(\frac{\rho_5}{\rho}\right) \qquad P_{t1} = P_{t8}$$

$$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right) \qquad P_{t2} = P_v$$

$$P_t = P_{t2} - P_{t1}$$

$$P_{v2} = \left(\frac{V_2}{1096}\right)^2 \rho_2 \qquad P_s = P_t - P_v$$

NOTES

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct 2 to 3 equivalent diameters long and of an area within ± 0.5% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. Variable supply system may be an auxiliary fan or throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.

Figure 15 Inlet Chamber Setup—Multiple Nozzles in Chamber

ANSI/AMCA STANDARD 210-85 ANSI/ASHRAE STANDARD 51-1985 for the fan should not incorporate major reversals which would complicate field testing. The fan must be durable, capable of generating a continuous flow at a constant power input, and extremely lightweight. Since orifices are most likely to be used for flow measurement purposes, the fan must be capable of generating maximum flows, against static pressure drops of up to 100 Pascals (assuming a maximum orifice size of approximately 240 cm^2). Ideally, the fan should operate off a 110 volt AC circuit, with less than 9 amps draw, and should be reversible, to permit a flow measurement in both directions. Finally, the diameter of the fan should not exceed the overall dimensions chosen for the duct and orifice.

Eventually, two EBM backward-inclined, centrifugal, in-line blowers with rotating motors were purchased for test purposes. An 8 inch diameter and a 10 inch diameter fan were employed in the lab tests. Despite their high cost, these blowers appeared to offer considerable advantages over most fans currently available. By mounting the fan blades on the armature, the fan does not tend to overheat at lower speeds and therefore maintains a more consistent and controllable speed.

Ideally, a number of alternative fans would also have been tested and compared with the centrifugal EBM fan, but such an approach would have entailed excess costs. Instead, an extensive review was made of the manufacturers' literature and specifications for various fan types. At the same time, the performance requirements for a fan were re-evaluated by means of using the 2 EBM blowers and other fans in our lab. This process resulted in a decision to reject the use of a centrifugal blower, in favour of an EBM axial fan. The EBM axial fan also benefits from a rotating motor with easier speed control.

In addition, an axial fan benefits from a reduced weight. For a 250 mm diameter fan the total weight is reduced from 5 kg to 1.7 kg. For a given diameter, an axial fan also requires much less space.

Although axial fans are considerably more sensitive to static pressure drops than centrifugal fans, this variable was found to be less significant than expected during lab testing. The fan in the Flow Tester operates essentially like a booster fan, and therefore benefits from the pressure drop already created by the installed fan system. For this reason it was found that a maximum static pressure drop for our test fan was more likely to be in the range of 40 to 50 Pascals (as opposed to over 100 Pascals). At these pressures it is expected that greater flow rates can be obtained using axial fans as opposed to centrifugal.

6.2 Orifice and Duct

The design of an optimum flow measurement system required extensive investigations and lab research. Various techniques for measuring flow were considered, including the use of inexpensive resistors (or thermistors), an enhanced pressure averaging grid (or Pitot traverse) similar to that used in the flow hood, and the use of a fan calibrated on the basis of speed. These approaches were eventually rejected in favour of our original proposal - that is to use an adjustable orifice opening. An orifice offers the advantages of high accuracy at both low and high flows. It is also relatively easy to produce to custom specifications and helps to minimize weight and space. An orifice is especially compatible with use of a fan assisted device, since its resistance can assist in creating positive and negative pressures.

An orifice also offered the opportunity for a system that would measure flow in both directions, thereby avoiding the need for reversing the entire test device. However, after discussion, the use of two-way flow was rejected. A two-way system would have to be calibrated in both directions, and any slight differences in the accuracy would inevitably create confusion in field test results, especially during research work. Also, because an orifice can easily be effected by fan turbulence, a one-way flow system allowed emphasis on flow-straightening upstream of the orifice, and the placement of a fan downstream of the orifice, for optimum performance.

Instead of two-way flows, a decision was made to mount the orifice in a duct which could be fitted to a hood on both ends, depending on the direction of flow desired. Since an adjustable orifice allows considerable back-pressure to be created within the device, it will still be possible to collect flow versus pressure data for both negative and positive pressures, without having to reverse the entire device.

A general approach to designing a duct and orifice system was to follow the specifications outlined in various national and international standards for orifice flow measurements. Well-established criteria exist for the maximum size of orifice relative to duct size, location of pressure taps, dimensions and thickness of orifice plates, location of fans relative to orifices, and other such factors. Where alterations to these established specifications appeared to be advantageous, our approach was to explore options in our lab by repeated testing of various configurations with our calibration chamber. In this way, we were able to collect sufficient data to make alterations to standard dimensions, in the interests of improving utility.

One of the issues that was explored through lab tests was the minimum distance from the air inlet to the orifice. Normally, an extensive length of duct is required in front of the orifice for purposes of flow straightening. A series of different duct lengths were arranged in our lab tests, and packaged one at a time with a section of duct containing an orifice and pressure taps. In this way, data was collected on the impact of various duct lengths, as well as alternatives methods for flow straightening, such as incorporating a bell inlet reducer and inserting flow straightening materials.

It was established that the use of flow straightening materials (a thin metal honey comb mesh) served as a substitute for duct length, without loss in flow, accuracy, or stability of reading. A 75 mm long duct with flow straightening materials was found to produce the same differential pressure across the orifice (at a constant flow) as could be obtained using a 1575 mm section of duct without a flow straightener. This data is summarized in Table 1. The use of an inlet bell was found to be as effective as a flow straightener in maintaining differential pressures with short duct lengths. Table 2 compares a 75 mm duct with both a flow straightener and an inlet bell.

For portability and safety purposes, advantages can be obtained using flow straightening materials as opposed to a bell inlet. It is proposed to insert a plastic flow straightening grid at the inlet of the device. Mounting the flow straightener closer than 75 mm to the orifice resulted in major changes in differential pressures.

Additional tests were conducted to ascertain minimum distances between orifice location and fan location. Table 3 illustrates the effect of reducing this distance from 375 mm to 75 mm. These and other test results indicated that the minimum distance between an orifice and a fan, in a 250 mm duct, was approximately 175 mm.

The size and construction of orifice plates is another critical issue that required some testing. To permit good resolution at low and high flows, a series of orifice sizes are essential. The diameter of an orifice in a round duct is limited to 70 percent of the diameter of the duct. The duct size is determined by the flow requirements for the device and the type of fan to be used. For reasons of portability it was desirable not to exceed an approximately 250 mm diameter fan. It is preferable to avoid flaring open the duct size for a larger orifice since this creates excess turbulence in air flow. Consequently, the maximum orifice size is approximately 175 mm.

The sizing of the smaller orifices depends on the kind of resolution desired from the pressure gauge for orifice pressure differentials. In an effort not to go much below 10 percent of full scale for our minimum pressure readings, we established a minimum reading of 10 Pascals. This approach results in the flow ranges for different orifice sizes as shown in Table 4.

Table 1: A COMPARISON BETWEEN A 1575 mm DUCT AND A 75 mm DUCT WITH A FLOW STRAIGHTENER

Duct (mm)	Hood (Pa)	Δ P Nozzle Wall	Δ P Orifice Plate
1575	0	40.5	39.0
1575	0	22.5	22.0
75	0	40.5	38.5
75	0	22.5	22.0

Table 2: COMPARISON OF A 75 mm DUCT WITH A FLOW STRAIGHTENER AND WITH AN INLET BELL

Description of Duct	Δ P Nozzle Wall	Δ P Orifice Plate
75 mm without flow straightener	40.8	30.5
75 mm with flow straightener	40.5	39.0
75 mm without flow straightener, with bell	41.0	39.0

Table 3: EFFECT OF REDUCING DISTANCE BETWEEN FAN AND ORIFICE

	Hood			
Distance (mm)	Size (mm)	(Pa)	Nozzle (Pa)	Orifice (Pa)
375	580 X 390	0	42	39.0
175	580 X 390	0	42	38.5
175	580 X 390	0	42	41.0
175	580 X 390	0	42	38.0

Table 4: FLOW RANGES FOR DIFFERENT ORIFICE SIZES

Orifice Size (mm)	L/s at 125 Pascals	L/s at 10 Pascals
175	226	60
125	115	31
75	39	11
37	10	2.8

(Calculations based on nominal K values)

On this basis it was established that at least three orifices sizes (and probably four) would be required to accurately measure over the flow range to be encountered in house ventilation systems. In addition, an extremely large orifice may be of value, exclusively for measuring high flows at low static pressures (thereby greatly extending the flow range for the device).

A variety of types and sizes of orifices were cut from aluminum and cardboard materials for test purposes. The simplest approach to fabricating orifices appeared to be stamping different diameter holes out of 3/8" sheet aluminum. The largest sized orifice plate could be permanently fitted in place, with smaller orifices then inserted through the end of the device and held in place against the larger orifice plate using magnetic tape. This approach was used for lab tests, but was found to be awkward because of the need to remove flow straightening devices to change orifice plates. An alternative approach was explored, whereby a groove is cut in the duct and orifice plates are inserted vertically into the duct. Eventually, a decision was made to reject separate plates entirely, and instead use an adjustable-sized orifice opening.

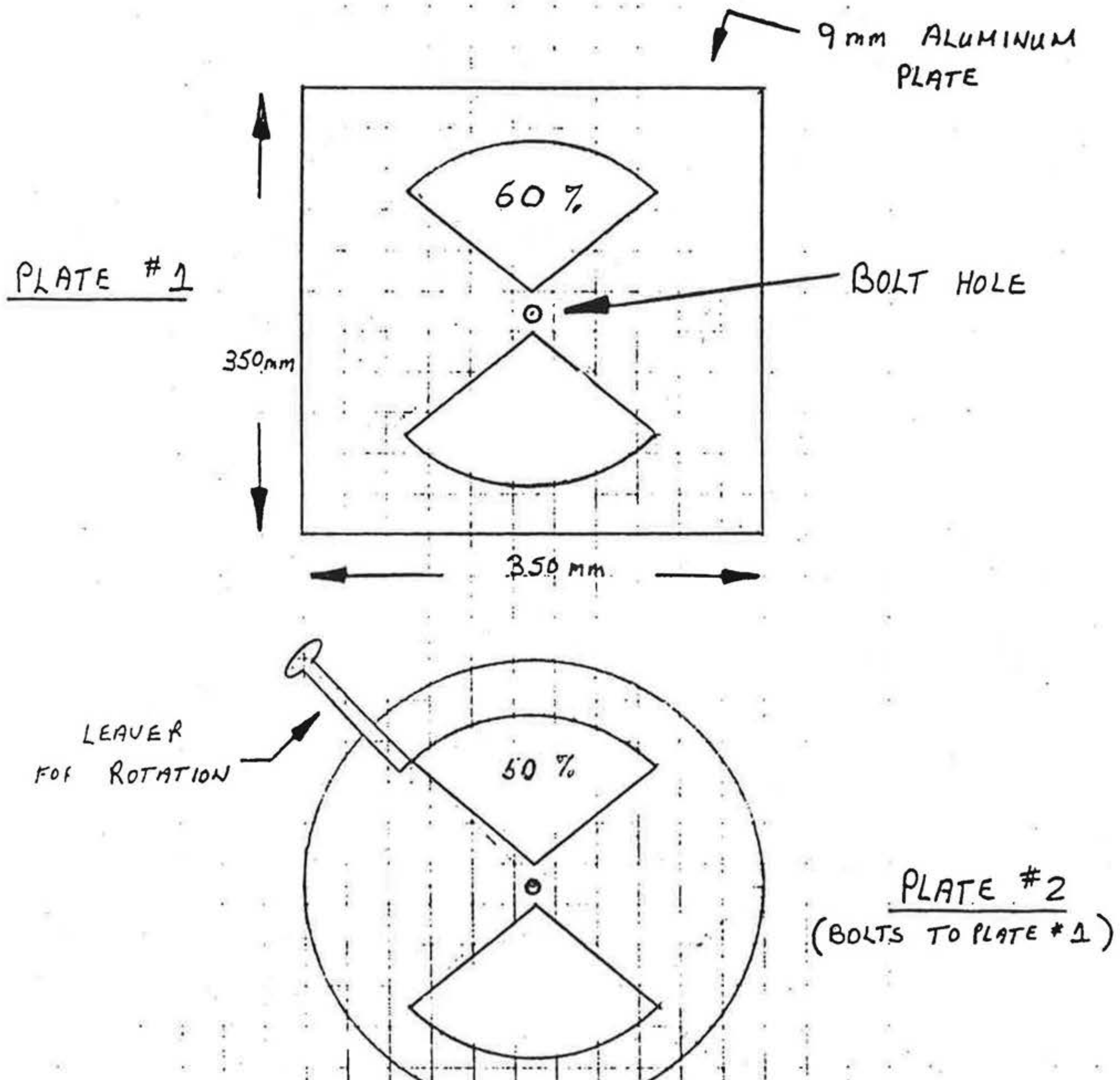
Initial investigations of adjustable-area orifices suggested that this approach might be too complex and costly for our purposes. Discussions with personnel at the HVI Flow Measurement Lab and other institutes revealed no existing adjustable-area orifices for our use. However, further investigations revealed a variety of iris diaphragms available from precision scientific equipment suppliers and optical suppliers in Europe and Southern California. Iris diaphragms appeared to exist that would suit our purposes well, but the price was excessive (approximately $700), and concern existed that the pressures experienced by the orifice may deform the shape unpredictably.

Eventually, a decision was made to have a local machine shop cut an adjustable orifice plate for use inside the device. A design was developed by Sheltair that appears to be as simple and inexpensive to produce as a series of different orifice plates. However, it would have the advantage of not requiring insertion or removal of plates to vary the size. Sheltair's initial design for an adjustable orifice is illustrated in Figure 3, and consists of two aluminum plates bolted together at the centre, each containing two pie-shaped orifices. One plate has an orifice consisting of approximately 60 percent of the area. The second plate has two orifices which comprise approximately 50 percent of the area. As the two plates are rotated, two symmetrical and identical sharp-edged orifices are created varying in size from 10 percent to 60 percent of the total potential area. Adjustment of size is effected by means of a lever attached to the moveable orifice plate.

A truly adjustable orifice creates the possibility of eliminating the need to measure pressure differential at the orifice plate. Instead, flow could be determined by simply using orifice size, with the fan at constant speed, as an indication of flow. This approach would be advantageous in that it avoids two adjustments, and gets around the difficulties encountered in fine tuning and lag times with fan speed controls. However, the requirement that the device be capable of measuring flows at varying hood pressures means that a practically infinite number of calibrations would be required before this approach could be operationalized. Instead, it was proposed to have an adjustable orifice that goes from open to mid-way closed to completely closed, offering the user three potential ranges.

The construction of the duct is another issue closely related to the type of orifice and fan. Initially, we planned to use a round duct, mounted on some kind of trolley, similar to an Electrolux vacuum cleaner. (We began to call the Duct Test Device a "Ductolux.") However, by reducing the duct length, and fan size, an opportunity was recognized for producing a device small enough and light enough to be held by the operator during the test (similar to the Flow Finder developed by ACIN in Holland). Lab tests indicated that at least a full minute would be required to conduct a test with the device. Lifting various weights over our heads, we concluded that the maximum weight for a device that is to be held above one's head for a full minute is approximately 5.5 kg. (This is approximately equivalent to the Shortridge Flow Hood, and exceeds the weight of the Flow Finder by 1.8 kg.)

Figure 3: THE SHELTAIR ADJUSTABLE ORIFICE



It was finally decided to construct a light-weight square duct, 350 mm square, and 450 mm long. The Version 2 Flow Chamber will be constructed from anodized aluminum foam board. Use of a square duct greatly simplifies the attachment of handles and monitoring equipment, and increases the stability of the device. The square sides also create space inside the duct for the sensitive pressure sensors, and permits a larger overall orifice size for a higher flow measurement capability. In addition, a square duct allows for easier mating to existing flow hoods, thereby greatly simplifying the design of a detachable hood. And finally, a 350 mm square duct is capable of covering, and therefore testing, many of the existing grilles and registers in a house without the need for any separate hood attachment.

6.3 Hoods

A variety of different attachment hoods were constructed out of plywood and cardboard and tried out in houses and in our lab. In addition, a survey was undertaken of dimensions for different devices in houses which would require hoods, including fireplaces and range hood fans.

Fireplaces represent the single largest item for which a hood is to be used. Because of their extreme size, it was initially proposed to connect to a fireplace by simply covering the fireplace opening with a piece of board material, and fitting the test device to a cutout in this board. It was feared, however, that this might significantly impact on the kind of flows experienced by fireplaces during operation, and this approach was rejected. (Field trials may be required to resolve this issue at some later time.)

Ten existing fireplace openings were measured to determine typical sizes. In addition, two fireplace suppliers were canvased. The width of fireplaces were found to vary from 475 mm to 1225 mm. Heights of fireplaces varied from 475 mm to 800 mm. Several fireplaces had protrusions of up to 25 mm around the edge, and other had brick extensions of up to 20 mm. On the basis of this survey, it was concluded that a hood dimension of 950 mm X 700 mm would be capable of covering at least 90 percent of all fireplace openings, and that a loose skirt and drawstring around the outside of this hood would be an advantage in coping with protrusions and in gerry-rigging a tight fit on exceptionally large openings.

After concluding that a fairly large hood will be required for connecting to fireplaces, it was proposed to use the same hood for other large openings in houses including double-stud supply air and return air openings, range top fans, and furnace fronts. If such an approach proves feasible, it is hoped that the combination of a square flow measurement device, and a single detachable hood for larger openings, would cover virtually all situations to be encountered in houses.

An exception is the kitchen range hood fan, mentioned previously, which requires some kind of board to cover the hood prior to attachment of the test device. In addition, sealing materials such as urethane backer rod, polyethylene tape, and foam rubber may be necessary for filling cracks between bricks at fireplaces, and around protrusions and unusual inlet/outlet configurations.

The necessity for an extremely light-weight, collapsible, and large flow hood led to discussions with Ernie Shortridge of Shortridge Instruments, who manufactures a variety of hoods with similar features. Eventually, a tentative arrangement was made to have Shortridge Instruments produce a customized flow hood for our purposes, making use of the refined technology already incorporated in their flow hoods. Unlike existing flow hoods, our test device does not require a low slope to minimize turbulence or resistance. Consequently, we have proposed a hood with a depth of only 300 mm, as opposed to 800 mm for a typical Shortridge flow hood. Our hood would maintain the existing dimensions for Shortridge hoods at the small end (350 mm X 350 mm), but increase to a larger opening than is currently available (700 mm X 950 mm).

Lab tests were conducted on various flow hood designs to determine the impact of air velocities and pressure measurements systems on the flow measurement accuracy. A piezometric ring pressure tapping was found to slightly preferable to a single pressure tap, since they provide more stable readings and slightly lower reading dues to less impact from velocity pressures. Just as useful as a piezometric ring, was found be to be a section of open-cell foam around the flange of the flow hood, in which to locate the pressure tap itself. The combination of the piezometric ring and open-cell foam produced extremely stable readings under all test conditions.

Extensive testing in the lab was conducted to determine if the high velocity air stream in the centre of the flow hood needed some kind of settling means or baffling to prevent interference of air flow patterns of inlet grilles. For the two varieties of grilles tested in the lab, the high velocity air flow appeared to slightly reduce the amount of air flowing into the grille, presumably due to increased turbulence around the inlet vanes. The effect of this high velocity turbulence was found, however, to be largely insignificant within the accuracy requirements of the device, and a decision was made not to incorporate any flow settling or baffling device in the flow hood.

Additional testing was conducted with flow hoods to determine the essential free area around an inlet to avoid interfering with air flows due to the proximity of the flow hood wall. Under the test conditions, flow hoods were found to have very little impact on flow measurements, even when a distance of less than 50 mm separated the edge of the inlet and the wall of the flow hood. In actual test situations in houses, it will usually be possible to maintain at least 50 mm clearance, unless existing obstructions are present.

The Shortridge flow hood is constructed from a urethane-impregnated nylon cloth that is easy to patch and is completely airtight. The large face of the hood is fitted with a closed-cell foam gasketing material. For purposes of the test device Shortridge fitted the large end with an additional skirt of urethane-impregnated nylon, incorporating a drawstring. This skirt was designed to allow mating of the hood with devices where protrusions exist, or with odd-shaped openings.

6.4 Pressure Measurements

Two pressure measurement gauges were be required. One gauge was needed to measure pressure at the inlet or outlet of the device. These pressures are important for accuracy purposes, since they impact directly on the final flow results. The gauge must be capable of fine resolution around zero pressure, and presumably should also be able to measure pressures as high as what is normally experienced in houses, and in chimneys and vents.

It was assumed that a pressure range of -40 to +40 Pascals would be sufficient for establishing positive, zero, and negative pressures at the hood.

The second pressure measurement gauge was for determining differential pressure across the orifice plates. It is assumed that a range of 0 to 125 Pascals would be adequate.

The use of fluid manometers, and magnahelic gauges, was rejected due to their sensitivity to mounting positions, and poor resolution. Also, it was felt to be advantageous if the gauge is electronic, since this would greatly facilitate computer calculation and display.

Although electronic differential pressure transmitters are relatively expensive, their price has dropped drastically over the last year, and several suppliers have been identified that can provide suitable devices for less than $200 US, (eg. MODUS Instruments, Inc. and Validyne Instruments). These transmitters produce a voltage output of pressure in ranges from 0.1 inches of water column up to 10 inches of water column, with an accuracy of ± 1 percent of the range. They are extremely lightweight, compact, long lasting, and fast to respond. The accuracy and sensitivity is better than what we required, and they are virtually position-insensitive. They can also be zeroed prior to test, or automatically zeroed. For these reasons, we proposed to incorporate two electronic pressure transmitters in the Version 2 prototype. These devices represent by far the highest single cost component for the device, and presumably this decision would need to be rethought if the device was to be produced in volume.

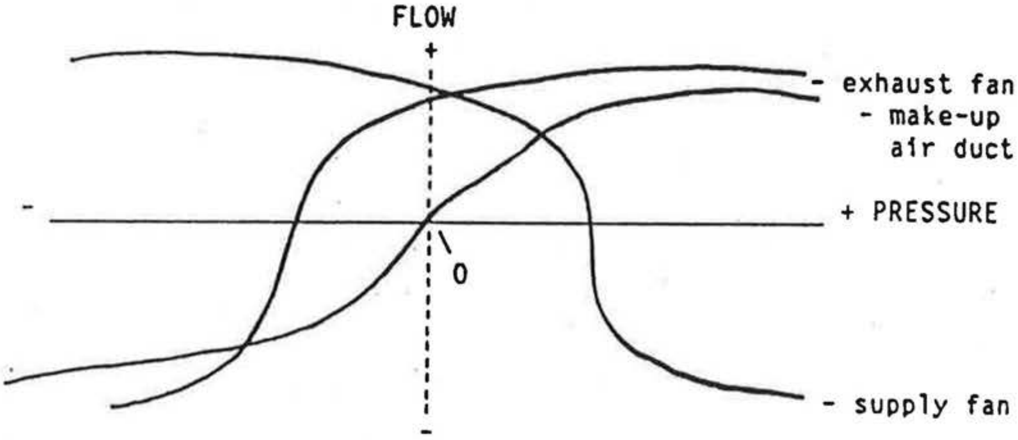
6.5 Microprocessor and Display

A variety of approaches were considered for calculating and displaying flow and pressure information. Initially, it was hoped that some method of automating the entire test procedure might be feasible, at least for flow and pressure measurements. The test procedure is remarkably similar regardless of the type of device that is being tested. After the flow tester (and hood) has been mated to the system in the house, the fan can be cycled from stop to maximum flow and back again, while pressure is sampled and converted to flow. Presumably, this type of procedure could be automated so that the fan cycle occurs over a specified time period while data is logged at varying intervals. With such an automated procedure, flow and pressure data could be displayed graphically in a similar format for all devices. A rough example of what a computer printout might look like for a typical automated test is presented in Figure 4.

Curves such as those shown above would be produced for both passive and active venting systems, and for supply and exhaust fans. Unfortunately, without knowing precisely who is going to use the flow tester and in what context, it is difficult to predict all the requirements of the data collection process. For this reason, it was decided not to attempt any automated test feature. Instead, it was proposed that Version 2 of the flow tester include an LED readout of flow and pressure, calculated from temperature and pressure readings sensed and sampled automatically.

A series of LED readouts mounted on the face of the flow tester could provide updated readings of air flow, hood pressure, air temperature, and leakage area,

Figure 4: EXAMPLE OF A TYPICAL AUTOMATED TEST PRINTOUT



averaged and updated every few seconds. In this way, the operator of the flow tester could quickly create a flow-versus-pressure graph for any venting system, by noting hood pressures and flows at different intervals. Alternatively, the device could be used for measuring leakage areas in venting systems (or houses) and for monitoring the real-time performance of any system under more dynamic circumstances.

The sensing systems could consist of a thermistor or I.C. thermometer (for air temperature), and two differential pressure transmitters. Sensors will be connected to an analog-digital converter, and then to a 68000 Motorola computer chip for sampling and calculation. Time averaged computer outputs will be transmitted to an LED display driver and four LED displays. The task of packaging this hardware will be sub-contracted to Star Heat Exchangers, a B.C. company that has recently put together a similar microprocessor-based system for incorporation in HRV products.

6.6 Thermocouple Array and Installation

Mike Swinton of Scanada Consultants Limited was requested to elaborate on the requirements for a Thermal Tester (i.e. a device that would test the thermal effectiveness of chimneys). It is expected that the Thermal Tester will be used for further validation of computer modeling work completed by Scanada on behalf of CMHC. Mike Swinton's recommendations are expected to be particularly useful during the application of our device in field conditions.

At least two different strategies were considered for testing thermal effectiveness of chimneys. The first was to use heavy gauge, Teflon-coated thermocouple wire inserted at various locations up chimneys or along duct systems, and then generate heat in the system using the heating appliance (where one exists) as opposed to using a portable heat source. This seemed to be the only possible approach for masonry chimneys, where the temperatures at the chimney top are expected to be quite low, even with 5 or more kilowatts of heat input from a large furnace. Presumably, this type of test could be done simultaneously while using the Flow Tester connected to the face of the furnace. Such an approach would permit simultaneous measurement of temperatures up a chimney, and pressures and flows at the base of the chimney. The disadvantages of this approach include the imprecise energy input data from a heating appliance and the higher temperature rises and variable air flows created by an appliance and (producing a more dynamic situation). In addition, many duct systems which may need to be tested for thermal effectiveness would not necessarily incorporate a known heat source (or a controllable heat source), and a portable heating device will be required, in any case.

A second strategy towards testing vents and ducts for thermal effectiveness is to use only a portable and controllable heat source, and also control air flow into the system. This strategy offers the advantages of wider application and greater ease of use. It may also turn out to provide acceptable resolution even for testing chimney systems with high masses (although field tests are required to resolve this issue).

It was proposed that a portable electric heat source be used, in combination with a fan of known flow characteristics, and that temperature be measured by means of a fast-response thermistor array, connected to a computer monitoring and display system. Initially, it appeared to be excessively complicated (and risky) to incorporate the heat source, sensors, and computer display into the air flow measurement system of the Flow Tester. Consequently, the two testers were developed separately, and only combined at a later date when field testing and construction of the device revealed obvious advantages in doing so.

A variety of devices were explored for purposes of inserting a thermometer up a chimney. Eventually, the best device was determined to be a high-quality, tensile steel electrician's tape mounted in a spool, and designed for feeding up large wall cavities. A cage has been fabricated around the top of the electrician's tape so that as it is unwound and inserted up a chimney, the tip of the tape is held away from the walls of the chimney. No easy way as yet has been determined for locating the very top of the chimney, except by exiting the house and observing the tap as it begins to protrude from the chimney top. The electrician's tape (with a thermometer attached) is illustrated in Photograph 9.

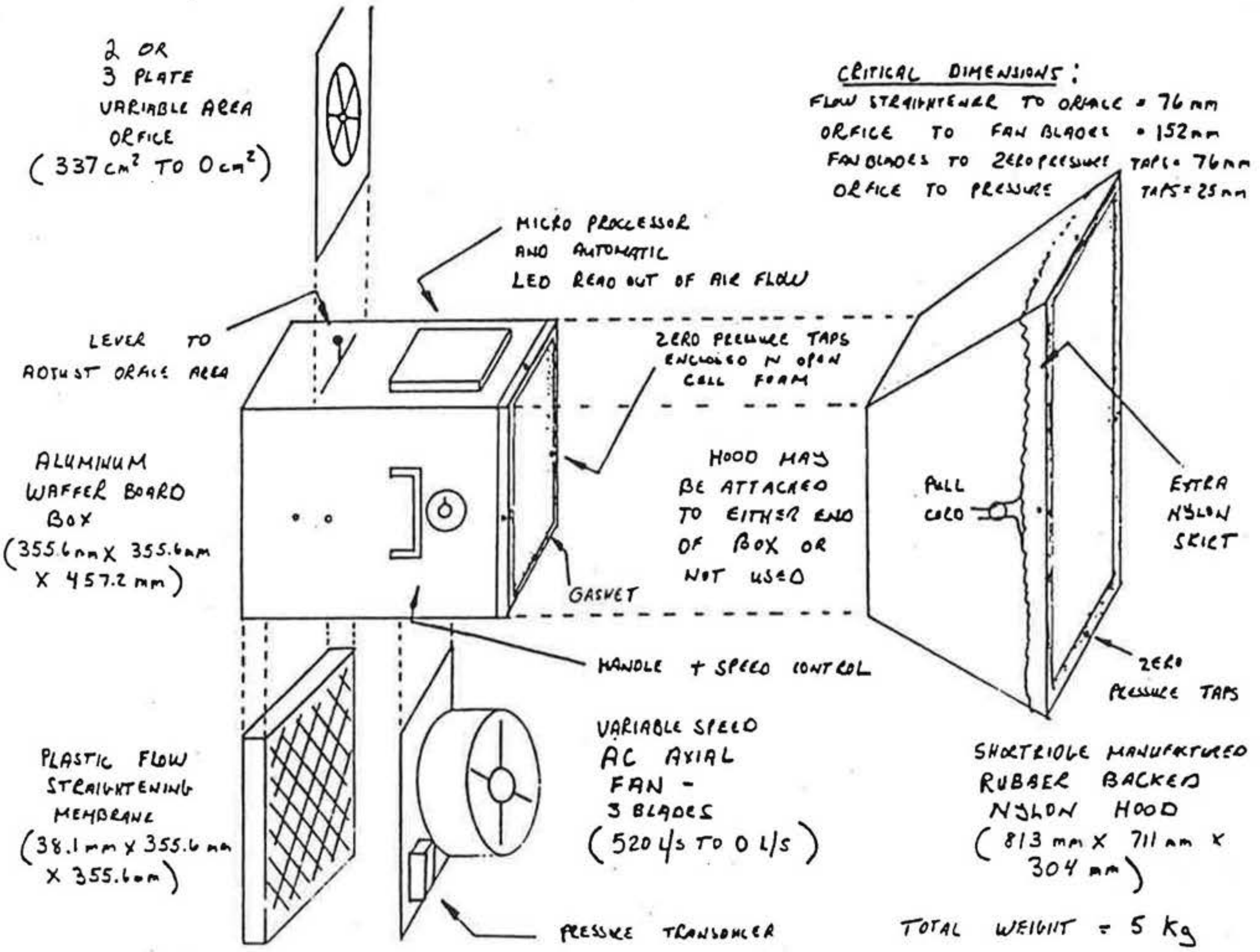
As a heat source, it was initially proposed to use a commercial heat gun generating 1400 watts and approximately 10 L/s flow. A heat gun is a convenient heat source because it is designed for hand-held operation, and is therefore safe, durable, and easy to use. Heat guns are available in varying wattage up to 1400 W, and therefore provide the maximum heat delivery that is likely to be obtained from a house circuit without blowing fuses. The heat gun was tested to determine sensitivity of air flow to static pressure changes in the system under test. It was found that the variations in flow typical of ducts and vents will not significantly alter the free flow rates for the heat gun. However, the heat gun circuitry was difficult to adapt into a hood for the DTR, and, when the heater was later incorporated into the DTR, the heat gun was rejected in favour of a duct heater.

For purposes of temperature sensing, monitoring, and display, it was proposed to use an Independent Energy Goldline DM30 Programable, Digital Temperature Monitor. The DM30 is a low-cost, stand-alone monitor designed for installation with solar heating systems. It can be connected with a computer but incorporates a keyboard and display of its own. The device monitors temperatures from up to six thermistors, in degrees Celsius, with a temperature accuracy of ± 0.5°C over a range of -32°C to 108°C. The DM30 weighs 540 g, is battery operated, and, presumably, can be mounted on a shoulder strap for easy reference during testing. In addition to monitoring six temperatures, the DM30 will store the minimum and maximum temperatures for one of the temperature locations. Presumably, these minimum/maximum temperatures would be taken at the chimney top, and will correspond with the start and end temperatures for the test. The DM30 will also record the test time in seconds, from start to finish. (It can also be used to shut off (or turn on) the heat gun by means of a relay switch, although this does not seem a useful feature at present.)

Photograph 9: CHIMNEY INSERTION DEVICE AND THERMOMETER

An advantage to using a heat device with the DTR and electrician's tape is that an entire chimney system can be tested separately from the appliance, under controlled conditions, with known heat input and air flow. Because the electrician's tape is extremely thin and flexible, it can be inserted at the base of the chimney and then the vent connector re-connected. The thermal hood can be fitted to the vent connector (or to an inlet grille) using an insulated, flexible hood. The thermal performance test is thus a relatively convenient, and standardized test that will provide the operator with data on heat input, air flow, temperatures at varied locations, and minimum and maximum temperatures at the chimney top. Flows and pressures can also be accurately monitored, with the DTR.

Figure 5: EARLIEST SCHEMATIC OF DTR (COMPLETED PRIOR TO BUILDING AND MODIFYING THE DEVICE FOR FIELD TESTING)



THE DEVELOPMENT AND EVALUATION OF A DEVICE FOR TESTING RESIDENTIAL DUCTS, VENTS, AND CHIMNEYS

APPENDIX III

BUILD AND EVALUATE PHASE

March 10, 1988

INDEX

1. INTRODUCTION

The second phase of the project involved the building of a Version 3 Prototype Duct Test Rig and its evaluation on a complete range of residential ventilation systems. In the process, the Duct Test Rig evolved considerably from the schematics developed during the Design Phase (Appendix II). This Appendix describes the major changes that occurred. Some of these changes were incorporated into the Version 3 Prototype during the process of building and evaluation. Other changes were adopted for our fourth and final Prototype.

This Appendix also includes a summary of the flow and pressure data collected during our tests of ventilation systems.

2. A SUMMARY OF DESIGN CHANGES

With the evolution of the Duct Test Rig, it is apparent that the device has become a portable flow chamber capable of performing field tests on installed systems. The design of the Duct Test Rig is not dissimilar from an ASHRAE/ANSI rectangular flow chamber with a nozzle wall in the centre. It is simply a smaller, field version of a flow chamber and, as long as a way can be found to mate this chamber with whatever device is being tested, the resulting data on pressures and flows should be trustworthy and accurate for most, or all, research purposes. Essentially, it is a basic tool that can be applied to many different tasks, depending on the kinds of accessories available. The field evaluation has produced a number of new or modified accessories.

2.1 Orifice Design

The three-piece orifice that was designed and presented in the Design Phase was found to be too small in area to permit the maximum flow required for the Duct Test Rig. Without using an iris diaphragm, there seemed to be no alternative but to use a series of fixed orifices and to design the Duct Test Rig box in ways that these orifices could easily be replaced. Experimentation with the prototype revealed that an orifice larger than approximately 250 mm in diameter would be affected by the flow straightener (which represented a greater restriction). Within the proposed dimensions for our flow chamber, a 225 mm diameter would be the maximum orifice size.

A series of orifices were cut out of Kydex plastic and calibrated with Sheltair's flow calibration chamber. The turbulence created by the sharp-edged orifices limited the amount of air flow, and flow range that could be obtained for a single orifice diameter. It was also difficult to ensure a perfect orifice area, and, therefore, each orifice would have to be separately calibrated for any replacements or future editions of the Duct Test Rig. To overcome these problems with fixed orifices, a decision was made to use fan inlet rings - pre-manufactured by companies producing centrifugal blowers.

After phone calls to all North American manufacturers, suitable fan inlet rings were located from EBM. A complete range of inlet rings was ordered and obtained on a rush basis from Germany. The orifices ranged from approximately 50 mm to 300 mm in diameter, and were shaped like a venturi ring approximately 25 mm deep. These inlet rings are manufactured to high tolerances, and could eliminate the need for re-calibration. A further advantage was the much smoother, less turbulent flow created by the venturi orifices - producing a larger flow range for each orifice size.

The Duct Test Rig box was modified with piano hinges and butterfly clamps to permit the front section of the box - containing the flow straightener - to be hinged open for easy replacement of the fixed-size orifices. This approach was used during the Duct Test Rig field evaluations. Flow/pressure data for the inlet rings was obtained from tests with the flow calibration chamber. The Duct Test Rig was mounted on the end of the chamber by removing one of the walls. The results of this calibration are presented in Figure 1.

Figure 1: CALIBRATION OF FAN INLET RINGS

Diameter of Inlet Ring (cm)	C value*	n value*
8	5.03	0.497
13	11.46	0.509
25	0.86	0.39

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* Flow in l/s = C ΔP^n

Field evaluations of the Duct Test Rig fixed-size orifices revealed that a fixed size orifice was not suitable when trying to determine the flow versus pressure relationships. To create any significant amount of back pressure when testing an exhaust device, it was often necessary to reduce the size of the orifice. This meant dismantling the Duct Test Rig in the middle of a test on a single ventilation system. The field experience emphasized the value of an adjustable orifice, and instigated a second search for an affordable iris diaphragm to be used in place of fixed-size orifices. Fax, Telex, and phone queries were sent to a variety of manufacturers, and, eventually, an appropriate size and price of adjustable orifice was discovered in Finland. This device is now on order and is expected to be incorporated in the final version of the Duct Test Rig.

Although the fixed-size orifices proved cumbersome in field testing, they, nevertheless, appeared to confirm the value of orifices per se as a suitable approach to flow measurement of residential ventilation systems. No other technology is adequate for measuring the extreme range of flows encountered in houses. On a number of occasions, an orifice with a diameter of only 25 mm was required to track the extremely low flows through vents and passive inlet ducts. If an adjustable orifice can be fitted to the existing prototype, the Rig should be capable of an extremely high rate of accuracy over a wide flow range.

2.2 Carrying Tripod

Despite the light-weight design of the Duct Test Rig, the field evaluations revealed major problems for one-man operation. To understand the problem, trying holding a book above your head for approximately two minutes, with both hands, and flipping the pages. Now imagine trying to hold a 5 kg box while trying to control the speed precisely and maintain a good fit between the gasket and wall or ceiling fan. Very tricky. Additional difficulties were encountered with trying to fit the Duct Test Rig into tight spaces like above toilets or in corners of rooms. These experiences emphasized that, even with two people using the Duct Test Rig, it is extremely inconvenient for a person to have to hold the device throughout a test.

A solution for this problem was found in the form of an adjustable camera tripod, manufactured in Italy and sold for less than $100. A customized aluminum extrusion of webbing or frame was created that could be bolted on the top of the tripod, similar to a camera. The Duct Test Rig can then be laid across this frame, either vertically or horizontally (depending on whether you are testing wall or ceiling mounted system). The height of the Duct Test Rig can then be varied by cranking the tripod from 300 mm up to approximately 2300 mm. The Duct Test Rig can also be firmly pinned against any wall or ceiling surface, since the tripod has a crank and can be used to apply a positive connection once the device is set up.

The tripod also proved useful when setting up for testing furnace blower and furnace flue flows, since these can be fairly long duration tests. By mounting the Duct Test Rig at waist or shoulder height, on the tripod, the operator can conduct the test and record the data in a much more efficient fashion. The tripod is sufficiently lightweight and small that it will be included as part of the accessories to the Duct Test Rig.

2.3 Reversible Foam Gasket

The original design of the Duct Test Rig incorporated a 12 mm thick neoprene gasket around the ends of the Duct Test Rig so that the Rig could pressed against any wall or ceiling opening for an airtight connection. The field evaluations revealed a high number of irregularities around the grilles and openings that were being tested. In many cases, the foam gasket we were using had inadequate throw to provide a tight seal. For example, siding on the outside of a house could present a 25 mm corrugation around the outside of a hood - considerably in excess of the overall weatherstrip dimensions.

The second problem with the design of the Duct Test Rig was that the flow straightener was mounted approximately 25 mm inside of the outside edge of the Rig, and whenever a hood or other item protruded from the duct under test, the flow straightener would hold the gasketed edge of the Duct Test Rig out from the surrounding wall or ceiling surface. This was particularly a problem with external testing of dryer hoods and HRV's.

A solution to both these problems was achieved through custom manufacturing a lightweight foam collar, approximately 70 mm deep and designed so as to slip over the end of the Duct Test Rig chamber.

The foam collar was fabricated from a specialty foam rubber, rigid but lightweight. laminated with a spray adhesive. This foam collar proved to be extremely versatile. It could, optionally, be slipped over either end of the Duct Test Rig, measuring exhaust or supply flows. It could also be left off entirely if not needed. The thickness of the foam allowed the Duct Test Rig to mate to even extremely irregular surfaces. And, if small gaps were left around the foam in such situations, there were not, apparently, significant in influencing the flow measurements, since the zero pressure approach causes little or no leakage around the hood.

2.4 Downstream Duct Requirement

The original design of the Duct Test Rig incorporated a variable-speed axial fan mounted in the centre of a flow chamber. This design experienced a couple of serious problems. Firstly, a huge swirl occurred downstream of the axial fan which interrupted zero pressure readings around the hood. A second problem was encountered when the Duct Test Rig was mated to a restrictive duct or vent, and used to create a positive pressure. Because of the gaps that existed between the fan blade and its inlet ring, back pressures were being transferred upstream into the orifice chamber and, if high pressures were encountered, they would influence our flow readings.

Fortunately, both these problems were completely solved by fabricating a 100 mm long, 250 mm diameter straight duct section and attaching this to the trailing edge of the fan inlet ring. This short length of duct managed to completely eliminate the swirl impact on the zero pressure taps around the perimeter of the hood, and prevent any back pressures from being transferred around the perimeter of the fan blades.

2.5 Separate Control Module

Our initial proposal included a control module that was mounted directly on the surface of the Duct Test Rig's flow chamber. This approach had seemed to the simplest one, allowing the operator to hold and operate the Rig while easily reading the displays. This design, however, proved to be problematic during the field evaluations. The greatest problem occurred when trying to match the Duct Test Rig to a variety of ducts and vents, at different angles and locations. Frequently, the control module would be hanging upside down, or backwards, with respect to the operator. Cramped conditions also made it difficult to see the Duct Test Rig control module properly and to control the fan speed. And lighting made it difficult to read the control module, especially with reflections on the digital panel meter.

The solution to these problems was to construct a separate control module, that can be mounted, optionally, on top of the Duct Test Rig, or detached and hung over the shoulder - connected to the Rig with an umbilical cord or sheath containing wires and pressure taps. This retrofit was incorporated into the Duct Test Rig during the process of field evaluation and was found to work well. In combination with the tripod, it is still possible to use the Duct Test Rig as a one-man operation, since the operator can remain at a distance from the Rig while conducting the tests. The detachable control module also facilitates a two-person operation. The separate control module includes the speed control, two pressure transducers, and all the computer chips and display panels.

2.6 Computerized Readout Proves Too Costly

The initial plan was to design and build a Duct Test Rig control/display to convert pressure transducer signals and temperature signals into flow outputs using an analog to digital converter, a computer chip, and an EPROM containing orifice equations. A digital panel meter on the Duct Test Rig would thus continuously display key data including: hood pressure, internal air temperatures, remote air temperatures, air flow in litres per second, and ELA values in square centimeters.

An extensive amount of research and discussion ensued to try to incorporate such a computerized display in the Duct Test Rig for this project. Written quotes were received from four different contractors for constructing this module, including Sciemetrics Instruments, Ottawa (who were prepared to adapt their existing product line of data acquisition and control systems); Star Heat Exchangers, of Coquitlam (who had fabricated similar control and display modules for use in heat recovery ventilators); a local equipment instrumentation company (that designs similar controls and displays for plant machinery); and Shortridge Instruments, of Colorado (who have incorporated much of this type of technology into their air data multimeter). Prices ranged from $2,800 to $5,000 for a single control module for our prototype. Of course, because of the micro-circuitry involved, these one-off orders were very costly. Any further units would be cheaper by a factor of 10. Because the complexity and cost of these devices exceeded our budget, we have been forced to consider alternatives. Computerized control and read-out will have to wait until at least five or ten of these devices are being constructed at a time.

Our compromise approach is to have direct digital read-out of pressure and temperature and provide the operator with the option of using a hand-held computer (or simple paper graph) to correlate the orifice pressure and orifice size with the actual flow. If flow also needs to be corrected for temperature (which is rarely required in residential situations due to the extremely low error resulting from density changes), then this would be a further input for the hand-held computer. This approach was followed for the field evaluations and produced no problems.[1] By means of innovative use of volt meters, it was possible to obtain a fairly inexpensive digital read-out directly in units of degrees Celsius, or Pascals.

2.7 Chimney Thermal Tester

The initial design of the chimney thermal testing component of the Duct Test Rig incorporated a separate unit to provide heat to a vent or duct, and to match flow rates through the vent or duct. Although this device was fabricated and tested, it was found unnecessary. Instead, a series of hoods were designed that could snap on to either end of the Duct Test Rig flow chamber. These hoods reduced the Duct Test Rig opening to a round duct fitting suitable for connecting to flue pipes. Inside the duct fitting, we incorporated a heating element. A variety of heating elements were tested for this purpose. A car heater was used, and, later, two barbecue briquette lighters were squeezed and wrapped together to fit inside a 75 mm duct. Eventually, it was discovered that the best and most convenient approach was to use a CSA approved, 150 mm diameter. in-line duct heater with 1 kW heat output. This device was mounted to a expander so that it could be attached to the Duct Test Rig, and, on the other end of the heater, a series of spun aluminum expanders and reducers can be slipped on to fit the device to flues or ducts ranging from 75 mm to 200 mm in diameter. This duct heater is lightweight, safe, reliable, and it has a temperature over-ride on it to prevent overheating. During field testing, no situations were encountered where the heater output was shut down to avoid excess temperatures. However, to ensure that the test does not continue while the heater has shut off due the fail safe, an LED is being used to alert the operator.

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[1] When conducting a large number of tests on a variety of ventilation systems, it was not found necessary to have an immediate read-out of flow data. Instead, the data was collected and then quickly computed into flows at the end of the testing period.

The duct heater and expanding/reducing kits worked well in combination with the electrician's fish tape and solid state thermometer system designed and tested during the previous phase of work. The AD590 thermometer provides a very rapid and accurate output in millivolts equivalent to degrees Kelvin. This thermometer is being connected to additional circuitry so that temperature reads out in degrees Celsius. A switch on the volt meter directs the output from the remote AD590 (at the chimney top presumably) to the panel meter, or directs the output from an additional AD590 mounted inside the Duct Test Rig, for a readout of air temperatures in the orifice chamber.

The electrician's fish tape and thermal tester were easy to insert into the chimneys during field evaluations and the system appears to work well. Although the duct heater produces only 1 kW of heat output, it was sufficient to generate a significant increase of flow in these chimneys. The air flow was easily matched and measured through the Duct Test Rig.

3. FIELD TEST PROCEDURES

A newspaper advertisement was placed to identify houses where occupants would be willing to permit Sheltair to evaluate the Duct Test Rig on a variety of ventilation systems. Although it was hoped to complete all the field evaluations on six or fewer houses, it was necessary to visit houses in order to include in the test data the results of air flow and pressure testing on a complete range of systems.

Because of the difficulties encountered with the fixed-size orifices, it was not always possible within the time allowances to conduct flow measurements at varying rates of back and forward pressures. However, zero pressure measurements were conducted on all systems in each of the houses tested. A more detailed pressure versus flow profile was also produced, but only on a small number of systems. No flow versus pressure data were collected on forced-air distribution systems within houses since the potential for back and forward pressures seemed less significant, and was difficult to measure.

To the best of our knowledge, the flow data collected using the Duct Test Rig is extremely accurate, with possibly less than ± 5 percent error. It is still too early to estimate the instrument and operator error. The method error is superior to any alternatives but cannot be determined without an extensive series of experiments.

An exception to the high level of accuracy and repeatability, is the test data collected conducted on fireplaces. Despite the custom designed hood for mating the Duct Test Rig to the outside of fireplace openings, the connections to the fireplaces were never very good. Very rough surfaces around the fireplace were almost impossible to seal well, and some amount of leakage occurred inevitably around the edges of the hood. In addition, it is certain that an additional amount of leakage is also occurring through masonry materials around the firebox - particularly leaky areas behind the brick facade at the front of the fireplace. Air can thus leak into the firebox bypassing the Duct Test Rig. For these reasons, the Duct Test Rig underestimates flow through fireplaces, probably in the range of 5 to 15 L/s, depending on the draft pressures created by the fireplace, and the design and construction of the firebox.

4. RESULTS OF THE FIELD TESTS

Tables 1 to 7 summarize the flow, pressure, and temperature data collected during the field tests.

Table 1: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
4435 Dawn Dr. Delta, B.C. New 2 Storeys	Bath Exhaust Main Floor	200 mm X 200 mm Broan F650	0	10.7	
	Bath Exhaust Second Floor	200 mm X 200 mm Broan F650	0	11.7	
	Masonry	Site Built	5	33.7	Closed Damper Fireplace
			10	16.2	
	Living Room		15	21.0	
			20	24.4	
			25	28.3	
			30	30.4	
			35	34.1	
			40	36.1	
	Range Hood Kitchen	4 X 12" Broan 58000	0	66.8	
5451 Grove Ave. Delta, B.C. New 2 Storeys	Bath Exhaust Main Floor	200 mm X 200 mm Broan F650	0	5.5	
	Bath Exhaust Second Floor	200 mm X 200 mm Broan F650	0	6.2	
	Range Hood Kitchen	Nutone LL6100	0	14.0	Difficult to connect
2127 W. 6 Ave. Vancouver, B.C. 12 years old 3 Storeys	Masonry Fireplace	24" X 32" Firebox Opening Site Built	5	15.5	Tight fitting damper - closed
			10	23.1	
			15	29.9	
			20	34.7	
			25	40.1	
			30	43.8	
			35	48.7	
			40	53.3	

Table 2: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
2376 W. 13 Ave. Vancouver, B.C. 45 years old 2 Storeys	Bath Exhaust	Nutone Q-Test	0	25.3	Fan operated at lowest speed.
	Furnace		50	36.5	No heat input. Flow versus pressure for chimney opening.
			45	35.0	
			40	33.0	
			35	31.0	
			30	29.0	
			25	25.0	
			20	25.0	
			15	18.0	
428 Sea Shell Dr. Delta, B.C. New 2 Storeys	Dryer Laundry Room	100 mm diameter Whirl Pool	0	25.5	Used Extendable duct (one-man operation)
	Hot Air Register Family Room	100 mm X 250 mm	0	14.0	On exterior of house. A reasonably tight fit.
	Hot Air Register Family Room	100 mm X 250 mm	0	14.0	
	Bath Exhaust Main Floor	200 mm X 200 mm Broan F650	0	11.0	
	Bath Exhaust Second Floor	200 mm X 200 mm Broan F650	0	14.0	
	Hot Air Register Front Entrance Hallway	100 mm X 250 mm	0	18.0	
	Range Hood Kitchen	Nutone	0	50.0	
	Return Air Main Floor Hallway	150 mm X 550 mm	0	96.0	Very difficult to fit, had to tape return air. Needed foam extender.

NOTE: Impossible to connect to either fireplace with existing hood because: one was marble with a rough face; and the other was flat brick with a protruding door.

Table 3: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
2222 Qualicum Delta, B.C. New 2 Storeys	Vacuum Inlet Living Room	50 mm diameter Central Vacuum	0	18.0	
			0	17.4	
			0	20.0	
	Range Hood Kitchen		0	40.0	Measure from exterior of house.
	Vanee Garage		0	90.73	Both the outlet and intake were marked with flow gas measurements of 87 L/s.
			0	68.84	
	Dryer Laundry	Hot Point Cameo II	0	33.0	
	HRV Basement	Vanee	0	10.9	Fresh air grille outlet
3424 W. 6 Ave. Vancouver, B.C. 40 years old 2 Storeys	Hot Air Register Living Room Main Floor		0	6.8	Loose fit
	Return Air Living Room Main Floor		0	17.5	
	Hot Air Register Family Room Main Floor		0	19.0	
	Masonry Fireplace Family Room Main Floor	Site Built	0	57.0	After 3 min. operation.
			0	64.0	After 5 min. operation.
			5	39.0	Pressure test on fireplace chimney with damper closed. Difficult to make a tight seal between hood and brick face of fireplace.
			10	48.0	
			15	56.0	
			20	65.0	
			25	71.0	
			30	78.0	
			35	84.0	
			40	91.0	
			45	97.0	

Table 4: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
845 W. 46 Ave. Vancouver, B.C. 13-28 years old 1.5 Storeys	Hot Air Register Living Room South Wall Floor grille	100 mm X 250 mm	0	13.3	Householder had closed off grilles which produced low flows
	Hot Air Register Living Room South Wall Floor grille	100 mm X 250 mm	0	8.4	Householder had closed off grilles which produced low flows
	Return Air Living Room North Wall Wall grille	150 mm X 750 mm	0	33.4	
	Return Air Dining Room East Wall Wall grille	150 mm X 750 mm	0	29.2	
	Bath Exhaust Master Bath Ceiling	250 mm X 150 mm	0	22.6	
	Furnace	Airco	0	8.1	Covering combustion air and draft air intakes
			60	13.2	
			120	14.5	

Table 5: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
109 W. 3 Ave. Vancouver, B.C. 50 years old 1 Storey	Bath Exhaust		15.3	8.6	
			11.7	9.8	
			10.0	10.5	
			6.0	12.2	
			3.1	13.7	
			0	16.5	
			-1.79	18.0	
			-3.8	20.0	
	Bath Exhaust		21.9	5.0	
			19.92	5.2	
			13.9	11.4	
	Intake grille Washroom	200 mm X 200 mm	0	15.0	
	Masonry Chimney	200 mm X 200 mm	0	41.0	Test at base of chimney with 2.2 kW heat supplied.
			0	45	No heat
	Wall Intake	150 mm diameter 1.8 m long 100 mm diameter grille	5	9.21	
			10	11.58	
			15	13.43	
			20	15.1	
			25	16.5	
			30	17.9	
			33.8	18.79	

Table 6: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
Litton, B.C. 2 Years Old 1 Storey	Floor Register Living Room		0	19.36	41 cfm
	Floor Register Kitchen (by door)		0	16.74	35.5 cfm
	Floor Register Bathroom		0	16.16	
	Floor Register Back Bedroom		0	19.1	
	Floor Register Bedroom #2		0	19.4	
	Return Air Bedroom #2		0	2.6	
	Return Air Side Bedroom		0	0	
	Supply Side Bedroom		0	19.1	
	Horizontal Supply Kitchen		0	4.2	
	Supply Living Room		0	5.9	
	Ceiling Supply Basement Bedroom		0	27.0	
	Ceiling Supply Storage Room		0	24.9	
	Ceiling Supply Basement Hall		0	26.8	

Table 7: RESULTS OF FLOW TESTS ON RESIDENTIAL VENTILATION SYSTEMS

House Address And Description	Equipment Type and Location	Equipment Size & Manufacturer	Hood Pressure (Pa)	Air Flow L/s	Comments on Procedure
continued: Litton, B.C. 2 Years Old 1 Storey	Ceiling/Open Basement		0	22.0	
	Ceiling/Shut Basement		0	10.6	
	Ceiling/Shut Basement		0	10.7	
	Ceiling/Shut Basement		0	11.2	
	Hood		2.75	16.9	Taped and Supported
	Return Air Living Room		0	17.6	
	Return Air Hall		0	9.4	
	Return Air Hall		0	16.3	Hood mostly blocked

THE DEVELOPMENT AND EVALUATION OF A DEVICE FOR TESTING RESIDENTIAL DUCTS, VENTS, AND CHIMNEYS

APPENDIX IV

DUCT TEST RIG
USERS' MANUAL

March 29, 1988

CONTENTS

1. AN INTRODUCTION TO THE DUCT TEST RIG

1.1 Applications

The Duct Test Rig (or DTR) is an all-purpose device for making air flow, air pressure, and heat loss measurements in residential ventilation and venting systems.

It can be used by one or two persons, and is intended to provide rapid, accurate feedback on how the system is performing.

Essentially, the DTR is designed for three tasks:

1. air flow, air pressure, and air temperature measurements at inlet or outlet grilles, and at the entrance or exit opening of ducts and chimneys;

2. air temperature measurements at remote locations like chimney tops or exhaust hoods; and

3. heat generation and delivery to ducts, vents, and chimneys.

It can do all these tasks at the same time if desired. It can also be used to control the conditions under which the measurements occur. For example, flow into an exhaust fan can be measured at selected amounts of backpressure, or forward pressure; or chimney top temperatures can be measured at selected amounts of heat input and air flow.

The DTR can be adapted to many possible applications. So far, it has been successfully used to measure the performance of the following systems:

- bathroom exhaust fans,
- kitchen range hoods,
- clothes dryers (from outside the house),

- central vacuum systems,
- fireplaces (operating and not operating),
- masonry chimneys,
- B vents,
- furnace/chimney systems (operating and not operating),
- circulating blowers on warm air furnaces,
- warm supply registers,
- return air inlets,
- through-the-floor diffusers,
- make-up air ducts, and
- inlet and exhaust openings for air-to-air heat exchangers.

1.2 Operating Principles

The Duct Test Rig (DTR) is comprised of two major components and a number of accessories. One major component is the "flow chamber" which contains an electrically powered fan and an orifice plate for flow measurement. The other main component is the "control module" which provides pressure and temperature readouts and fan motor speed control.

The flow chamber contains a variable speed fan and an orifice plate with variable settings. The variable speed fan is used for back pressure compensation - in other words, to compensate for the flow losses that would otherwise occur because of internal restrictions within the DTR.

The orifice plate is fitted with pressure taps on either side. The pressure drop across the orifice provides the flow measurement. This pressure drop is read in Pascals and converted to flow using the calibration curves or formulas.

Orifice Plate (flow measurement):

The orifice plate is fitted with pressure taps on each side so that pressure drop across the orifice can be measured. This pressure drop is displayed on the panel meter located on the control box panel. The pressure range of the meter is 0 to 500 Pa. (This range is not fully utilized since the DTR maximum pressure drop limits at about 240 Pa.)

The variable orifice plate has 5 click-stop settings. A calibration curve of FLOW versus PRESSURE is provided for each setting. In addition the variable orifice plate can be removed to provide maximum flow through a fixed nozzle.

Hood Pressure Control:

The DTR is fitted with pressure taps at each end of the box. A foam gasket fits to either end of the flow chamber to create a tight seal between the DTR and any small opening. A nylon hood is provided to fit larger openings and this is also fitted with pressure taps. These pressure taps are connected to the control box and a panel meter on the right hand side of the box reads the pressure to a resolution of 0.1 Pa. Care must be taken not to exceed the range limits of this sensitive pressure transducer which is +- 50 Pa. (NOTE: the panel meter will not read below -39 Pa and reads -39 Pa even if the pressure is, for example, -100 Pa.)

The DTR contains a variable speed fan which is used for two basic purposes:

1. The fan eliminates the flow restriction caused by placing the DTR in front of the ventilation device under test.

   This is accomplished by setting the hood pressure to zero by varying the speed of the DTR fan. Hood pressure is measured at the entrance of the ventilation device using the pressure taps at the ends of the DTR.

Depending on whether the ventilation device is supplying or exhausting the pressure taps of the DTR closest to the ventilation device are used and these are selected using the HOOD PRESSURE SELECT VALVE on the control box.

If properly zeroed prior to test the hood pressure can be brought to zero within less than 0.5 Pa.

2. The fan produces a pre-determined amount of back pressure, or forward pressure, to determine pressure sensitivity of the ventilation device.

   Vary the fan speed and/or the orifice plate to establish a positive (50 Pa max.) or negative (-39 Pa max.) backpressure. Follow the instructions above if unfamiliar with the method of hood pressure measurement.

1.3 Basic Components

The basic components of the DTR have been itemized and are briefly described in the following list. Refer to the Figures 1, 2, and 3 for proper identification:

Control Box External Components (Figure 1):

1. Pressure or Temperature display using a Novatron N351-02 panel meter.
   - Pressure units are in Pascals
   - Pressure indicates the PRESSURE DIFFERENCE between the hood (i.e. either end of flow chamber) and the ambient pressure
   - Temperature units are in Celsius
   - Temperature indicates either internal flow chamber air temperature (T1) or the remote temperature probe (T2)
2. An ON-OFF switch, and a course speed control.
3. Fine speed control.
4. Zero adjustment for flow pressure transducer.
5. Zero adjustment for hood pressure transducer.

6. Display hold/run switch.
7. Temperature probe 4-pin connector.
8. Fuse holder (5 amp. quick action).
9. Hood pressure selector valve.
10. 4 quick connects for pressure tubing:

<u>Intake</u>

Hood. . . . . .Clear
Flow. . . . . .Black
Flow. . . . . .Red
Hood. . . . . .Blue

11. Hood pressure/temperature selector.
12. 4 meter 16/3 fan connector cable with 4 pressure tubes.
13. Flow pressure display using a Novatron N351-02 panel meter - pressure units are Pascals. Use Table 1 to get flow.

<u>Control Box Internal Components (Figure 2):</u>

14. Pressure transducer for flow pressure.
15. Pressure transducer for hood pressure.
16. Pressure transducer circuit board.
17. 12 volt 1 amp CT transformer.
18. Temperature transducer circuit board.
19. Tubing to connect pressure transducers.

<u>Portable Flow Chamber (Figures 3 and 4):</u>

20. Hood pressure tap.
21. Removable flow straightener.
22. Upstream pressure tap.
23. Orifice control rod.
24. Adjustable orifice.
25. Fixed orifice ring.
26. Downstream pressure tap.
27. Handles.
28. Fan inlet screen.

29. Temperature transducer and connector.
30. 4 external quick connects for pressure tubing.
31. EBM axial fan and motor.
32. Flow tube with flow straightener attached.
33. 3-prong male 120 VAC connector.
34. Outlet pressure tap

Duct Test Rig Components (Figure 5)

Flow Chamber Accessories:

35. Thick removable foam gasket.
36. Red nylon collapsible hood (transition from 350 X 350 mm to 1000 X 200 mm).

Temperature Measurement Accessories:

37. Hook up cable with 2 - 4-pin connectors and one 2-pin connector.
38. Electricians fish c/w AD590 sensor mounted in a centering cage, wiring and 2-pin connector.

Duct Heater:

39. 1 kw duct heater fitted with on-off switch and light. The duct heater is mounted on a flange with thumbscrews for easy attachment to the DTR.
40. Spun aluminum expanders and reducers for connecting to chimneys and ducts from 75 mm to 175 mm in diameter.

Tripod:

41. Tripod for supporting DTR up to 2900 mm above the floor.
42. Rectangular aluminum bracket which connects to tripod head and supports DTR in its vertical or horizontal positions.

Figure 1:
CONTROL CABINET

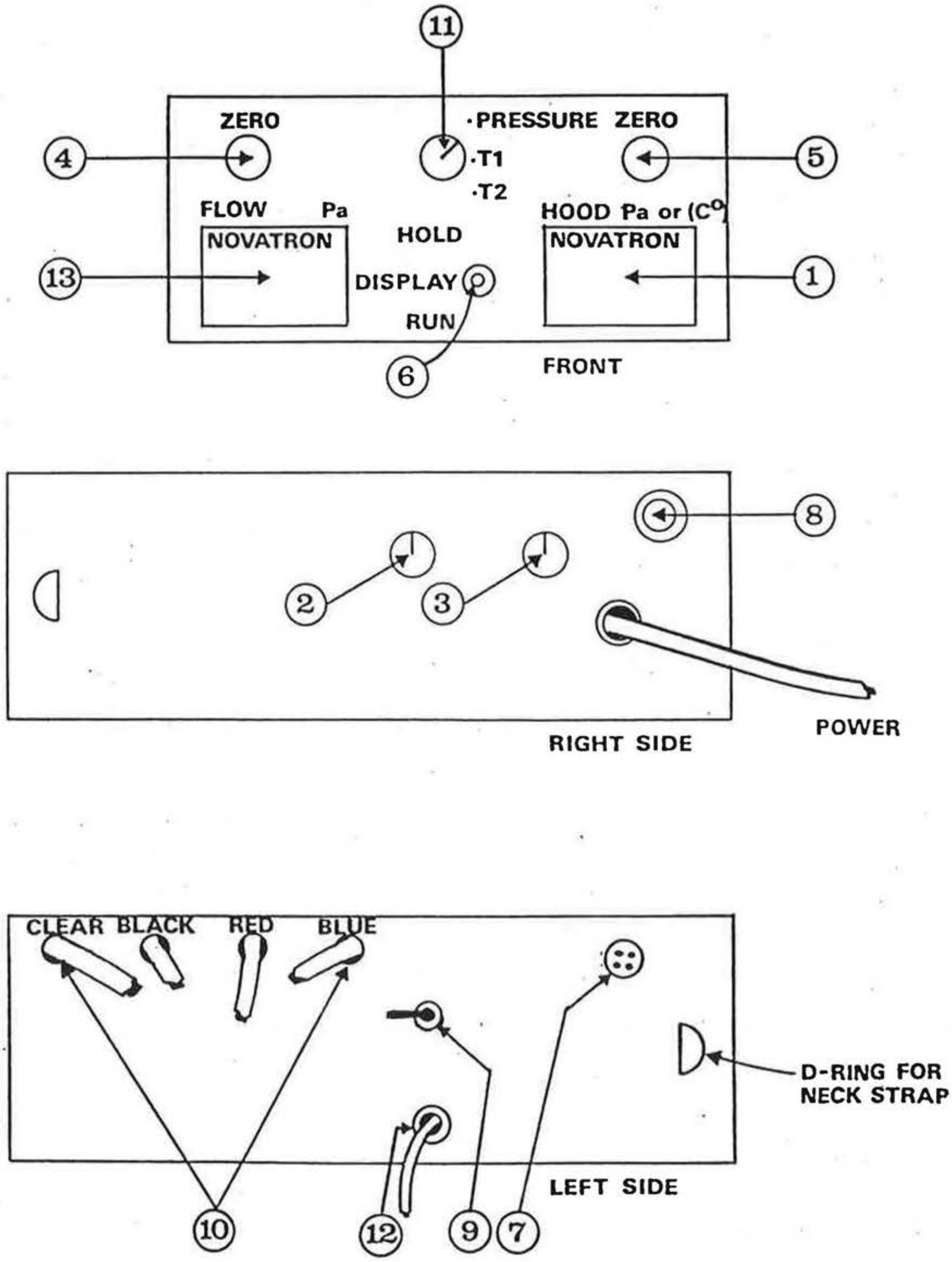


Figure 2:
CONTROL BOX INTERNAL LAYOUT (PLAN VIEW)

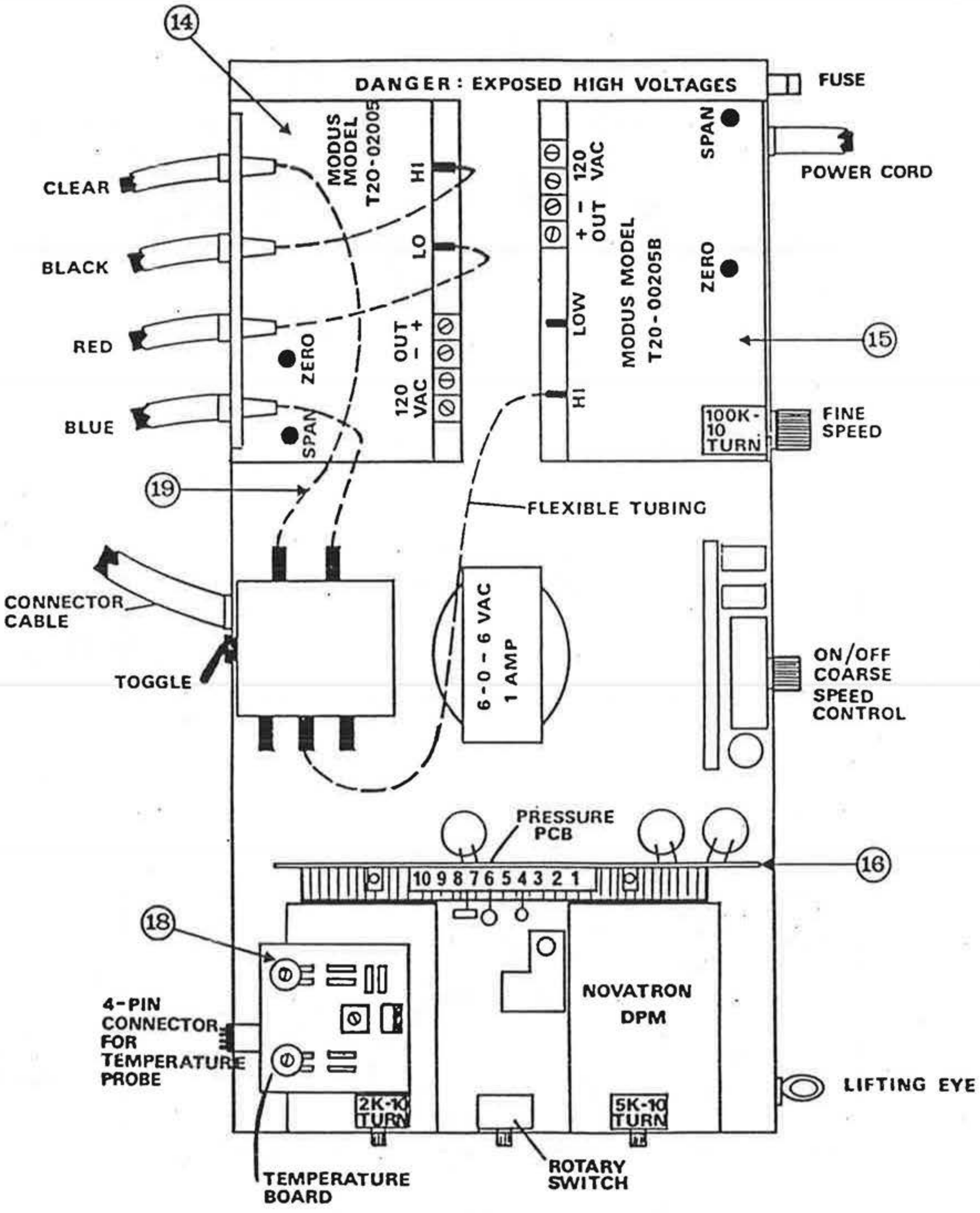


Figure 3:

PORTABLE FLOW CHAMBER (PLAN VIEW)

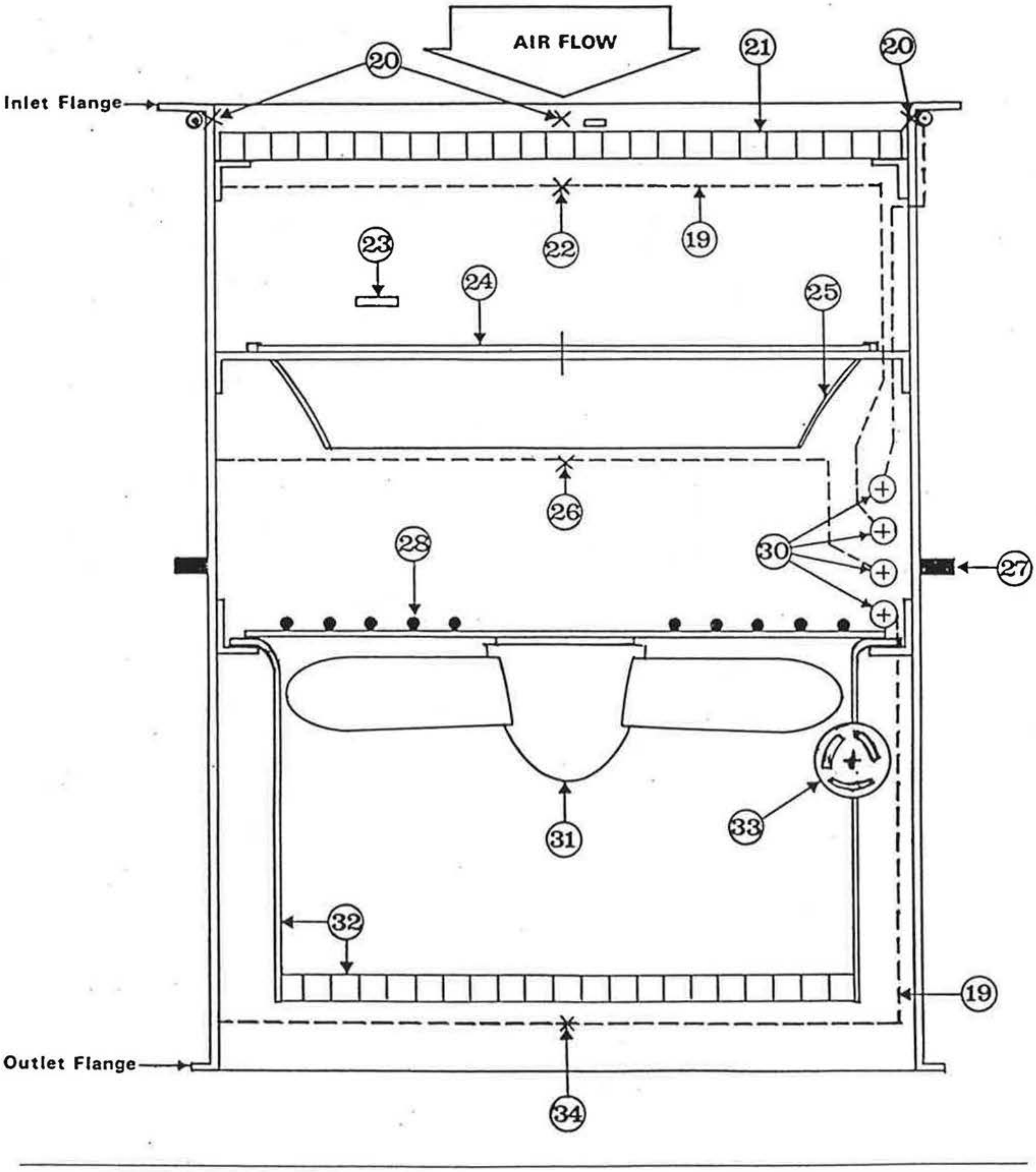


Figure 4:
CUT-AWAY DRAWING OF FLOW CHAMBER

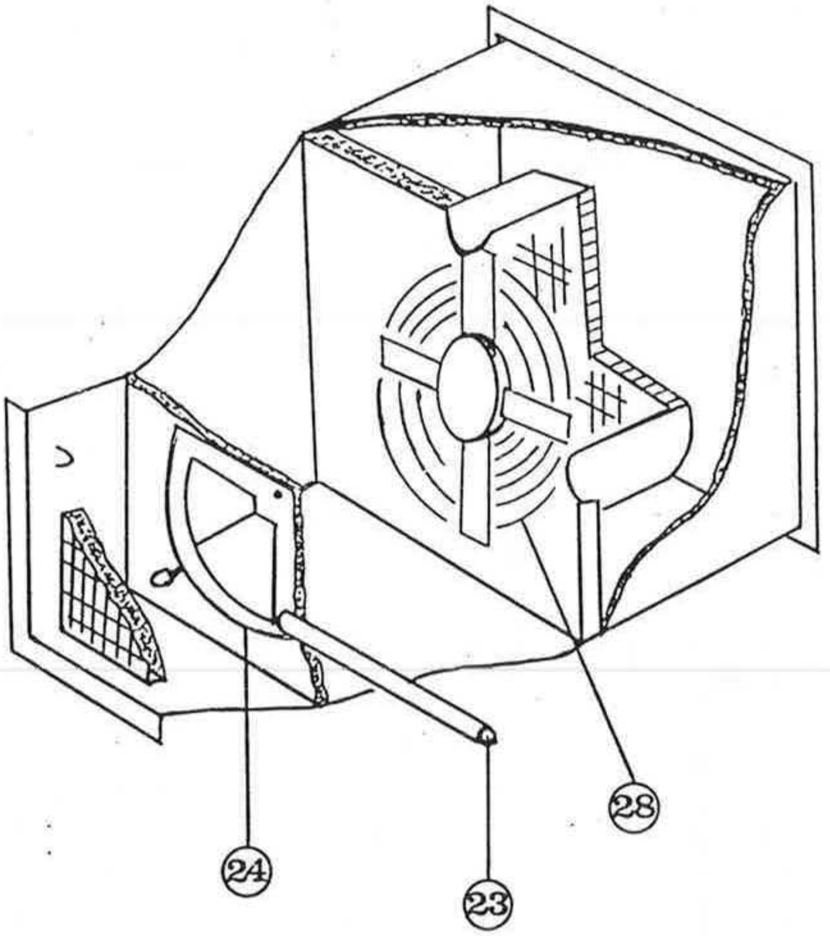


Figure 5:
DUCT TEST RIG COMPONENTS

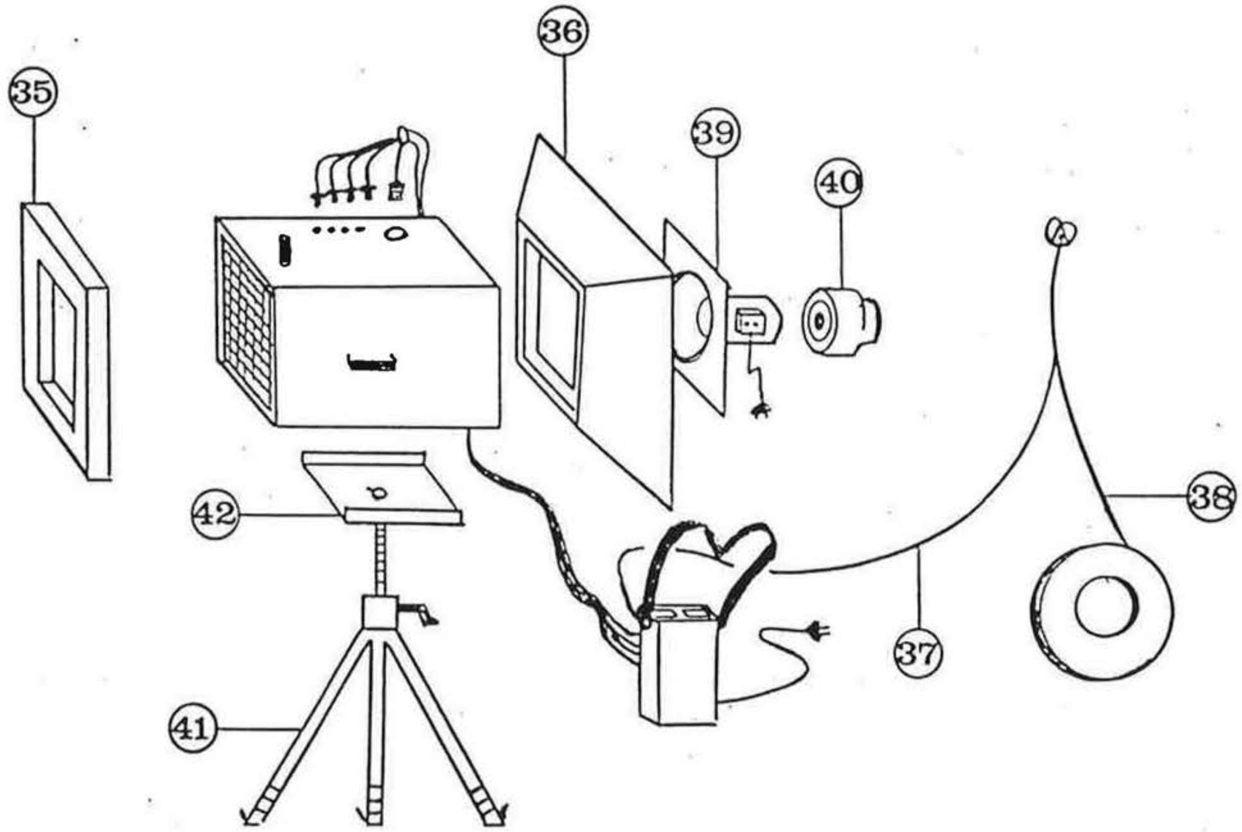
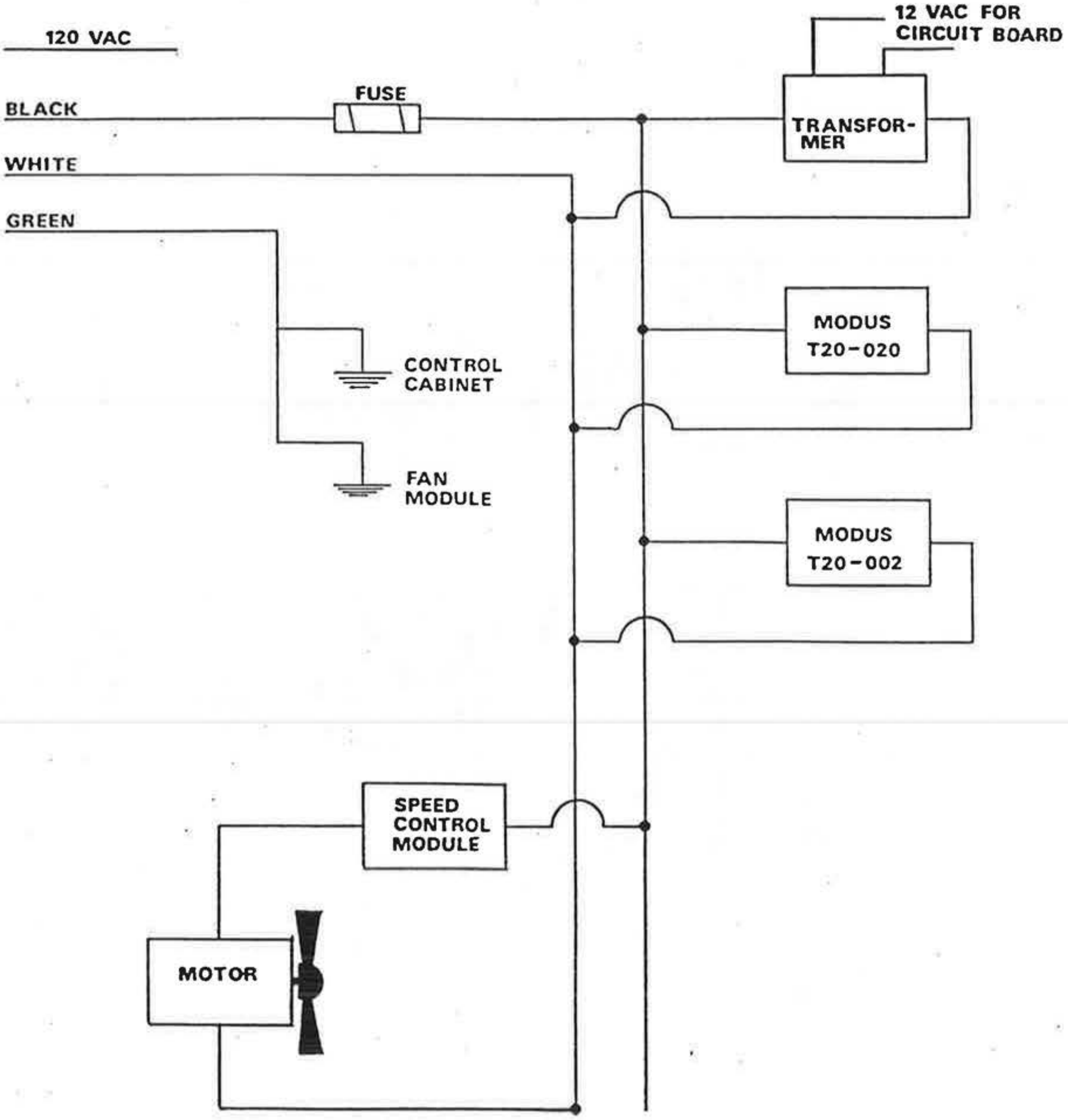


Figure 6:
DUCT TEST RIG WIRING DIAGRAM



2. OPERATING PROCEDURES

2.1 Set-Up

- Connect the Controls: Plug the control module into the flow chamber and connect the pressure tubes. The tubes and their connectors are colour coded. Also connect the temperature probes if temperature measurement is desired. When these are all connected the control box may be plugged into the main supply. Once plugged in, the digital panel meters should turn on. (Adjust the display switch to RUN if necessary. If they do not operate, refer to the maintenance instructions).

- Zero the Meters: Make sure that the selector switch is at the PRESSURE setting (not at T1 or T2). With the DTR plugged in and the fan turned off, adjust the two zero potentiometers on the front panel of the control box until both flow and hood pressures read zero.

  During the zeroing procedure the fan must be off and there should be no air flow through the DTR. In other words the DTR cannot be zeroed if it is positioned in front of a supply fan, return air duct, or other ventilation device as there will be air flow through the rig which will create measurable pressures.

2.2 Exhaust and Supply Fans

Inlet and Exhaust Grilles:

- Select a Suitable Hood: Select the thick foam hood for inlets less than 350 mm X 350 mm. For larger inlets, select the red nylon hood.

* Mount the Hood on the Correct End: Mount the hood on the DOWNSTREAM end of the DTR for inlet grilles (marked "O" for out), and the UPSTREAM end of the DTR for outlet grilles (marked "I" for in).

* Set the hood pressure select valve: Choose the EXHAUST position (lever pointing forward) for inlet grilles. Choose the SUPPLY (lever pointing back) position for outlet grilles.

* Place Flow Chamber Over the Inlet or Exhaust Grille: The flow chamber can be held in position over the grille if an assistant is available. Due to the size and weight of the chamber it is often more satisfactory to use the tripod and cradle.

* Select Suitable Orifice Setting: Once the flow chamber is in position over the fan, adjust the orifice size using white plastic control rod mounted on the side of the flow chamber. Push the lever in to reduce orifice size and pull it out to increase orifice size. Black lines on the lever indicate approximate location of the click stops. Set the orifice at a setting suitable for the flow to be measured. Use Table 1.

* Use Fan Control to Zero Hood Pressure: Turn on the DTR fan and slowly increase the speed until the hood pressure reads zero. Try to ensure that the hood pressure reading does not exceed 50 Pa or go lower than -38 Pa so that the pressure transducer is not overloaded.

* Re-Adjust_Orifice_Size_if_Necessary: Hood pressure should be zero, and orifice pressure should be greater than 10 Pa. If the hood pressure cannot be brought down to zero at maximum fan speed then a larger orifice size is required. Turn fan speed down prior to adjusting orifice size.

If the flow pressure cannot be increased above 10 Pa then a smaller orifice size is required to bring flow pressure into a more accurate range.

- Record the Flow Pressure: This flow pressure can be converted to an air flow by using one of the calibration equations specified for the orifice setting selected (Table 1).

- Adjust the Fan Control and Orifice Setting: If desired, the flow through the exhaust or supply fan can be measured for varying amounts of back pressure, or forward pressure. By adjusting the fan speed control and orifice setting, the DTR can be used to create any amount of restriction or fan assistance for the ventilation device.

- Measure and Record Air Temperature: If the temperature of air flowing through the flow chamber is less than 16°C or more than 24°C, a temperature correction of air flows may be warranted. The easiest method for making temperature corrections is to choose a correction factor from Table 2. These correction factors are used to multiply the calculated air flow. (Barometric pressures can also be recorded by calling the weather station and asking for station pressure. Otherwise, assume station pressures are close to the norm for your area.)

  For temperature measurement connect the 4-pin temperature sensor cable to both the control module and the fan module. The flow chamber end has an additional 2-pin connector which will not be required. Turn the selector switch from pressure mode to T2 and read the temperature in degrees C on the LED display.

2.3 Circulating Air Systems

Forced air distribution systems can be tested using the DTR. The flow chamber can be connected directly to the furnace blower compartment, or can be used to measure air flow at supply registers and return air openings. Leakage in the system can be determined by calculating the difference between actual supply and air flow at the furnace blower. Variations in supply temperatures can also

Table 1

ORIFICE PLATE CALIBRATION

A = variable orifice plate removed.
B = maximum opening of variable orifice plate (VOP)
C = next largest opening of VOP
D = third largest opening of VOP
E = second smallest opening of VOP
F = smallest opening of VOP

The orifice plate calibration is:

Flow Range** (L/sec)	Setting	Equation*
117 to 363	A	Q = 36.6 * SQ.RT.(P)
60 to 252	B	Q = 19.0 * SQ.RT.(P)
27 to 123	C	Q = 8.42 * SQ.RT.(P)
14 to 61	D	Q = 4.27 * SQ.RT.(P)
7 to 38	E	Q = 2.46 * SQ.RT.(P)
5 to 25	F	Q = 1.79 * SQ.RT.(P)

* P = pressure in Pascals
Q = flow in litres per second

be measured by the DTR, to identify inefficiencies caused by such factors as leakage, thermal mass of ductwork and thermal losses in ducting. Large variations in supply temperatures and supply flow may be affecting occupant comfort.

Warm Air and Return Air Registers:

* Follow instructions for supply and exhaust fans (Section 2.2) using the correct technique depending on whether the DTR is used at an outlet grille (supply register) or at an inlet grille (return air opening).

Furnace Blower:

* Furnace blower capacity can be measured by connecting the DTR to the blower compartment. Cardboard adapters must be fabricated on-site for this kind of test. Use one piece of cardboard to close off the return air plenum. Use another piece of cardboard to replace the blower compartment door. Cut a hole in the cardboard door slightly smaller than the DTR hood (eg. 300 X 300 mm) for testing air flows.[1] Before recording the orifice pressure, manually operate the furnace blower control, and adjust the DTR fan speed control until the hood pressure is equivalent to the static pressure for the return air ductwork.

2.4 Ductwork

Duct work will normally be tested to find the actual impedance (or resistance to flow), and the unintentional leakage area. The values can be characterized by an ELA (Equivalent Leakage Area) measurement. The ELA is defined as the area

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[1] After fitting the DTR to the blower compartment, it is useful to know the static pressure of the return air duct. This can be measured by covering the open end of the DTR with more cardboard, temporarily removing the cardboard covering the return air opening, and reading the hood pressure.

of a sharp edged orifice equivalent to the impedance of the system. A small ELA indicates a high resistance. Alternatively, the ductwork can be blocked at the far end, in which case the ELA represents an area equivalent to the unintentional leakage area of the ductwork.

The ELA will usually vary with pressure so it may be beneficial to take a number of measurements and plot the results. This procedure is similar to fan depressurization tests of houses, and the same calculations and computer programs can be adopted for this purpose. Typically, measurements are taken at 50, 40, 30 ,20 and 10 Pa induced pressure (provided by the DTR). The ELA can be manually calculated by plotting the pressure data on the X axis and flow data on the Y axis. Using LOG-LOG paper will enable the data to be connected with a straight line as the data will conform to an equation of the form:

- $\text{Flow}(Q) = C * (\text{Pressure})^n$; where C and n are constants. C is the Y intercept and n is the slope of the resulting graph.

Equation:

$Q = C * P^n$

take the log of both sides

$\text{Log } Q = \text{Log } C + n * \text{Log } P$

where n= slope

$\text{Log } C = Y$ intercept

The ELA will normally need to be calculated for the nominal pressure which the ducting must contain. Once the pressure is determined (eg. 10 Pa) then the graph is read to determine the flow at this pressure.

The ELA is calculated using the equation:

$Q = K*A*\mathrm{SQ.RT.}(2gh)$

where K = orifice discharge coefficient

Q = flow in L/s

A = area in cm^2

$2gh = 2 * P / 1.2\ kg/m^3$

P = pressure in Pa

Re-arranging and Correcting for Units:

$Q = A * K * 0.129 * \mathrm{SQ.RT.}(P)$

K is the discharge coefficient for a hole in a flat plate and is assumed to be 0.61 as defined in CGSB 149.10 M86, Determining the Airtightness of Buildings by the Fan Depressurization Method.

$A = Q / [0.07746 * \mathrm{SQ.RT.}(P)]$

A simpler approach that may be more appropriate for testing ductwork is to forego testing flow and variable pressures. Instead, a flow measurement at a single pressure is converted to an equivalent leakage area.

At 10 Pa, the equation becomes:

$A = Q * 4.0$

2.5 Chimneys and Make-Up Air Ducts

With chimneys and make-up air ducting, the ELA, air flows at various induced pressures, and thermal characteristics are important variables.

The ELA and air flow at various induced pressures can be measured using the techniques described for ductwork (Section 2.4).

Thermal characteristics are also important when determining the effectiveness of a chimney or a duct. Usually, the chimney will be thermally tested, although the same procedures will apply to ducts. A chimney with high thermal mass will heat up slowly, as will one of excessively large cross-sectional area. An effective chimney is generally one that has adequate cross-sectional area for the required flow and is well insulated so that the chimney heats up quickly and is less susceptible to pressure-induced spillage or backdrafting.

To determine the thermal characteristics of a chimney, the DTR is equipped with an in-line duct heater to serve as a heat source. A temperature probe is inserted up the chimney, into a duct, using the electricians fish-tape so that temperature rise can be monitored at the chimney top (or duct termination).

Using the In-Line Duct Heater:

- Connect the Duct Heater to the DTR: The duct heater is normally connected to the downstream end of the DTR so that flow can be measured (or controlled) throughout the test.

- Insert the Fish-Tape: Insert the fish-tape, complete with wire cage and temperature probe, into the flue and feed it up the flue to approximately 450 mm below the chimney top (optimal placement of the temperature probe will depend on chimney construction and other variables).

- Connect the Duct Heater to the Furnace Flue Pipe: Use the 75 mm to 200 mm reducers and expanders as required. It is usually convenient to first place the DTR on a cradle and tripod; since the chimney testing will require a number of minutes.

- Connect the Temperature Probe to the Control Module: Use the 4-pin connectors and check that it is reading correctly by selecting T1 on the selector switch. T1 is the remote thermometer at the end of the fish-tape. T2 is the internal temperature of the DTR.

- Turn the Selector Switch to PRESSURE: To zero the pressure at the duct entrance, turn the selector switch to pressure and turn on the fan.

- Turn On the Duct Heater: Time the temperature rise in the duct, recording elapsed time and temperature at intervals of approximately 30 seconds. The time and temperature at which the temperature plateaus is a good measure for thermal performance of the chimney.

3. DATA INTERPRETATIONS

3.1 Recording Pressure and Temperature

Flow pressure is read from the left hand LED display while hood pressure is read from the right hand LED display. Temperature is also read from the right hand LED display when the selector switch is turned to one of the two temperature settings.

Standard measurement recording should include the time, location, description of device under test, temperature, flow pressure and hood pressure as well as technicians name. Any anomalies in the DTR set-up or test protocol should be noted.

3.2 Calculating Air Flows

Air flows can be determined using the formulas (shown earlier in Table 1), which can be programmed into a pocket computer, or using a graph of these formulas. Additional density corrections are normally negligible but if significant variations from standard temperature and pressure are encountered density corrections may be applied as listed in Section 3.3.

3.3 Density Corrections

Density corrections may be required for temperature and barometric pressure. A simple correction factor to account for temperature and barometric pressure variations can be obtained from Table 2.

Table 2

CORRECTION FACTORS FOR TEMPERATURES AND BAROMETRIC PRESSURES

Temperature at Flow Station (°C)	Barometric Pressure (kPa)			
	87 to 97	97 to 100	100 to 103	103 to 106
-25 to -14	0.98	0.95	0.93	0.92
-15 to - 4	1.00	0.96	0.95	0.93
- 5 to 4	1.01	0.98	0.96	0.95
5 to 14	1.04	1.02	1.00	0.98
25 to 34	1.07	1.03	1.02	1.00
35 to 44	1.09	1.05	1.04	1.02

More accurate corrections are rarely required, but can be conveniently integrated into a pocket computer using the following formulas:

- **Temperature:**
  - **To correct the measured flow multiply it by:**
    - **SQ.RT. [(Temperature + 273.2)/293.2]**

- **Barometric:**
  - **To correct the measured flow multiply it by:**
    - **SQ.RT. [101.3 kPa/(Barometric pressure in kPa)]**

4. MAINTENANCE

4.1 On-Going Maintenance Requirements

There are no periodic maintenance requirements as the motor is lubricated for life. Breakdowns or equipment deficiencies which occur should be promptly repaired to lessen the chances of costly breakdown in the field.

Every 6 months the DTR and accessories should be checked for wear.

Loose or missing bolts and washers should be repaired or replaced.

The pressure taps should be checked to see that they are clear of obstruction and are firmly attached to the cabinet walls.

Wire and cable and connectors should be checked for integrity, damaged insulation, overheating and should be replaced if necessary.

Check that all pressure and temperature functions are operating and producing sensible numbers. Re-calibrate or repair as required.

Run the fan and check for unusual noises, scraping, squeaking etc.

Operate the variable orifice and confirm that the click stops are operating and that the stops hold the orifice in correct location.

4.2 Calibration

Temperature Probes

1. Relative Calibration:

   Remove the 4 screws holding the cover plate on the control box. CAUTION: Exposed 120 VAC inside box so be careful. On the left hand side of the box just inside of the temperature probe plug is a circuit board. Adjust one of the black potentiometers so that both temperature probes read the same.

2. Absolute Calibration:

   Use a calibrated thermometer as a reference. Alternatively boiling water and ice may be used to calibrate 0 and 100 C however do not immerse the AD590 probes directly in the water or ice. A good technique is to use a small copper tube with one end sealed and insert the AD590 into this. The sealed end of the copper tube can then be placed in the water without the AD590 getting wet.

   The black potentiometers establish the range for each of the two AD590's and are adjusted to change temperature calibration.

   The white potentiometer is used to set absolute zero at -2.732 volts so that the panel meter will read in degrees C. This pot. controls the zero setting of both T1 and T2 simultaneously and should not normally require adjusting.

Pressure Transducers

1. The pressure transducers are factory calibrated and should not require further calibration. Zero can be set using the front panel mounted 10 turn potentiometers. If for some reason the transducers drift out of the range

of these pots, then it will be necessary to open the cabinet and adjust the Modus zero internally. CAUTION: Exposed 120 VAC inside the box.

2. Each of the Modus pressure transducers has a zero and a span adjustment. These adjustments are made through small holes in the top of the Modus boxes using a very fine jeweller's screw driver. The zero adjustment is close to the center of the Modus and the span is located near one end.

   Refer to the Modus literature for further information.

3. Additional span adjustments are located on each side of the pressure sensor circuit board located at the rear of the panel meters. These span potentiometers are factory set and should not normally require adjustment. Their purpose is to adjust the Modus span so that the panel meters can correctly read the Modus voltage.

4.3 Air Flow Re-Calibration

Return the unit to Sheltair for re-calibration.

4.4 Equipment Specifications

Specification sheets for components of the DTR are attached.